ESTIMATING EXCAVATION REVISED

By Deryl Burch

Revised by Dan Atcheson

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1

Get Started Right

Construction cost estimating is demanding work, no matter what type of construction is involved. But I think estimating earthwork is the hardest of all. Why? For two reasons: First, excavation has more variables and unknowns — you don't know what's down there until you start digging; second, you have to rely on information from many sources — some of which may not be accurate.

That's why every earthwork estimator needs special skills:

- The ability to read plans and specifications
- An understanding of surveying and engineering practice
- A facility with mathematical calculations
- The ability to anticipate environmental and legal issues
- An abundance of good common sense

If you can bring common sense to the task, this manual will show you how to do the rest. I'll help you develop all the skills every good earthwork estimator needs.

Of course, I can't cover everything on every type of job. But I'll include the information most earthwork estimators need on most jobs. Occasionally, you'll have a job that requires special consideration. But if you understand the principles I'll explain here, you should be able to handle anything but the most bizarre situations.

A couple of subjects I think are important to cover here are the "by hand" approach to many earthwork problems, as well as the basics of computer earthwork estimating software. Both are meaningful topics for the earthwork estimator today. I've met many younger estimators who do earthwork take-offs with a computer who can't even

describe what the existing or proposed surfaces of the project would look like in the real world. Finding the centerline of a sloping surface in a basement requires knowledge based on the experience of doing "by hand" or manual earthwork take-offs. Those who've calculated earthwork take-offs on paper will make better use of their software. So, even though computers are used more and more for earthwork project take-offs, having a background in the math involved in project calculations will improve your capabilities when using a computer program. While computer programs generally don't make mistakes, it's very common for a mistake to be made by the person feeding the data into the computer. If you haven't a reasonable idea of what the result should be, you won't know if the software has given you a completely wrong answer. No software is a substitute for good judgment and sound estimating experience.

In this first chapter, I won't do much more than touch on a few important points you should understand:

1. why you have to estimate quantities
2. the importance of plans and specs
3. working accurately
4. keeping good records

After making these points in this chapter, I'll describe a step-by-step estimating system, from making the site survey to writing up the final cost summary. I'll teach you a process for making consistently accurate earthwork estimates. Part of this process is calculating the cubic yards to be moved. That's the heart of every earthwork estimate. I'll cover quantity estimating in detail. Then I'll explain how to find labor and equipment costs per unit. We'll also consider soil and rock properties and how the equipment you use affects bid prices.

Why Calculate Quantities?

In the past, many smaller dirt jobs were bid on a lump-sum basis rather than by the cubic yard. Dirt contractors based their bids on guesses: What equipment will I need and how long should it take? Making estimates this way overcame a big problem for many of these excavation contractors — they didn't know *how* to estimate soil and rock quantities.

I think those days are over. Today, fuel and labor costs are too high and the competition is too intense to risk "seat-of-the-pants" guesses. A few mistakes and a couple of surprises and you're going to be looking for some other type of work. Only the best survive for long in this business. And most of the survivors know how to make accurate bids by the cubic yard. Fortunately, making good quantity estimates isn't too hard once you've mastered a few simple skills. I hope that's why you're reading this book.

I've found that all good earthwork estimators are also good at calculating earthwork quantities. Here's why:

No one's going to do it for you. You have to do it yourself or it's not going to get done right. Many engineers, architects, and even some builders know how to figure soil and rock quantities, but few take the trouble to do it. Instead, they depend on the earthwork estimator to do it. If the engineer calculates quantities, he'll give the numbers in cubic yards, but won't specify what types of cubic yards are being presented. I've know some engineers who don't understand the concepts of soil swell and shrinkage. They simply give the cubic yards based on length × width × depth calculations and leave it up to the estimator to convert those quantities into loose and compacted cubic yards for the cut and fill quantities, respectively. I've also found that engineers make mistakes in calculating the quantities. There's an old estimator's saying: "An engineer does not an estimator make." These are two totally different professions.

Today, most owners, engineers and architects request excavation bids based on the cubic yards moved. That's now the accepted procedure for most projects, from single-family homes to roads and commercial jobs. Some projects are still bid lump sum, but those are the exceptions. It's common for the actual amount of dirt moved to be more or less than expected, so the best way to protect your business is to bid by the cubic yard. If it turns out you have to move more dirt than the plans show, instead of having to eat the extra cost, you'll get paid for it. It's as simple as that.

General and Special Quantities

If you agree that excavation bids should be based on quantity estimates, the next step should be obvious. Every estimate must start by figuring the quantity of soil to be moved.

I recommend you begin any project estimate, no matter how large or small, by dividing the excavation into two categories: general quantities and special quantities.

General quantities include any work where you can use motorized equipment such as scrapers, hoes and loaders at their designed production rate.

Special quantities include anything that requires special care or lower production rates. Examples are most rock excavation, nearly all hand excavation, and backhoe work around sewer lines, underground utilities, or existing structures. Naturally, prices for special quantities are higher than prices for general quantities.

Keeping these two quantities separate protects you. Most excavation contracts have a clause that covers extra work. Unanticipated rock deposits, special soil problems and unusual trenching problems are extra work that you should be paid extra for. If you've bid a higher price for special quantities, you'll get paid at that price per cubic yard for the additional work. Otherwise you could end up chipping out rock at the price of moving sand.

Calculating Cubic Yard Cost

Here's the basic formula for costs per cubic yard: Labor and equipment cost per hour multiplied by the hours needed to complete the work, divided by the cubic yards of material to be moved, or

$$\text{Cost per CY} = \frac{\text{Cost per Hour} \times \text{Total Hours}}{\text{Total Cubic Yards}}$$

Does that seem simple? It's not. You may know your hourly labor and equipment costs right down to the last penny. But estimating the time needed is never easy. And calculating volumes for sloping and irregular surfaces is very demanding work.

Here are a few things about the formula for computing costs per cubic yard that you should take note of.

1. It's based on labor and equipment costs for your business. That's important and I'll have more to say about it later.
2. It assumes you know the quantity of soil or rock to be moved. That's going to take some figuring.
3. Even after you've calculated the cost per hour and quantity of soil, you're not finished. You need to estimate the time needed. Usually that's the hardest part. To do that, you have to decide on the equipment (method) to use.

Of course, the quantity of material (yardage) is a very important part of our cost formula. But the excavation method (type of equipment) also has a major influence on cost. The most expensive equipment (cost per hour) will usually be the most productive (move soil at the lowest cost). But the machine with the largest capacity isn't always the best choice for every outhaul. I'll explain why later. For now, just understand that making good equipment selections helps reduce costs.

Reading Plans and Specifications

Many excavation projects let out for bid are based on a set of plans. Plans are scale drawings that show the finished project. Plans are supplemented with written descriptions called specifications (or specs). Specs explain in words what the plans can't or don't show. Ideally, the plans and specs, read together, should answer every question about the job. They shouldn't leave anything up to interpretation. The better the job done by the engineer or designer, the more likely the plans will be clear and complete.

Plan reading is an important skill for every earthwork estimator. But this isn't a book on plan reading. If you need help with reading plans or you don't understand the plans and drawings in this book, pay a visit to your local library or search the internet. You'll find there are several manuals that explain basic plan reading.

Look for Notes on Special Problems or Conditions

As an excavation estimator, you're expected to understand every detail in the plans and specs for the jobs you bid. Read these documents completely. They're worth careful study. Note everything that affects your excavation work. Some engineers and architects aren't very well organized. They can put instructions and notes almost anywhere on the plans. Read every page carefully, regardless of what you think it's about. Use a yellow highlighter and mark anything in the specifications that affects your work, such as the type of compaction required for the fill material. That'll make it easier to find later if you need to look it up.

Utility Lines

Pay particular attention to notes that spell out the contractor's responsibility. For example, you may find a note somewhere on the plans that relieves the engineer or architect of responsibility for damage to utility lines. It may say something like this:

> NOTE: While every precaution has been taken to show existing utilities in their proper location, it is the contractor's responsibility to determine their actual location. No assumption should be made that no other utility lines fall within the limits of construction.

That means that if you break a pipe, such as a water main or a gas line that wasn't marked on the plans, it's entirely your fault and you have to shoulder the costs. So if you suspect utility lines may be a problem, ask the utility companies to locate their lines for you. Most will be happy to do that at no cost. But they may want ample advance notice.

Changed Conditions

Also pay attention to notes on natural obstacles (such as rock) or anything that's buried on the site. Is there an abandoned underground storage tank or old basement in the area to be excavated? The plans may also mention drainage problems and unsuitable soil deposits, probably in the cross-section drawings or special provisions of the specs.

A.I.A. contracts, and most federal government contracts, spell out what happens if you encounter *changed conditions* at the jobsite. An example of changed conditions would be if the soil type isn't what was indicated in the contract documents, or isn't normal for the type of work you're doing. In that case, you're entitled to extra pay for dealing with those changed conditions.

Owners and engineers have written volumes of contract language excusing themselves from liability for test borings and other information they provide to bidders. Some contracts even say that you're responsible for conditions at the site, if those conditions aren't as indicated in the bidding documents. That's ridiculous. To protect your business, be sure there's a *changed conditions clause* in the contract so you'll get extra pay if conditions aren't what the test borings showed, or conditions are very unusual for the type of work being done.

Other Costs

Search the plans and specs for everything that may affect cost. That's always your starting place. But it's not the end of your search. Many cost items won't show up in either the plans or specs. For example, you'll have to find out from the city or county building department what permits will be required. Also, city, county or federal law may set minimums for wages, employee benefits and insurance coverage.

Here's another pitfall to watch for: Who pays to have the project staked out by a surveyor or engineer? In most cases, the designer will pay for surveying — the first time. If you knock over any survey stakes during actual work, you'll probably have to replace them at your own expense. Work as carefully around the stakes as possible. But if job layout makes it impossible to avoid moving stakes, allow enough in your bid to pay for another survey.

Make sure you understand how you'll be paid. On larger projects, you're usually paid per cubic yard, based on the difference between the original soil cross section and the cross section when work is finished. We'll talk more about cross sections later in this book.

On many smaller projects, your payment may be based on the engineer's estimate of yardage. If that's the case, look for a provision in the specs that gives you an option to have final cross sections made at your own expense. Experience will help you decide if a final set of cross sections is to your advantage. But I recommend that you always take off quantities yourself. Don't assume the plans are right. Anyone can make a mistake, but you could end up paying the price.

Undercutting

Undercutting is removing additional dirt from an area below the finished grade line. There are several situations where this is necessary. The most common is where clay or a rock ledge is close to, but not above, the finished grade line. Figure 1-1 shows a typical situation with a rock ledge below the surface. Most structures can't be built directly on rock. If the rock weren't there, you would excavate to the finished grade line and be done. But because the rock is just below finished grade, you have to cut deeper. That's the undercut. Then you have to backfill the undercut with a suitable material, such as select sand. The sand provides a buffer between the rock and the foundation.

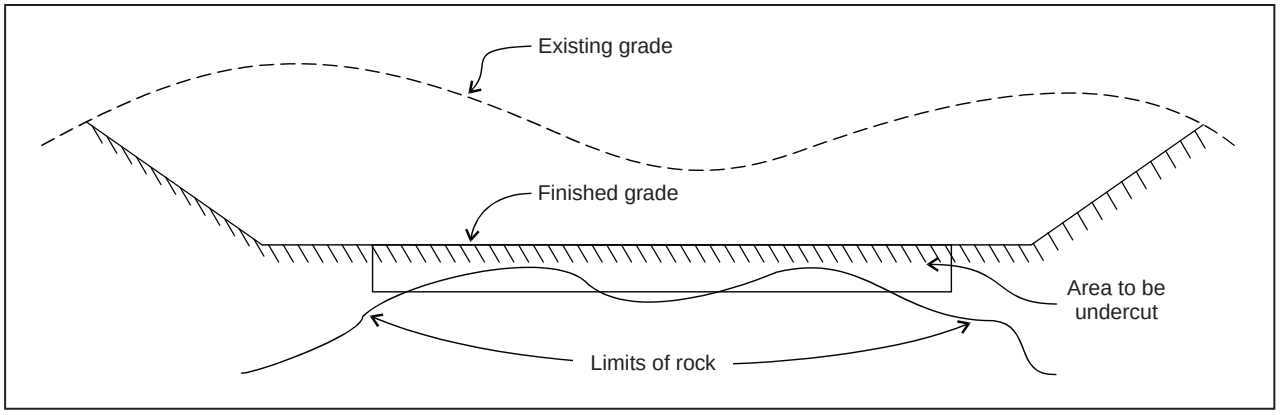

Figure 1-1
Undercutting for rock

There's probably nothing in the specifications that gives you the right to collect for undercutting and backfill. But it's expensive work and the cost shouldn't come out of your pocket. Where undercutting may be necessary, include it in your bid as a separate item on a per cubic yard measure.

Undercutting is also needed when trenching for underground utilities, such as storm drains and sanitary sewer lines. The undercut makes room for bedding material to be placed under the pipe. Most plans will show only a designated flow line elevation. But based on the plans and your good judgment, you'll have to decide how much and what type of bedding to install below the pipe. Each cubic yard of bedding requires a cubic yard of undercutting. Some engineers specify this, and others don't. Figure 1-2 shows an example. Undercutting may also be required on roads, parking lots and sidewalks — anywhere there's a load on the soil.

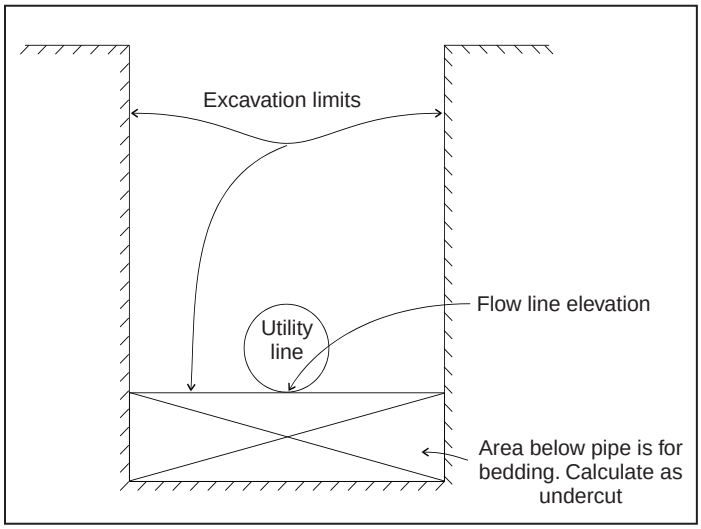

Figure 1-2
Undercutting for pipe bedding

Overfilling is the opposite of undercutting. When backfilling a large area, you can usually bring the backfill right to grade without cutting away excess backfill. But in a small area, it's usually easier to bring the area

above the final grade line by 2 to 4 inches, then cut off the excess. This is still called undercutting. Of course, you can't expect to get paid for removing the 2- to 4-inch excess. But it's still a cost of the job.

Accuracy Is Essential

Accuracy is the essence of estimating. If you can't work accurately, you're in the wrong business. But don't get me wrong. I don't mean that you have to account for every spadeful of soil on every estimate. On small projects, there are times when you can ignore small differences in elevation. On most jobs these small plus and minus areas will average out to almost nothing. But a 1-inch mistake in elevation over the whole job can cost you thousands of dollars. Even a $^1/_{16}$-inch error over a few acres can hurt you.

Here's an example. Assume you're bringing in fill on a city lot measuring 125 feet by 150 feet. Because of a mistake in grade, your estimate of imported soil is wrong. It leaves the entire site 1 inch below the specified finished grade. How much more soil will be needed to correct the 1-inch mistake?

Here's the formula for volume:

$$\text{Volume (in cubic feet)} = \text{Length (in feet)} \times \text{Width (in feet)} \times \text{Depth (in feet)}$$

In this example, you know the length and width in feet, but the depth is only 1 inch. To use the formula, convert 1 inch to a decimal part of a foot. You can either refer to the conversion chart (see Figure 1-3) or divide 1 by 12, since 1 inch = $^1/_{12}$ foot. Either way, you'll find that 1 inch equals 0.0833 feet.

Now you're ready to use the formula for volume:

$$\begin{aligned}\text{Volume (CF)} &= 125 \times 150 \times 0.0833\\ &= 1{,}561.88\end{aligned}$$

How many cubic yards is that? Since there are 27 cubic feet in a cubic yard, divide the cubic feet by 27:

$$\begin{aligned}\text{Volume (CY)} &= \frac{1{,}561.88}{27}\\ &= 57.8\end{aligned}$$

Trucking in almost 58 cubic yards of soil won't be cheap. If imported soil costs you $25 a cubic yard, your 1-inch mistake is a $1,450 error. That could make the difference between profit and loss on this job.

Inches	Decimal feet	Inches	Decimal feet
1/16	0.0052	7/8	0.0729
1/8	0.0104	15/16	0.0781
3/16	0.0156	1	0.0833
1/4	0.0208	2	0.1667
5/16	0.0260	3	0.2500
3/8	0.0313	4	0.3333
7/16	0.0365	5	0.4167
1/2	0.0417	6	0.5000
9/16	0.0469	7	0.5833
5/16	0.0521	8	0.6667
11/16	0.0573	9	0.7500
3/4	0.0625	10	0.8333
13/16	0.0677	11	0.9167

Figure 1-3
Inches to decimal feet conversion chart

Your Estimating Procedure

The more organized and logical your estimating procedure, the more accurate your estimates will be. If you have the tools, papers and information you need close at hand, you're off to a good start. Then you can focus your attention and concentration on producing an accurate estimate. If you're cramped for space in an uncomfortable office with poor lighting, and trying to work without all the equipment and information you need, errors are almost inevitable.

Work Area and Equipment

Start by organizing an efficient work area. It should be large enough so you can lay out all the plans on a table and still have room to write and calculate. Provide enough light to make reading comfortable, and keep the work area free of shadows. This is especially important when working with transparent overlays or other light-duty paper where you might mistake shadows for lines.

Although it's not essential, I like using a light table. You can place a drawing on it, overlay it with another paper, and see through both of them. It's great for working with plan and profile sheets, overlays on grid, or take-off sheets. It's a good idea to tape a sheet of drafting paper over a site plan. You can set up a grid and write all your calculations on the paper and file it away after the take-off is done. That way, you won't be marking up the drawings if you have to return them to the engineer. You don't want the engineer or anyone else to see how you did your take-off.

A large wall-mounted marker board is useful for showing, studying, or sharing an equation or idea, and can be a very handy addition to your work area.

A good calculator is a must. I recommend buying a calculator with both a digital and a paper printout. You need the printout to check your figures. Make sure you have an engineer's scale and drafting triangles for checking and drawing lines, a small magnifying glass, tape for holding overlays, and the normal collection of pencils, pens, erasers, and paper.

Later in the book we'll talk about using a planimeter to take off quantities. Although it's relatively expensive, a good planimeter will soon pay for itself. Take care to select one that's sturdy and has all the needed instructions and attachments.

A computer is even more expensive, but there are few estimators now who aren't using one. There are programs on the market that can handle anything from simple calculations to a complete estimating program, with cross sections, quantities and printouts. But no program is a substitute for a good estimator who understands estimating procedures and practices — which is the purpose of this book.

There are two advantages to using a computer. The first is time, an estimator's most valuable asset. A computer can help make your time more productive. Second, a computer makes it easier to keep cost figures for equipment and labor. Records from past projects and estimates can make current estimates more accurate.

If you don't currently use a computer in your work, don't jump in without first doing some research. There's tons of estimating software, thousands of different computers on the market, and hundreds of dealers. Take the time to make yourself familiar with the options. Talk to dealers. More important, talk to other estimators who use computers in their estimating. Read trade magazines, especially the ads for estimating software. And don't go out and buy a computer and then look for estimating programs to run on it. First, choose the estimating program you like, and then buy the computer that will run that program. Otherwise, you may find the computer you bought won't run the program you like.

The Work Process

When you've got your work area and equipment set up to work efficiently, you're on the path to accurate estimates. To stay on that path, it's important to approach the work with a logical and organized procedure. That speeds up the work and reduces mistakes. Let me describe the method that works for me. I think it'll work for you, too.

When starting a project, first read all documents describing the job. Take notes on any situation that's not a normal work requirement. Are there utilities that must not be disturbed? Do the documents indicate specialized material types from soil boring logs? Do they stipulate any arrangement for rock on the site? Watch carefully for the compaction and testing requirements. Testing is expensive and your project could be delayed while testing is being performed. Look for any special provisions set out by the designer. Then head out for a field visit. You'll find details about the site visit in the next chapter.

After returning from the field, review the documents again, looking for unusual situations that the site visit brought to your attention. Then make a complete written outline of all work that needs to be done, in the order in which it will be performed. Set up files for each separate section. Make a list of additional data such as quad sheets, local conditions, and any other information you need to gather.

Here's the order I usually use.

1. Consider any drainage, traffic or work zone protection that needs to be done. Are there any onsite streams that must remain open, or roadways to maintain? These would probably be lump sum items, not items you'd take off quantities for. Just make sure you don't miss any of these special items.

2. After studying the plans and the site, you should have a good idea if there's enough fill on the site, or if you'll need a borrow pit. Will you need a place to put excess material offsite? Begin now to make arrangements for needed borrow and storage sites, sampling of material for approval by the engineer, and purchase of any material that's needed. Also, check with heavy equipment dealers in the area to make sure any specialized equipment you'll need to do the project is available for rent. I've even heard of contractors who take a risk and rent equipment in advance in order to keep the competing contractors from getting the equipment.

3. Now consider the topsoil requirements. Review the material sample, the requirements for replacement, and availability of storage area on the site. Calculate the amount of usable material and the amount of waste that must be disposed of.

4. Will there be any special excavation, like rock work or the removal of existing structures or facilities? Make sure you include all work and any special equipment you'll need. Will you need to rent equipment? What about rock drills and saws, blasting material, or cranes?

5. Begin calculating the general quantities with the cut or fill work over the entire project. Start in the same place and proceed throughout the project the same way for every estimate. One way to make sure you cover the entire project is to set up a grid system with a corresponding file system. As you finish work in each grid, mark it off, file it, and move on to the next grid.

6. Next, calculate all the utility lines, keeping the figures for each area separate. Be especially careful in estimating the tie-in between new and existing lines. Allow a little extra time for lines that aren't exactly where the plans show them to be.

7. Then consider the roads, parking lots, and paved or special drainage ditches. Again, keep the quantities for each separate. One note of caution: Remember to consider the base and sub-base when figuring final elevations.

8. Buildings, basements, sidewalks and other similar structures are next. After you've calculated each structure separately, add them all together to get a structure total.

9. Finally, calculate the topsoil. And don't forget that if you've used a borrow pit, you may have to place topsoil there also.

10. Now you're ready to start putting together all that information to come up with a realistic quantity total for the complete project. Fill out the final quantities sheet. Remember to attach all worksheets, scratch paper and calculator printouts so you can recheck your totals.

Review your final sheet, looking for potential problem areas. If possible, have someone else check all your calculations and extensions. If that's not possible, set the estimate aside and go through it again a few days later. You'll have a fresh approach that may spot errors or omissions.

The last step is to go through all the documents and make sure they're in order. Then file them. Don't throw anything away — not even the scrap paper. Why are those records valuable? Keep reading; that's next.

Record Keeping

Once you've learned to read plans carefully and work accurately, there's still one more important step in good estimating practice: record keeping.

Think of your estimates as accumulated wisdom. Treasure them. Keep them handy. Make sure they're easy to understand. They should show how each figure was developed. Why? There are at least four reasons.

First, planning the work is a big part of every estimator's job. You can't estimate any type of earthwork without making decisions about equipment. Once you've selected equipment for estimating purposes, document your choice on the estimate worksheets.

If your bid is accepted, you'll probably want to do the work with the same equipment assumed in the estimate. What if months have gone by and you can't remember how the figures were developed? You have to start selecting equipment and estimating costs all over again. If the equipment assumed in your estimate isn't the same as the equipment actually used, comparison of estimated and actual costs may be meaningless.

Second, you're going to refer to most estimates many times over months or even years. You shouldn't have to guess about how each figure was developed. That wastes time and can exhaust your patience. I've seen estimators who should know better use

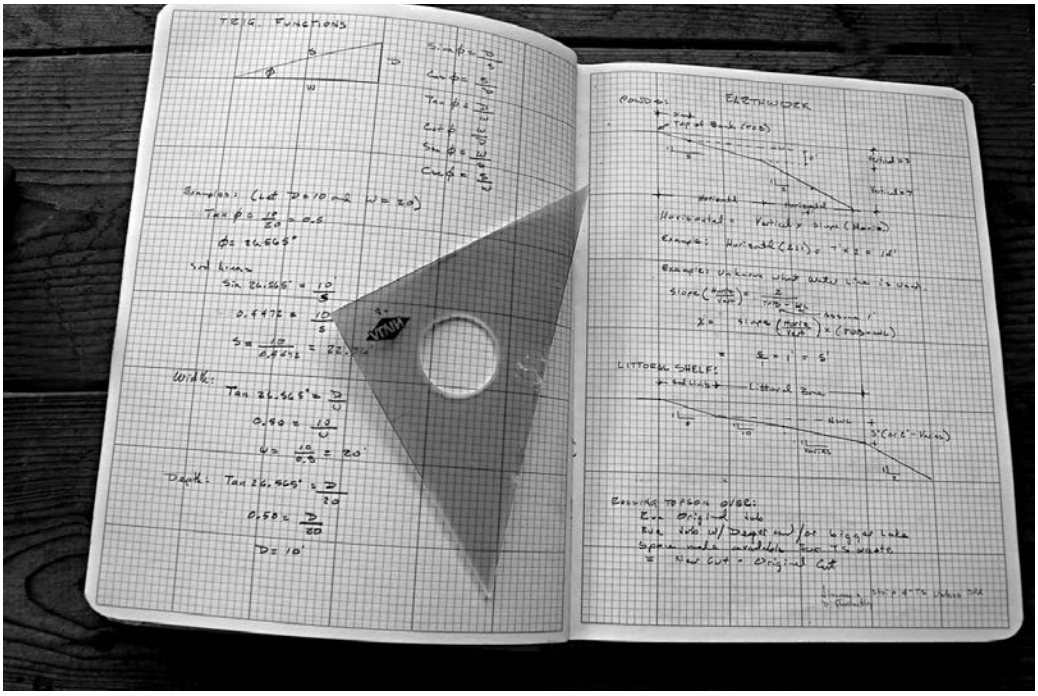

Figure 1-4
Formula book

the back of an envelope to figure special quantities. After entering the final cost, they discard the envelope. Later, if there's a question about the estimate, how can they verify the figures? They're gone!

When you write a calculation or create a drawing for possible future use, take the time to clearly describe the calculation and label each drawing very clearly. Over the years, I've created good ways to solve problems, and then later discovered that I didn't know how I came up with those solutions so I could duplicate them. Because I didn't make good notes or include well-labeled drawings, my solutions were one-time successes that I couldn't carry forward for future work. Now, whenever I find calculations that are needed over and over on different projects, I carefully draw diagrams and write out the equations, and then place them in a special book for future reference. (See Figure 1-4.)

Third, old estimates are invaluable when compiling new estimates. Every estimate, especially if you actually did the work, provides a frame of reference for future jobs — even if labor and equipment costs have changed.

Fourth, every estimator makes mistakes. That's no embarrassment. But repeating mistakes is both foolish and expensive. The best way to avoid repeating mistakes is to preserve every scrap of estimating evidence — in a neat, tidy, well-organized file. Make notes on what worked and what didn't. Review those estimates and notes when estimating similar jobs.

Save everything. Good record keeping can come in handy as backup to justify a claim for extra work or as a means of proving your claim in court if a dispute goes into litigation. Also, someday you may want to write a book. I saved my notes and estimates and wrote a book. You're reading it.

Use Public Records

To the professional estimator, there's no such thing as too much cost information. Collect all the estimating data you can. It helps if you know where to look for it. I canvass city and county engineering departments, public works departments and maintenance departments for whatever information they can provide. They know about bid prices, soil conditions, abandoned streets, utility lines, sewer, and water problems. Use the resources available from your city and county government.

Aerial maps at the county tax office and contour maps from the United States Geological Survey offer clues to possible water and soil problems. There are USGS offices in most states. They're often located in the capitol, or in cities with universities. Check your local phone book or local engineering groups for the address of the nearest office. City, state and county highway departments will have information on soil problems they've found under highways in the area.

Understanding Plan or Drawing Measurements

There are three scenarios you may encounter with plans or drawings that will make your job as an earthwork estimator more difficult. They are: drawings that have been enlarged or reduced; a drawing that has only a measurable area; and being forced to measure a plan drawn in an engineering scale with a common ruler. Let's look quickly at how to deal with these three situations.

Determining the Actual Scale of a Plan

When a print has been reduced or enlarged, you can still use the given scale to measure plan dimensions accurately. The factor by which the plan scale has been reduced or enlarged can be determined by the following formula:

$$\text{Scale Factor} = \frac{\text{Printed Plan Dimension}}{\text{Scaled Dimension (using original scale)}}$$

Example: You are given an original scale of 1" = 20'. Find the scale factor if a given plan dimension of 250 feet measures 55 feet at the original scale of 1" = 20':

$$\text{Scale Factor} = \frac{250'}{55'}$$

$$= 4.545$$

You'll need to multiply any dimension scaled at 1" = 20' by 4.545 in order to obtain the correct length. Note: Never apply the factor to a printed dimension entered directly into your calculator. Apply the factor only to dimensions measured with your scale.

Some computer programs have a "compensate scale" feature that automatically determines the correct scale to use on any enlarged or reduced drawing; however, you can check your accuracy in setting the compensate scale feature by using the following formula:

$$\text{Actual Scale} = \frac{\text{Printed Dimension} \times \text{Original Scale}}{\text{Measured Dimension (using original scale)}}$$

Example: Determine the actual scale of the drawing discussed in the previous example.

$$\text{Actual Scale} = \frac{250' \times 20'}{55'}$$

$$= 90.91 \text{ feet per inch}$$

Determining Plan Scale When Only Area is Given

In this situation you have a grading plan with a plan scale of 1" = 40'. The engineer has also given you the dimensions of the site, with an area of 5.76 acres. However, no other dimensions are given on the plan, not even a scale bar. Using the given plan scale provided, the work area measures 18.3 acres. Obviously, the plan has been reduced, making the given scale incorrect. What scale should you use to produce the correct results? Use the following equation to solve the problem:

$$\text{Correct Scale} = \frac{\text{Given Scale} \times \sqrt{\text{Given Area}}}{\sqrt{\text{Site Perimeter Area}}}$$

$$= \frac{40 \times \sqrt{5.76}}{\sqrt{18.3}}$$

$$= 22.44 \text{ feet per inch}$$

When You Have the Wrong Measuring Tool

Years ago, while visiting a friend, I was asked to measure the length of a line on a plan drawn at an engineering scale of 1" = 40', and all my friend had to measure the line with was a common ruler. The line measured at $3^{3}/_{16}$ inches long. To convert the length to the correct scale, I expressed my measured length as a decimal equivalent of inches and multiplied the result by the plan scale. The decimal equivalent of $3^{3}/_{16}$ inches is 3.1875 inches, so my calculation was:

3.1875 inches × 40 feet = 127.5 feet

To apply this principle to areas, convert each area dimension to its engineering dimension and multiply them together. For example, if an area measured with a ruler is $3^{1}/_{2}$ inches by $1^{1}/_{4}$ inches on a plan drawn at 1" = 40', it has actual dimensions of 3.5 and 1.25 inches in decimal form. Convert these dimensions to engineering scale dimension:

3.5 inches × 40 feet per inch = 140 feet

1.25 inches × 40 feet per inch = 50 feet

So the actual area at a 40-foot scale is:

140 feet × 50 feet = 7,000 square feet

What If You Don't Have Plans?

Up to this point, we've assumed that you're bidding the job from plans and specs provided by an architect or engineer. But you may be asked to bid on a small job that wasn't designed by an engineer or architect. Then you'll have to create your own plan. It may also be up to you to determine quantities and prepare a contract.

In any case, always figure soil quantities and get a written contract on every job, large or small. The responsibilities and liabilities are all yours, so plan and execute your bid with care. Use the procedures and guidelines in this book — even if there are no plans.

If the owner doesn't have a plan prepared by an architect or engineer, collect as much information as possible from the owner. Does he or she know of any soil problems at the site? Is it your responsibility to request the survey and staking? Are any permits needed? When should the job be completed? Where are the utility lines? What conditions might delay the work?

Whether the job is big or small, whether you've got no plan or a very complete plan prepared by the best engineering firm in the state, make a visit to the site as part of your estimating procedure. That's important — important enough to be the subject of an entire chapter. And that's the next chapter in this book.

2

The Site Visit

A site visit is an important part of every earthwork estimate. If you skip this important step, your estimate is just a guess. In this chapter we'll cover how to prepare for that visit and what to look for when you get there.

Review the Plans First

Before you go to the site, take time to completely review the plans. Make an itemized list of any special problems or unusual requirements you pick up from the plans and specifications. Take that list with you, and check each item while you're in the field. Later in the chapter I'll discuss in more detail what to include on your checklist.

The amount of information provided on the plans will determine how much work you have to do to prepare for the site visit. If you have a complete set of plans and specifications, it's easy to list the questions that you need to answer. But if it's a small project with not much earthwork, the plans may not tell you all you need to know. Then it's up to you to work up the quantities and requirements for your part of the job.

Most engineers and architects are very good at what they do. But unless the project has a lot of excavation or is specialized, like highway construction, they often don't furnish complete data in the earthwork area. It's up to you to make sure that the plans accurately reflect conditions at the site itself. If you have any construction experience, you know that the way things look on paper and the way they are in the field are often different.

Incorrectly Drawn Site Plans

Some site plans are drawn with incorrect elevations. I've seen projects where the design engineers have had an error of 1 or 2 feet due to bad benchmarks or assuming ground elevations from previous surveys. Be wary of plans drawn from aerial photographs. I once worked on a project where the engineers used the top of vegetation for the existing grades in a marsh area. The vegetation was at least a foot higher than the soil in which it was growing.

When you visit the site, watch for features that aren't shown on the site plan. For instance, unexplained mounds, an abandoned swimming pool or ponds are dead giveaways. If you discover a benchmark or another good reference point in the area, spot check the elevations in a few locations on the site. Be sure to take a camera with you to record the physical conditions. Carefully document each photo you take and give the reason why you took that photo.

If the existing elevations on the site plan are higher or lower than the actual elevations on the site, you'll do more work than you anticipated. More material importing or exporting will be required, increasing your material and hauling expenses and throwing your estimate off.

If you're awarded a job and you suspect the plan elevations are incorrect, contact the engineer before starting work and ask that a new survey be taken. If he refuses, hire your own licensed surveyor to shoot grades before you start work. You might have to sue to get paid for the extra work, but on large projects, it could be worth the expense.

Make the Visit Productive

Your visit to the site can make a significant difference in the amount of your bid — and the size of your profit. That's why professional estimators often earn their annual salary from just one job. They can analyze the jobsite to anticipate problems that might interrupt work scheduling, situations that require specialized equipment, or shortcuts that will speed the work along. Then they work up bids that guarantee the contractor healthy profits.

Several years ago, a friend of mine was estimating a large shopping center project. It involved moving about half a million yards of material, including more than 300,000 yards to be hauled from the site. The designated disposal site for the material was $2^1/_2$ miles away by the major road. There was a much shorter route — less than a quarter mile — but it crossed a bridge with only a 5-ton rating. The other contractors all bid the job using the $2^1/_2$-mile haul route. Except my friend. He got in touch with the county that owned the bridge and made them a proposition. He would remove the existing

bridge and replace it with an arch culvert. All they needed to pay for was the pipe; he'd cover all the labor and equipment costs. It was a win-win situation. Of course, they were happy to oblige. Using the much shorter haul distance, his company won the bid. They made enough extra profit to pay for the culvert installation and more. The estimator really earned his salary on this project.

On another project, the same estimator earned his keep by steering his company clear of a bad situation. The project was a large subdivision in a rural area. A general provision said that even though the plans didn't show any utility lines in the area, the contractor was responsible for any lines and for keeping uninterrupted service if any were encountered. Even though it was a dry period in late summer, the estimator noticed that one area had lush grass growing on it. Suspecting either a spring or sewer system leak, he took a sample and had it analyzed. Sure enough, it was raw sewage. Several older homes in the area had septic tanks installed in a line, with the discharge in this open area. He included the cost of correcting the problem in his bid. None of the other estimators did, so naturally, their bids were lower. The contractor who "won" this bid paid dearly for it.

Unfortunately, few of us with many years of estimating under our belts can gloat over situations like that. We've all had at least one instance where we won a bid by forgetting or overlooking something. It takes knowledge and experience to make the site visit productive. Most know-how comes from experience on past projects. But even an inexperienced estimator can use good common sense to come up with cost-effective ways to do a job. For instance, it's a definite bidding advantage if you already have a project nearby, provided you can schedule the progress of each job to use equipment and supervision conveniently at both sites.

Use the site visit to plan the construction scheduling and to anticipate equipment and labor requirements. The actual conditions of the site will dictate the type of equipment needed and the way the work is done. Let's look at some of the things you'll consider during the site visit, beginning with the accessibility of the site.

Accessibility

First, consider the physical location of the site. How remote is it? What roads or streets lead to the site? Are there any one-way streets leading to the site? All these will have a direct bearing on the work. If the site is isolated or undeveloped, with poor or nonexistent road access, it will take longer — and cost more — to move equipment and material in and out of the worksite.

If you'll have to bring dirt in or take it out, consider the distance to the borrow pit or dump site. And I don't mean make a guess. I mean actually measure it with your odometer. I recommend driving the route several times, using different roads to find the shortest and best route. If all the surrounding streets carry heavy traffic, it will slow down the movement of equipment to and from the worksite.

When you're forced to use heavily trafficked roads, make a log of the length of each leg, as well as the travel time required along each segment of the route. Travel time usually varies, depending on the traffic, number of stop lights and the speed limit. Traveling the route several times will allow you to find an average travel time, as well as provide you with an idea of what times during the day are best suited for hauling.

Example: The route is 31 miles, and you've divided it up by the speed it takes to travel each section. If you've determined the travel sections and miles per hour are as follows, how long will the trip take?

1. 20 miles at an average of 55 mph (20 ÷ 55 mph) = 0.36 hours for the high-speed section.
2. 6 miles at an average of 40 mph (6 ÷ 40 mph) = 0.15 hours for the medium-speed section.
3. 5 miles at an average of 20 mph (5 ÷ 20 mph) = 0.25 hours for the slow-speed section.

Add the times required to travel each section to get the total trip time; then multiply by 60 minutes to convert decimal hours to minutes:

0.36 + 0.15 + 0.25 = 0.76 hour × 60 min = 45.6 minutes

Look for any safety-related problems that might require additional manpower. Will traffic problems require the use of one or more flagmen? What about bridges? Are there any low-weight-limit bridges or narrow bridges that you can't use to bring equipment or material to the job? Check with local authorities to find out how you're required to handle traffic situations.

Degree of Job Difficulty

When you've surveyed the accessibility, turn your attention to the site itself. Is the area open, or are there obstructions like buildings, trees, sidewalks, or utility lines in the way? Any of these will slow down production. If specialized equipment is needed, will it be available in the area, or will you have to bring it in from a distance? If the site is near homes or businesses, those will affect any blasting that might need to be done. Is there a noise ordinance enforced?

Consider the environment around the work area. Is potable water, or any water, available at the site? If not, you'll probably have to bring in water trucks. What about too much water? During your site visit, take complete notes on any variable that could affect your bid.

Are there any steep slopes that would require unusual equipment? This is a good time to decide what size and type of earthmoving equipment to use. Consider whether

there's enough room for the equipment to turn and move economically. While the size of the job might warrant a 20-yard-capacity scraper, is it too large to operate around the obstructions? Steep or unstable slopes usually mean you're going to have to use tracked machines instead of wheeled. As a rule of thumb, you'll have to use track machines on any slope that's greater than 3 in 1. When making your decision, consider the ground conditions, traction, and the distances and directions you'll have to move. And remember that track machines have a slower working speed. We'll talk more about working on slopes later in the book.

Surface Conditions

Drainage problems, steep slopes, dense vegetation, and sharp or large rocks scattered on the surface will all hamper production. Drainage is one of the biggest problems you'll encounter. Will dewatering be required? If so, what's going to happen to the water that currently drains across the project area? You may have to provide drainage channels to reroute water or pump the water out during construction. But you can't just divert water onto streets or roads. You may need to obtain a special permit from the city, county or state for temporary channel relocation during construction.

Be sure you know where the water is coming from as well as where it's going when you divert or pump it. A friend of mine in Michigan ran a pump all weekend and didn't do a thorough study of the water's path. Monday morning his company was confronted with some very sad news. They'd flooded a huge furniture store down slope.

What about removing water that's needed in adjacent areas? Check for trees near the dewatering zone. I recently heard of a project involving many lawsuits because dewatering removed needed landscape water and killed several old and beautiful trees in homeowners' yards. Mistakes like these will put you out of business.

On some jobs you'll need to estimate the volume of trees and brush to be removed. Most plans mark the trees that need to be removed, but they seldom give the volume. There are so many variables that your best estimate is often just an educated guess. But I have a method that should give you a reasonably accurate volume estimate.

Calculating Brush and Tree Volume

The method assumes that you'll be cutting large trees into truck-size lengths. The total volume of the material has two parts: The volume of the tree trunks, called the base volume; and the volume of the foliage (branches and leaves). To find the foliage volume you first need to know the area of the forest. You can find this from aerial photographs, or by measuring it in the field.

The volume of each part (trunks and foliage) will depend on the types of trees to be cleared, as well as the time of year you'll be cutting them. In the following example, we'll assume that the trunk volume is 0.1 cubic feet per square foot of forest area, and

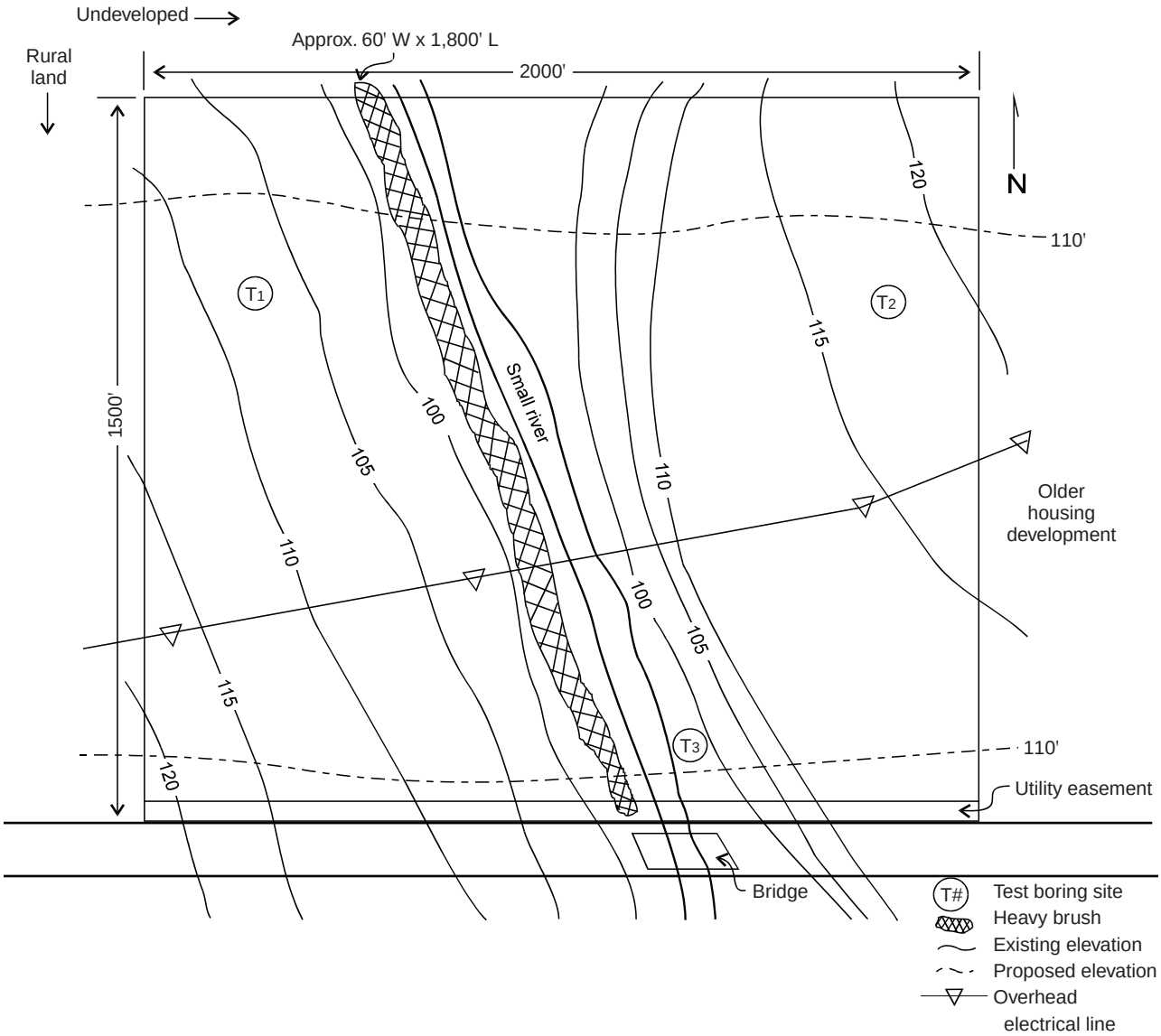

Figure 2-1
Sample earthmoving job

the foliage volume is 0.04 cubic feet multiplied by the average tree height per square foot of foliage area. These are cubic feet volumes that I've developed over time to use as constants when estimating forest volumes.

Look at Figure 2-1. We're going to use this for a sample project later in the chapter. For now, we'll use it to calculate the total volume of the forest area. The forest area shown is 1,800 feet long and 60 feet wide. Measurements taken at the site establish an average tree height of 35 feet.

The first step is to find the foliage area in square feet:

Foliage area = Width of forest area × Length of forest area
= 1,800 × 60
= 108,000 SF

Next, you need the volume of the base:

Base volume = Forest area × 0.1 CF/SF
= 108,000 SF × 0.1 CF/SF
= 10,800 CF of base volume

Now, you need the volume of the foliage:

Foliage volume = Forest area × Average tree height × 0.04 CF/SF
= 108,000 SF × 35 FT × 0.04 CF/SF
= 151,200 CF of foliage volume

Finally, you're ready to find the total volume:

Total volume = Base volume + Foliage volume
= 151,200 + 10,800
= 162,000 CF

To convert this to cubic yards, divide by 27:

162,000 CF ÷ 27 = 6,000 CY

There will be about 6,000 cubic yards of loosely packed material to haul off.

If the average tree height can't be measured directly, measure the length of the shadow cast by the tree, as well as the length of the shadow cast by an object of known length, such as a yardstick or 12-inch scale. The average tree height will be:

$$\text{Average Tree Height} = \frac{\text{Height of Scale} \times \text{Tree Shadow Length}}{\text{Scale Shadow Length}}$$

For example, let's say the shadow cast by a tree is approximately 25 feet and the shadow cast by a known 6-foot object is about 4.2 feet. The actual height of the tree is:

6 × 25 ÷ 4.2 = 35.7 feet

Subsurface Conditions

Even if you have the results of soil tests on the site, the actual conditions of the soil below the surface are really anybody's guess. Because soil testing is very expensive, most jobs don't do a lot of it.

Water running on the surface indicates underground water seeps. If the work limits are below the local water table, you'll have to pump water from trenches and excavation portions of the job. Look for unsuitable materials (soil that's unstable under load) if there are any stream beds on the site. Many developers like to build housing projects along stream beds. But in the past, these were often local dumping areas. The local governing bodies may have approved dumping old rock, dirt or other material in these areas to fill them up to the grade of the surrounding areas. If you suspect this is true about the site where your bid project is located, you may want to request additional soil boring in the area. At least add a clause in your bid covering changes in soil stability.

Existing and Imported Soil

When you've evaluated all of these variables, it's time to look at the soil itself, both the existing soil and any soil that must be trucked in. Wet and heavy soil costs more to move than dry and light soil.

Check the compaction requirements. The more compaction needed, the more time required for rollers, the more rollers needed and the bigger the rollers have to be.

If fill isn't available onsite, locate a source of suitable material close to the job. If unsuitable material has to be trucked away and dumped, find a disposal site and get it approved.

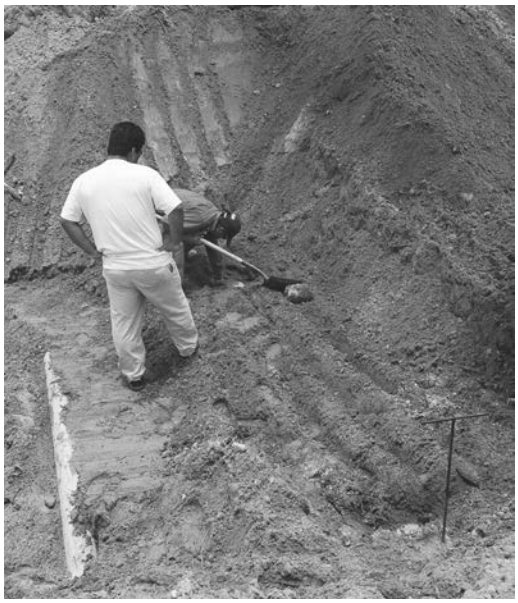

Figure 2-2
Locating existing utilities

Utilities

Try to determine if utility lines are shown in the correct location on the plans. Utility lines sometimes aren't where the plans show them. A variation of just a few feet can make a big difference in time when working in a confined area. Locating an existing line after you begin excavation can be very time consuming and labor intensive, often requiring the use of hand shovels. See Figure 2-2.

If there are existing storm or sewer lines, check the manholes for condition, material

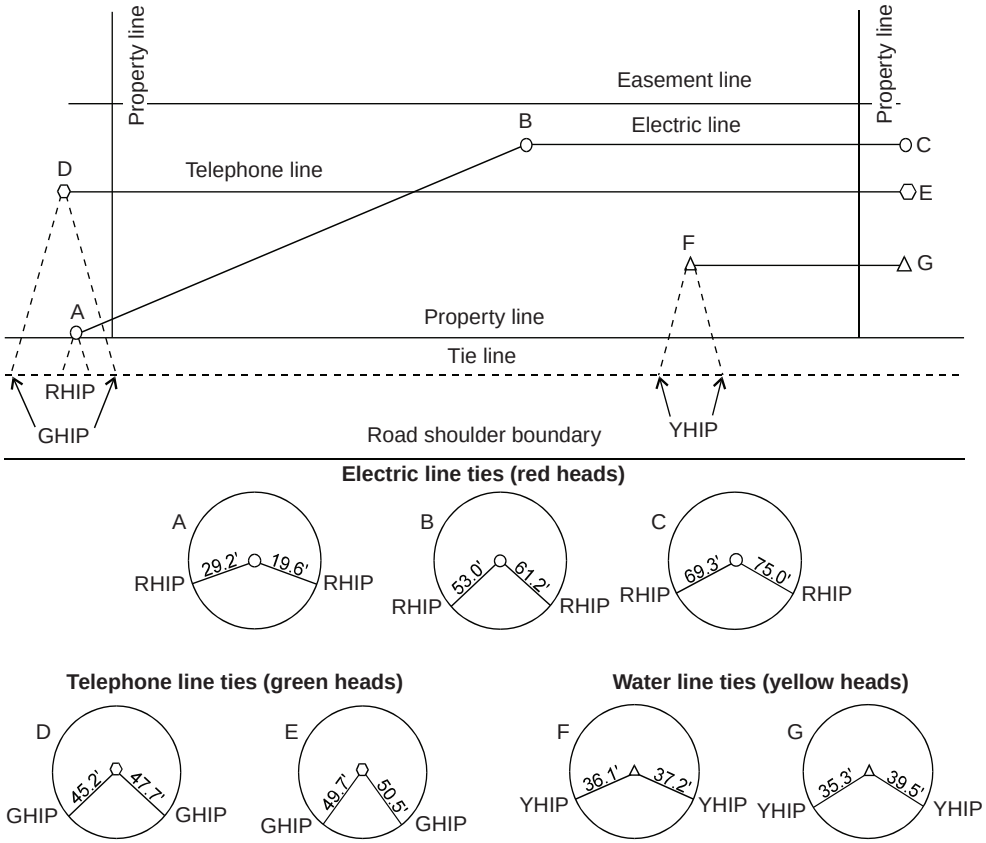

Figure 2-3
Tying down utility lines

and depth to flowline. Also check for size, direction and number of inlets and outlets in the manhole. Compare this with the plans. Check for overhead wires that would be in the way of working equipment. Will temporary electric or phone connections be needed during the construction period? If any utility lines have to be relocated, find out how much advance notice the company needs to move them. Also find out which costs or permits will be the contractor's responsibility.

When you've located the utility lines, it's a good idea to mark the location permanently. The flags used by the utility companies are likely to be destroyed or misplaced during construction. I recommend using survey-type ties to mark them. Surveyors use them to "tie down" points so they can be re-established later on.

Look at the electrical line in Figure 2-3. It starts at point A on the left at the bottom of the easement, then goes up to point B at the top of the easement, and on out in a straight line to point C. After the electrical company places flags along the line, I'd tie down only the points where the line changes direction: points A, B, and C.

All that's needed to mark the lines is a tape measure about 100 feet long, a hammer and some markers. You can make a marker by folding a 12-inch piece of colored survey

flagging over several times, until it's about 2 inches wide. Then push a concrete nail through the middle. These markers are called heads. A red marker is called a red head, green is called a green head, and so on.

To mark the first tie, stand on the road shoulder line facing point A on the electrical line. Move to the left a few feet and drive a red head in the pavement. Repeat this process by moving to the right a few feet.

Draw a circle like the one in Figure 2-3. Then measure from point A to each red head and record the distance. In the figure, the point on the left is 29.2 feet, and on the right 19.6 feet. Record these distances as well as the mark they're measured from. In this case they're both measured from a RHIP (red head in pavement). You could also place the heads on buildings or trees.

To find point A again, extend a tape measure from the left point 29.2 feet. At the same time extend a tape measure from the right point 19.6 feet. Where the two come together is point A. In Figure 2-3, we've shown the same tie-down process for the phone line using green heads and the water line with yellow heads.

Project Size

Is the site large enough to allow for all the storage room needed? Is a site office required on the plans? If so, what are the requirements? Consider whether building materials and equipment can be stored on the jobsite without interfering with the work. Finally, is there room on the site to store topsoil or unsuitable excavated material that has to be removed? Figure 2-4 shows a pile of good topsoil and several piles of shredded foliage on a project site.

Local Needs

There are several questions that will need answers if the job's in a location you're not familiar with. First, find local suppliers for rental equipment, fuel, repairs, parts and any other operational needs. Check out their policy on credit or payments. Get an agreement in writing if possible. If you plan to use local workers, are there enough qualified people readily available? What wages will they expect? Are there other projects in the area that'll be competing for labor or rental equipment?

Traffic Control

If the project will need traffic control, check with the local authorities to see what they require. Most of them spell out traffic control requirements very clearly. There are exact standards for barricades, delineators, flashing lights and other safety

Figure 2-4
Stockpiled topsoil

precautions. Some area authorities require a barricade log. That means additional labor costs to patrol and repair broken traffic control devices every day, including Sundays and holidays.

Security

If the jobsite is in an isolated location or an area with a high crime rate, you may want to hire a security company with a night watchman. Material theft, vandalism of equipment or destruction of completed work can be a major financial loss. Most of it won't be covered by insurance. That makes it a cost of doing business. Be sure that cost is included in your estimate. In high-risk situations, the cost of a fence or a security company may be small compared to the cost of repairing equipment or replacing material.

Also consider public safety. Your job will probably draw sidewalk superintendents. Everyone loves watching heavy equipment at work. Will you need protective fencing around the area? Or is there a better way to keep people out of danger? A contractor friend once discovered a blind man who'd stumbled onto his construction site, tapping his white cane along the top edge of a vertical embankment 12 feet deep. He immediately installed a fence around the entire project.

Site Visit for a Sample Project

Figure 2-1 shows a drawing for a small project. The project owner wants to install an 8-foot diameter metal culvert along the existing stream bed, using the excess material to cover the pipe and bring the area to a level grade at elevation 110. Test borings were taken at points T1, T2, and T3. There are no engineering plans or specifications except the drawing, which was prepared by a surveyor to show existing conditions. The owner added the proposed 110 elevation grade lines. If I were estimating this job, here's how I'd handle the site visit.

Prepare a List of Questions

Before going to the site, I'd prepare a short list of specific questions and get a copy of the site visit checklist. Here are some of the questions I'd include in my specific list.

A) The property borders a four-lane highway.

1. Will access be permitted onto the highway? Where? By whom?
2. Is the highway divided? If so, how far in each direction is a turnaround point or street?
3. What's the speed limit? Will trucks entering the highway be a safety problem?
4. Heavy trucks entering the site will probably damage the shoulders. What are they made of and how will we repair them when finished?
5. Will drainage pipe be needed during construction?
6. Will work be close enough to the road to require barricades?
7. Will a permit be needed to get a road right-of-way?

B) The heavy brush and trees along the western side of the creek will present several problem areas.

1. How large is the vegetation? What equipment will be needed for grubbing?
2. What kind of trees are in that area? Can they be sold for their material? Are there any firewood types?
3. It would appear that there's little or no room on the site to stockpile debris and trees. Is there a place close by? Is permit burning allowed in this area? If not, where's the closest landfill that accepts trees? In some areas, certain trees can't be burned. For example, it's illegal to burn citrus trees in Florida.

4. What is the approximate volume of trees and brush? (We did this calculation earlier in the chapter.)

C) The stream or small river itself will need to be addressed.

1. Is it a protected stream? Check with the Corp. of Engineers.
2. Could flooding during construction cause problems?
3. Can equipment cross it during the first work phase?
4. The test borings show rock possible at about the stream flowline. Inspect the entire stream bed for rock outcropping.

D) Is a silt fence required around the project? Silt fencing provides slope protection and prevents storm water from carrying sediment away from the site. It's a requirement for many projects.

E) Utility easements and lines. Contact each utility that may have lines in the area. Ask them to locate their lines prior to the site visit. Request a copy of their construction drawings in the area if they're available.

1. When I go out to the site, I make survey ties to all utility lines that have been located. That way I can relocate them if the utility company flags get destroyed.
2. I also note all the surrounding utilities and their types, and see if they look like they're in the easement. Never take anything for granted. On this project, the owner said the overhead electrical line shown on the drawing was abandoned. But what about the easement? I'd get a written abandonment notice from all utilities involved, and also check at the local Recorder of Deeds office for any other easement or restrictions that might be tied to the property.
3. During my visit, I found that there's another line on the poles that's not electrical. My investigation reveals that it's a television cable company's line. Because the electrical company said their lines were abandoned, we probably wouldn't be legally responsible for damage to the cable line. But why risk it? It's better to be a good neighbor, and save yourself time. I always try to foresee and prevent problems.

F) The test borings shown in Figure 2-5 tell me a lot when I examine them closely in the office. In the field, I'll look for evidence of past dirt work that could be a problem.

1. Two things are evident from the test borings. First, there's about the same amount of topsoil in T3 (bottom land along the river) and T1 (high ground). That indicates there's been very little flooding. Any significant flooding would have left larger deposits of topsoil near the river when the water receded.

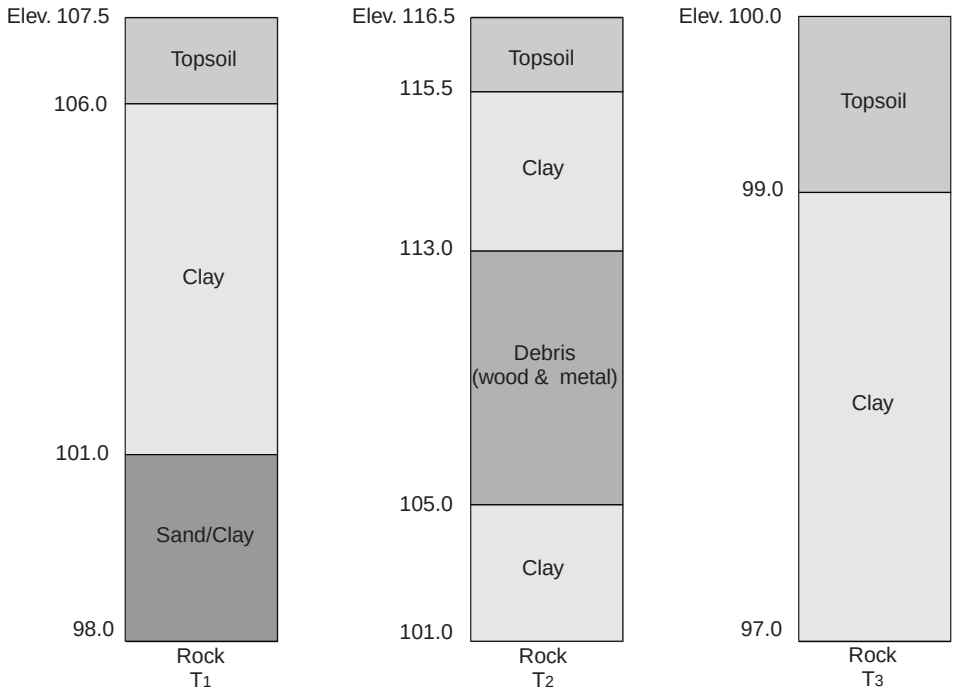

Figure 2-5
Test borings (not to scale)

2. Second, T2 shows a section about 8 feet deep with particles of wood, metal and other deleterious material. This indicates a probable dump site. The contour lines on the east side of the creek increase more rapidly than those on the west. The lack of any major vegetation and the presence of an older housing area just east of the area are good clues that the area was once used as a dumping ground. When the homes were built, it's likely that trees, building debris and other items were pushed into the valley. Then the area was covered with soil. The only way to be sure is to order additional test borings.

G) It looks like there's enough clay on the site to reach compaction requirements. A check with the company that did the borings might give me some additional soil information.

H) Check boundary line agreement.

1. At the site, I look at each boundary line, and check the field location of fences, structures, trees, and streets adjacent to the project site. If a survey has been done, I check the way the corner points line up with the surrounding property.

2. If there's a large discrepancy between the survey points and the existing evidence, I'd check with property owners to work out this problem.

In general, I look at each and every item on the plans while I'm in the field. I view each with the movement and construction work in mind so I can anticipate any problems. It's important to not overlook anything, and not assume anything. Get everything in writing that concerns any other individual or company. I always use a checklist. A copy of my version is at the end of this chapter.

Site Visit Checklist

Whenever I go into the field on a site visit, I take along two lists. The first is a list of specific questions based on the current plans and specifications, like the one we just discussed. The second is my standard checklist for site visits. Of course, my checklist may not be exactly what you need. But every estimator needs a checklist to work from. If you don't have one that works for you, start with mine, then add any items you feel need to be there. Maybe you've overlooked something once and don't want to do it again — put that on your list.

Don't Forget Overhead

On every job you have costs that aren't associated with any particular trade or phase of construction, but are the result of taking on that particular job. These costs are usually called direct (or job) overhead and can be thought of as administrative costs. They aren't labor, material, equipment or subcontract items. In fact, many direct overhead items don't show up in the plans or specs. You have to find them and price them yourself.

Direct Overhead (Field or Job Costs)

The list below includes the items that are usually included as direct overhead. My advice is to review this list before you complete every estimate. Naturally, not every job has every cost item listed below. But on most jobs, reading over this checklist will help you discover several items you may have forgotten.

- Blueprints
- Bonds (bid, completion, maintenance, street encroachment, street repair)
- Debris removal (trucking, dump fees)

- Dust protection
- Expendable tools
- Field office (storage, tool crib) and field office utilities
- Field supplies
- Insurance (worker's comp, property damage, bodily injury, fire, builder's risk, equipment floater)
- Layout and surveys
- Licenses (business license, state contractor's license)
- Mobilization and demobilization
- Moving utility lines
- Night watchman
- Permits (blasting, building, sidewalk, street obstruction, Sunday work, temporary, wrecking, debris burning)
- Photographs
- Protection of adjacent property
- Repairing damage
- Signs
- Silt fence
- Site inspection
- Supervision (superintendent, foreman, engineer, timekeeper, payroll clerk, material checker)
- Taxes (excise, payroll, sales)
- Telephone and Internet
- Temporary fencing, lighting, utilities and toilet
- Testing
- Vehicle and travel expenses
- Water (on some projects, water must be imported)
- Weather protection
- Wheel track prevention (stone construction entrance)

You can probably think of other direct overhead items. Most contractors include the cost of supervision and other nonproductive labor, such as the cost of estimating the job. In my opinion, the time you spend on each job should be charged against each

job. Other contractors include all office work under indirect overhead, even if the work relates to some particular job. I won't say that's wrong. It's just not the way I do it. The important thing is to remember that these are very real costs and must be included somewhere in every estimate. Since they're the result of taking a particular job, they fit nicely under direct overhead for that job.

Indirect Overhead (Business or Office Expenses)

Even after all job costs are compiled, there's still more overhead to include. Every business has expenses that can't be charged directly against any particular job. Here are some examples:

- Advertising
- Amortization
- Book, magazine and software subscriptions
- Car and truck expenses
- Depreciation
- Donations
- Dues
- Licenses and fees
- Maintenance and repair
- Office insurance (fire, liability, worker's comp, and hospitalization)
- Office rent
- Office utilities (telephone, Internet, water, power, gas, sewer)
- Office staff (clerical, management)
- Payroll taxes
- Pension and profit sharing
- Postage
- Principals' salaries
- Professional fees (accounting, legal)
- Stationery, copying and supplies
- Travel and entertainment
- Uncollectibles

These are all indirect overhead or office costs. They differ from direct overhead because they go on even when work in the field stops.

Controlling indirect overhead is where a small contractor can get an edge over the larger contracting companies. Big companies have fancy offices staffed with full-time personnel. It's just about impossible for them to keep their overhead low. If you can run a compact, efficient, low-overhead operation, you may have the advantage at every bid opening.

A small utility line contracting business, for example, should limit their overhead to no more than 10 percent of gross receipts. It's important for small businesses to keep their overhead low — if overhead is too high, they won't be competitive.

On the other hand, big contractors usually get the bigger jobs, which increase gross receipts. If a big contractor can manage his firm efficiently, he'll have an advantage over a smaller contractor. For example, both contractors have to purchase or rent a copy machine, but the big contractor will make more copies which reduces his per-page costs. Also, it doesn't take much longer to do a take-off on a big project than it does on a small project. The same items are usually required for either project, but the larger project has more of each item.

In the next chapter we'll continue looking at site conditions. Because the condition of the soil is so important to the estimating process, we'll do an in-depth study of soil problems and their effects on the final quantities.

Site Visit Checklist

Job No Location Date

Weather

Plans:

_____ Do the plans and drawings match what the site looks like?

_____ Are they accurate in reference to direction?

_____ Do they show the surrounding properties in degree needed?

_____ Do they show everything needed? If not list what you need.

1.

2.

3.

4.

Comments

Photos Taken:

1.

2.

3.

4.

General Specifications:

Individual Item	Agree/Not	Needs
1.		
2.		
3.		
4.		

Traffic:

_____ Is there traffic movement in or around the site?

_____ Will traffic barriers be needed? _____ Will a flagman be needed? _____ How long?

_____ Will one-way or dead-end streets affect construction?

_____ Will schools or other special zones affect construction time?

_____ Will rush hour traffic be a problem?

_____ Are there traffic counts available for busy streets?

_____ Are there restrictions such as bridges, culverts, etc?

Comments

Clearing and Grubbing:

_____ Are limits of clearing and grubbing defined? _____Are they shown on plans?

_____ Is there room for permit burning? _____Is there salvageable wood?

_____ Location of disposal area

Comments _____

_____

_____

_____

_____

_____

Utilities:

_____ Are there utilities on site? _____Do they agree with plans?

_____ Do they need to be located in field? _____Are all normal utilities accounted for?

_____ Will connections be necessary? If so, which ones?

1. _____
2. _____
3. _____
4. _____

_____ Will relocation be necessary? If so, which ones?

1. _____
2. _____
3. _____
4. _____

List name, phone for each utility company

1. _____
2. _____
3. _____
4. _____

_____ Will temporary service be needed? If so, which ones?

1. _____
2. _____
3. _____
4. _____

_____ Are utilities that will be needed during construction near the site?

Comments _____

_____

_____

_____

_____

_____

Drainage:

_____ Is there drainage across property now? _____Is it taken care of in plans?

_____ Will drainage increase or decrease when project is completed?

_____ Will flow need to be continued during construction?

_____ Will temporary structures be needed? _____ Are private easements involved?

Comments

Sanitary or Storm Sewer:

_____ Are there any sanitary or storm sewer lines on the property?

_____ Are they to be saved? _____Are they to be removed?

_____ Will continuous flow need to be maintained?

_____ Will connections need to be made? If so, to which ones, how?

1.

2.

3.

4.

_____ Inspect all manholes, drop inlets or other structures. Note size, structure type, materials, depth, number of inlets and outlets, their locations, and approximate flow.

_____ Will an additional right-of-way or easement be needed to make connections or ties?

Comments

General Appearance:

_____ Does general layout fit plans and surrounding area?

_____ If dry period, is area dry? _____Are wet spots apparent?

_____ Will noise be a problem to surrounding neighborhoods?

_____ What about pedestrian safety? _____Parking area for workers?

_____ Does the type of topsoil, and or vegetation match that shown on the plans?

Miscellaneous comments

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3

Properties of Soils

Geology, the study of the Earth's history and especially its rock crust, is important to every earthwork estimator. Of course, there's no way to cover the details of such a technical subject in one chapter — and you really don't need to be a soils engineer to estimate earthwork — but you do need to understand some basic principles about soil and rock.

So, in this chapter we'll discuss how different traits — stability, compaction, moisture content, drainage and soil movement — affect the final quantities on earthwork projects. They determine what type of equipment you'll use, how long the job will take, and the working rules that'll apply. To understand those traits, you need a little background on the makeup of the materials you'll be dealing with.

Soil Classifications

Classifying soil is a difficult and highly technical problem. All soil is a combination of one or more classifications. While all soils run in layers, the actual makeup of each layer can vary widely. For instance, one location may have a mixture of 60 percent clay and 40 percent sand. In a similar location, the soil might be 20 percent clay and 80 percent sand. That's why it's important to get all the information you can about soil conditions in your project area.

Your best source of information about soil conditions in a given area is probably the local American Soil Conservation Service (ASCS) office. They're located throughout the country, usually several in each state. Check the Internet for the Soil Conservation

Service in your area or look in your local phone book under the Federal Government pages. Your local office should have a book showing the limits and makeup of the individual layers, and some information about water runoff and slope stability.

For example, there's a soil called Knox in northwest Missouri. We don't know the origin of the name, although it was probably named after the person who first identified it. This soil has very distinctive characteristics, including the ability to stand almost vertical without eroding. There may be similar soil in other areas with a different name. And there may be soil called Knox in another state with totally different characteristics. So don't rely on what you think you know about soil types. Always get and use local soil information. Use the descriptive list of soil types following as an introduction to the subject.

1. *Bedrock* is sound hard rock in its undisturbed state. It's in its native location and is usually massive in size.
2. *Weathered rock* is rock that has weathered to the stage between bedrock and soil. It'll have seams, and is often broken up into small deposits with soil in the seams.
3. *Boulder*s are fragments of rock that have broken off of the bedrock. Anything over 10 inches in diameter is called a boulder.
4. *Cobbles* are smaller rock in the 2-inch to 10-inch size range.
5. *Pebbles* are even smaller, ranging from 1/4 inch to 2 inches in size.
6. *Gravel* is a mixture of small rock particles ranging from 1/4 inch up to 6 inches in size.
7. *Pea gravel* is a mixture of particles 1/4 inch or less in size.
8. *Bank run gravel* is a mixture of sand and gravel that's excavated directly from the earth's surface.
9. *Sand* is small rounded particles of weathered rock. It's usually graded into fine, medium or coarse sizes.
10. *Silt* is made up of very fine particles of rock, often having the texture of baking flour.
11. *Clay* is made up of very fine particles of inorganic material.
12. *Hardpan* describes many different mixtures of gravel, sand, and clay that have a hard texture.
13. *Till* is a mixture of sand, gravel, stones, silt, and some clay.
14. *Caliche* is a mixture similar to till, only it's held together by desert salts, such as calcium carbonate.

15. *Shale* is a soft gray stone-like substance.

16. *Loam* is a mixture of sand, silt, or clay and organic matter. Another name for this is topsoil — because if there is any topsoil on an undisturbed site, it'll be on the surface.

17. *Adobe* is a heavy clay.

18. *Gumbo* is a fine claylike mixture.

19. *Mud* is a mixture of various earth materials and water.

20. *Peat* is partly-decayed organic material.

21. *Muck* is a mixture of organic and inorganic material.

22. *Loess* is a silt-like material that occurs in small deposits where it was carried by blowing winds.

Soil Moisture Content Affects Project Costs

The moisture content in soil is a critical point for the estimator. Dirt that's too dry or too wet requires additional handling with expensive equipment and labor. That raises the cost per cubic yard. On large jobs, you'll probably have the results of soil tests. On smaller jobs, there may be little if any data available. Here you're playing with fire. Surprises are inevitable, and they won't be pleasant or cheap. Where you don't have data, take the time to investigate all available sources for information on the area. Here are some additional places you can get information:

1. Check with local residents. Do they have any information on water tables? If they've farmed the area, how did the soil react?

2. Contact the local county or city engineer. See if they have soil tests from areas near your project.

3. Contact local utility companies. From burying their utility lines, they may know if there are problem areas.

4. Check with local engineering firms, especially any that specialize in soil engineering.

5. Check the project site for clues to the amount of water in the area. Swampy areas, lakes or streams indicate high moisture. Lush growth of trees, grass or other vegetation also shows moisture. Lack of vegetation, barren ground, or sand indicate a lack of moisture in the area.

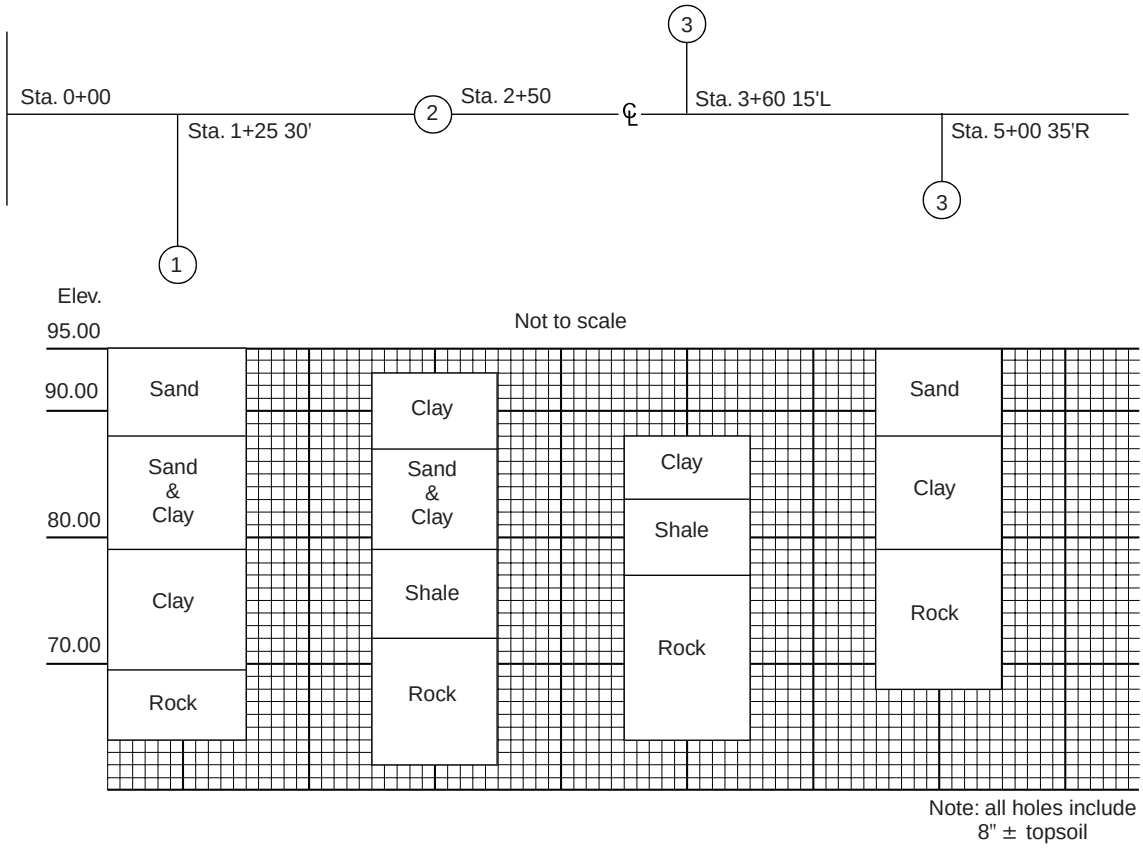


Figure 3-1
Boring log

Pre-Construction Field Testing

Testing by soil engineers is expensive. That's why there will be plenty of information available on large jobs, but little or no data for small jobs. Let's look at how to understand and use the information you're able to gather about the jobsite.

Until the actual excavation starts, there's no way to know for sure what's under the surface. To make educated guesses, soil engineers drill boring holes at specified locations throughout the site. They auger a hollow pipe into the ground and remove samples of the soil or rock they encounter. After recording the depth of each layer of material in a boring log, they send it off to a lab to be classified.

Figure 3-1 shows a boring log. There's a project layout on the top of the page showing the locations of the boring holes. The rest of the page shows the actual elevations and depths of the soil and rock specimens removed from the boring hole. While this method doesn't always identify all of the soils on the site, it's the best information

Soil type	General appearance	Cast		Ribbon
		Dry	Wet	
Sand	Granular appearance, free flowing when dry.	N	Y	N
Sandy loam	Granular soil; mostly sand mixed with some silt and clay, free-flowing when dry.	Y	Y	N
Loam	Uniform mixture of sand, silt, and clay; gritty to the touch, somewhat plastic.	Y	Y	N
Silt/loam	Mostly silt mixed with some sand and clay; may have clods, but clods are easily crumbled to a powder.	Y	Y	N
Silt	Contains at least 80% silt particles; has clods that grind to a very fine, flour-like powder.	Y	Y	Y
Clay/loam	Fine textured soil, more clay than in silt loam (see above), may be lumpy; when dry resembles clay (see below).	Y	Y	Y
Clay	Fine textured soil, large masses may be broken into smaller very hard lumps, but does not pulverize well or easily.	Y	Y	Y
Organic soils	Soil lacks any discernible structure, consists of plant fiber and decomposed organic matter, muck and peat included.	N	N	N

Figure 3-2
Fill classification of soils

available on the typical job. There could be small deposits of foreign material on the site between the test holes. But most soil layers cover a relatively large area, so engineers can estimate the approximate locations and size of the various soil layers.

In most instances the borings will show that there are layers of different soil types, one on top of another. Each of these soil types will behave differently when wet or when handled in a specific way. The chart in Figure 3-2 shows how to identify the various soils in the field, under both wet and dry conditions. The column headed Cast on the right, indicates the tendency of the soil to retain its shape after it's squeezed in the hand. *Ribbon*, in the next column, shows the ability of a soil to be rolled out into a ribbon or "worm" using the palm of the hand on a hard surface.

Soil Stability

Engineers study soil makeup to learn about the stability of each type of soil. Will it distribute the building load evenly? Will it stand or slide when formed into a slope? This is just as important to the estimator as it is to the engineer. How well a particular soil will stand on steep slopes determines the type of equipment you'll use and how you'll

Safe Bank Slopes	
Soil or Rock Type	**Maximum Allowable Slopes (horizontal:vertical)**
Stable Rock	Vertical (90 degrees)
Type A Soil	¾:1 (53 degrees)
Type B Soil	1:1 (45 degrees)
Type C Soil	1½:1 (34 degrees)

Figure 3-3
Maximum allowable bank slopes

move and place fill material. This is especially important where deep trenching is required. Figure 3-3 shows recommended bank slopes for various soil types. The soil types are classified as follows:

- Type A soils include clay, silty clay, sandy clay and clay loam. Cemented soils, such as caliche and hardpan, are also considered Type A.
- Type B soils include angular gravel (similar to crushed rock), silt, silty loam and sandy loam.
- Silty clay loam and sandy clay loam don't fit neatly into either classification, so you might see them classified as either Type A or Type B, or both.
- Type C soils include gravel, sand, loamy sand, wet soil from which water is seeping, or submerged rock that's unstable.

Soils with a variety of layers are generally classified based on the weakest layer, but each layer may also be classified individually. If the soil is unstable, you'll have to plan for shoring or for lining the trench walls. Get as much information as possible before you begin your estimate, because building these supporting structures sometimes requires the skills and equipment of a specialized subcontractor.

Site Samples

When you do the site visit, be prepared to take some samples. Take along a small shovel, a large spoon, water, and a piece of thick glass about 6 inches square. If there are creeks on the site, how has the water affected the creek banks? Banks that are straight up and down indicate good stability. If they're sloped, is the degree of slope uniform throughout the site? If not, there may be a layer of unstable material. Keep an eye open for anything that suggests unstable soil. Are there visible seams that show different soils? Look for crumbly material or shale, which is less stable than clay.

Find a spot along the creek where the topsoil level is easily accessible, or dig a hole down through the topsoil. The topsoil is usually a dark, fine-grained material. When it's moist you can roll it into a ball between your palms. But if you keep rolling it, it will soon dry out and crumble.

Take a sample of each separate layer you encounter and try to roll a ball with each layer. Add a little water if the sample is too dry. The most stable materials will stay compacted in a ball even with continuous rolling.

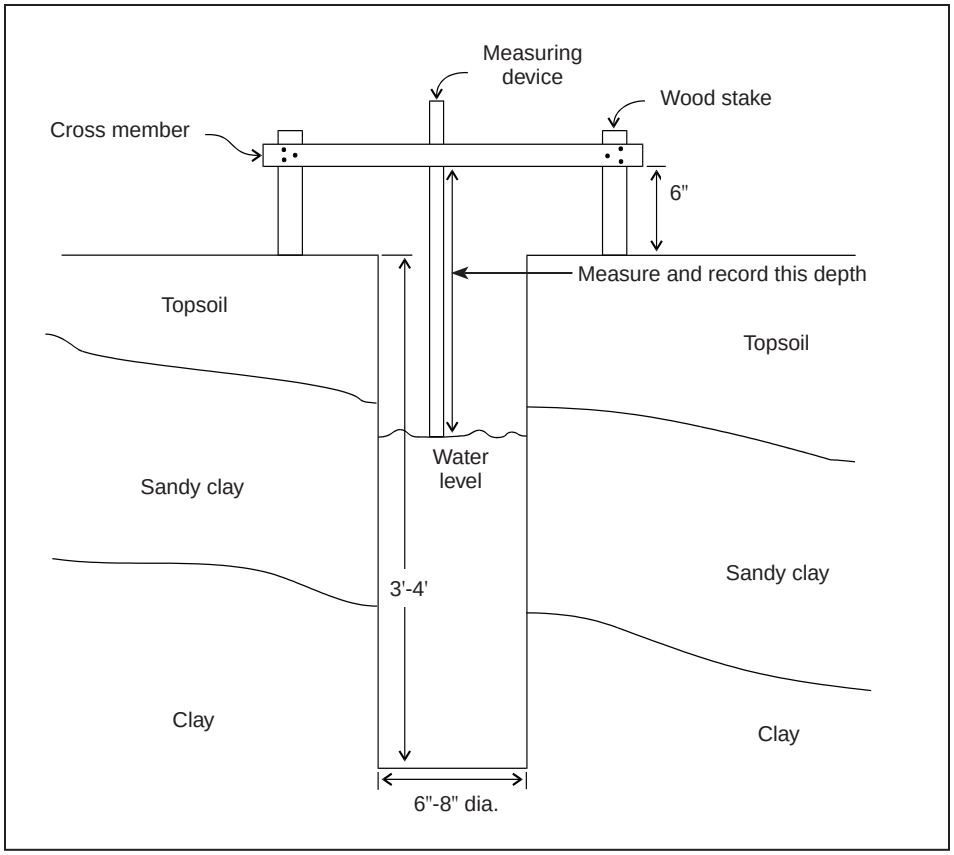


Figure 3-4
"Perc" test setup

Soil is more stable and compacts better when it has the ability to cling together. This characteristic is called plasticity. There's a simple test you can do to get an idea of how plastic the soil is. Take a small ball of the material and wet it until it's almost saturated. Place the ball of soil on the glass. Start rolling it back and forth, making a worm out of the material. Move it back and forth till you have a worm about 5 inches long. Cut it into two or three pieces, then roll the pieces back into a ball and repeat the process. If you can make the worm again, cut it, and reroll it several times, you have a soil with good adhesive abilities.

Easy Percolation Test

Engineers run a percolation test to find out if soil can handle sewage discharge from private septic lines or effluent from large treatment plants. During your site visit, you can perform a simple version of this test that yields a good indication of soil characteristics. Figure 3-4 shows the setup.

Dig a hole about 6 to 8 inches in diameter and 3 to 4 feet deep. Record the depth and type of soils you encounter. Perform the ball-rolling test I described earlier on a small sample of material from the bottom of the hole. Then place a stake on each side of the hole and nail on a cross piece, as shown in the illustration. Fill the hole with water to just below the start of the topsoil layer. Measure and record the distance from the cross member down to the water line. After one hour, measure again and record the distance from the cross member to the water line. Repeat the process at two, four, and 24 hours.

This isn't an exact test, but it stands to reason that if the water disappears from the hole in the first hour or two, the soil is very porous. If it disappears in four hours, it's probably porous but with some stability. If there's still water in the hole after 24 hours, the soil is probably clay or some other material that compacts well. Notice I said probably. Maybe there's a high water table, or a layer of rock that prevents the water from draining off quickly.

Of course, the more holes you dig, the more likely you'll get meaningful results. You can't depend on the results of this test alone, but if you combine all the bits and pieces of information you can get together, you should be able to draw a fairly accurate picture of the existing ground conditions.

Soil Testing in the Lab

Soil testing is a quantitative quality control method for compacted fill materials. It's the designer's job to prescribe and monitor soil testing. The most commonly specified soil tests for commercial building construction are:

- Liquid limit, plastic limit and plasticity index
- Unified soil classification
- Moisture-density relations
- In-place (field) density tests

Fine-grained soils are classified based on their compressibility or plasticity, and fall into one of four "limit" categories: liquid, plastic, semi-solid, and solid. The *liquid limit* is the point where soil goes from a stable adhesive soil to a liquid. The *plastic limit* is the opposite — the point where it goes from a stable adhesive soil to a semi-adhesive and crumbly soil. To compact well, soil has to be between these two limits. There are tests to determine the liquid and plastic limits of soil.

Liquid Limit

One way to determine the liquid limit of soil is with a liquid limit test cup, like the one shown in Figure 3-5. To perform the test, a moistened soil cake is placed in the

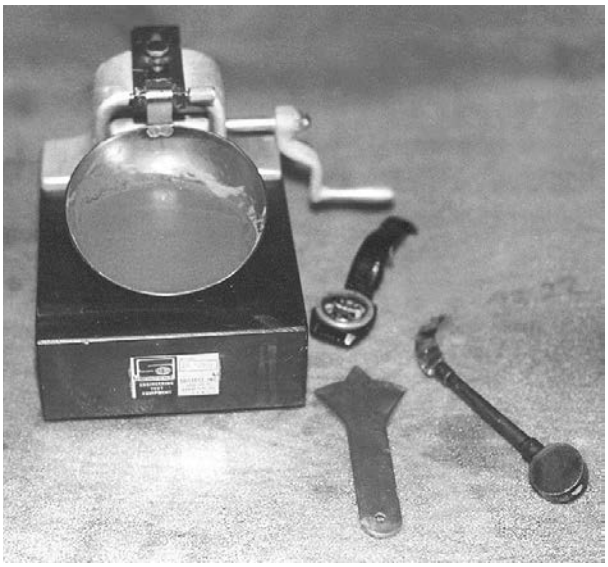


Figure 3-5
Liquid limit test cup and grooving tool

cup, and split into two pieces with a grooving tool. The cup is then repeatedly dropped a distance of 1 centimeter, until the two halves of the soil cake flow back together along the groove. Through trial and error, by adding or removing moisture, the liquid limit is achieved when 25 blows to the cup (at two blows per second) cause the soil to run back together. At that point, the sample is immediately weighed, dried, and weighed again. To put liquid limit into percentage terms, divide the moisture weight at the liquid limit by the dry sample weight, and then multiply that outcome by 100 percent. In this case, the moisture weight at the liquid limit equals the wet sample weight minus the dry sample weight.

Plastic Limit

The plastic limit test (also known as the *worm test*) determines the moisture content level at which soil changes from a plastic to semi-solid state. Basically, that's when a soil sample begins to crumble as it's rolled into a $^1/_8$-inch-diameter thread (resembling a worm). Calculating plastic limits in percentage terms is the same as calculating the liquid limit: Divide moisture weight at its plastic limit by the dry sample weight, then multiply the result by 100 percent.

Plasticity Index

The *plasticity index* (P/I) of a given soil is the difference between the soil's plastic and liquid limits. The plasticity index is an indication of the soil's clay content and its moisture-retaining capabilities. A large plasticity index indicates high clay content, resulting in an increased ability to retain water. High clay content implies a greater tendency for the soil to swell when wet, and shrink when dry. As a general rule, soils with a plasticity index greater than 15 are considered "troublemakers."

The Unified Soil Classification System

The Unified Soil Classification System (USCS) is the test method most widely used for construction and engineering purposes. Each soil is given a two-letter designation, with the first letter describing the major soil constituents and the second letter describing the soil's gradation or plasticity (*compressibility*). The five basic soil constituents and their abbreviations are: gravel (G), sand (S), silt (M), clay (C), and organic matter (O). For this test, *gravel* is rock-like material whose particle sizes range from 3 inches (76.2 mm) to 0.08 inches (2.03 mm). *Sand* ranges from 0.08 inches to 0.0029 inches (0.076 mm), and *silt* ranges from 0.0029 inches to 0.00024 inches (0.006 mm). *Clay* particles are 0.00024 inches and smaller.

The term *clay* is used to define both mineral-type and particle size. In terms of mineralogy, clay is a hydrated aluminum silicate mineral. There are roughly a dozen distinct clay minerals. Clay minerals are composed of flat layers of molecules arranged like pages in a book. Water can get between these molecular layers, increasing the distance between them, which is why clay expands when it gets wet. If a small quantity of water gets between the layers, the water molecules chemically bond to the atoms in the clay mineral. This causes soils containing clay to stick together. However, excessive moisture causes more than one layer of water molecules to form between each clay layer, making the layers prone to sliding past each another. That's why clay (and soil containing clay) is "slimy" when fully saturated with water.

In terms of particle size, any material composed of particles less than 0.006 mm is referred to as clay. Calcite, quartz, garnet, dolomite, feldspar, pyrite, mica, wood chips, spores, and volcanic ash (all non-clay materials) have been found to be within the clay size dimension. These relatively inert clay-sized particles aren't actually expansive clay minerals. Consequently, knowing the percentage of clay-sized particles alone is of little value when determining the expansiveness of the soil. Since the smallest sieve available in a soil testing lab is a No. 200 (0.0029 inches, or 0.075 mm net opening), the clays can't be separated from silts in a soil analysis. You need to know the soil's plasticity index when determining its expansive behavior.

Here's a quick and (literally) dirty way to determine if a soil has high clay content: Roll a moist sample of the soil into a ball approximately 1 inch in diameter, and throw it against a wall. If the soil has high clay content, the soil ball will stick to the wall like a paper spit wad. Highly scientific.

The second letter in the USCS two-letter naming system generally relates to a soil's gradation or plasticity (compressibility). Abbreviations used to describe gradation and plasticity include: well-graded (W), poorly-graded (P), low plasticity (L), and high plasticity (H).

Organic matter, represented by the *prefix* (O), is partially-decomposed vegetable matter which will continue to decompose with time. The decomposition will create troublesome voids in the soil, so organic matter must be removed from soil prior to compaction. Organic material can be identified by color and odor, or by a radical reduc-

Figure 3-6
Sieve shaker

tion in the plastic and liquid limits after drying. Soil containing a large percentage of fibrous organic matter is classified as peat, and given the symbol (PT).

Grading Soil Particles

The purpose of soil *grading* is to determine grain-size distribution in the soil. To determine how well-graded a soil sample is, all cobbles (particles greater than 3 inches in diameter for this test) are removed and the material is washed to remove organic matter. Then the sample is dried and passed through a series of sieves, starting with a 3/4-inch sieve, and ending with a No. 200 (much finer) sieve. The sieves are linked together (racked) with the 3/4-inch sieve on top, the No. 200 at the bottom, and intermediate sizes in between. A catch pan, placed below the No. 200 sieve, collects particles small enough to pass all the way through. After pouring the sample into the rack, the unit is placed into a shaker for between 12 to 15 minutes. See Figure 3-6.

After shaking, the sieves are removed, one at a time, from top to bottom, starting with the 3/4-inch sieve. The contents of each sieve is weighed and recorded.

To calculate grain-size distribution, the weight of the soil retained in any given sieve is divided by the total dry sample weight.

Coarse-Grained Soils

If less than 50 percent of the total sample passes through the No. 200 sieve, the soil is said to be *coarse grained*. If 50 percent or more of a coarse-grained sample passes the No. 4 sieve (4 net openings per square inch), it's classified as sand, and will be given the *prefix* S. If less than 50 percent passes the No. 4 sieve, the soil is classified as gravel, and is given the *prefix* G.

If less than 5 percent of the total coarse-grained sample passes the No. 200 sieve, it's classified as *well-graded* (*suffix* W) or *poorly-graded* (*suffix* P), depending on grain-size distribution. If more than 12 percent of the total coarse-grained sample passes the No. 200 sieve, the soil is classified as silty, or clay-like. If the portion of the coarse-grained sample passing the No. 200 sieve falls between 5 and 12 percent, it requires dual classification, such as GW-GM or SP-SC.

If the portion of the sample passing the No. 40 sieve exhibits little or no plasticity (or compressibility), it will be classified as silty and will be given the *suffix* M. If it exhibits plasticity, it will be classified as *clay-like* and will be given the *suffix* C.

Symbol	Description	Stability as Construction Material
Coarse-Grained Soils (Less than 50% pass No. 200 sieve)		
GW	Well-graded gravel	Excellent
SW	Well-graded sand	Excellent
GP	Poorly-graded gravel	Excellent to good
SP	Poorly-graded sand	Good
GM	Silty gravel	Good
SM	Silty sand	Fair
GC	Clayey gravel	Good
SC	Clayey sand	Good
Fine-Grained Soils (50% or more pass No. 200 sieve)		
ML	Low-plasticity silt	Fair
CL	Low-plasticity clay	Good to fair
OL	Low-plasticity organic	Fair
MH	High-plasticity silt	Poor
CH	High-plasticity clay	Poor
OH	High-plasticity organic	Poor
PT	Peat or organic	Unsuitable

Figure 3-7
Unified Soil Classification System symbols and descriptions

Notice that the words "prefix" and "suffix" have been used in conjunction with the classifications. These are important differentiations.

At this point in the discussion, the soil classification symbols in Figure 3-7 should be making sense to you.

Fine-Grained Soils

If more than 50 percent of the total sample passes through the No. 200 sieve, the soil is said to be *fine grained*. Fine-grained soil ratings, with regard to silty or clay-like classification, are the same as those for coarse-grained soil.

If the liquid limit of the sample passing the No. 40 sieve is less than 50 percent, the sample is considered to have *low compressibility*, and is given the *suffix* L. If the liquid limit is 50 percent or greater, the soil is considered *highly-compressible*, and is given the *suffix* H.

Granular soils are generally sands and gravels that are held in position by friction between the contact surfaces of the particles. When they're wet, granular soils can be formed into different shapes, but they'll crumble into separate easily-identified particles when dry. Granular soils are considered by the American Association of State Highway and Transportation Officials (AASHTO) to be Type G or S soils.

Cohesive soils consist primarily of silts and clays held together by molecular attraction (the same force that causes water to adhere to your skin). Cohesive forces are strong, even when the soil is dry. Cohesive soils are considered by the AASHTO to be Type A soils.

Compaction Fundamentals

Compacted soil reduces water penetration, thereby controlling water flow and drainage. Without compaction, voids (pockets of air) between soil particles allow moisture to enter and exit, which causes soil swelling and shrinkage — a problem that's compounded if the water freezes. Over time, poorly compacted soil tends to settle, along with any structure built on it. A settling foundation or slab will eventually cause walls, ceilings and floors to crack and doors to become out-of-plumb and bind. In extreme cases, settling can lead to structural failure. Sometimes, the only remedy is to demolish the entire structure, replace and properly compact the fill, and then rebuild. For that reason, it's imperative that the soil be compacted properly before any construction begins.

Compaction Testing

Probably the single most important soil property is its density after compaction. As we discussed, soil is made up of many particles of different sizes. The closer together these particles are, the more stable the soil. After the engineers have classified the type of soil and the load-bearing needs of specific areas within a project, they can calculate the required density of the soil for each area. The required density is the degree to which a soil needs to be compacted in order to support the anticipated loads imposed on structural areas. This requirement is usually expressed as a percentage of the maximum compaction that can be obtained in a soils lab, with 100 percent representing that maximum.

We'll discuss this "percentage" in more detail later in this chapter. The percentage obtained in a soils lab will be used as a density "benchmark" for the compaction required in the field throughout the project. The two most widely-used tests for determining the percentage for most projects are the Standard Proctor Test and the Modified Proctor Test, both developed in the early 1930s by R.R. Proctor, a field engineer for the City of Los Angeles.

Figure 3-8
Mechanical Modified Proctor Test

The Standard Proctor Test

The Standard Proctor Test is also known by either the American Association of State Highway and Transportation Officials (AASHTO) test designation T99-70, or the American Society of Testing Materials (ASTM) test designation D-698. When undergoing a Standard Proctor Test, the fill material sample is crushed finely enough to pass through a $^3/_4$-inch sieve. The soil is then placed into a cylindrical steel mold, 6 inches in diameter and 7 inches deep, in three separate layers, or lifts. Each lift is compacted by 25 blows from a 5.5 pound, 2-inch-diameter hammer falling from a distance of 12 inches. The total energy imparted to each cubic foot of soil during the Standard Proctor Test is 12,375 foot-pounds. This test is usually specified for fill material placed under buildings, sidewalks, utility trenches, and landscape areas.

The Modified Proctor Test

A Modified Proctor Test (AASHTO 180-70 or ASTM D-1557) is used to test fill material for areas that will carry heavy loads, like highways, airport runways, and so on. The modified test uses the same cylindrical mold, but the material is placed in the mold in five lifts instead of three, and each lift is compacted 25 times with a hammer weighing 10 pounds, mechanically dropped from a height of 18 inches. See Figure 3-8. The energy imparted to each cubic foot of soil during the Modified Proctor Test is 56,250 foot-pounds.

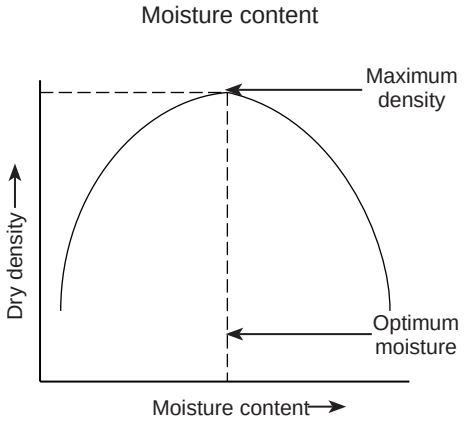


Figure 3-9
Moisture density curve

Both Proctor Tests are first run on soil that's relatively dry. Water is then added to the sample and the test is repeated at least three times until compaction reaches its maximum, and then begins to drops off. Figure 3-9 is a moisture-density or Proctor curve. It shows the relationship between moisture content and dry density. Dry density is the soil's dry weight, which is constant. Its wet weight varies. Optimum moisture content is the point at which you can achieve maximum soil density for a given compaction effort. Most tests peak at about 90 percent with a moisture

content of about 8 percent. However, depending on the compaction effort used in the field, there are times when a soil can be compacted to more than 100 percent of that obtained in a lab.

Calculating Dry Density

The procedure for determining dry density is performed with at least three samples with varying moisture levels, from little water to too much water. The results are then plotted on a moisture-density curve, as dry density (in pounds per cubic foot) versus moisture content (as a percentage of dry sample weight). The optimum moisture content is the moisture content expressed as a percentage of dry sample weight that produces the greatest density under standard laboratory conditions.

All Proctor curves will show a well-defined peak. That peak indicates the maximum density for a given compaction effort at a certain moisture content. This condition is known as the point of optimum moisture. Soil that's too wet or too dry must be brought into this range by adding water to dry material or drying out wet material. For most soil, that means adding water or drying it until the moisture content is about 8 percent.

For any given soil type, the optimum moisture content decreases and the maximum dry density increases as compaction effort increases. Each soil behaves differently with respect to maximum dry density and optimum moisture content. Therefore, each soil type will exhibit a unique control curve.

Too little or too much water reduces soil density. Too little water creates friction between soil particles and prevents them from sliding into a more compacted condition. Too much water causes soil particles to float out of the voids. That's why quicksand can't be compacted. Quicksand is fine sand or silt through which water is moving upward with enough pressure to prevent the grains from settling into firm contact with one another.

The moisture content of the soil may vary a great deal, even within one project. Different soils have different water-holding capabilities. For example, sand will require less moisture than loam in order to obtain good compaction. The elevation, amount of shade, weather, and many other factors make it possible to have moisture contents ranging from 2 or 3 percent to 20 percent or higher in different areas on a site. When these soils are mixed together during construction, it's difficult to estimate the resulting moisture content. It takes an experienced superintendent and good machine operators to make the job run smoothly. They can tell by the feel of the soil as they roll it between their palms and the way their machines respond just what kind of material they're working with.

The amount of moisture in soil plays an important part in the compaction process. That's why you need to understand the reaction of soil and water when they're mixed together.

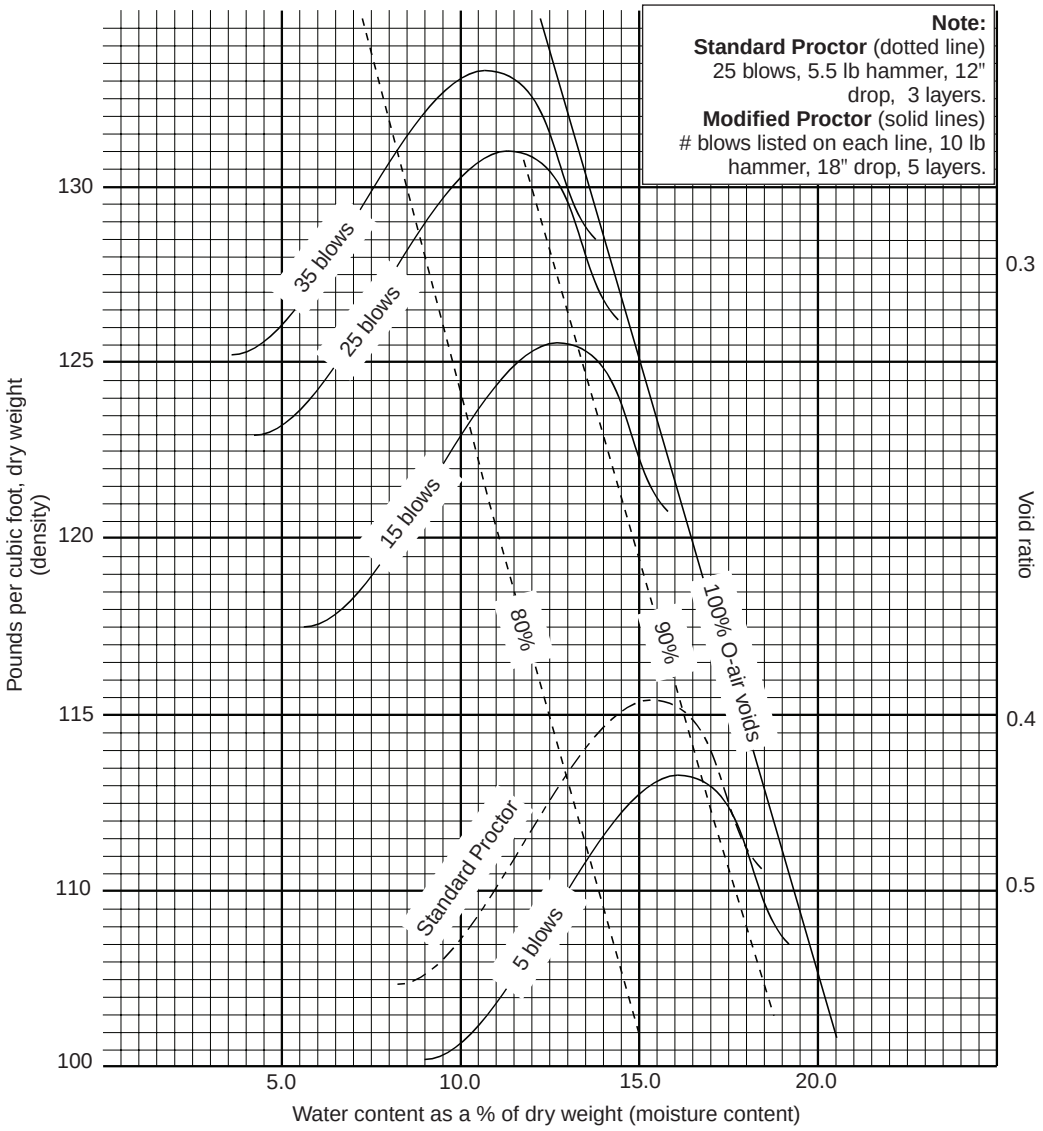


Figure 3-10
Compaction test diagrams

To reach the required compaction you must control both the moisture content and compaction effort. Look at the five curves on the graph in Figure 3-10. The dotted curve represents the Standard Proctor Test. The four solid curves represent more extensive compaction efforts, showing different moisture and density information for the same soil sample (silty clay). The unit dry weight on the left side represents the density. It's expressed in pounds per cubic foot. Moisture is shown as a percentage of dry weight. Note: when you increase the impact effort, less moisture is required to attain maximum density. The void ratio on the graph is a complex soils-engineering subject and is of little concern for the estimator. However, because it's useful to have some knowledge of void ratios so you can communicate with a soils lab, I've provided a short discussion on the subject a little later in the chapter.

When running either version of the Proctor test, a noncompacted portion of the moistened soil sample is set aside and weighed, and then oven-dried and reweighed to obtain the wet and dry sample weights, respectively. Subtracting the dry sample weight from the wet, you'll get the water weight, which is then used to calculate moisture content. Moisture content is the sample's water weight divided by the dry sample weight. To convert the moisture content figure into a percentage, multiply it by 100.

The next step toward calculating dry density is to determine the compacted sample's dry weight. To do that, the compacted sample's wet weight is divided by the moisture content percentage plus 1. When the dry weight is established, it's then divided by the compacted soil volume. The result is dry density in pounds per cubic foot (pcf).

Let's use real numbers to help illustrate how the whole calculation works. Assume the noncompacted wet sample and dry sample weights are 300 grams and 280 grams respectively, and the compacted wet sample is 4.3 pounds with a 0.033 cubic-foot volume. The water weight is 20 (300 – 280) grams. Dividing the water weight by the dry sample weight yields 0.071 (20 ÷ 280 = 0.071), or 7.1 percent for the moisture content. That means that the compacted sample dry weight is 4 (4.3 ÷ 1.071 = 4.014) pounds. Therefore, the dry density equals 121 pounds pcf (4 pounds ÷ 0.033 cubic feet of compacted soil volume = 121.212).

Specifications require that in-place soil density (density of fill material in the field) be within a certain percentage of the maximum dry density obtained in the testing laboratory. The percentage requirement depends on soil type, location, and intended use. Soil placed as fill in a grassy area is usually specified at 85 percent of maximum dry density. Soils under building slabs and sidewalks are usually specified at 90 percent of maximum dry density for cohesive soils or 95 percent of maximum dry density for noncohesive soils.

Let's say the specifications require compaction in the field to be within 95 percent of Standard Proctor range when the maximum dry density is found to be 115 pcf. To determine the dry density required, multiply the maximum dry density (115 pcf) by 0.95, which equals 109.25 pcf.

If you know the in-place soil density, you can work the problem in reverse to calculate the degree of compaction, using the soil's maximum dry density. Simply divide the in-place density by the maximum density. Using figures from the previous example, this would be 109.25 pcf divided by 115 pcf, which equals 95 percent.

The Void Ratio

We've been focusing on the Proctor Test to measure soil compaction, but there's another way to express density: the void ratio. The fewer the number of voids the soil contains, the more dense the material. If you're curious, try this experiment. Fill a water glass to a certain mark with marbles, and then add water up to the level of the marbles. Remove the marbles, and measure the water. Then fill the same glass to the same point with sand, again adding water to the same level. Remove the sand, and measure the water. There'll be a lot less water remaining in the glass with the sand than there was when it held marbles. Why? The sand particles are smaller and closer together, so there's less space (voids) between them than there is between the marbles.

Figure 3-11
Nuclear meter and sand cone test

For the same reason, a mixture of several different types of soil will usually compact tighter than each of the separate soils would compact on their own. The mixture will allow fewer voids.

Field (In-Place) Soil Density Testing

The most accurate (and convenient) way to determine in-place soil density and moisture content is with a nuclear density gauge (nuclear meter, ASTM 2922). To perform this test, a steel stake approximately $^5/_8$-inch in diameter is driven into the compacted soil with a hammer, and then removed. The gauge's probe is then placed into the hole, where it emits gamma radiation. The radiation is partially absorbed by the soil, while the remainder is transmitted to the gauge, where it's measured. Denser soils absorb a higher percentage of the radiation. A second counter on the gauge determines soil moisture content. An advantage to using a nuclear testing gauge is that it leaves the soil undisturbed. Nuclear testers can also be used to determine the density of asphalt paving.

There are several methods that can be used to determine the weight and volume of a small amount of soil extracted from a hole excavated from a fill area. To determine the weight, simply weigh the extracted soil. To determine the volume, material can be poured into the excavated hole and measured. If the soil is impermeable, water can be poured into the hole from a container of known volume. If the soil is porous, you can line the hole with plastic wrap before filling it with water. Or, you can use fine sand instead of water. The test involving the use of sand is referred to as the *sand cone test*. See Figure 3-11. To perform the sand cone test, fill the excavated hole with sand from a container of known volume. Subtract the volume of sand remaining in the container from the known volume to find the volume of the excavated hole.

Soil Testing and Compaction Testing Costs

Every good estimator knows that compaction requirements determine the type and amount of equipment needed. But not all of them take into consideration the amount of testing and when it'll be done.

Engineers and architects require compaction tests on many jobs. After all, the tests assure them that the material is being placed and compacted correctly. That's the only way they can be sure that the soil will support the structure under construction. These tests are done under the supervision of a certified soils engineer.

On large jobs, the plans and specs will spell out how many compaction tests are required, and whose responsibility they are. A common requirement is one test for each 5,000 square feet of fill on each 6-inch lift. On a government project, the controlling agency will usually do the test or hire a private firm. Either way, they'll absorb the cost. On large private jobs, the owner will generally pay a soils engineer to do the test. If the contractor wants additional tests, he'll probably have to pay for them.

On smaller projects, there may not be any tests required. But the contractor will be held responsible for improper compaction if the structure settles later. That's why many contractors pay a soils engineer to do the tests, or else perform some of the simple tests themselves. If there's any doubt at all, the investment in soil testing is well worth it, so be sure to include these costs in your estimate.

Each test takes about an hour to run. But stopping work while it's being done is expensive. Most contractors schedule around the tests, so workers aren't idle. They may bring in one 6-inch lift, compact it, then move over and work in another area while the test is being done. It the test fails, they'll have to remove the material, replace it and recompact it. Since they only work one lift at a time, they only have to remove one lift if a test fails.

Soil testing costs will vary from project to project, but here are the major cost factors to consider:

- *Number of tests required per soil layer (lift):* Testing compacted fill is usually specified on a per-square-footage-of-fill basis, with a minimum number of tests required per lift. Therefore, testing costs will depend on the surface area of the fill, and the number of lifts placed.
- *Types of tests required:* Different types of tests require different methods, equipment, and time to perform, so costs vary accordingly. For example, a sand cone test costs more to perform than a nuclear gauge test.
- *Distance from the testing lab to the site:* Most testing labs charge for mileage to and from the site. Also, if the trip requires overnight travel, expect to be billed for overnight expenses.

Figure 3-12
Tamping-foot roller with dozer blade attachment

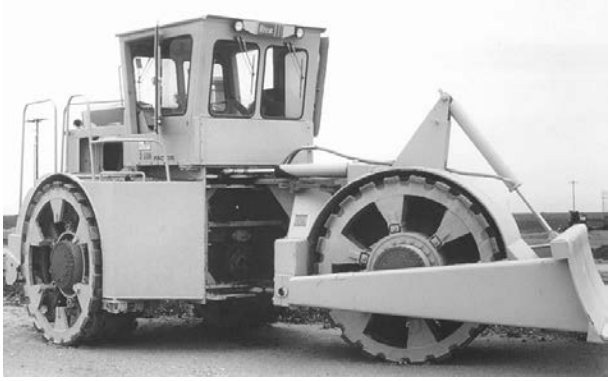


Figure 3-13
Segmented-pad roller

- *The testing lab's minimum number of tests-per-trip policy:* Most testing labs will charge for a minimum number of tests per trip, regardless of whether or not the additional tests are required or performed.
- *Variation in fill material-types, or the number of distinct borrow sources:* A soil analysis and laboratory compaction test is normally required for each type of soil placed.
- *Overtime:* Most testing labs charge time-and-a-half for labor required beyond normal working hours, on holidays, and on weekends.
- *Special report preparation:* Any test report or engineering analysis preparation requiring the expertise or stamp of a registered professional engineer is normally billed on an hourly basis.

Equipment Required to Achieve Density

You have to consider both the number and types of equipment you'll need to properly compact the soil on each project. Most fill is laid in 6-inch lifts. If the fill is dry, water trucks have to spray water on the material before compaction work can begin. If it's wet and muddy, you can dry the material by disking and blading it back and forth several times to let the sun and air dry it. If time is a problem, it's possible to add drier material to the soil in order to reduce the moisture content.

You can attain compression of most soils by a combination of weight and vibration. A tamping-foot roller, shown in Figure 3-12, will often compress the soil adequately. A sheepsfoot roller is useful in compacting plastic soils. As the roller makes repeated passes increasing the soil density, it will "walk out" of the soil. A segmented-pad roller (Figure 3-13) will achieve better compaction than a sheepsfoot roller and create less

Figure 3-14
Combi-roller

Figure 3-15
Pneumatic roller

Figure 3-16
Wacker remote-controlled compactor

surface disturbance. A combi-roller is used to smooth and finish base courses, gravel roads and bituminous pavements. They're also effective for compacting non-cohesive soils and small rock. See Figure 3-14. Use pneumatic rollers (Figure 3-15) for smoothing base courses, bituminous pavements and compacting granular soils.

To achieve compaction in tight places, you can use manually-operated machines. They are available as vibrating-plate compactors, vibrating-roller compactors and impact-rammer compactors. Remote-controlled compactors are also available for compacting soil in dangerous areas, such as deep trenches. See Figure 3-16.

Drainage and Soil Movement

The drainage on the project — before, during, and after construction — is affected by the soil's water-holding capabilities. Rains or upstream drainage can cause problems in porous soils that absorb water easily. It takes longer for the soil to dry out, and can delay the project completion.

During construction, each day's work must be left in a condition that allows the best possible drainage. Ponding water takes longer to dry out. In areas with steep slopes, high water runoff and other drainage problems, you need to allow time for building

temporary drainage ditches to carry the water around or away from the work area. While this isn't a pay item in the contract, it pays for itself because there's less delay after a rain.

The soil's makeup and moisture content also affect the way it moves. Soil with a high sand content is more easily moved by wheeled equipment. Dense clay and other high-moisture soils require tracked equipment in most instances.

Wet material can be pushed and loaded by machines in larger amounts than dry material, which tends to spill over. But the wet material doesn't push as easily or as smoothly. It usually takes a pusher tractor to help load the scrapers. The wet material also won't dump smoothly from the scrapers. You may need an additional blade or dozer to level the material down into the lifts.

When material is wet, allow extra time for extracting stuck machines, and for track cleaning. In extremely dry or sandy soil, the equipment needs to be serviced more often than usual. That raises the hourly operating cost. In a later chapter, we'll talk about calculating operating cost, including working in various conditions.

There are two other crucial soil properties that affect every earthwork estimate — swell and shrinkage. We'll cover those in a later chapter.

4

Reading Contour Maps

Every good earthwork estimator has to be good at reading and understanding contour or topographical (topo) maps. In this chapter I'll explain the essentials of contour map reading: how they're prepared, what the symbols mean, and how to find the information needed to calculate earthwork quantities.

Planimetric and Topographic Maps

You'll use two types of maps when preparing estimates. Planimetric maps show the position of both natural and man-made features of the terrain on the earth's surface. A road map is a planimetric map. It shows the surface area in two dimensions but doesn't give us much information about the third, the ground elevation.

A contour or topographic map (or topo map) shows most features of the planimetric map plus the contours of the earth's surface. Contour lines on a topo map also show the third dimension (surface elevation) that's missing on a planimetric map. This added dimension is referred to as *relief*. I'll say more about relief on topo maps later in this chapter.

Datum is a term used to define what we know about specific points on a map. On both planimetric and topo maps, there are two main types of datum. Horizontal datum is information on the location of specified points on a horizontal plane. For example, a point at the beginning or ending of a street is defined by its horizontal datum. The earthwork estimator uses horizontal datum, of course. But vertical datum tends to be much more important. Vertical datum is the distance up or down from a given reference point, most often sea level.

A government agency provides the National Geodetic Vertical Datum, a calculation based on the average sea tide at a specific time at 26 tide-monitoring stations throughout the United States and Canada. The average of these points is considered to be sea level and is assigned the elevation of zero. Every point on the earth's surface can be assigned an elevation above, below, or at this level. Map elevations in the U.S. and Canada are based on this National Geodetic Vertical Datum.

You can probably find an example of the National Geodetic Vertical Datum at your local general aviation airport. At the airport near my home, the control tower has a sign stating that the runway is 1023 feet above sea level. On charts for pilots, this point is shown as "elevation 1023," meaning that a particular point on the field is 1023 feet above sea level. Unless specified otherwise, consider any elevation you see on a topo map as being feet above or below sea level. An area that's below sea level will be labeled on the map as a minus number. For example, Badwater, Death Valley is the lowest region in the U.S., with an elevation of –282.0, so it's 282 feet below sea level.

Topo maps sometimes indicate measurements in terms of degrees, minutes and seconds. At the equator, a degree is $^1/_{360}$ of the Earth's circumference. Each degree is divided into minutes ($^1/_{60}$ of a degree) and seconds ($^1/_{60}$ of a minute). A degree is equal to 70 miles, a minute is 1.2 miles and a second is 0.02 miles, but these measurements don't usually concern the earthwork estimator.

Relief Marking on Topo Maps

Topo maps use relief markings (symbols, contour lines, color changes, and shading) to show natural earth features and man-made changes like buildings, railroads, highways, and dams. But only contour lines actually show points of equal elevation.

The Department of the Interior U.S. Geological Survey publishes topo maps of the United States on quadrangle sheets (called quad sheets). The scale for these maps is either 1:24,000, or 1:100,000. Figure 4-1 shows part of a USGS 1:24,000 quad sheet. A full 1:24,000 quad sheet covers an area of about 65 square miles.

The USGS also provides an illustrated PDF file on the Internet called Topographic Map Symbols. In it you'll find all the symbols used on USGS topo maps, both illustrated and described. You can download the file for free at:

http://egsc.usgs.gov/isb/pubs/booklets/symbols/topomapsymbols.pdf

Topo maps have many uses in construction. Engineers use them to design drainage structures, plan streets, curbs, gutters, and so on. You'll be using them to take off elevation points to find the amount of earth to be moved.

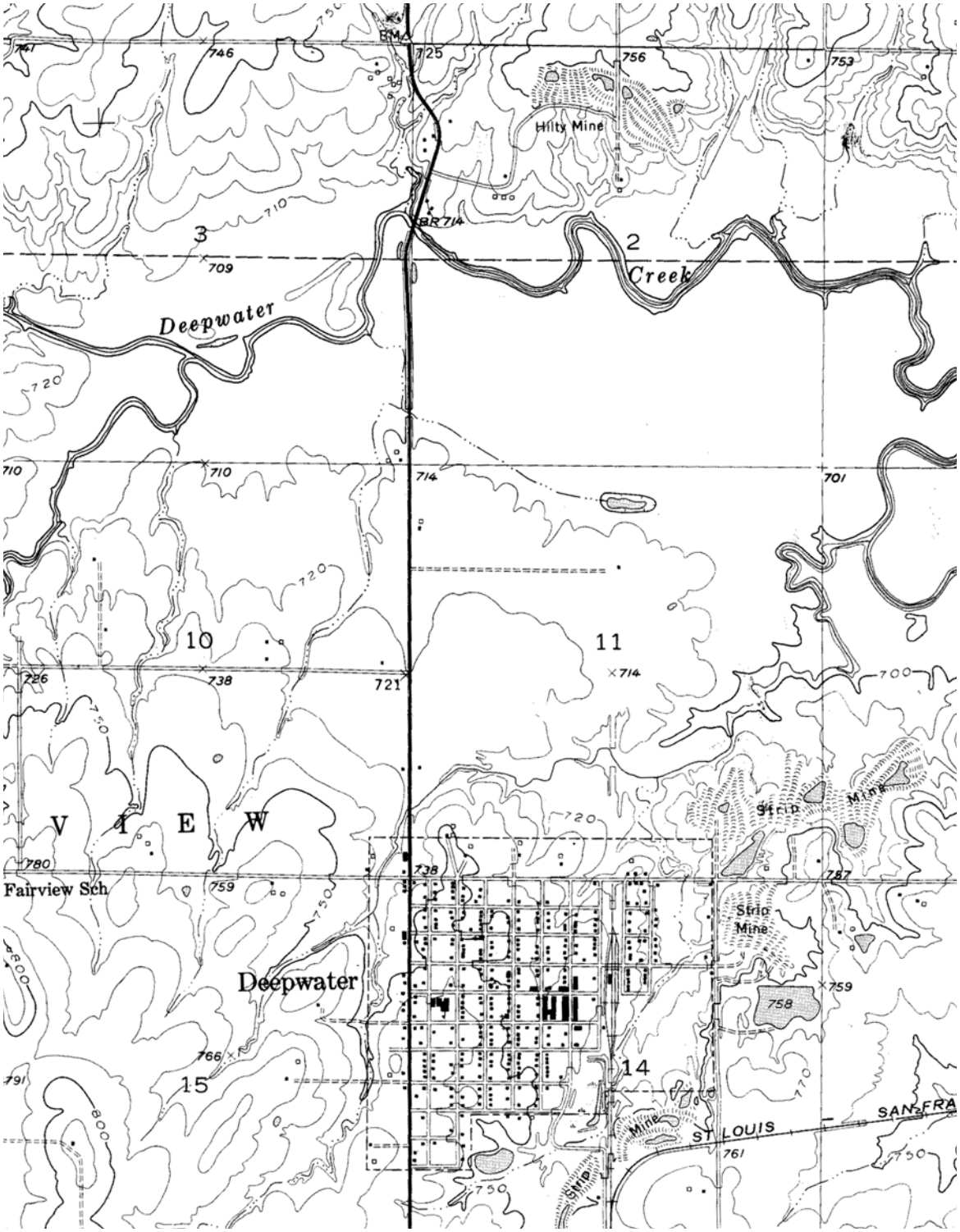


Figure 4-1
Portion of a USGS 1:24,000 quad sheet

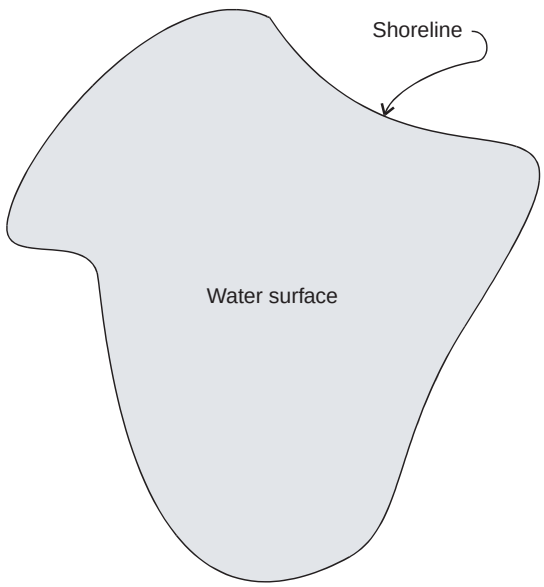


Figure 4-2
Coutour line defining the shoreline of a lake

Understanding Contour Lines

A contour line on a topo map connects points of equal elevation. These contour lines are your best source of information on the shape of the earth at the building site. On small jobs, you may figure earthwork quantities from a topo map that has only the project boundaries laid out. The builder and engineer probably haven't given much thought to how the dirt work should be done or how much earth has to be moved. They leave that up to you.

You'll begin your earthwork calculations by laying out a project grid — squares drawn on tracing paper that you've taped down over a topo map of the jobsite. Then you'll write finish elevations on the grid beside the existing map elevations. The difference between the two is the amount of soil that needs to be moved. Making those calculations is commonly called the "pull-off," since you remove the tracing after your take-off is done and save it for future reference. In the event you don't get the job and have to return the plans to the designer, no one else will be able to see your take-off work and know how you did it.

Characteristics of Contour Lines

A contour line is an imaginary line following a specific elevation throughout the area of the map. Figure 4-2 shows a simple example. The elevation is the same at all points around the edge of a lake. A contour line drawn at the elevation of the lake would follow the shoreline exactly. You can think of all contour lines the same way. I've often looked over a site and visualized where the shoreline would be if the site were filled with water. A contour can also be visualized as the line that would be formed if you cut a horizontal slice through the earth at any given elevation.

Contour lines make the map a little harder to read, but without them, you wouldn't be able to estimate excavation quantities. Reading topo maps takes a little practice. Learning will be easier if you remember these properties regarding all contour lines:

1. Contour lines are almost always drawn freehand.

*In this figure, regardless of width, the space between adjacent vertical lines equals a 1-foot change in elevation. The spaces' different widths indicate changes in relative slope.

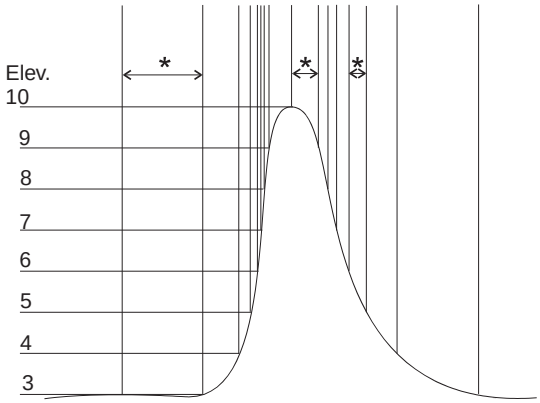


Figure 4-3
The closer together the contour lines, the sharper the rise or fall of the terrain

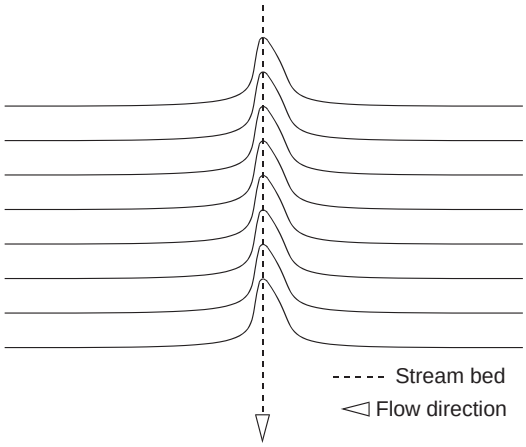


Figure 4-4
Contour lines form Vs where they cross a stream bed, valley, or ridge

2. Contour lines connect points of the same elevation.

3. Contour lines never touch another contour line unless the earth's surface is nearly vertical, and they cross only where there's an overhanging cliff.

4. Every contour line closes (returns to where it began) eventually. Of course, in some cases you may need several adjacent map sheets to follow a particular contour line all the way around to where it began. It may continue for miles before closing on itself.

5. Contour lines never break or split into more than one line.

6. The closer the lines are together, the steeper the slope. The farther the lines are apart, the flatter the slope. Look at Figure 4-3.

7. When a contour line crosses a valley or gully, it forms a V, with the V pointing uphill and upstream. Figure 4-4 shows contour lines crossing a stream bed.

8. When a contour line crosses the top of a ridge, it also forms a V. The V points downhill. Try picturing Figure 4-4 without the broken line and arrow. Now you know what contour lines that cross a ridge look like on the downhill side.

9. Contour lines that close on themselves on the same map represent a hill, a depression, or a totally flat surface.

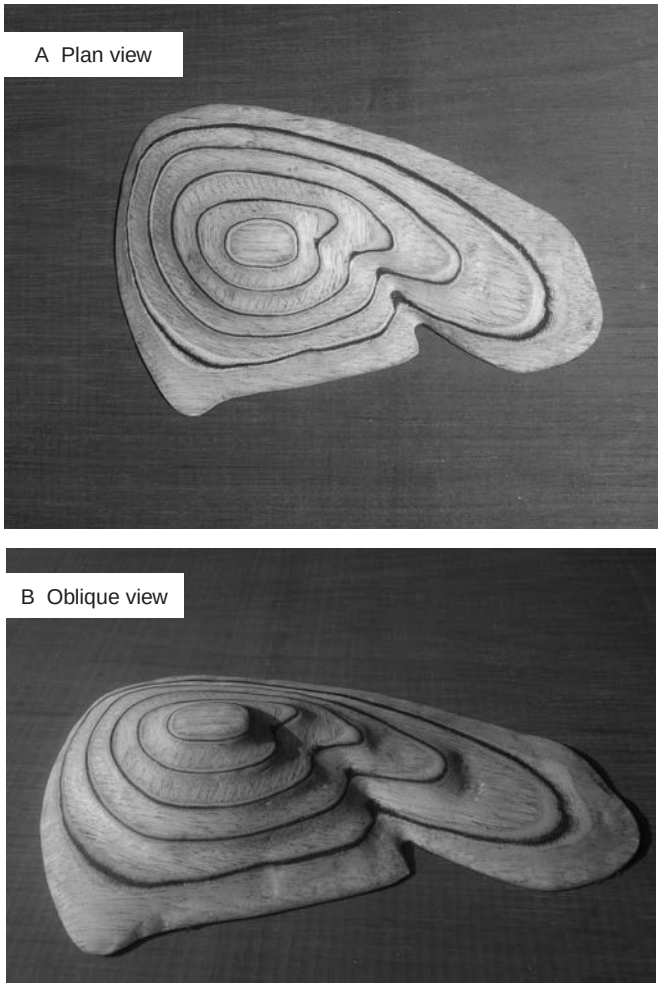


Figure 4-5
Mountain contour lines

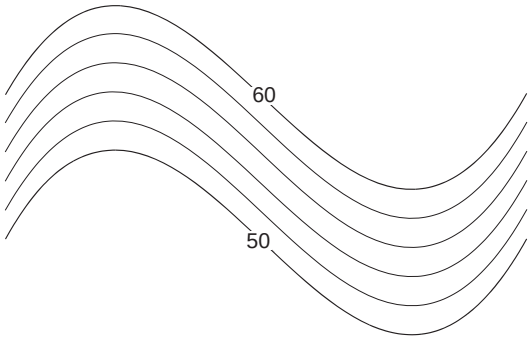


Figure 4-6
Intermediate (light) and major (dark) contour lines

Contour Interval

Contour lines add a third (vertical) dimension to a topo map and can be used to represent any difference in elevation, such as 1, 10, 100 or 500 feet. This is known as the *contour interval*, the difference in elevation between one contour line and another. A relatively flat area might use a contour interval of 1 foot. Each line shows a 1 foot difference in elevation. In the mountains, a topo map may have an interval of 500 feet to avoid clustering lines into unreadable masses.

Figure 4-5 shows how a small mountain might look in both a top plan (A) and an oblique view (B). Notice that the contour lines are closer together where the mountain is steeper.

Make a point of noting the contour interval anytime you use a topographic map. This data is easy to find on most maps. The USGS quad sheets, for example, list contour interval right in the center of the bottom margin.

Many topographic maps also include intermediate contour lines. These secondary contour lines give you a more detailed picture of the terrain. In Figure 4-6, the four lighter lines between the dark lines (labeled 50 and 60) are intermediate contours. Typically, intermediate contours have no elevation tags, and there's no listing of their interval. Fortunately, these lines are easy to figure out. The four light lines in Figure 4-6 divide the area between 50 and 60 into five smaller areas. So the interval used here is 2 feet. Reading from 50 to 60,

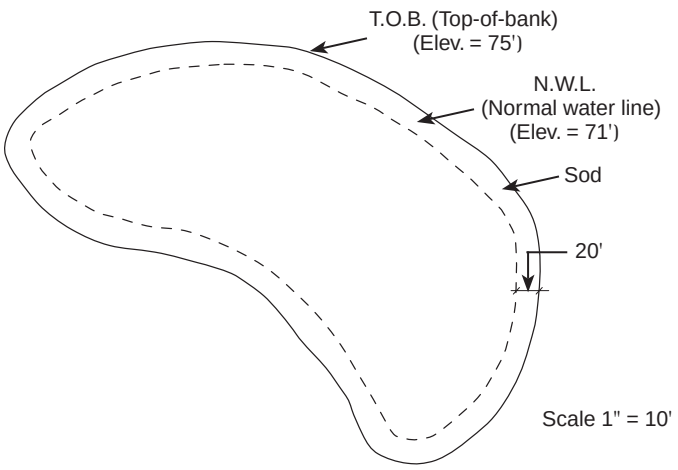


Figure 4-7
Incomplete lake contour map

the intermediate elevations are: 52, 54, 56, and 58. Other types of lines, broken or dashed, also denote intermediate contours on maps.

Contour Lines in Lakes and Ponds

Sometimes it's up to you to add some missing pieces of information to the contour map. For example, the designer might show just the top-of-bank and normal water line (NWL) contours of lakes and ponds, and give a general cross section of how the lake should be built or recontoured. See Figure 4-7.

Now look at Figure 4-8. Here you have the lake cross section with all the horizontal distance information added. Engineers that draw plans give this required information. It's a blueprint for any pond. I'm not absolutely sure why they require each and every slope to be the way they're shown here, but I believe the design is for safety. It was found years ago that children sometimes got into older lakes that weren't designed

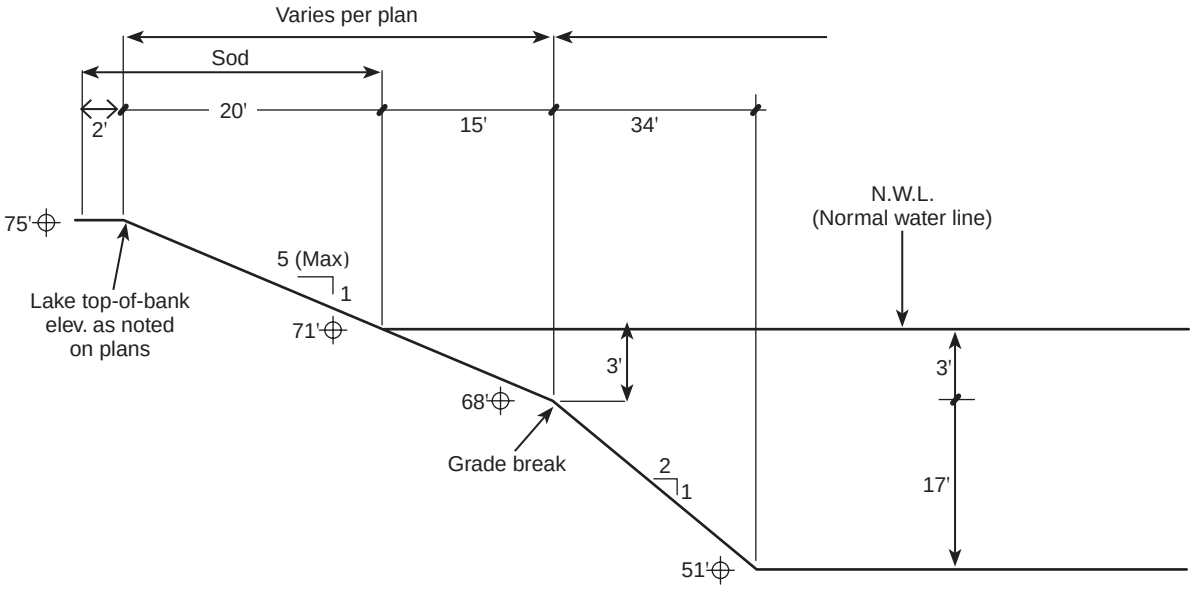


Figure 4-8
Lake cross section with horizontal distance data added

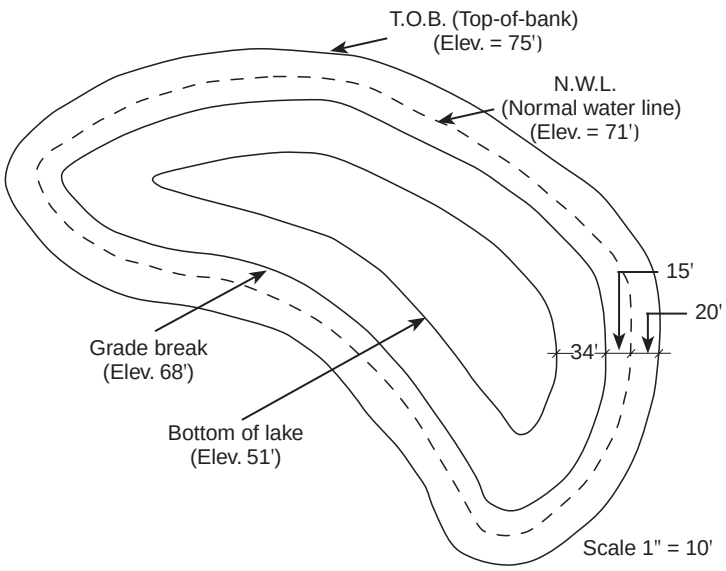


Figure 4-9
Lake drawing with complete set of contour lines

with a 5 to 1 slope near the banks and slid into the deeper water and drowned. I used this cross section because it's used for the design of all ponds in my area. It may be that the design is different in other states, but the math for figuring out all the required contours would be used in a similar fashion.

So, let's see how to determine the horizontal distance from the normal water line (NWL) contour to the grade break contour. With a 5-to-1 slope, there are 5 feet of run for each 1 foot of fall. Total fall in this case is 3 feet (from elevation 71 to elevation 68). That means the total run equals 5 × 3, which is 15 feet.

Next, you need to determine the horizontal distance from the grade break contour to the bottom-of-lake contour. The slope given for this distance in Figure 4-8 is 2 to 1. So, multiply 17 feet of fall by 2, which equals 34 feet of run.

Now, all that's left to do is trace the grade break and bottom-of-lake contours back onto the site plan. Figure 4-9 shows what your site plan will look like when completed.

Changing Pond Bank Slopes

In some areas, older retaining ponds are now being reconfigured with gentler slopes because of the threat to child safety. Let's look at an example of the work required to change the bank slope of such a pond. Figure 4-10 shows an existing pond, 10-feet deep with a side slope of 1:1. It needs to be excavated so that the final slope is 3:1. We need to determine the additional excavation required to obtain the new slope.

The formula to find the horizontal change for the top-of-pond location is:

Horizontal Change = (Run of New Slope × Pond Depth) – Original Top-of-Pond Location

With an original pond slope of 1:1, the original top-of-pond is located 10 feet horizontally from the bottom of the pond, so:

Horizontal Change = (3 × 10 feet) – 10 feet = 20 feet

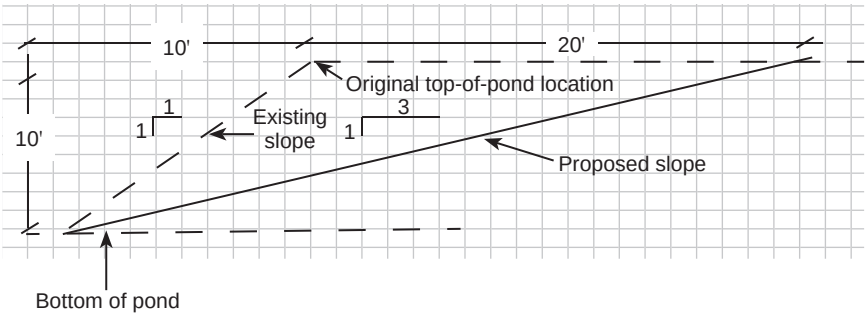


Figure 4-10
Pond configuration

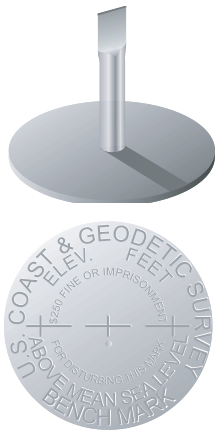


Figure 4-11
A U.S. Coast and Geodetic Survey benchmark monument

The end area of the additional excavation is:

½ × Horizontal Change × Pond Depth = End Area Excavation

½ × 20 feet × 10 feet = 100 square feet per linear foot of excavation ÷ 27

End Area Excavation = 3.7 cubic yards per linear foot

Benchmarks and Monuments

By now we know that contour lines connect points of equal elevation. But how can we be sure what elevation each contour line represents? Fortunately, all that has been figured out for us. Early in our country's history, the federal government began making surveys and setting survey monuments that all surveyors now use. Every populated part of the country (and a lot of unpopulated areas) have been surveyed and marked with monuments. The engineering department in your county or city can identify the location of monuments in your area.

Figure 4-11 shows a U.S. Geodetic Survey benchmark monument. These bronze markers are embedded in either concrete or rock. The cross at the center marks the exact location of a reference point with a known elevation. Some benchmarks show the elevation on them. The benchmark in Figure 4-11 doesn't show the actual elevation, but a topo map that includes this benchmark will show the marker's location and that point's exact elevation above mean sea level. If you look back at Figure 4-1, you'll see a benchmark located along the top, labeled BM 725.

Placing Survey Markers

Surveyors usually place survey reference points on a solid surface that won't be affected by earth movement during normal freeze-thaw cycles. Good locations for

survey markers include concrete footings and heavy spikes driven into power poles, large trees, exposed natural rock outcroppings, or ledges. Because survey markers have to be used regularly during design and construction, they should be as close to the project as possible without being in the way of construction.

You should be familiar with the two types of benchmarks that surveyors place. A *permanent benchmark* is as precise as possible given the conditions of the project. They're normally placed about every 300 feet on relatively flat terrain. Where the terrain or obstacles make moving from one benchmark to another time-consuming, they may be spaced as close as every 50 feet. They're always designated with the standard notation BM.

Temporary benchmarks (designated as TBM) aren't as accurate or as stable as regular benchmarks. They're established for a short period of time, or for a specific portion of the work within a project.

There are also two different types of elevation numbers used by the estimator: real elevations and project elevations.

Real elevations are the actual elevation of the points above sea level set from existing known elevations.

Project elevations are commonly used for engineering, estimating and construction because the actual elevation above sea level is usually of no practical interest. The engineer will pick a point (such as the top of a curb), identify it as the beginning BM, and assign some elevation to this point.

To make the math easier, the beginning project elevation is usually assigned the number 100 or 1000. Most engineers use a number high enough so that every elevation used when designing and building the project will be a positive (rather than a negative) number. This is what's called a datum plane. It's easier to add and subtract positive numbers. It also makes a mistake less likely.

In the next chapter we'll begin working with quantities taken off from topo maps. Two surfaces are shown on a topo plan – existing and proposed. The original or existing surface is the ground or earth's surface before any work is done. The final or proposed surface shows how it should look when excavation work is completed.

5

Area Take-off from a Topo Map

If I were asked to identify the most important chapter in this book, this is probably the one I'd choose. Taking off quantities from topographical maps is the heart of the earthwork estimator's job.

In this chapter I'll add more information to the already complicated topo maps we've looked at. And, we'll go into more detail on the second set of lines showing the proposed final grade. These additional lines tend to make the map even more confusing, but they're an essential part of understanding the work to be done.

I'll also show you how to estimate soil quantities by comparing contour lines, which is the best way to do your calculations, and I'll suggest some problem areas to watch for.

Comparing the Contour Lines

A contour map is a simple two-dimensional representation of a three-dimensional land form. A template is another name for the finished contour line, often used when the finished contours are very flat or gradually sloping. Figure 5-1 shows the difference between the two, and how they might look used together.

Look at Figure 5-1. Line A-A is known as a section line, or pick-up line. Assume that a road will be built along this line, with the middle of the road along line A-A. At each point where A-A crosses a contour line, there's a vertical projection from the line down to the graphic of contour. In this case, the graphic of contour in Figure 5-1 connects elevations from 104 through 101. There's also the template, which plots the finished grade line.

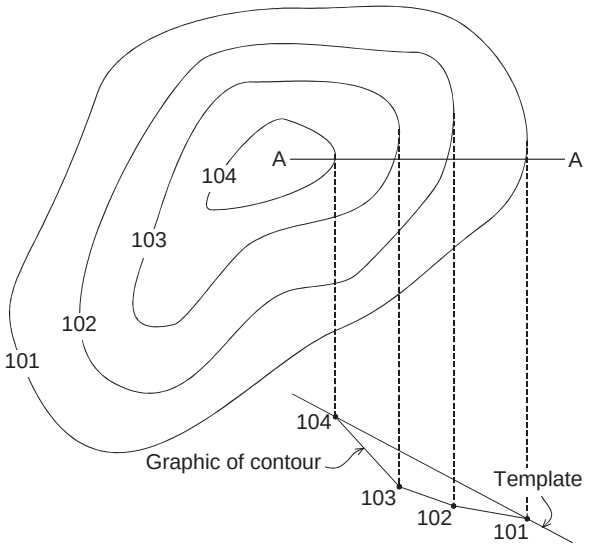


Figure 5-1
Contour lines and a finished grade template

You should understand that Figure 5-1 is just an illustration to show how the lines work together. On an actual job, of course, both lines are plotted on graph paper.

On topographic maps, don't expect a particular type of line, such as solid or dashed, to always mean the same thing. There aren't any hard and fast rules that apply when it comes to topo map symbols. One map may use solid lines to plot existing grades and dashed lines to show the finished grade. And the next map you use is as likely to reverse the meanings as it is to repeat them. All mapmakers are free to choose the types of lines and symbols they prefer. But it's also the mapmaker's responsibility to assign a meaning to each element used, and to provide users of the map with a key. This key is called a *legend*, and one appears on every map. The legend lists each type of line and symbol found on the map and its assigned meaning. Get in the habit of checking the legend on every map you use. Make sure you know the map symbols, grid square information and location designation system before you start work. Regardless of how contours are drawn, it's helpful to use colored pencils or pens to outline. That'll make the plan easier to read and the take-off easier to do.

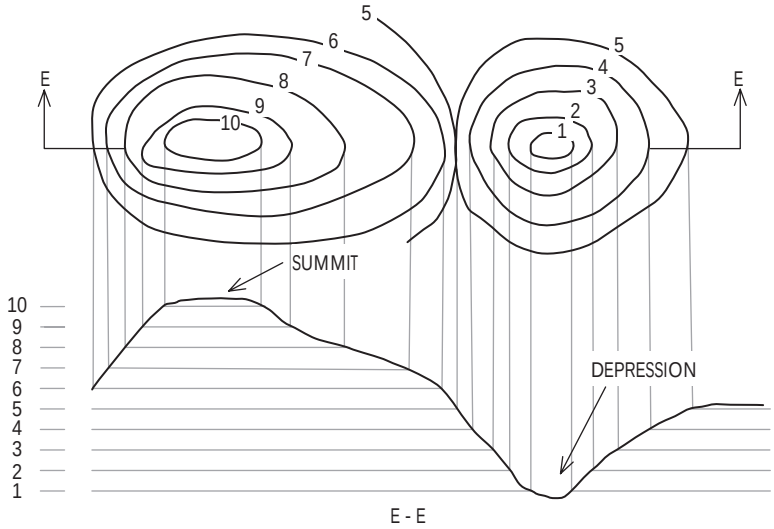


Figure 5-2
Summits and depressions

Drawing a Profile Section

To draw a profile of any region of interest shown on a topo map, draw straight lines perpendicular to the contour lines. See Figure 5-2. Place graph paper with a base line

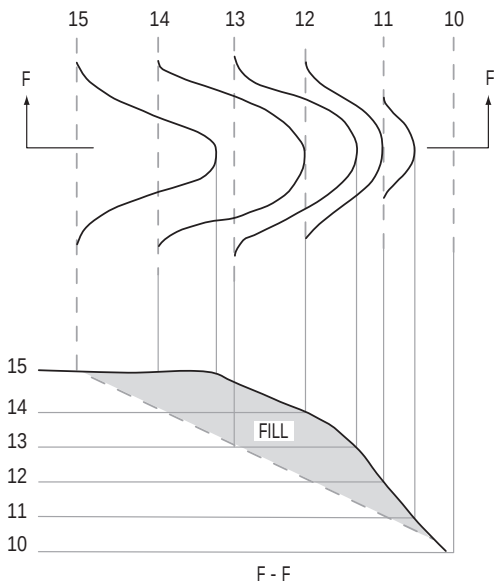


Figure 5-3
Proposed contour requiring fill

(line 1 in the figure) under and parallel to the section line (E-E). Draw additional lines parallel and above the base line spaced in increments equal to the contour intervals. Then project lines vertically from where the contours intersect the section line. Mark where they intersect correct elevation points on the lines drawn on the graph paper. Connect one point with the next to draw the profile. You can plot existing as well as proposed points on the graph paper to see where and how much work will have to be done along the section line. Figure 5-3 shows an example of a fill and Figure 5-4 shows the projected work for a cut.

Calculating Slope from a Profile Section

To determine the slope of a region, draw a section line through the region and project a profile view as just described. Then measure the length of the section, then the vertical change within the section. Divide the elevation change by the length of the section, then multiply the answer by 100 to obtain the percent of slope for the region. For example, if the profile shows an elevation change of 3 feet through a 40-foot distance, the slope will be:

$$3 \div 40 = 0.075 \times 100 = 7.5\ \%$$

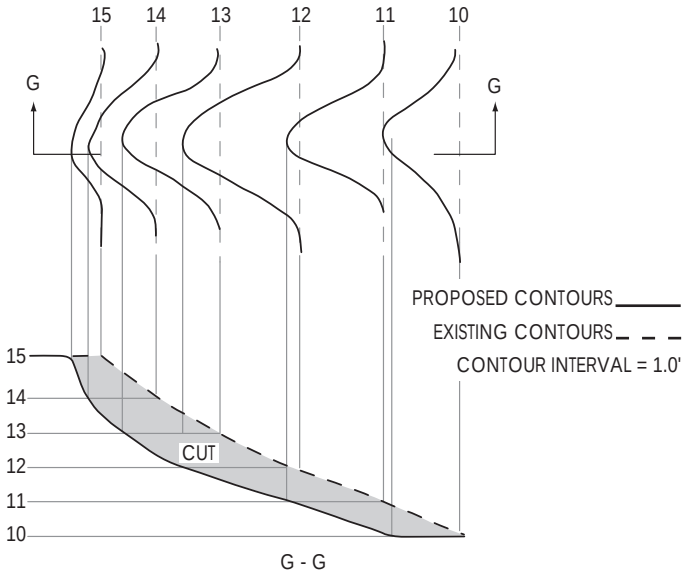


Figure 5-4
Proposed contour requiring cut

Solid vs. Dashed Contour Lines

This book mirrors the variety found in real topo maps and site plans by being inconsistent. As stated earlier, you'll find that solid lines don't always show finished grades, and broken lines don't necessarily mark existing grades. I've also used a variety of ways to designate locations, grid corners and so on.

No matter what types of lines appear on a topo map, one set of contours always shows the existing grades. This is your "before" picture of the site. Another set of contours marks the finished grades on the same map — these contours are the "after" picture of a jobsite. The difference between these sets of contour lines represents the quantity of material to be moved as cut or as fill.

Estimating with a Grid System

It's easier to estimate work if you divide the job into many small sections and estimate the earthwork for each section. Then total the excavation for all sections to find quantities for the whole job.

There are three advantages to using a grid system:

1. It's easier to see the work area.
2. Calculations are easier when figuring small areas.
3. Your work is more accurate when you can average quantities from several small work areas.

The grid helps you focus on a smaller part of the topo map, simplifying the task. Begin by laying out a grid of small squares on a piece of lightweight tracing paper or film. I recommend using tracing paper because it's inexpensive and can be filed for future use, if needed. Figure 5-5 shows a simple grid.

Figure 5-6 shows a section of a contour map with a 50-foot grid overlay. At first glance this may look like a hopeless tangle. But let's take it step by step so you can see for yourself that it's not all that complicated.

Start with the grid lines. The grid pattern should extend out to the limits of the project, including all areas where earth will be moved. In this case the grid sheet is square. But you can make a set of grids large enough to cover any shape you want. If a small portion of the work area extends beyond the grid sheet, cover it with a single grid square, or several in a row.

There are three primary rules that apply when estimating with a grid system:

1. To make the calculations easier, all grid squares should be connected to adjoining squares by at least one common line.
2. Each individual grid square must have its own identification.
3. Keep a record of the map page or section number and the grid square designation when you do your calculations for each square.

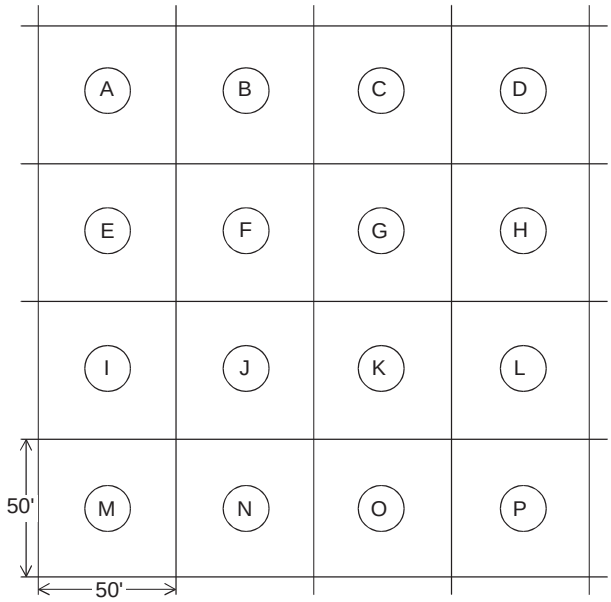


Figure 5-5
A simple 50' × 50' grid

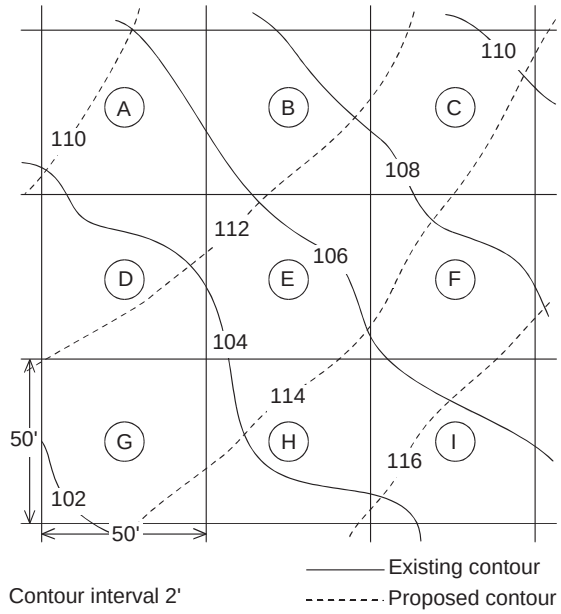


Figure 5-6
A partial site plan overlaid with a grid

Here are some additional rules that I find handy to keep in mind.

Try to place your grid lines where:

- There's a change in the direction of slope.
- There's a radical change in the direction of contour lines.
- There's no activity (along the daylight line where the work stops).
- There's a structural area, such as a building slab or paved area.
- There's an abrupt change in elevations, such as along a retaining wall.

Choosing Your Identification System and Scale

The method you use for identifying grids is entirely up to you. Use any method you find convenient to label each square, but avoid cluttering the drawing with confusing information. Most estimators use the letters of the alphabet instead of numbers. That's what I've done in my examples. Letters won't be mistaken for, or confused with, contour line elevations. And the letter system expands easily to fit any size grid. You can use double letters (AA, AB) or add a number to the letter (A1 to Z1; A2 to Z2; A3 to Z3). Find a system that makes sense to you and is easy to follow. Then stick with it. Being consistent is the best and easiest way to minimize errors.

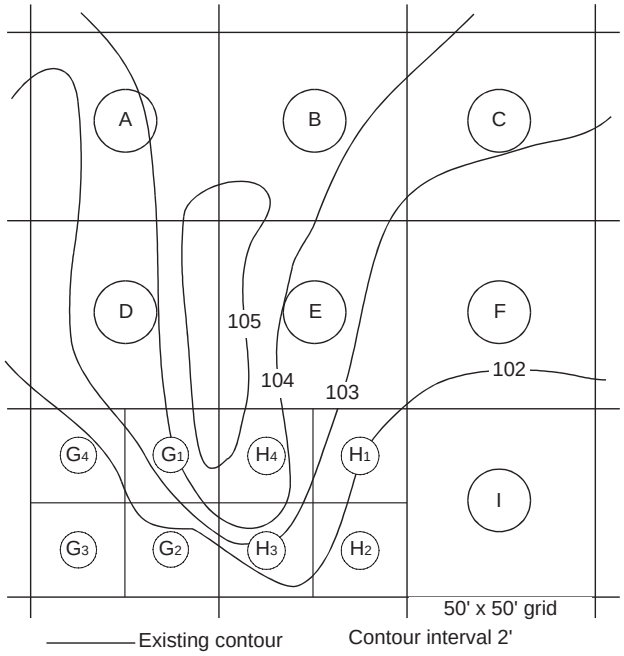


Figure 5-7
Dividing the grid for steep areas

The scale you use will depend on the size of the plan sheets, the difference in elevation between contours, and your skill. If there's not a great difference between the highest and lowest contour lines, it's safe to use a large grid. However, if the difference is large, you're better off using a small grid. Figure 5-5 uses a 50-foot by 50-foot grid that's scaled so 0.6 inch equals 50 feet. Figure 5-6 uses a different scale, 0.8 inch equals 50 feet.

Where the map shows sharp changes in ground contour, divide a grid square into four smaller squares. Look at Figure 5-7. I've divided grid squares G and H into four equal sections and used numbers from 1 to 4 to identify each.

Reading the Contour Lines

Now consider the contour lines themselves. In Figure 5-6 the existing ground contour is shown with solid lines. Ignore, for a moment, everything but the solid contour lines in that figure. Notice how the lines show a gradual increase in elevation from 102 in the lower left corner to elevation 110 at the upper right.

Next, concentrate on the finished contours shown in Figure 5-6, represented by the dashed lines. See how the contours increase from elevation 110 in the upper left corner to elevation 116 in the lower right corner. Of course, this map is relatively simple. Most of your jobs will be more complex. But the map shows the points I want to emphasize.

Subcontour Lines

When an area is relatively flat, the contour lines will be far apart. That makes it hard to precisely establish zero lines and other reference points. To make your job easier, establish points between the contour lines that you'll connect into subcontour lines. They have the same characteristics as contour lines but show midpoint elevations that are useful when making quantity calculations.

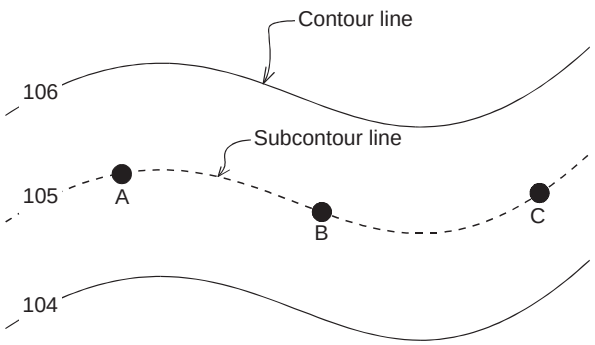


Figure 5-8
Plotting a subcontour line

In Figure 5-8, notice the wide distance between contour lines 104 and 106. To lay out the subcontour line, use a scale to find and mark several points exactly half-way between the 104 and 106 contour lines. You'll see in Figure 5-8 that I marked three midpoints, labeled them A, B and C, and connected them with a dashed line. That's the 105 foot contour line. Although I guessed at the path of the 105 foot contour, chances are good that it's close enough for most excavation estimating work.

Doing the Take-off

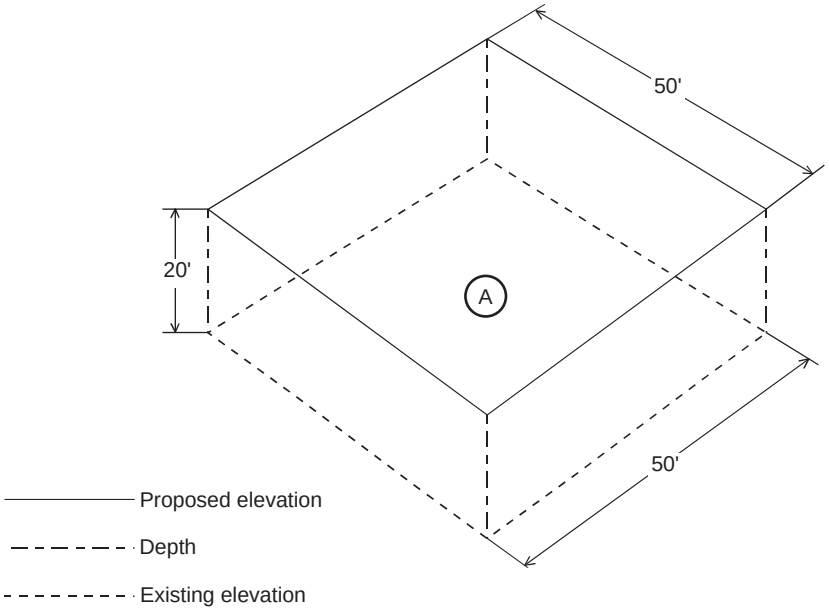


Figure 5-9
Calculating the volume of a grid square

To find the excavation quantity, you need to know the elevation of the existing and finished contours for each square in the grid. To determine these elevations, start by finding both elevations at each corner and then calculate their average.

If all the contour lines were level, comparing the two elevations would be simple. Figure 5-9 shows this exact situation. Grid square A measures 50 feet on each side and has a single existing elevation (a level base) and a single proposed finished elevation (a level top). The difference between the existing and proposed elevations in the figure is 20 feet at all four corners, so the depth of work required is identical throughout that grid.

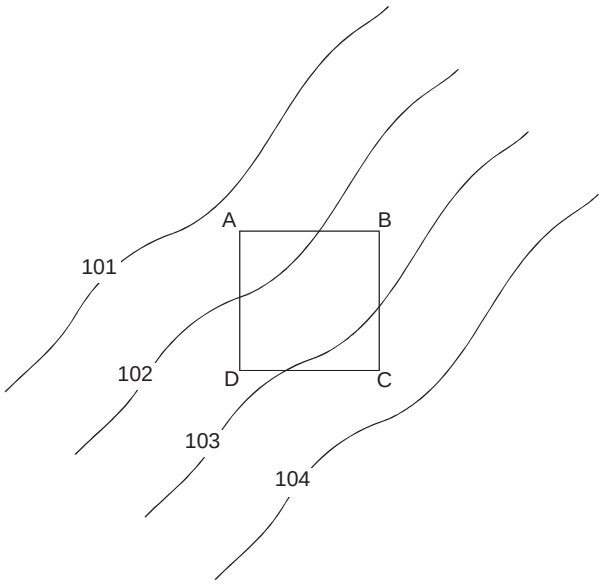


Figure 5-10
Single grid square overlaying existing contours

Calculate the volume in cubic yards using this formula:

Volume (CY) = (Length × Width × Depth) ÷ 27

= (50 × 50 × 20) ÷ 27

= 50,000 ÷ 27

= 1,851.85 CY

In the real world it's never that easy. Grid squares rarely have just one level plane for either the before or completed surface elevation. And as for contour lines lining up with the grid corners, forget it. You'll almost always have to do some calculating to find the corner elevations. Another name for that process is interpolation (or "guesstimating").

Interpolating Corner Elevations

Figure 5-10 shows a single grid square laid over part of a topo map. Points A, B, C and D mark the corners of the grid square. In an ideal situation, each corner would fall precisely on some contour line. Finding those elevations is as easy as copying a number. Figure 5-10, however, comes closer to reality. All four points fall between contours. To find the corner elevations, we interpolate. That's an educated guess, based on measuring how far away the corner is from the two closest contour lines. We assume that the closer the corner is to a contour line, the more similar its elevation is to the contour line's elevation.

Let's start out with a simple interpolation problem. Say that we want to know the elevation of point Z in Figure 5-11. To find this elevation we interpolate, because Z falls between two contour lines. In this example I'm using an engineer's scale to measure distances.

The contour interval in Figure 5-11 is 1 foot, and on my scale that measures as 10 units. The next step is to measure the distance from Z to each of the contour lines. Measuring from the 101 foot contour line to Z, I get a distance of 4 scale units. And, measuring from Z to the 102 foot contour line, I get a result of 6 scale units. That's all the data we need to interpolate the elevation at point Z. Let's take it step by step.

Step 1: Find the value of one scale unit in feet.

We already know (from Figure 5-11) that 1 foot is equal to 10 units on my engineer's scale. So, 1 scale unit is equal to $^1/_{10}$ or 0.1 foot.

Another name for a number like the one we just found is a constant. A constant makes it easier to change a measurement made or calculated in one unit system to its equivalent in another unit system. In this example, I measured in units of scale marks. However, we need an elevation measurement in units of feet. Because we've found the constant, all we do to change scale marks to feet is multiply two numbers:

Scale mark (unit) × Constant = Feet

Step 2: Assume a smooth, even slope exists between contour lines.

So, we'll assume there's an even slope from the 101 foot contour line to the 102 foot contour line.

Step 3: Change the scale measurements to feet.

We already know how many scale marks separate point Z from each contour line: Z to 101 equals 4, and Z to 102 equals 6. We want to change those measurements to feet at this point.

Here's our chance to use the constant we found earlier:

Scale mark × Constant = Feet

4 × 0.1 = 0.4 foot

6 × 0.1 = 0.6 foot

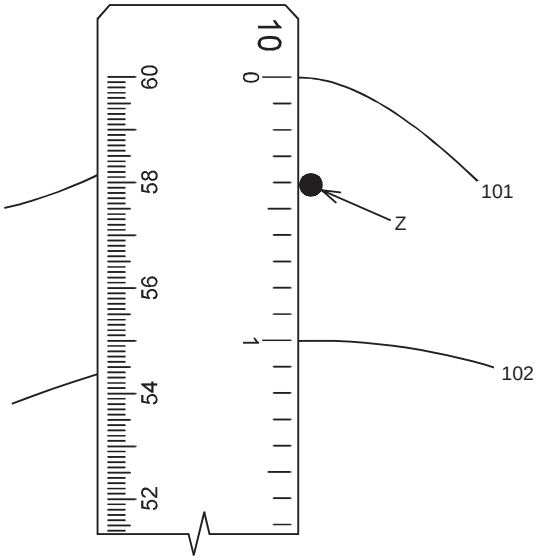


Figure 5-11
Using a scale to interpolate an elevation

In this example the results run to just one decimal place. Results often run to three or more decimal places, but I recommend always rounding them off to just two places. That's accurate enough for our purposes, as I'll explain later.

Step 4: Find the elevation.

There are two ways to go in this last step. Whichever method you choose, the math is simple and the answer comes out the same. Each method uses a different set of data, and one method uses subtraction, the other uses addition. You're the one doing the estimate, so it's up to you to choose.

But before we look at the options, remember, when you choose an option, you're also choosing the set of data you'll use. The link between the data and the option makes it very important that you don't mix your data, or your methods. (Details follow the example.) Here are the options:

Option 1

Elevation Z is equal to the sum of the lower contour line elevation (101 feet) plus the separation distance in feet (0.4 feet):

101 + 0.4 = 101.4 feet

Option 2

Elevation Z is equal to the upper contour line elevation (102 feet) minus the separation distance in feet (0.6 feet):

102 – 0.6 = 101.4 feet

You can see that with either method, the elevation at point Z is clearly 101.4 feet.

Now let's tie up some loose ends. Why doesn't rounding make the take-off inaccurate? There are three reasons. The first is relative size. Just compare the size of any error to the size of the other elements. For example: Suppose that in Step 3 of the interpolation we multiplied 8 by 0.0385. The answer is 0.308, which I'll round to 0.31. By rounding 0.308 to 0.31, I added 0.002 feet to the interpolated elevation. That's too small to make a significant difference in the total amount of earth you have to move.

The second reason rounding doesn't hurt take-off accuracy is that rounding will lower a value as often as it raises one. In rounding that's done consistently to a group of numbers, about half will go up in value and the other half will go down. In the end, all the tiny errors (+ and –) cancel out. Their net effect is zero.

The third reason is that the paths of existing contour lines are interpolated between point elevations often taken at widespread intervals in the field. There's no guarantee that the existing elevations are drawn precisely, so a minor error isn't going to make that much difference.

But don't get the idea that interpolation's foolproof. It isn't. Remember my warning: *Each option in the examples uses a different set of data — Don't mix data or methods!*

The unwary estimator can get careless or confused and add instead of subtracting (or vice versa), or do the right calculation using the wrong elevation or measurement. Any of those mistakes can result in a big

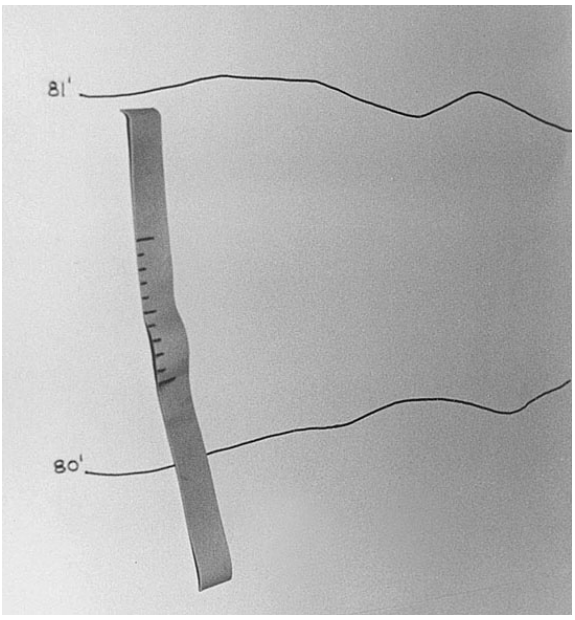


Figure 5-12
Make a rubber band scale

error. At best, you'll look and feel foolish — and careless. At worst, you stand to lose the job, or you'll win the job and lose your shirt. Your best defense against these kinds of errors is to work carefully and systematically. And, always follow the same sequence of steps.

Another way you'll avoid errors is by taking the time to check your work. Here are two quick and easy rules to make sure your interpolation results are accurate:

1. Add distance (measured contour to point) to the low elevation.
2. Subtract distance (measured point to contour) from the high elevation.

Make a Tool for Locating Unmarked Points

When you have to figure elevations at several intermediate points, it's easier to make a simple tool you can use over and over. I like to use a plain rubber band, at least ¼ inch wide and 4 inches long. With the band relaxed, mark a beginning point with black ink and another point 1 inch away on the band. Then use an engineer's scale to mark nine fine ink lines on the band between the beginning point and the 1-inch mark, as shown in Figure 5-12. Now you've got a stretchable tool for estimating the elevation of any point where the distance between contour lines is 1 inch or more.

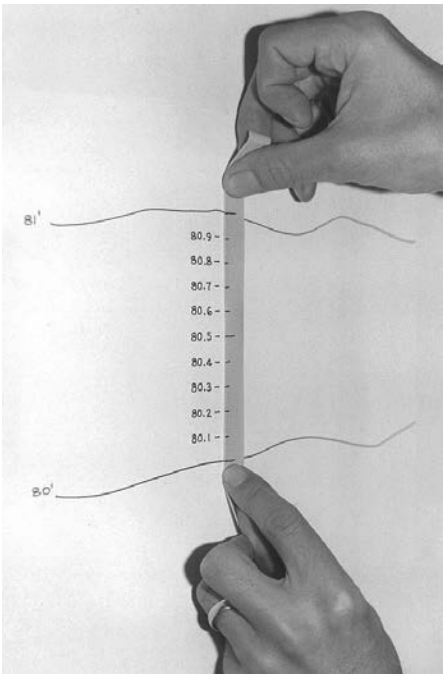


Figure 5-13
Stretch rubber band marks between contour lines

To use it, set the first mark at the contour line on one side of the point of unknown elevation. Stretch the band past that point until the top mark is on the next contour line. You now have the rubber band stretched between two contour lines with the unknown point somewhere between. See Figure 5-13. Count the marks between one contour line and your point. Multiply the number of the mark (in tenths) by the contour interval. That's the

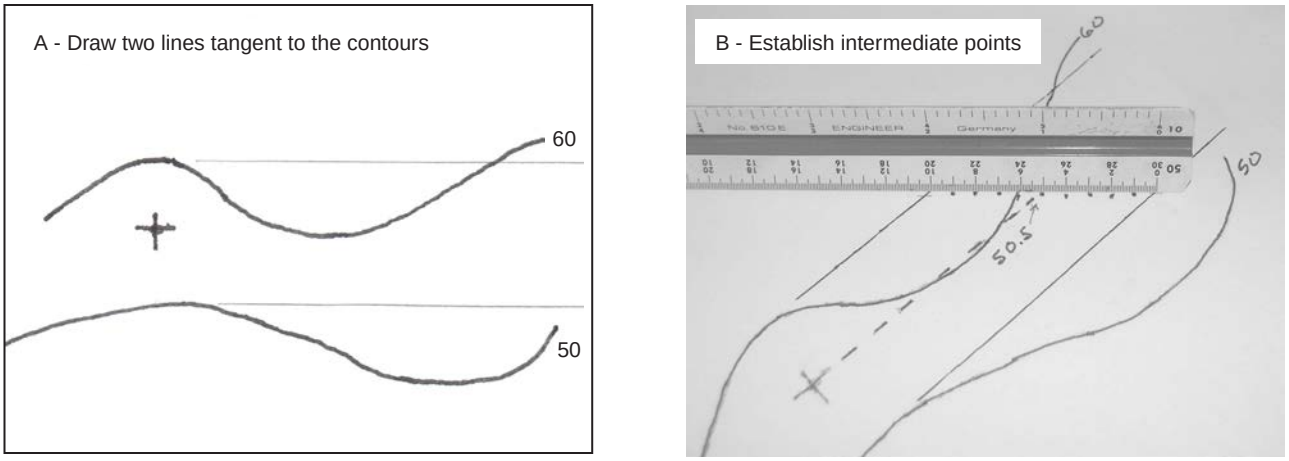


Figure 5-14
Scaling increments using intermediate points

difference in elevation from the contour line to the point. For example, if your contour interval is 10 feet and the point is at mark 3, multiply 0.3 by 10 feet to get 3 feet. Or, using our stretched rubber band, our contour interval is 1 foot and the point is at mark 80.3, multiply 80.3 by 1 foot to get 80.3 feet.

Locating Unmarked Points Using Intermediate Measurements

In the examples in Figures 5-11 and 5-13, our scale measured exactly ten increments between the two contours. Most of the time, you won't find that to be the case. When your unknown elevation point doesn't align with a scaled increment, here's how to find the elevation. Draw two lines tangent to the contours, and parallel to each other. See Figure 5-14A. Then turn the scale at a diagonal between the two contours, and through trial and error, find a scale that can divide the distance down the diagonal line into ten increments. See Figure 5-14B. You can transfer the increments measured to the location of interest between the contours we're measuring by drawing intermediate lines parallel to the original parallel lines. This will again give you a proportionate elevation reading.

Interpolating Corner Elevations Using a 1:10 Engineering Scale

As we've seen in previous examples, the simplest way to take all measurements is with a scale that's easy for you to read. I suggest an engineering scale of 1:10.

Start your measurements at a contour of lower elevation. Measure the distance to the next contour (C), and then the distance to a point of interest (P), such as a corner of a grid.

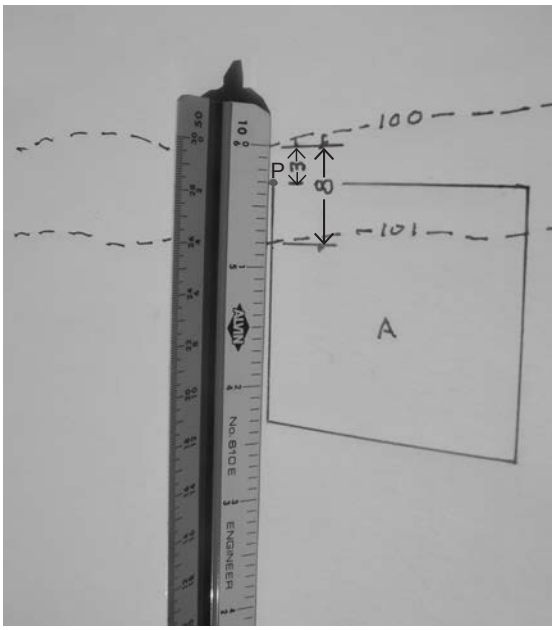


Figure 5-15
Finding distance and elevation of unknown points

Where P = distance measured from the lower contour to the point of interest and C = distance measured from the lower contour to the next contour, the formula for the actual distance from the lower contour line to the point of interest will be:

Actual distance to point = P × 10 ÷ C

I used 10 in the equation above, assuming we're using a 1:10 scale for our measurements. Had we used a 1:20 scale instead, the formula would be: P × 20 ÷ C.

Using the drawing in Figure 5-15, let's determine the elevation at the upper left corner of Grid A. We'll start our measurements from Contour 100 (the lower elevation) and measure the distance to the next contour (C), and the distance to the point (P) — which is the upper left corner of Grid A. Contour 101 (C) is at 8 on the scale and the distance to the point (P) is at 3, so:

Actual distance to point = 3 × 10 ÷ 8

= 3.75 scale units from Contour 100

The elevation at point (P) is 100.375, or 100.4 feet.

As an earthwork estimator, your biggest use for interpolation is in finding grid square corner elevations. Test your interpolation skills now, using the single 50-foot by 50-foot grid square shown in Figure 5-16. Interpolate both existing and proposed elevations for each corner. When you're done, check your results against those in Figure 5-17. If they

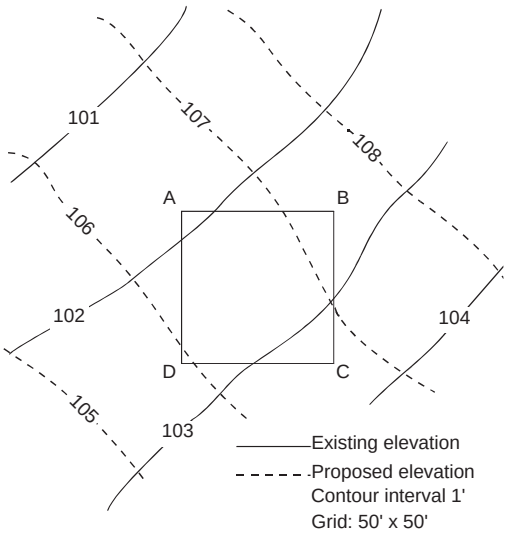


Figure 5-16
Single grid square and partial site plan

Corner	Existing elevation	Proposed elevation
A	101.86	106.50
B	102.63	107.43
C	103.46	106.71
D	102.72	105.93

Figure 5-17
Interpolated corner elevations for Figure 5-16

match within ± 0.1, good work! You're ready for the next step — calculating excavation volumes. If your answers didn't match those in Figure 5-17, review this section before going on. Then try your hand at the interpolations again.

While it's important for you to know how to precisely determine elevation points between contours — and sometimes you have to be very precise, on most jobs, an experienced estimator will simply eyeball it. Be aware that the site plans you're working with were created using existing elevation data points that aren't drawn with great precision — no engineer, survey crew or project owner can afford the cost of shooting precise elevation points taken only a few feet apart. And some sites are so overgrown with vegetation and trees, it would be impossible to shoot true elevations until trees and brush were cleared. So no matter how carefully you calculate the distances, you're calculating from estimated points. I'm not advising you to be careless with your takeoffs — just be realistic. At the start of your career, be extra safe and do the math; after a while, in most cases you can just use your eyes.

Calculating Volume Using the Cross Section Method

Figure 5-18 is a three-dimensional projection showing the same grid square as Figure 5-16. This odd-looking shape is a truncated prism. Notice that it's made up of two planes. One plane, based on the existing elevations, has corners labeled A, B, C and D. The second plane, based on the proposed elevations, has corners labeled A1, B1, C1 and D1. The area between these two planes represents the excavation volume. As an earthwork estimator it's your job to calculate that volume. It's the difference between the existing and proposed elevations, which in this case will be the volume of fill required.

Since we've already found the existing and proposed elevations for each corner, the rest is simple subtraction:

A. 106.50 – 101.86 = 4.64

B. 107.43 – 102.63 = 4.80

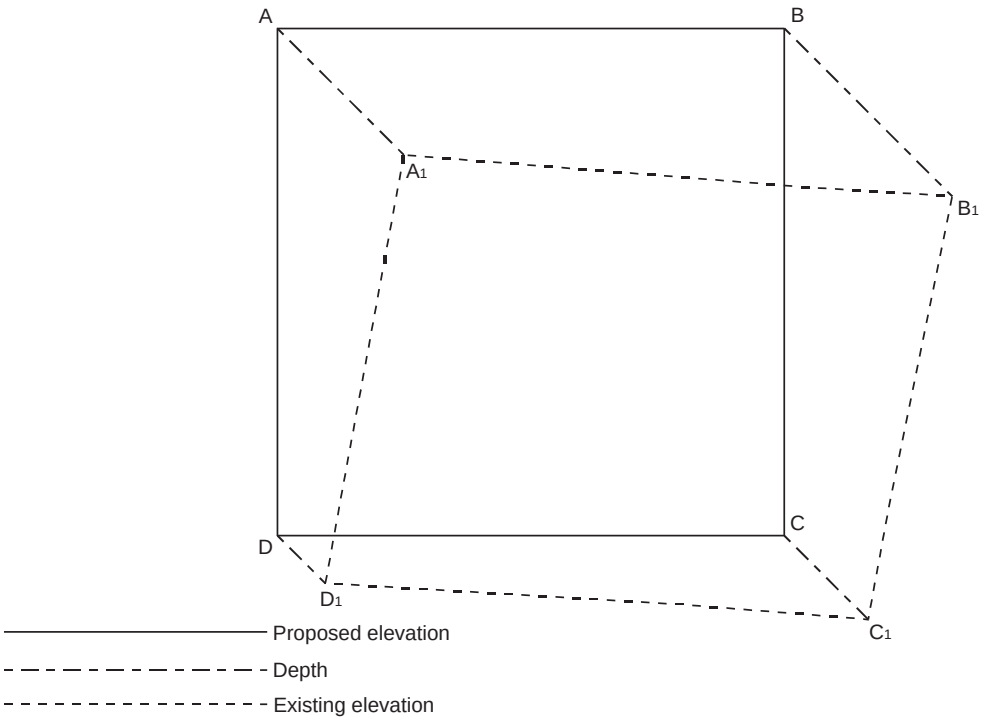


Figure 5-18
This truncated prism is a three-dimensional view of the grid square in Figure 5-16

C. 106.71 – 103.46 = 3.25

D. 105.93 – 102.72 = 3.21

The sum of the four depths divided by 4 will give us the average depth. Here's the math:

Average depth = (4.64 + 4.80 + 3.25 + 3.21) ÷ 4

= 15.9 ÷ 4

= 3.975 feet

Rounding off to two decimal places, our average depth is 3.98 feet.

We now have all the data we'll need to calculate excavation volume using the cross section method. Figure 5-16 supplied us with the following information:

Grid length = 50 feet

Grid width = 50 feet

Here's our formula:

Volume (CY) = (Grid length × Grid width × Average depth) ÷ 27

Volume (CY) = (50 × 50 × 3.98) ÷ 27
= 9,950 ÷ 27
= 368.52 CY

That means we're talking about 368.52 cubic yards of fill.

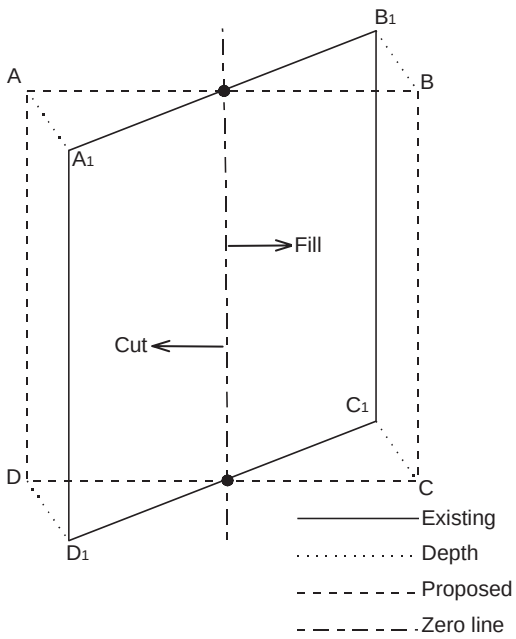


Figure 5-19
Grid square divided into cut and fill areas with a zero line

Calculating Cut and Fill Areas

The system I've just described will work when the grid square is either all cut or all fill. But in some cases you'll have to calculate both cut and fill in the same grid square, and separate the totals into different areas. You may come out with minus numbers. Adding minus numbers is the same as subtracting them.

Figure 5-19 shows a grid square that covers both fill and cut areas. Picture a hillside that you'll cut down on one side and fill in on the other to end up with a flat area. The grid square in the figure also consists of two planes. Points A1, B1, C1 and D1 define the existing elevation plane. Points A, B, C and D define the proposed elevation plane. The points where the planes intersect are zero points. At a zero point the existing and proposed planes have exactly the same elevation. A line connecting two or more zero points is called a *zero line*. A zero line, such as that in Figure 5-19, divides a project into two areas: an area of cut and an area of fill. In our example, the cut area is to the left of the zero line and the fill area is to the right of the zero line.

It's easy to divide a project into cut and fill areas if you follow these steps:

Step 1: Locate and mark the zero points (the intersection of existing and proposed contour lines with the same elevation).

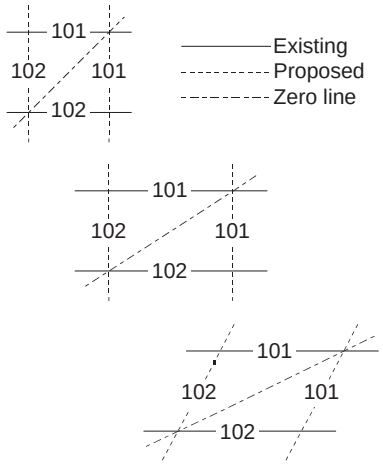


Figure 5-20
Examples of zero line paths

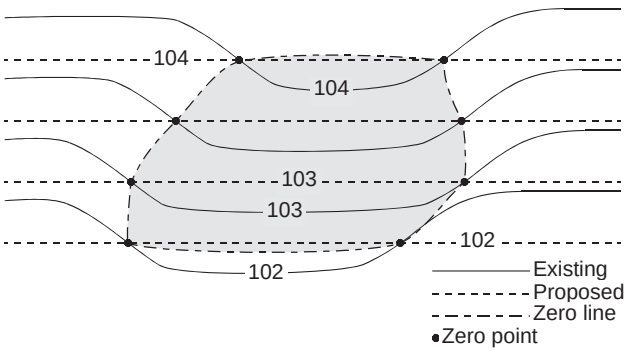


Figure 5-21
A complete or closed zero line

Step 2: Connect the zero points from one edge of the grid square to the other to get a zero line that divides cut from fill.

The exact path of a zero line depends on the paths of the existing and proposed contour lines. However, as you see in Figure 5-20, if the existing and proposed contour lines form a square, rectangle, or parallelogram, then the zero line is a diagonal.

Here are some other rules that will help you understand how a zero line works.

- The zero line runs through all locations where existing and proposed contour lines of the same elevation intersect. There's also a zero line where earthwork is stopped by the presence of manmade or natural structures, such as curbs or walls.
- At any point where a zero line intersects a contour line, there'll be another contour line of the same elevation at that point of intersection.
- Like any contour line, a zero line also eventually closes on itself, as shown in Figure 5-21.

The Zero Line as a Work Boundary

So far, we've only thought of the zero line as a line separating cut areas from fill areas on the site plan. However, the zero line is also a boundary separating "work" areas from "no-work" areas. In fact, a site plan isn't complete unless the zero line closes on itself at the outer work boundary. Figure 5-22 illustrates the site plan from Figure 5-23, with additional subcontour detail. A work boundary takes shape as you connect the dots between intersecting existing and proposed subcontour lines.

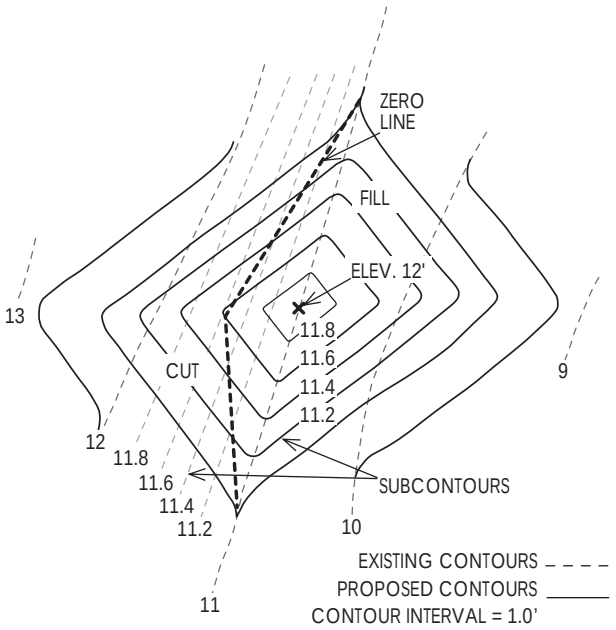


Figure 5-22
Revised zero line accommodates proposed high point on site plan

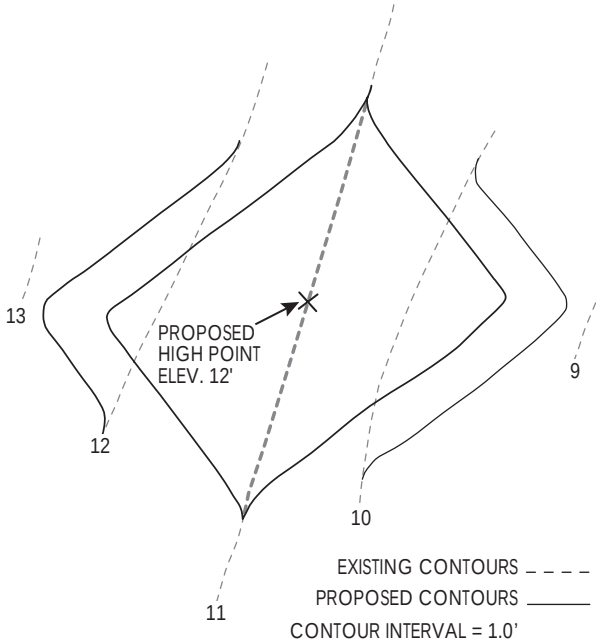


Figure 5-23
Site plan with proposed high point

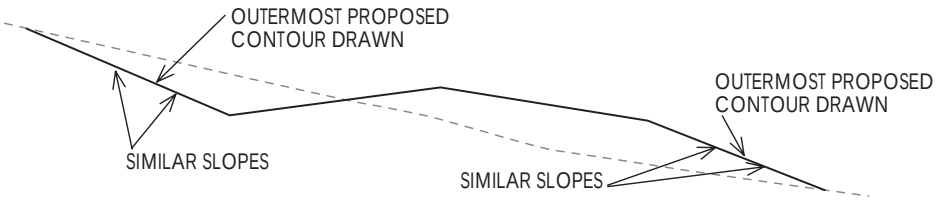


Figure 5-24
Extending contours based on known slopes

You may have noticed in these examples that the proposed grade line is incomplete beyond the outermost proposed contour lines. To draw the complete work boundary, you can make the following assumption: Existing and proposed slopes (beyond the outermost proposed contour line) extend in a similar fashion to the slopes within the region. Figure 5-24 illustrates the contour extension, and Figure 5-25 shows the site plan with complete work boundary.

Adjusting the Zero Line for Topsoil Stripping

The zero line will shift to a new position if the depths of topsoil stripped (TS) and topsoil replaced (TR) differ. Figure 5-26 illustrates this shift.

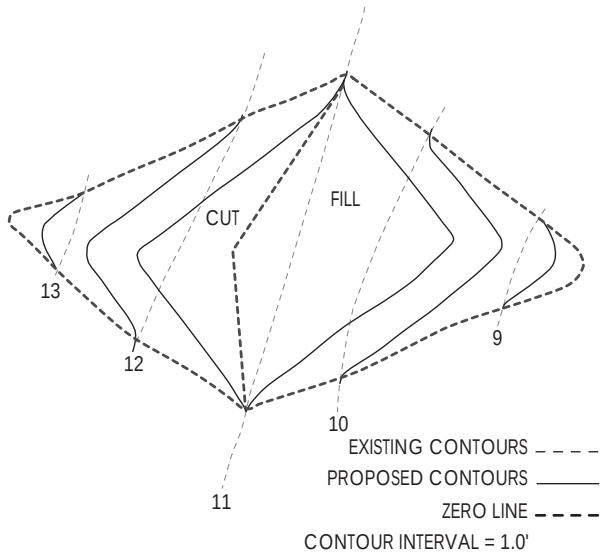


Figure 5-25
Site plan with complete work boundary

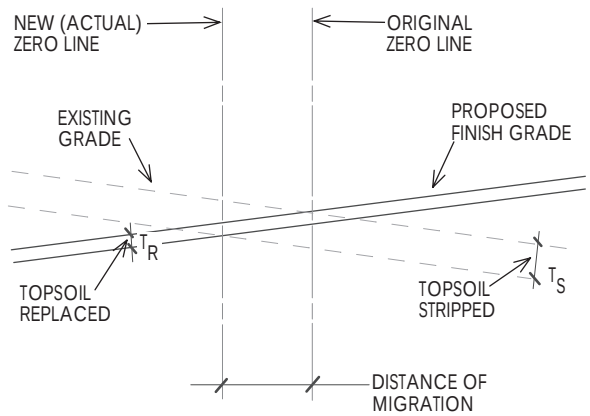


Figure 5-26
Zero line, adjusted for difference between topsoil stripped and topsoil replaced

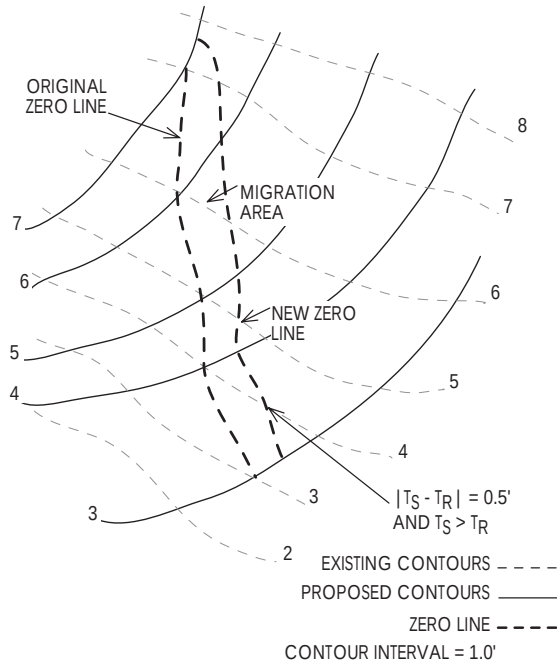


Figure 5-27
Zero line, adjusted for difference between topsoil stripped and topsoil replaced

The zero line's elevation shift will equal the difference between the depth of topsoil stripped and the depth of topsoil replaced. As a general rule, if more topsoil is stripped than replaced, the zero line shifts to a higher existing elevation. For example, Figure 5-27 shows the outcome when 2 feet of topsoil are stripped, and only 1.5 feet replaced. The net change is 0.5 feet, so the zero line shifts to a higher existing elevation by that amount.

In cases where more topsoil is replaced than stripped, the zero line shifts to a lower existing elevation. The math is the same as in the example above: simply take the difference between stripped topsoil depth and replaced topsoil depth.

Adjusting the Zero Line When it Crosses a Slab or Paving

You'll also need to adjust the zero line whenever it intersects structures, such as curbs, slabs and retaining walls. Figure 5-28 shows a zero line at the top of a slab.

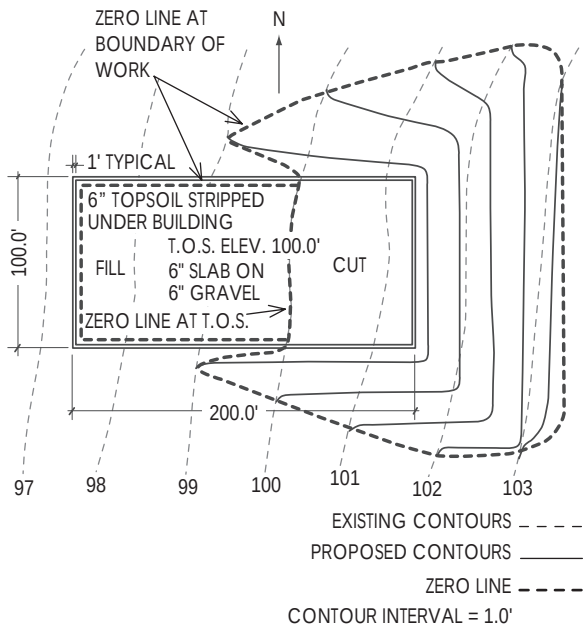


Figure 5-28
Zero line intersecting a slab

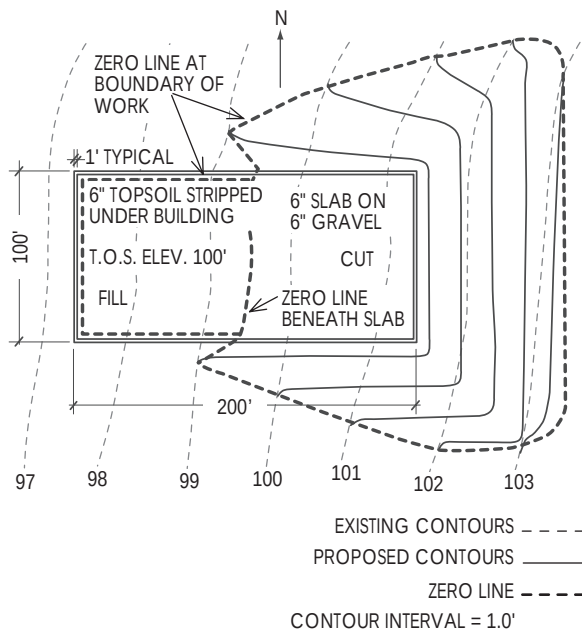


Figure 5-29
Zero line, adjusted for slab on gravel

If the original zero line crosses the top of the slab, then the adjusted zero line will be parallel to the original zero line. To determine the adjusted zero line's elevation, start with the top-of-slab (T.O.S.) elevation, and add the stripped topsoil thickness. Then subtract the thickness of the slab and underslab. In Figure 5-28, the top-of-slab elevation is 100 feet. Adding 6 inches for the stripped topsoil to that figure yields 100.5 feet. Since there's 6 inches of slab on 6 inches of gravel, we then subtract 12 inches (1 foot) from 100.5 feet, which leaves an adjusted zero line elevation of 99.5 feet. Figure 5-29 shows the site plan with adjusted zero line.

Determining Where the Zero Line Crosses a Grid Line

There are many methods that we can use to determine the path of the zero line. One way to determine the location of the zero line is to draw a series of cross sections across the zero line at strategic locations. This method is time-consuming; however, it's sometimes a necessity.

Another way to determine the path of the zero line is to find the locations where the zero line intersects grid lines. These points of intersection are found by using a proportion that relates horizontal distance to depth of cut (or fill). This method assumes that there's a uniform slope between successive existing or proposed contour lines. For example, let's determine the path of the zero line through Prism E in Figure 5-30.

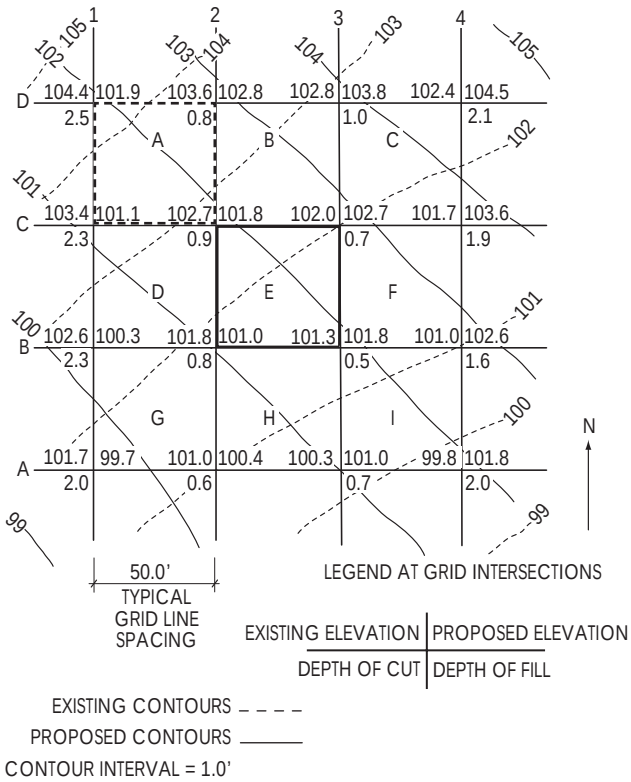


Figure 5-30
Site plan with cut and fill requirements

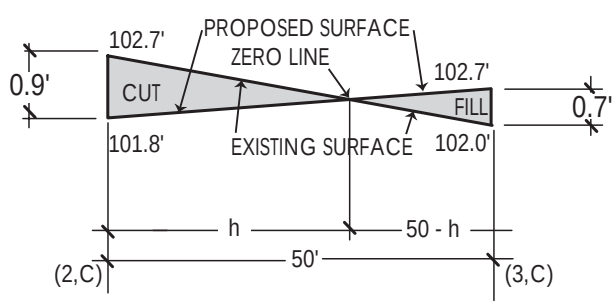


Figure 5-31
Detail cross section of Prism E

Examining the existing and proposed elevations at the corners of Prism E reveals that cutting is required in the western portion of the prism and fill is required in the eastern portion. Therefore, the zero line runs in a north-south direction and intersects Grid Lines B and C. As we look north at a cross section at Grid Line C between the corners (2,C) and (3,C), we can see the cross section in Figure 5-31.

This cross section reveals two similar triangles whose altitudes (h and 50' – h) are proportionate, that is:

$$\frac{0.9}{h} = \frac{0.7}{50' - h}$$

Solve for h:

$$0.9 \times (50 - h) = 0.7h$$

$$45 - 0.9h = 0.7h$$

$$45\ (-0.9h + 0.9h) = 0.7h + 0.9h$$

$$45 = 1.6h$$

$$\frac{45}{1.6} = \frac{1.6h}{1.6}$$

$$h = 28.125 \text{ rounded to 28 feet}$$

Therefore, the zero line intersects Grid Line C at a distance of 28 feet from the corner at 2,C. Using the same method (drawing cross sections isn't necessary), we can locate the intersection of the zero line with Grid Line B by using the proportion:

$$\frac{0.8}{h} = \frac{0.5}{50 - h}$$

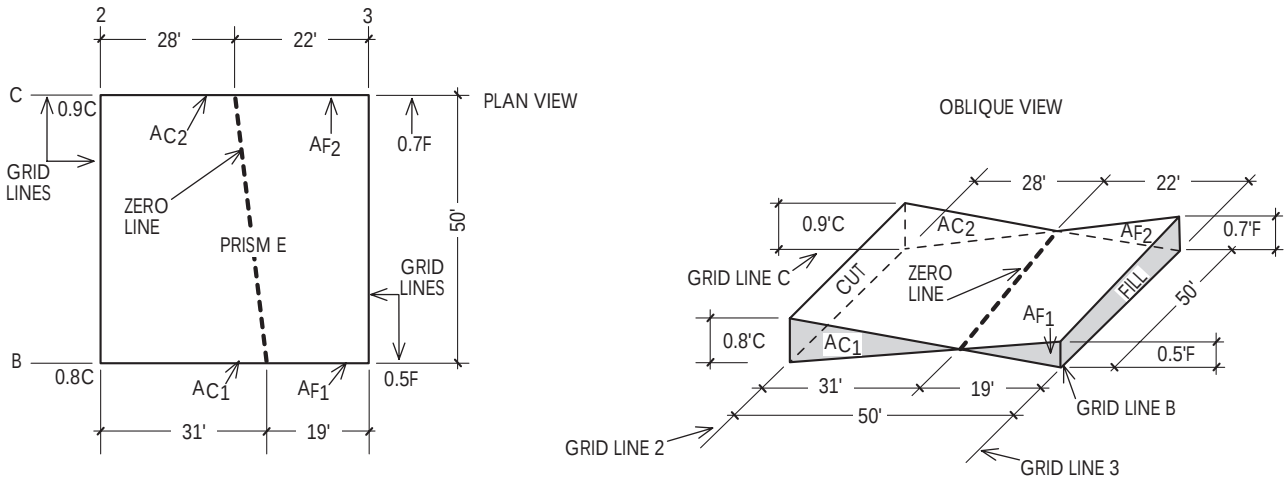


Figure 5-32
Detailed views of Prism E

Solving for h as on the previous page, we get:

$0.8 \times (50 - h) = 0.5h$

$40 - 0.8h = 0.5h$

$40\ (-0.8h + 0.8h) = 0.5h + 0.8h$

$40 = 1.3h$

$$\frac{40}{1.3} = \frac{1.3h}{1.3}$$

h = 30.77 rounded to 31 feet

h = 31 feet from grid corner 2,B

You can see the detailed view of our calculations in Figure 5-32.

The Average End Area Method

There are several methods we can use to calculate the volume in these cut and fill areas. For Figure 5-18 we used the cross-section method to calculate volume. We subtracted the existing corner heights from the desired corner heights, divided by 4 to find the average depth, and then multiplied the answer by the grid dimensions.

Another common way to figure volumes of soil is the *average end area method.* We find the average area of the two ends and multiply by the distance between them. The formula is:

Volume (CF) = [(Area 1 + Area 2) ÷ 2] × Grid length

Look at Figure 5-33. The end areas are the triangles labeled A1 and A2. Here's the formula used to calculate the area of a triangle:

Area = ½ base × height

First we'll calculate triangle A1:

Area (SF) = (12 × 10) ÷ 2
= 120 ÷ 2
= 60 SF

The end area for A1 equals 60 square feet.

Now repeat the calculation for triangle A2:

Area (SF) = (10 × 6) ÷ 2
= 60 ÷ 2
= 30 SF

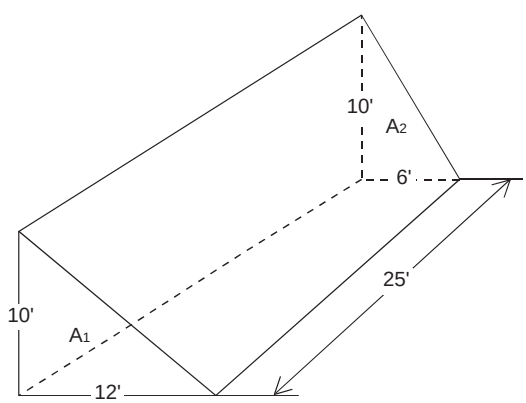


Figure 5-33
Calculating volume using the average end area method

You are now ready to calculate the volume of Figure 5-33 using the average end area method. Here's the math:

Volume (CF) = [(60 + 30) ÷ 2] × 25
= [90 ÷ 2] × 25
= 45 × 25
= 1,125 CF

I always convert volumes to cubic yards. Why? First, I know I'll have to make this conversion sooner or later, because the quantities are so large that cubic yards are the only practical units to use. Second, by consistently using cubic yards for any volume right from the start, I eliminate a huge possibility for potential errors. If I don't convert the volume for Figure 5-33 into cubic yards now, it'll be very easy to overlook it later on.

And that's no minor slipup — it's a major disaster. Throughout this chapter you'll see volume calculations set up with the results in cubic yards. I strongly recommend that you do the same in your work.

Converting cubic feet to cubic yards is easy. You just divide by 27. Let's convert the volume we just found for Figure 5-33 into cubic yards:

$$1{,}125 \text{ CF} \div 27 = 41.66 \text{ CY}$$

Let's say that no one noticed the discrepancy in the units, and you used 1,125 cubic yards, instead of 41.66, in your estimate. I think you'll agree that error makes a huge difference!

Being able to calculate end areas accurately is an important skill for an earthwork estimator. Most of the time you'll find the area of regular geometric shapes: rectangles, circles, and triangles. Occasionally, however, you'll need to find the area of a less familiar shape, such as a rhombus. If you need to refresh your geometry (What's a polygon and how do you find its area?), just go online and use a search engine. Most dictionaries and encyclopedias have the area and volume formulas too.

Frustums vs. Average End Area Method

Technically, the average end area method isn't the most precise formula to use when determining the volume of a solid like the one shown in Figure 5-33. However, the alternative, the volume of a frustum of a pyramid formula, is cumbersome and time-consuming to use. And, both produce very similar results. Figure 5-34 shows frustums of a cone and a pyramid. The equation for the volume of such a solid is:

$$\text{Volume} = \tfrac{1}{3} \times \text{Grid length} \times [A_1 + A_1 + \sqrt{(A_1 \times A_2)}]$$

Using the Frustum formula to solve the problem in Figure 5-33, here's how you'd find the volume:

$$\begin{aligned}\text{Volume} &= \tfrac{1}{3} \times 25 \times [60 + 30 + \sqrt{(60 \times 30)}] \\ &= \tfrac{1}{3} \times 25 \times [90 + 42.43] \\ &= \tfrac{1}{3} \times 25 \times 132.43 \\ &= 1{,}102.5 \text{ rounded to } 1{,}103 \text{ CF}\end{aligned}$$

$$\begin{aligned}\text{Volume (CY)} &= 1{,}103 \text{ CF} \div 27 \\ &= 40.87 \text{ CY}\end{aligned}$$

As you can see, the resulting difference between formulas is less than a cubic yard.

Frustums

$V = \frac{1}{3}h\ (B + B' + \sqrt{B \times B'})$

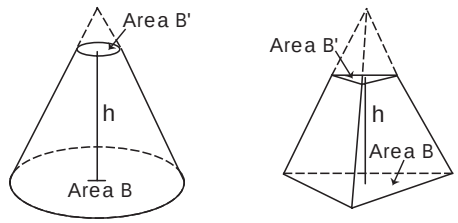


Figure 5-34
Formula for finding frustum of a cone or pyramid

The Prismoidal Formula Method

An even more accurate, but time-consuming, method than the average end area method for determining soil volumes is the prismoidal formula method, which states:

$$\text{Volume} = A_1 + 4AM + A_2 \times L \div 6$$

Where:

A_1 = End area at one end of the prism

A_2 = End area at the opposite end of the prism

AM = Median area
= Cross-sectional area of the solid at the center of the prism

And

A_1, A_2, and AM must be parallel and not equal to zero. (See Figure 5-35).

Let's look at an example using Figure 5-35. Where:

A_1 = 200 SF

A_2 = 500 SF

AM = 320 SF

L = 100 ft

$$\text{Volume} = A_1 + 4AM + A_2 \times L \div 6$$

$$\begin{aligned}\text{Volume} &= 200 + (4 \times 320) + 500 \times 100 \div 6\\ &= 200 + 1{,}280 + 500 \times 100 \div 6\\ &= 1{,}980 \times 100 \div 6\\ &= 198{,}000 \div 6\\ &= 33{,}000 \text{ CF}\end{aligned}$$

Now let's convert it to cubic yards:

$$\begin{aligned}\text{Volume} &= 33{,}000 \text{ CF} \div 27\\ &= 1{,}222 \text{ CY}\end{aligned}$$

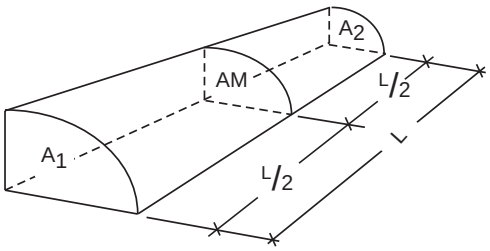


Figure 5-35
Prismoidal formula

Calculating the Volume of a Trapezoidal-Shaped Prism

As we've seen, there can be more than one way to calculate most volumes. I emphasized most, and here's why. The shape shown in Figure 5-36 A is a trapezoidal-shaped prism. The two planes, labeled A_1 and A_2, are trapezoids. A trapezoid is a four-sided geometric shape with one pair of parallel sides and one pair of nonparallel sides. As it happens, the only way to accurately calculate the volume of this shape is by using the average end area method. Don't use the cross-section method. The result it gives for volume is dangerously low. Let's calculate the volume of the same trapezoidal-shaped prism using both methods and then compare the results.

Using the Average End Area Method

We'll use the information from Figure 5-36 B. It shows only the two trapezoid-shaped planes A_1 and A_2. Notice the letters in parenthesis that appear next to the dimensions. The letters come from the formula used to find the area of a trapezoid:

$$\text{Area (SF)} = [(a + b) \div 2] \times h$$

Take another look at Figure 5-36 B and note that "a" and "b" are the parallel sides and "h" is one of the nonparallel sides in each trapezoid.

Here are the calculations for finding the area of A_1:

$$\begin{aligned}\text{Area } A_1 \text{ (SF)} &= [(10 + 9) \div 2] \times 50\\ &= [19 \div 2] \times 50\\ &= 9.5 \times 50\\ &= 475 \text{ SF}\end{aligned}$$

Here are the calculations for finding the area of A_2:

$$\begin{aligned}\text{Area } A_2 \text{ (SF)} &= [(8 + 7) \div 2] \times 20\\ &= [15 \div 2] \times 20\\ &= 7.5 \times 20\\ &= 150 \text{ SF}\end{aligned}$$

Here's the formula for the volume of a trapezoid, in cubic yards:

$$\text{Volume (CY)} = \{[(\text{Area 1} + \text{Area 2}) \div 2] \times \text{Length}\} \div 27$$

Plug in the numbers we just calculated, and you get:

Volume (CY) = {[(475 + 150) ÷ 2] × 50} ÷ 27

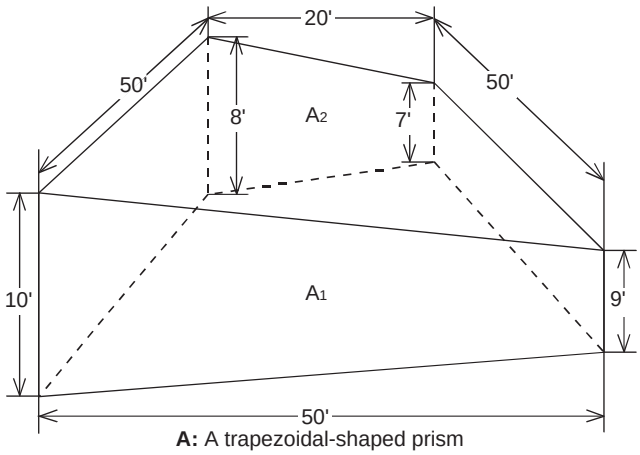
= {[625 ÷ 2] × 50} ÷ 27

= {312.5 × 50} ÷ 27

= 15,625 ÷ 27

= 578.7 CY

Round off the result to 579 cubic yards.



A: A trapezoidal-shaped prism

Using the Cross Section Method

We'll work from Figure 5-36 and begin by finding these dimensions: length, width, and depth. Length is consistent, and equals 50 feet. The other two dimensions vary, so we'll find averages for both depth and width.

Average width (ft) = (50 + 20) ÷ 2

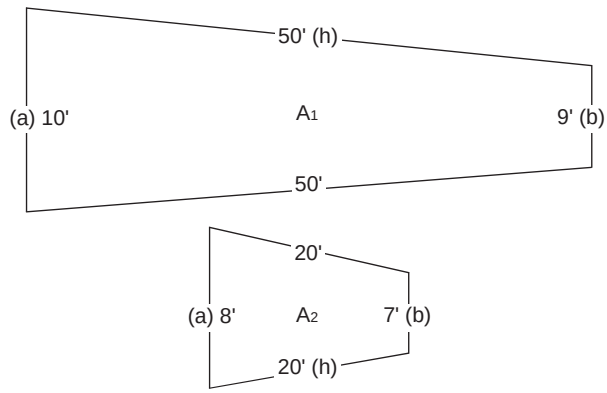
= 70 ÷ 2

= 35 ft

Average depth (ft) = (10 + 9 + 8 + 7) ÷ 4

= 34 ÷ 4

= 8.5 ft



B: Trapezoid planes from section A

Figure 5-36
Calculating the volume of a trapezoidal-shaped prism

Now we'll calculate the volume in cubic yards using this formula:

Volume (CY) = (Length × Average width × Average depth) ÷ 27

= (50 × 35 × 8.5) ÷ 27

= 14,875 ÷ 27

= 550.93 CY

We'll round the result off to 551 cubic yards.

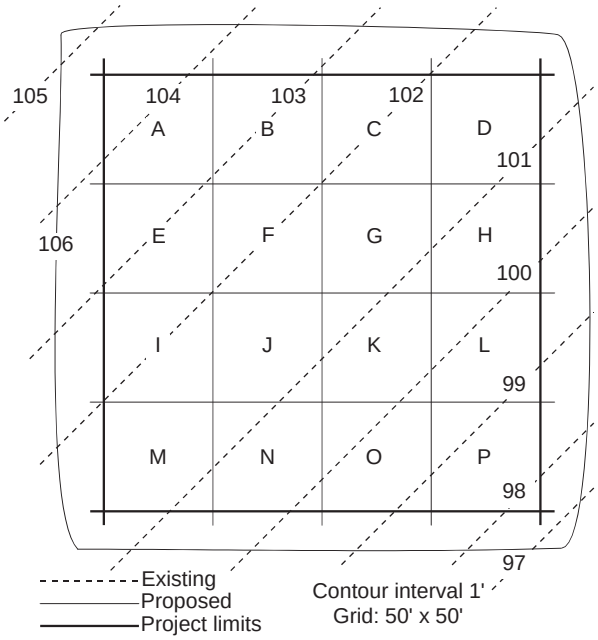


Figure 5-37
Site plan for sample project

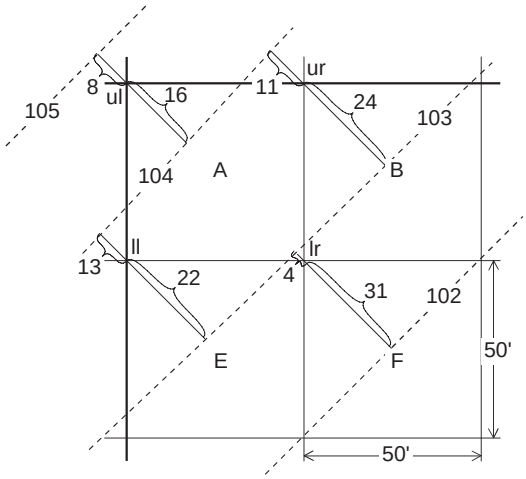


Figure 5-38
Detail, grid square A from Figure 5-37

Now let's compare the results of the two methods of calculating volume.

Cross section method: Total volume = 551 CY

Average end area method: Total volume = 579 CY

The difference is 28 cubic yards. That's how much you'd underestimate the job using the cross section method. In this business, big mistakes come with big price tags. Always use the average end area method for this kind of calculation.

Using Worksheets in a Take-off

We've covered the basics of doing take-offs from topo maps. It's now time to see how you can simplify, organize and streamline the process. Worksheets help you organize and simplify the whole take-off process. Constants help by making the math faster and easier. In this partial take-off, using the project layout shown in Figure 5-37, we'll use worksheets and constants. We'll start at grid square A. You'll find it easier to work from Figure 5-38. This shows only the top left quadrant of Figure 5-37, slightly enlarged.

Individual grid square area and volume worksheet Grid square: A Area = l x w 50' x 50' = 2,500 SF								
Factors	**Existing contour (symbol: - - - - - -)**				**Proposed contour (symbol: ———)**			
	ul	**ur**	**ll**	**lr**	**ul**	**ur**	**ll**	**lr**
Out	105	103	103	102				
In	104	104	104	103				
Diff	1	1	1	1				
Dist	24	35	35	35				
Out±	-8	+24	+22	+31				
In±	+16	-13	-13	-4				
Point elevation	105 - [(1/24) x 8] 105 - [0.042 x 8] 105 - 0.3 104.7	104 - [(1/35) x 13] 104 - [0.029 x 13] 104 - 0.4 103.6	104 - [(1/35) x 13] 104 - [0.029 x 13] 104 - 0.4 103.6	103 - [(1/35) x 4] 103 - [0.029 x 4] 103 - 0.1 102.9	106	106	106	106
Average elevation	(104.7 + 103.6 + 103.6 + 102.9) ÷ 4 414.8 ÷ 4 103.7				(106 + 106 + 106 + 106) ÷ 4 424 ÷ 4 106			
Fill volume (CY) = [(average proposed elevation - average existing elevation) x grid area] ÷ 27 = [(106 - 103.7) x 2,500] ÷ 27 = [2.3 x 2,500] ÷ 27 = 5,700 ÷ 27 = 212.96 CY								

Figure 5-39
Worksheet, grid square A

Individual Grid Square Area and Volume Worksheet

Figure 5-39 shows one type of worksheet I use for a quantity take-off. While it may seem extravagant to use a separate worksheet for each grid square, it's a good way to get started. Paper is cheap; mistakes are expensive. It's better to use a little extra paper and prevent mistakes. As your quantity take-off skill increases and you build confidence, you can consider combining more grid calculations on a single page. But even experienced estimators find that this type of worksheet reduces errors and makes it easier to check the work later.

The worksheet is divided into three main sections: top, middle and bottom. You use the top section to record general information such as project name/number, grid name and area dimensions. Record raw data and calculate existing contours and proposed contours in the middle section. Then, in the bottom section, calculate your cut and fill volumes for the entire grid square.

Let's take a close look at the middle part of the worksheet now, under *Existing contour and Proposed contour*. Start by looking at the information under the column headings.

Existing contour and Proposed contour: I have a dashed line after *Existing contour* and a solid line after *Proposed contour*. That's where you want to copy the existing and proposed contours of your site plan.

Notice that below the *Existing contour* and *Proposed contour* you find the same set of four column headings. These are the names we'll use for the corner points:

ul upper left

ur upper right

ll lower left

lr lower right

In each of these columns, we're going to make an educated guess about the elevation of one of the four corners.

Now let's run down the list of row headings shown in the far left column, starting with:

Factors: This is a collective heading for the next six row headings.

Out and In: Use these spaces to record the elevation of the contour lines that are outside and inside that corner. Out means the nearest line that's outside of the grid square itself. *In* is the nearest line that's inside the grid square. In Figure 5-38, contour line 105 is outside of grid square A at corner *ul* (upper left). Contour line 104 is inside grid square A at corner *ul*.

Most rules have exceptions and so do these. For example, take a look at corner *ur* in Figure 5-38. The bracketing contour lines are clearly 104 and 103. But, which one is the *Out* factor and which is the *In* factor? Notice that neither contour line is inside the grid square at this corner point. Furthermore, both contour lines do pass through grid square A elsewhere. Here's what I do:

In factor = The bracketing contour line closest to corner *ur*. In Figure 5-38 it's the 104 foot contour line.

Out factor = The bracketing contour line furthest away from corner *ur*. In Figure 5-38 it's the 103 foot contour line.

Or you can turn it around like this:

Out factor = The bracketing contour line at corner *ur* with the higher elevation. In Figure 5-38 it's the 104 foot contour.

In factor = The bracketing contour line at corner *ur* with the lower elevation. In Figure 5-38 it's the 103 foot contour.

It doesn't really matter which method you use. What does matter is consistency. Choose a method to deal with this situation, and stick with it.

Now, let's get back to the rest of the row headings listed under *Factors*. The next one is:

Diff: This is short for "difference." Use this row to record the difference between *Out* and *In* factors.

For example. Let's find *Diff* for corner *ul* in Figure 5-38. Since *Diff* = *Out* – *In*, just substitute the numbers and you get:

105 – 104 = 1

The difference or *Diff* is always the same as the contour interval on the site plan.

Dist: This, short for "distance," is the total measured horizontal distance that separates the *In* contour line from the *Out* contour line.

Figure 5-38 includes the measured distances from the corner points to each contour line. To find *Dist* for corner *ul* in grid A, for instance, all you do is add the measurements together. Here's the math:

8 + 16 = 24

Out±: Use this row to record the horizontal distance you measure from the corner point to the *Out* contour line. The + and – signs show whether the change in elevation between the corner point and the contour line is positive or negative. If that isn't clear right now, it will be after you follow along with these two examples taken from Figure 5-38, grid A.

Here's what we know about corner *lr*.

Out = 102

In = 103

The measured horizontal distance (102 to *lr*) is 31.

At corner *lr*, the *In* elevation (103 feet) is greater than the *Out* elevation (102 feet). That means there's a gain in elevation between corner *lr* and the 102 foot contour line. So the *Out*± factor is positive (+31).

Out± = +31

For the second example we'll use corner *ul*. Here's what we know about it:

Out = 105

In = 104

The measured horizontal distance (*ul* to 105) is 8.

At corner *ul* the *Out* elevation, 105 feet, is greater than the *In* elevation, 104 feet. That means the elevation drops between corner *ul* and the 105 foot contour line. So the *Out*± factor is negative (–8).

Out± = –8

***In*±:** Use this row to record the horizontal distance you measure between the corner point and the *In* contour line. The + and – signs serve the same purpose here as they do in the case of the *Out*± factor.

Follow along as we find the *In*± factor for corner *ul* of grid A in Figure 5-38.

Here's what we know about corner *ul:*

Out = 105

In = 104

The measured horizontal distance (104 to *ul*) is 16.

At corner *ul*, the *Out* elevation (105 feet) is greater than the *In* elevation (104 feet). That means there's a gain in elevation between the 104 foot contour line and corner *ul*. So the *In*± factor is positive (+16).

These two factors are very important, so be sure you record the data correctly and use the right sign. The only way to be certain that your data's correct is to check your work. Here's how I check these factors:

1. Check the signs using the following fact. A corner point always has an *In*± factor, as well as an *Out*± factor. One of the two factors will always be negative. The other factor must be positive. If the signs match, there's an error in your work.

2. Ignoring the signs, find the sum of the two factors. The result should match the *Dist* factor for the same corner point.

Let's look at the last two headings, *Point elevation* and *Average elevation*, in the left column on the worksheet (Figure 5-39). Both are multistep calculations.

Point elevation: Calculate it for each corner point using this formula:

Point elevation (feet) = High elevation – [(Diff ÷ Dist) × The negative ± factor]

Earlier we saw how to find both the ***In*±** factor and the ***Out*±** factor using corner *ul* as our example. Now let's try out this formula using the data for corner *ul*.

Point elevation (feet) = 105 – [(1 ÷ 24) × 8]

= 105 – [0.04 × 8]

= 105 – 0.32

= 104.7 feet

Average elevation: Find the sum of the four point elevations and divide by 4. To see what this looks like, check out the *Average elevation* row on the *Existing contour* side of the worksheet for grid square A.

Perhaps you're wondering what's going on in Figure 5-39 on the *Proposed contour* side? I have to admit it looks short on data. In Figure 5-37, you can see that contour line 106 surrounds the whole project. In other words, it's flat. If it weren't, you would repeat the same calculations we just finished on the *Existing contour* side for the *Proposed contour* side.

That leaves only the bottom section of the worksheet to cover. Let's start with a summary of the data we'll use:

Average existing elevation (AEE) = 103.7 feet

Average proposed elevation (APE) = 106 feet

Area grid square A, calculated in the top section = 2,500 SF

We'll begin by seeing how to tell if the excavated volume is cut or fill. Then we'll calculate the total excavation volume.

To find if you're dealing with cut or fill, compare the average existing and proposed elevations. If the existing elevation is larger, you'll have a cut volume. If the proposed elevation is larger, you'll have a fill volume.

Here's the formula you use to calculate fill volume in cubic yards:

Fill volume (CY) = [(APE – AEE) × Grid square area] ÷ 27

Plug the numbers for grid square A into the formula and you get:

$$\text{Fill volume (CY)} = [(106.0 - 103.7) \times 2{,}500] \div 27$$
$$= [2.3 \times 2{,}500] \div 27$$
$$= 5{,}750 \div 27$$
$$= 212.96 \text{ CY}$$

Now test yourself by completing your own calculations for grid square K. You'll find the enlarged view of grid K in Figure 5-40 helpful. Check your results against those shown in Figure 5-41.

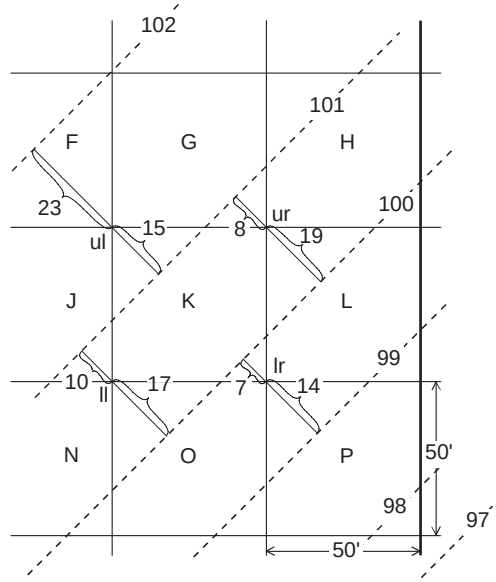


Figure 5-40
Detail, grid square K from Figure 5-37

Individual grid square area and volume worksheet Grid square: K Area = l x w 50' x 50' = 2,500 SF								
Factors	**Existing contour (symbol: - - - - - -)**				**Proposed contour (symbol: ———)**			
	ul	**ur**	**ll**	**lr**	**ul**	**ur**	**ll**	**lr**
Out	102	100	100	99				
In	101	101	101	100				
Diff	1	1	1	1				
Dist	38	27	27	21				
Out±	-23	+19	+17	+14				
In±	+15	-8	-10	-7				
Point elevation	102 - [(1/38) x 23] 102 - [0.026 x 23] 102 - 0.6 101.4	101 - [(1/27) x 8] 101 - [0.037 x 8] 101 - 0.3 100.7	101 - [(1/27) x 10] 101 - [0.037 x 10] 101 - 0.4 100.6	100 - [(1/21) x 7] 100 - [0.048 x 7] 100 - 0.3 99.7	106	106	106	106
Average elevation	(101.4 + 100.7 + 100.6 + 99.7) ÷ 4 402.4 ÷ 4 100.6				(106 + 106 + 106 + 106) ÷ 4 424 ÷ 4 106			
Fill volume (CY) = [(average proposed elevation - average existing elevation) x grid area] ÷ 27 = [(106 - 100.6) x 2,500] ÷ 27 = [5.4 x 2,500] ÷ 27 = 13,500 ÷ 27 = 500 CY								

Figure 5-41
Worksheet, grid square K

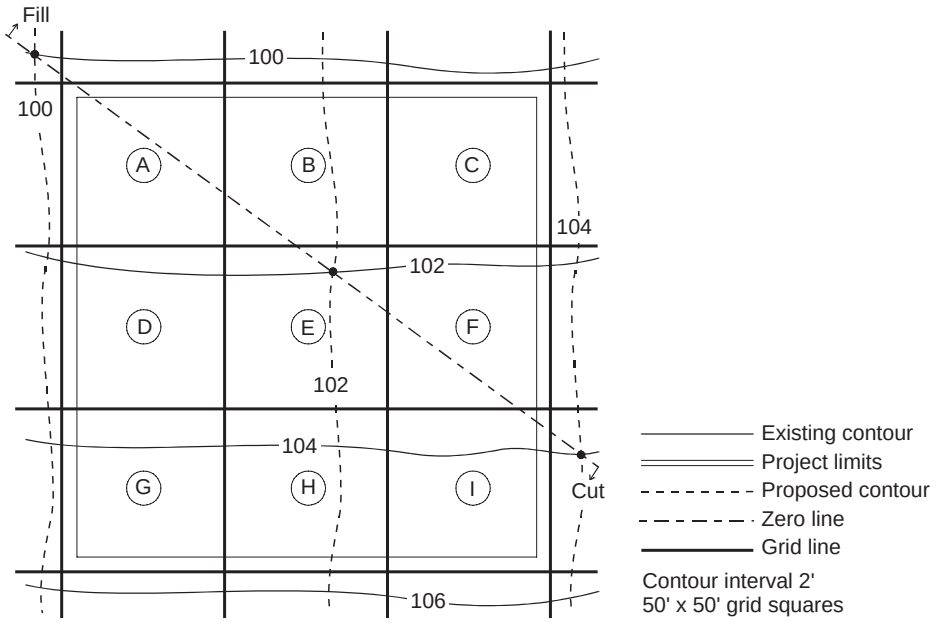


Figure 5-42
Sample project layout

Shortcuts for Calculating Quantities

Remember the basic rule for calculating the average elevation of grid squares: Total the elevation of all four corners and divide by 4. This always works, but it's not always the fastest way to get the job done. After you've gained some estimating experience, you'll learn some shortcuts that work for you. They save time, needless repetition, or they're just a lot less bother. I've included a few of my best shortcuts in the next example.

For my sample project, I'll use a small parking lot. Figure 5-42 is a topo map that's been made into the site plan for the project. The legend shows the contour lines and contour interval. Note the zero line running in a diagonal direction from lower right to upper left. It connects three points where existing and proposed contour lines of the same elevation meet. You'll recall that a zero line also divides a project into an area of cut and another of fill. In Figure 5-42, left of the zero line is cut, and right of the zero line is fill. There's a grid imposed over the topo map.

For practice, I recommend that you make a photocopy of the site plan in Figure 5-42. We're going to add subcontours to the project layout. On your copy, draw existing and proposed subcontours freehand, halfway between each pair of plotted contours. The result should look like Figure 5-43. Check the added subcontours for elevations 103, 102 and 101. These lines (existing and proposed) intersect at the zero line.

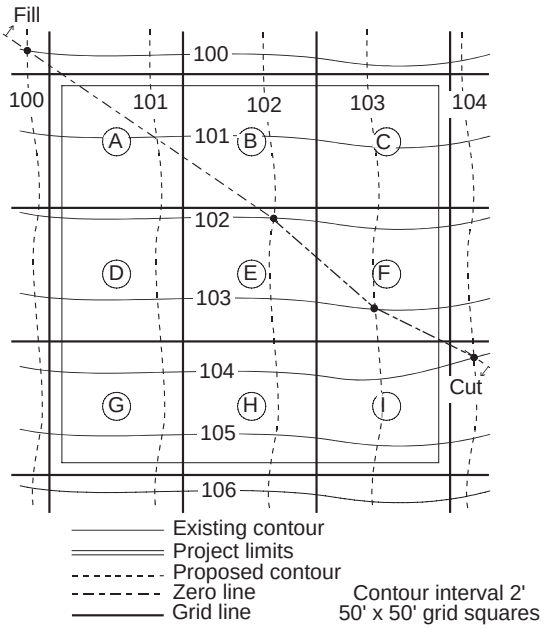


Figure 5-43
Site plan after adding the intermediate contour lines

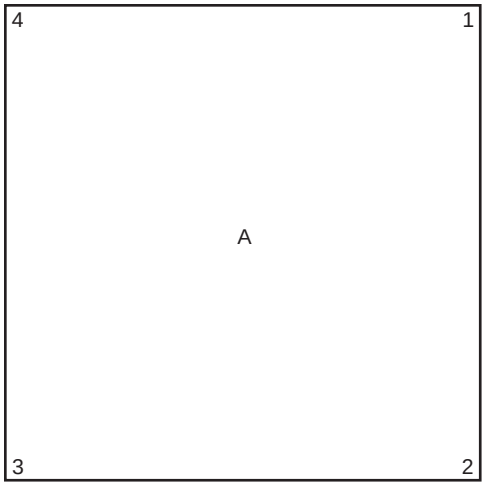


Figure 4-44
Grid square A with corner points labeled

Take a look now at Figure 5-44. It shows a different system for identifying grid square corners. In this system each corner position is a number. The top right corner is 1. Move clockwise around the square, ending with number 4 at the top left corner.

Figure 5-45 is a completed copy of the worksheet using this method of numbering the corners. We'll use it to find the corner elevations. It's very different from Figure 5-39, so let's take a close look. At the left is a column identifying the grid squares we're using for this project. Next to the identification for each grid square are five columns and three rows to record data and calculate corner depths for each grid square. Look for the heading *Element*, another name for corner point, and the headings for the corner points *1, 2, 3* and *4*. Below *Element* are *Proposed, Existing* and *Depth*. *Proposed* and *Existing* refer, as you know, to elevations. *Depth* is their difference.

Interpolate the existing and proposed corner elevations, in feet, for all nine grid squares. Compare your interpolated elevations with those shown in Figure 5-45. Then complete the worksheet by finding the difference between the two elevations and entering it in the *Depth* row.

The fill data and calculations appear in Figure 5-46. The top portion of this worksheet contains standard information: *Project, Date, By,* and *All (cut or fill)*. This information is filled in already in Figure 5-46 to read "Fill." The main part of the worksheet is a table with six columns. However, only three of these contain data: *Grid, Corner,* and *Total depth*. *Grid* refers to the grid square name. However, this list isn't complete. Three grid squares are left out: D, G, and H. Another look at the project layout in Figure 5-41 shows why. These three grid squares are entirely on the cut side of the zero line. Only grid square C is entirely on the fill side of the zero line.

Individual Grid Square Depth Calculations Worksheet
Job Number: 6973 **Project:** (Figure 5-42) **By:** L. Level **Date:** 06/25
Sheet 1 **of** 1 **Cut & Fill**

	Element	1	2	3	4
Grid A	Proposed	101.32	101.31	100.19	100.16
	Existing	100.11	101.54	101.86	100.22
	Depth	1.21	0.23	1.67	0.06
Grid B	Proposed	102.44	102.46	101.31	101.32
	Existing	100.2	101.75	101.54	100.11
	Depth	2.24	0.71	0.23	1.21
Grid C	Proposed	103.62	103.45	102.46	102.44
	Existing	100.17	101.73	101.75	100.2
	Depth	3.45	1.72	0.71	2.24
Grid D	Proposed	101.31	101.31	100.18	100.19
	Existing	101.54	103.48	103.5	101.86
	Depth	0.23	2.17	3.32	1.67
Grid E	Proposed	102.46	102.46	101.31	101.31
	Existing	101.75	103.5	103.48	101.54
	Depth	0.71	1.04	2.17	0.23
Grid F	Proposed	103.45	103.63	102.46	102.46
	Existing	101.73	103.47	103.53	101.75
	Depth	1.73	0.16	1.04	0.71
Grid G	Proposed	101.31	101.33	100.19	100.18
	Existing	103.48	105.40	105.53	103.5
	Depth	2.17	4.07	5.34	3.32
Grid H	Proposed	102.46	102.45	101.33	101.31
	Existing	103.55	105.40	105.43	103.48
	Depth	1.04	2.84	4.07	2.17
Grid I	Proposed	103.63	103.43	102.45	102.46
	Existing	103.47	105.31	105.29	103.5
	Depth	0.16	1.88	2.84	1.04

Figure 5-45
Depth calculations worksheet

Cut and Fill Prism Calculations Worksheet

Project: Parking lot (Figure 5-42) **Date:** 06/25 **By:** L. L. Level

All (cut or fill): Fill **Checked by:** J. Jacobs

Grid	Corner	No.	Depth	Total depth (feet)	Notes
A	1			1.21	
B	1			2.24	
	2			0.71	
	4			1.21	
C	1			3.45	
	2			1.72	
	3			0.71	
	4			2.24	
E	1			0.71	
F	1			1.72	
	2			0.16	
	4			0.71	
I	1			0.16	
Totals	13 corners			17.0*	*rounded

Figure 5-46
Fill calculations

Corner is the next column in Figure 5-46 that contains data. This column lists the corner points from each grid square that lie on the fill side of the zero line. Only grid square C has all four of its corner points listed in this column.

Now look at the *Totals* line for the *Corner* column. This is where you record the number of corner points on the fill side of the zero line. In this example it's 13.

The last data column is *Total depth*, and these numbers should look familiar. They're transferred here from the *Depth* rows in Figure 5-45. Just as you'd expect, it's not a complete list. Opposite the *Totals* heading for this column, enter the sum of numbers in the *Depth* row. For our project, that's 16.95. We'll round all the depths to one decimal place, so I'll use 17.0.

The next worksheet, Figure 5-47, looks almost the same as Figure 5-46. You use it the same way, but there are important differences. All the data on this worksheet comes from the cut side of the zero line. Use the *Grid, Corner,* and *Total depth* columns just like you did for the fill calculations. This time, however, you're working on the cut side of the zero line.

Cut and Fill Prism Calculations Worksheet

Project: Parking lot (Figure 5-42) **Date:** 06/25 **By:** L. L. Level

All (cut or fill): Cut **Checked by:** J. Jacobs

Grid	Corner	No.	Depth	Total depth (feet)	Notes
A	2			0.23	
	3			1.67	
	4			0.06	
B	3			0.23	
D	1			0.23	
	2			2.17	
	3			3.32	
	4			1.67	
E	2			1.04	
	3			2.17	
	4			0.23	
F	3			1.04	
G	1			2.17	
	2			4.07	
	3			5.34	
	4			3.32	
H	1			1.04	
	2			2.84	
	3			4.07	
	4			2.17	
I	2			1.88	
	3			2.84	
	4			1.04	
Totals	23 corners + 13 corners = 36 corners			44.8* - 17.0* (fill) 27.8 feet	* rounded to one decimal place
Average depth	27.8 feet ÷ 36 corners = 0.77 feet				
Volume (CY)	(9 x 50 x 50 x 0.77) ÷ 27 = 17,325 ÷ 27 = 641.66 CY				
Round volume (full CY)	642 CY				

Figure 5-47
Cut calculations

After you've totaled the cut corners and depth, adjust them to find the *Average depth*. Add the cut and fill corners to find the total corners. Then subtract the fill depth from the cut:

Total depth (feet) = Cut depth total – Fill depth total

= 44.8 – 17.0

= 27.8 feet

Use the *Average depth* row to calculate the average total excavation depth for the entire project:

Average depth (feet) = Total depth ÷ Corner count

= 27.8 ÷ 36

= 0.77 feet

The next heading in Figure 5-47 is *Volume (CY)*. In this example the total volume of cut is greater than the total volume of fill. Their difference is the total volume of spoil to remove from the site. In the reverse situation, their difference is the total volume of fill to bring onsite from elsewhere. In either case, use the following formula to calculate the volume (use GS for grid square):

Volume (CY) = Number of GS × GS length × GS width × Average depth ÷ 27

The key for Figure 5-42 gives the grid square dimensions as 50 x 50 feet. Length and width are both 50 feet. Add in the other numbers and you get:

Volume (CY) = (9 × 50 × 50 × 0.77) ÷ 27

= 17,325 ÷ 27

= 641.66 CY

Round up to full cubic yards, and you'll find the total volume of cut, less what we'll use as fill, equals 642 CY.

Calculate cut and fill separately until you feel comfortable using this method. Then you're ready for shortcuts — either the ones covered here or your own inventions. I use shortcuts whenever I can, and they're real time-savers. But don't jump the gun.

Let's see how you can streamline this take-off method. For starters we'll turn two worksheets (Figures 5-46 and 5-47) into one, and combine the cut and fill calculations. Figure 5-48 shows the combined worksheet, already filled in with the data from the parking lot project. You use a plus sign for fill and a minus sign for cut.

We've also used the blank columns we didn't use in the last example to minimize the math. Here's how it works. Take a look at corner B2 in Figure 5-42. This one corner point has three other names (C3, F4, and E1). But they're all the same point, so they all

Cut and Fill Prism Calculations Worksheet

Project: Parking lot (Figure 5-42) **Date:** 06/25 **By:** L. L. Level

All (cut or fill): Shortcut **Checked by:** J. Jacobs

Grid	Corner	No.	Depth	Total depth (feet)	Notes
A	1	+2	1.21	+2.42	
	2	-4	0.23	-0.92	
	3	-2	1.67	-3.34	
	4	-1	0.06	-0.06	
B	1	+2	2.24	+4.48	
	2	+4	0.71	+2.84	
C	1	+1	3.45	+3.45	
	2	+2	1.72	+3.44	
D	2	-4	2.17	-8.68	
	3	-2	3.32	-6.64	
E	2	-4	1.04	-4.16	
F	2	+2	0.16	+0.32	
G	2	-2	4.07	-8.14	
	3	-1	5.34	-5.34	
H	2	-2	2.84	-5.68	
I	2	-1	1.88	-1.88	
Totals		13 (+) + 23 (-) = 36		17.0* (fill +) - 44.8* (cut -) - 27.8 feet	* rounded to one decimal place
Average depth	27.8 ÷ 36 = 0.77				
Volume (CY)	(9 x 50 x 50 x 0.77) ÷ 27 = 17,325 ÷ 27 = 641.66 CY				
Round volume (full CY)	642 CY spoil				

Figure 5-48
Shortcut worksheet, calculations for cut and fill

have the same elevation. You don't need to list that same point four times, or calculate the same depth four times. All you do is list this point once, and then use the space in the *No.* column to indicate the multiplier and whether it's fill or cut. In Figure 5-48, find row B2. Check the data entered in the No. column and you see "+ 4." The plus sign shows that this is fill, and 4 is the multiplier to use in the following formula:

Depth × No. = Total depth

Bring forward the depth results we calculated from Figures 5-46 and 5-47 to the *Depth* column in Figure 5-48. Here's how the formula works with the numbers for B2:

$$\text{Total depth} = 0.71 \times 4$$
$$= 2.84 \text{ feet}$$

Here's another example, using corner G3. We know it's on the cut side of the zero line, and it's not a corner point for any other grid square, so under No. enter 1. Then carry forward *Depth* from Figure 5-47, and enter 5.34. Finish by calculating Total depth:

$$5.34 \times -1 = -5.34$$

Repeat these calculations for each line. Then move down to the *Totals* line. In the *No.* column you'll calculate three totals:

1. Total the + items.
2. Total the – items.
3. The sum of 1 and 2 (ignore the signs) equals the total corner count.

Your calculations for *Average depth* and *Volume (CY)* are the same as they were in Figure 5-47. And unless there's a math error, they'll produce the same results. This shortcut should save a lot of time. But there's a catch involved. It's easy to lose track of what's been counted and what hasn't been included in the *No.* column. Always check your work to make sure nothing has been left out or duplicated.

Finding the Volume of a Triangular-Shaped Area

So far we've only worked with grid squares. In the real world that's not always the case. There are situations where you'll use a triangle instead of a square. A triangle, for example, is better when only a part of a grid square's area lies within the project's limits. Sometimes you need data that's more detailed or precise for a specific grid square. The best solution is to break the square into triangles (two, four, or more).

Let's see how this works by calculating the volume of a triangular piece from a grid square. We'll use a portion of grid square "I" in Figure 5-42. Figure 5-49 is an enlarged view of grid square I. The zero line cuts through just below corner 1. This little triangular piece, called XYZ, is a fill area in a grid square that's otherwise all cut.

Here's what we know about this triangle:

- Point Y is also corner I1, so its depth is 0.16 feet (See Figure 5-45).
- The hypotenuse of triangle XYZ is the zero line, so the depth at X and Z is 0 feet.

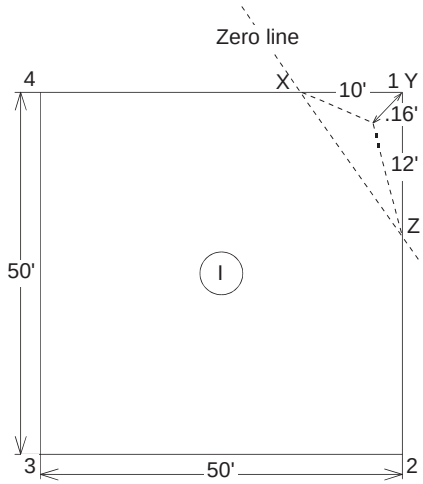


Figure 5-49
Finding the volume of a triangle

- ➤ Side YZ = 12 feet
- ➤ Side XY = 10 feet

Find the triangle's volume by following these simple steps:

1. Find the average depth, using the sum of the corner depths divided by the number of corners:

   Average depth (feet) = (0.16 + 0 + 0) ÷ 3
   = 0.16 ÷ 3
   = 0.05 feet

2. Find the area of this right triangle with this formula:

   Area = Base × Height ÷ 2
   = 12 × 10 ÷ 2 = 60 SF

3. Find the volume within the triangle XYZ in cubic yards using this formula:

   Volume (CY) = Area × Average depth ÷ 27
   = 60 × 0.05 ÷ 27 = 0.11 CY

4. We'll round that off, and call it a fill of 0.1 CY.

Many earthwork estimators use this easy method to calculate the volume of any triangle that the zero line creates. Just be careful not to forget the rest of the grid square after you pull the triangle out. How do you find the volume of a square that's missing a corner? The easiest way is to ignore the triangle. Just calculate the volume of the entire grid square, then subtract the triangle's volume. The result is the volume of the rest of the grid square. Let's try this out now on grid square I (refer back to Figure 5-47).

Here's what we already know:

- ➤ Corner depth at 1 = 0.16 feet
- ➤ Corner depth at 2 = 1.88 feet
- ➤ Corner depth at 3 = 2.84 feet
- ➤ Corner depth at 4 = 1.04 feet

Average depth (feet) = (0.16 + 1.88 + 2.84 + 1.04) ÷ 4

= 5.92 ÷ 4

= 1.48 feet

Volume (CY) = (50 × 50 × 1.48) ÷ 27

= 3,700 ÷ 27

= 137.04, or 137.0 CY

Volume (CY) = 137.0 CY – 0.1 CY

= 136.9 CY

Subtract the volume of the triangle, 0.1 cubic yard, to find that the rest of grid square I has a volume of 136.9 cubic yards.

Determining the Average Depth of Cut or Fill Within a Given Area

Use the following equations to determine the average depth of cut or fill within a given area:

Average depth of cut = Volume of cut (CY) × 27 ÷ Area of cut (SF)

or

Average depth of fill = Volume of fill (CY) × 27 ÷ Area of fill (SF)

For example, if an area of 5,000 square feet contains 2,500 cubic yards of cut, the average depth of the area will be:

Average depth = 2,500 CY ÷ 5000 SF = 0.5 feet, or 6 inches

Horizontal Slice Method

Figure 5-50 illustrates the horizontal slice method. To determine the volume of a hill, like the one shown in Figure 5-50, measure the areas within each contour, determine the average area, then multiply by the depth of the contour interval (CI). Repeat these steps through all of the contours.

In general, the horizontal slice method of taking-off earthwork is impractical because of all the work involved; but there are times when it can come in handy as an

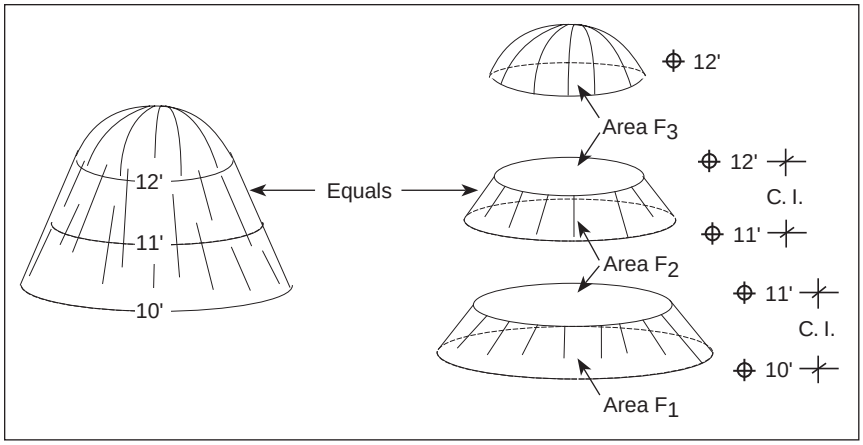


Figure 5-50
Horizontal slice method

estimating tool. For example, assume you have a square-shaped pond 100 feet long on each side at the top of the pond, and side slopes beneath the surface excavated at 1:1. Determine how many cubic yards would have to be excavated from the pond in order to lower the water surface 1 foot. See Figure 5-51.

Since the side slopes are 1:1, the surface area of the final water level will be 1 foot less at each side of the pond for a total of 98. The additional volume of excavation required to lower the water level will be:

$$\text{Volume} = [(100\text{ ft} \times 100\text{ ft}) + (98\text{ ft} \times 98\text{ ft})] \div 2 \times 1\text{ ft}$$

$$= (10{,}000\text{ SF} + 9{,}604\text{ SF}) \div 2 \times 1\text{ ft}$$

$$= (19{,}604\text{ cu ft}) \div 2 \times 1\text{ ft} = 9{,}802\text{ cu ft}$$

The volume expressed in cubic yards is:

$$\text{Volume} = 9{,}802\text{ cu ft} \div 27 = 363\text{ CY}$$

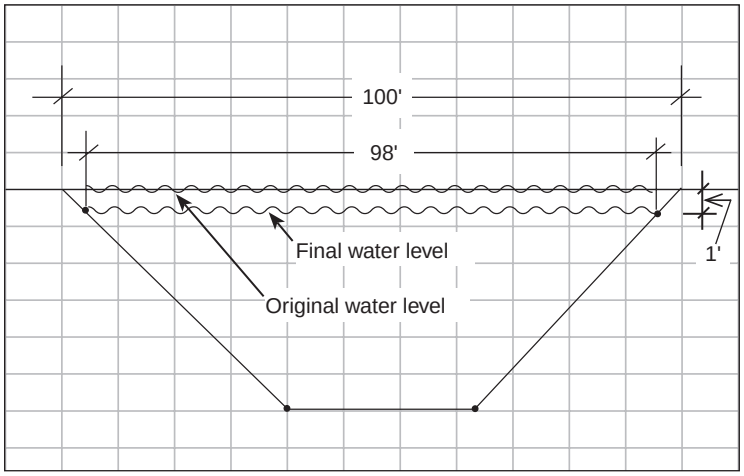


Figure 5-51
Lowered pond level

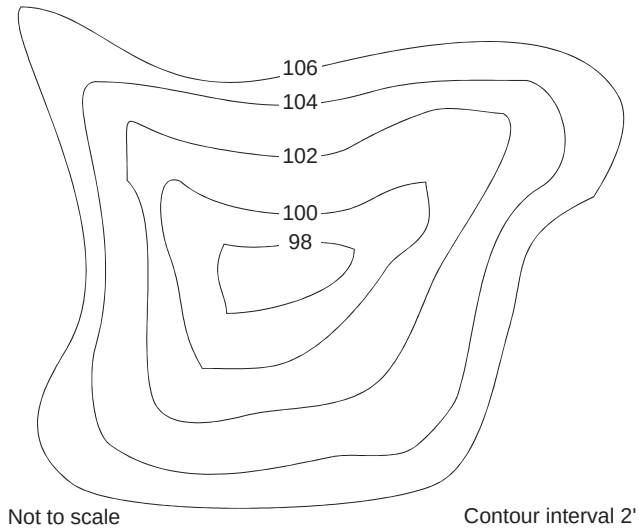


Figure 5-52
Finding the volume of a pond

Figure 5-53
Estimating tools

Suppose your jobsite includes a very steep slope, but you don't have a planimeter available to measure the area on a topo map. That doesn't mean you're out of luck. All you need is a little basic geometry and one property of the contour lines to make a rough estimate of the volume. Of course, the results aren't as precise as those from a planimeter. But if all you need is a rough guess, save yourself time and trouble by estimating this way.

You'll recall that all contour lines eventually close on themselves. So contour lines are circles, no matter how irregular they are. That means we can measure their length and call it a circumference. With the circumference of a circle, simple geometry produces the circle's diameter and area. The topo map gives contour interval. Combine that with a pair of consecutive areas and you have everything you need to calculate volume. Let's look at an example to show how easy it really is.

Figure 5-52 shows a drained pond that's to be filled in. Your job is to make a rough estimate of how many cubic yards of fill material it will take to do the job. To make it easy, we'll assume that the pond's level was lowered 2 feet at a time. This left a series of still-visible old shorelines at 2-foot intervals. In other words the shorelines are contour lines. We'll begin by measuring the length of these handy shorelines/contour lines. There are several ways to go about that. For instance, you could muck about on a muddy slope with a tape measure. A less athletic approach is using a map measuring wheel to trace the contour lines. Multiply the wheel reading by the map scale to find the actual length of the contour line. Or there's a third method. Lay a piece of string on the contour line, then measure the string.

Figure 5-53 shows some estimating tools that you'll find helpful in calculating measurements. These include a map roller, a digital measuring device, and an inventory counter that comes in handy for taking off items such as trees to be removed.

Equal Depth Contour Volume Worksheet

Project: Pond fill-in (Figure 5-52) **Date:** 6/30 **By:** L. Level

Map scale: 1" = 10' **Contour interval:** 2'

Contour line	Length (in.)	Circum. (ft.)	Diameter (ft.)	Area (SF)	Volume (CY)
106	18	180	57.3	2,578.5	161.8
104	15	150	47.7	1,788.8	
104	15	150	47.7	1,788.8	85.1
102	8	80	25.5	510	
102	8	80	25.5	510	23.6
100	4	40	12.7	127	
100	4	40	12.7	127	5.4
98	1.5	15	4.8	18	
			Total volume (CY)		275.9

Figure 5-54
Worksheet for Figure 5-52

I also recommend using a worksheet like the one in Figure 5-54. In the course of this example I'll regularly refer to the headings on this worksheet. Let's look at how to use them.

Map scale: Find this data on your site plan or topo map, then record it here. Figure 5-52 isn't drawn to scale, so I chose a scale of 1" = 10' to use for our example.

Contour interval: You'll also get this data from your topo map or site plan. In this case it's 2 feet.

Contour line: Record the elevation of the first contour line. For our example that's 106.

To measure contour line 106 using a string measuring device:

1. Select, and mark on your topo map, a start point on the 106 foot contour line.
2. Place one end of the string on that point, then lay the string directly on top of the 106 foot contour line.
3. Follow the contour line as closely as possible throughout its course until you return to start.
4. Mark that point on the string.
5. Straighten the marked string and measure the length you've marked on it with a ruler.

Length (in.): Use this space to record the length measured with the string. For our example, the length is 18 inches.

Circum. (ft.): Use this column to record the circle's actual circumference. For the example, the map scale is 1" = 10' and the length measured with the string is 18 inches, so the circumference is 180 feet.

Circumference = Length measured × Map scale

= 18 × 10 = 180 feet

Diameter (ft.): Use this column to record the circle's calculated diameter, after rounding it to one decimal place. Here's the formula for the diameter of a circle (assume pi = 3.1416):

Diameter = Circumference ÷ π (pi)

= 180 ÷ 3.1416

= 57.2956 or 57.3 feet

Area (SF): Record the area, rounded to one decimal place. Find the area of the circle using the following formula:

Area (SF) = (Diameter × Circumference) ÷ 4

= (57.3 × 180) ÷ 4

= 10,314 ÷ 4

= 2,578.5 SF

Next, repeat these steps to find the area of the 104 foot contour line. With that information, we can begin to calculate the volume in cubic yards of each contour level, as follows.

Volume (CY): Here's the formula to calculate volume in cubic yards:

Volume (CY) = {[(Area 1 + Area 2) ÷ 2] × Contour interval} ÷ 27

Volume (CY) = {[(106 contour area + 104 contour area) ÷ 2] × 2} ÷ 27

= {[(2,578.5 + 1,788.8) ÷ 2] × 2} ÷ 27

= {[4,367.3 ÷ 2] × 2} ÷ 27

= {2,183.65 × 2} ÷ 27

= 4,367.3 ÷ 27

= 161.75 CY

You'll note that Figure 5-54 is completely filled in. Think of this as an opportunity to test yourself. Do the calculations yourself for contour lines 102, 100 and 98. Then check your answers against mine.

Total volume (CY): On this line you'll simply record the sum of the *Volume (CY)* column. This is your rough estimate of the excavation volume for the project. For the pond job in Figure 5-54, the total volume works out like this:

161.8 + 85.1 + 23.6 + 5.4 = 275.9 CY

Round that to full cubic yards, and call it a total of 276 cubic yards of fill.

Of course, this method works just as well when you flip the pond inside out, and make it a hill. Picture Figure 5-52 with the elevations beginning at 98 and ending at the center with 106. If you think you need the practice, feel free to repeat all the calculations. However, there isn't any need to do so. Here's why. The total cut to level this hill to the 98 foot contour is 276 cubic yards.

You'll always overestimate the actual volume when you use the horizontal slice method. That's because the contour line isn't a perfect circle. The more regular it is, the more accurate your results. The more irregular it is, the more inaccurate your results.

We've covered a lot of ground in this chapter. But I hope you've followed along in the examples. It's one of the ways I try to make difficult concepts easier. Before going on to the next chapter, I recommend reviewing anything that seems a bit hazy. The material we've covered so far is your foundation, so be sure it's solid before you start Chapter 6.

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6

Roadwork Take-Offs

There are two common ways to calculate roadwork excavation quantities: the plan and profile method and the cross section method. In this chapter we'll take a look at both methods. My preference is the cross section method because it results in a more precise take-off.

Plan and Profile Method

The plan and profile method is the fastest method, but not the most accurate. The only information given is a profile down the centerline of the road, or left, right and centerline profiles. However, it does enable good quantity control as the project is built. The contractor can calculate quantities any time during construction by restaking the project and shooting new elevations. He can then figure the quantities removed and quantities remaining. Most contractors leave the survey stakes in place as long as possible to facilitate this restaking. Figure 6-1, Figure 6-2 and Figure 6-3 show plan and centerline profile sheets.

The designer of any earthwork job has two objectives: First, to create a relatively flat finished surface that still allows good drainage; second, to move as little material as possible, import no soil to the job and haul none away. That's called balancing the cut and fill quantities. We'll talk about this later in the book. For now, we'll focus on the difference between cut and fill, and how it affects the take-off.

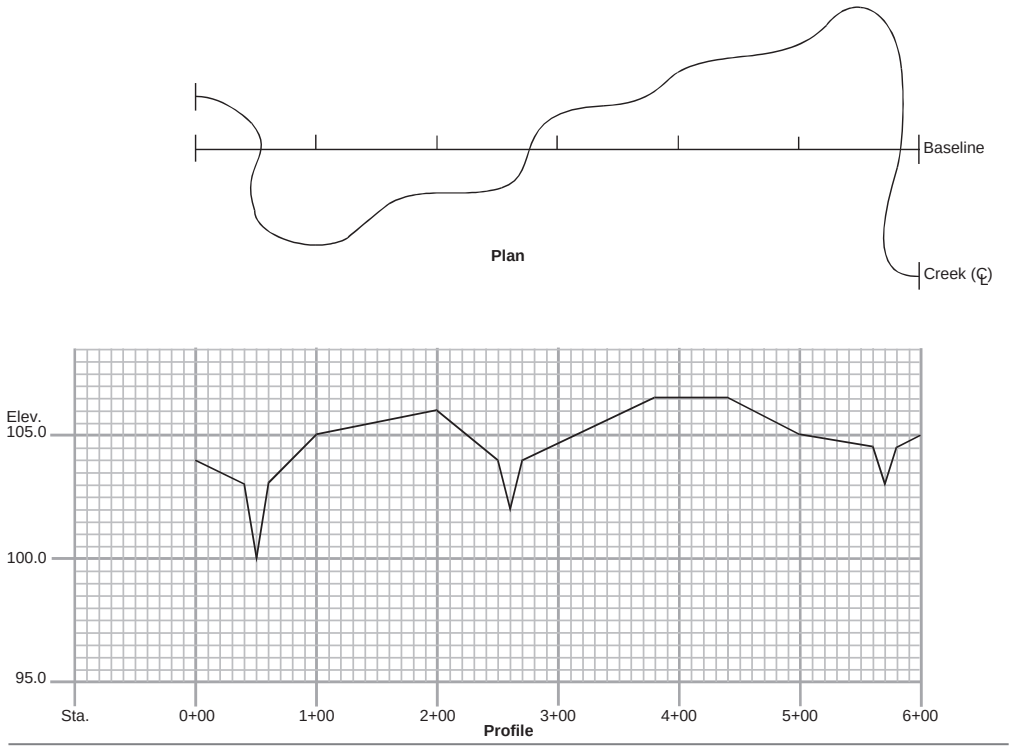


Figure 6-1
Surveyors stake at significant elevation changes

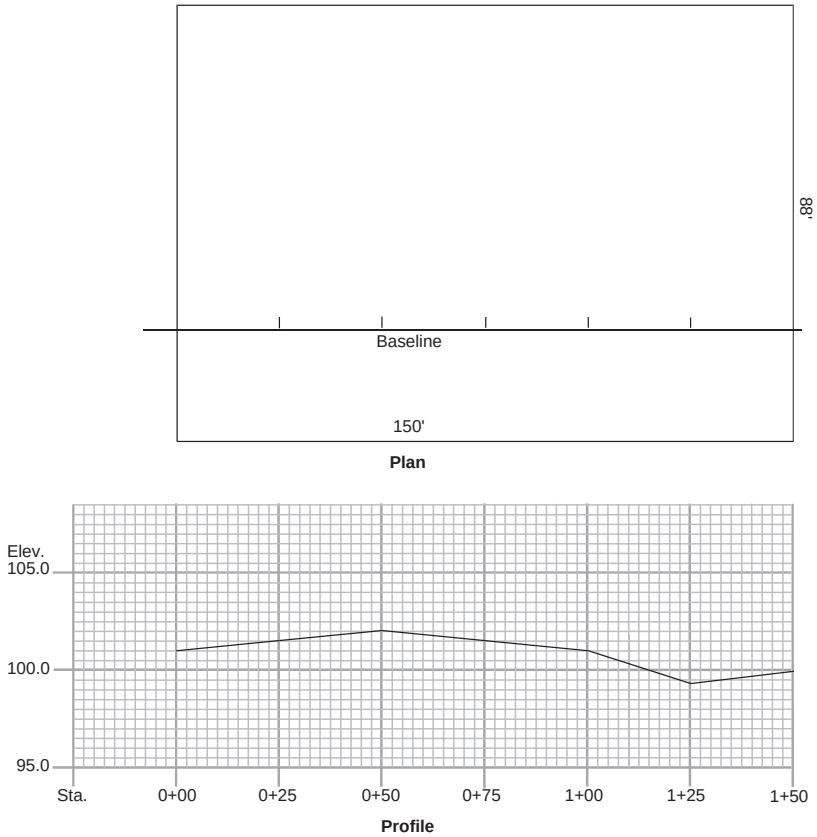


Figure 6-2
Plan and profile sheet

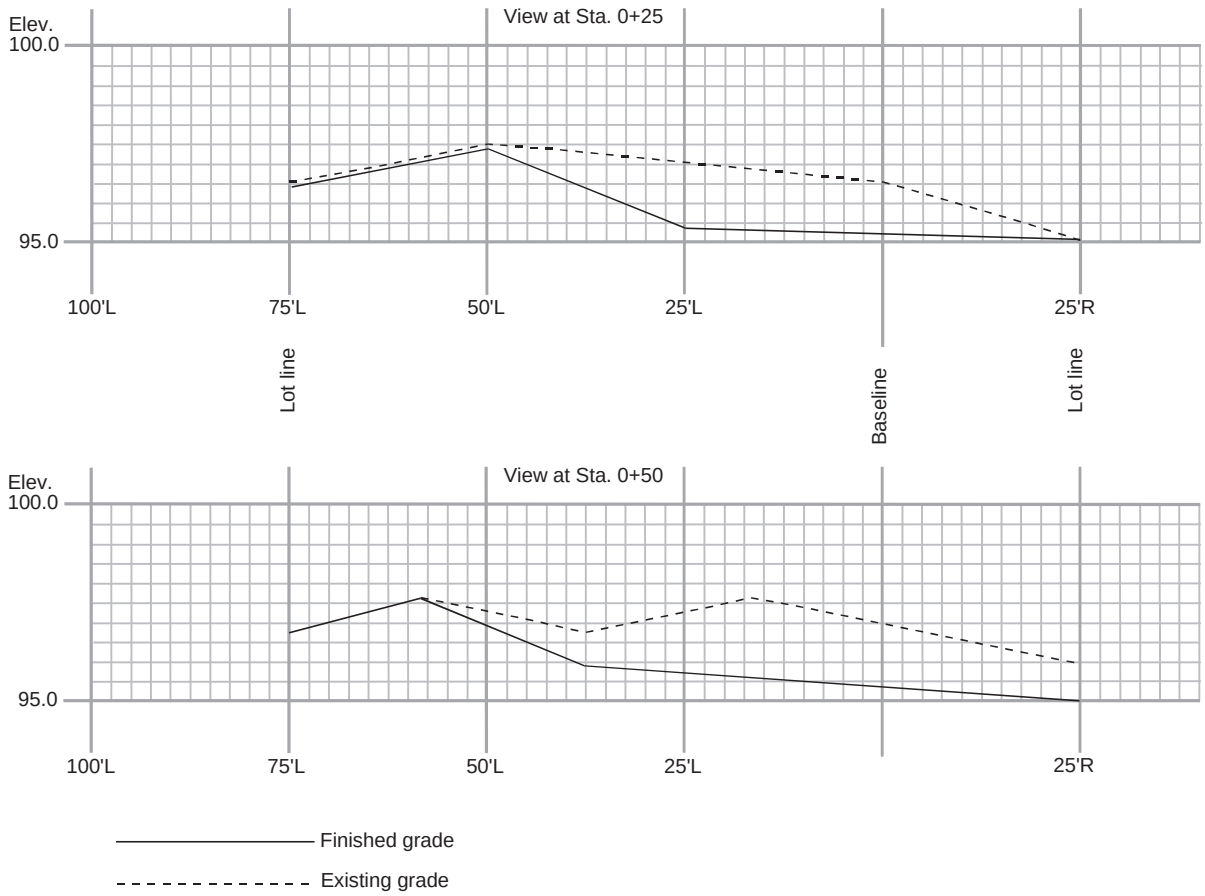


Figure 6-3
Existing and proposed profiles

Before we begin, let me clear up one area of possible confusion. You may come across several names for the finished ground line. For some reason, engineers, architects and contractors all use different terms for this. Engineers usually call it the *design elevation, design plan,* or *finished profile*. Architects refer to the *proposed elevation*, *future elevation*, or *final elevation*. Contractors talk about *grade line*, or *final grade line*. But fortunately, they all agree that the grade of the ground before starting work is the *existing grade line* or *elevation line*.

Understanding Surveys

As you might guess by now, an excavation estimator's job requires reading survey maps created by land surveyors. You should understand what surveyors do and the meaning of the maps they create. That's why I'll devote part of this chapter to surveying. Of course, I'm not going to make you a professional surveyor. I'll just provide the essentials: how the surveyor arrived at the elevation points on the worksheets, and how they affect your take-off quantity.

Plan and Profile and Cross Section Sheets

Surveyors and engineers work with two types of paper when doing earthwork design: plan and profile sheets and cross section sheets. Both are created on lightweight paper that's easy to reproduce, usually 22 by 36 inches in size. Plan and profile sheets are blank on the top half to allow room for the layout or any design needs. The bottom half is for plotting the points. It's divided into 1-inch squares drawn with heavy lines. Each 1-inch square is divided into 100 smaller squares drawn with lighter lines. The cross section paper is composed entirely of the plotting squares. Both sheets have a place for project name, dates, changes, and name of the person who did the work.

When plotting a cross section, be careful about the scale. Select a scale appropriate for your project. Consider these variables:

- Overall width and length of the jobsite
- Difference in elevation between the highest and lowest points
- Frequency of the cross section layout stations
- Degree of accuracy needed

Surveyors choose a scale that will allow them to plot the entire cross section. For the average project (200 to 400 feet wide), using a scale of 1 inch equals 25 feet will work for the horizontal scale (along the bottom of the section from left to right). A 400-foot section would be 16 inches long. For smaller projects, 1 inch could represent 10 feet, while for a larger project 1 inch equals 100 feet would be a better choice.

The vertical scale is normally more exaggerated than the horizontal scale. Using an exaggerated vertical scale makes the profile drawing clearer and the plotting and take-off more accurate. You'll most often see 1 inch equals 5 feet (or 10 feet). Here again, the difference between the highest and lowest points will determine the scale to use. A 2-foot rise in a vertical scale of 1 inch equals 100 feet would be almost imperceptible. In fact, it would be less than the width of a pencil mark. On the other hand, a 2-foot rise on a 1 inch equals 5 feet scale is almost half an inch.

Ideally, the scale used should make the drawing fill the space available — both vertically and horizontally. The larger the drawing, the more accurate the section and the easier your calculations. Figure 6-4 shows a cross section drawn at about the right scale. Of course, we've reduced it here.

Field and Office Procedure

A surveying or engineering crew will stake out a road centerline profile on the project, or a centerline and right and left shoulder profiles. Then they put in stakes at 100-foot intervals along the road. These locations are called stations and are written Sta. 0+00, for example. Sta. 0+00 is the beginning station. Sta. 1+00 is read as "station one plus balls." It's 100 feet (+00) from the start. Sta. 4+00 is 400 feet. Sta. 192+00 is 19,200 feet from the beginning of the project.

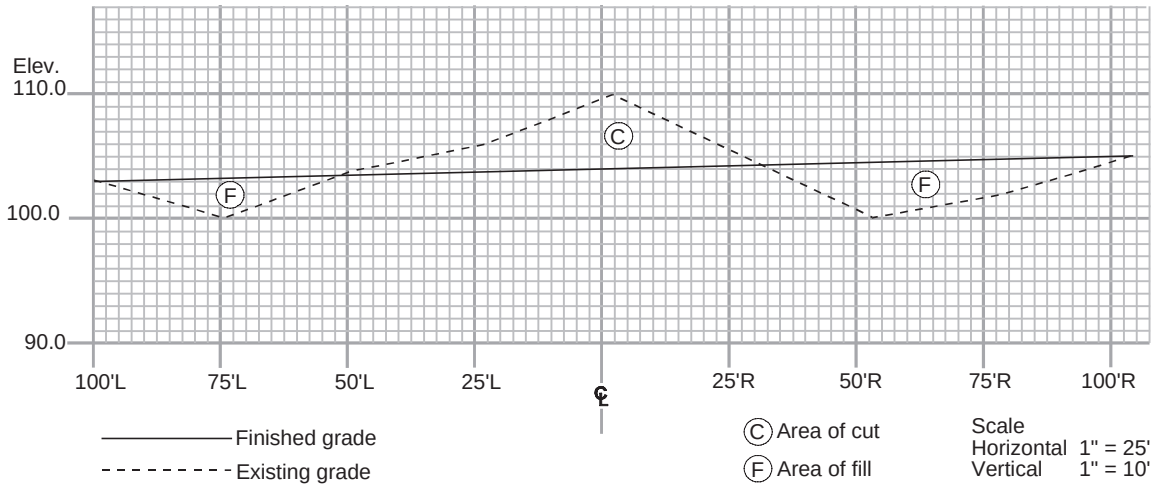


Figure 6-4
Cross section drawn at appropriate scale

Along the proposed road, the staking party will also put in a stake every place the ground either rises or falls significantly. They measure from the previous 100-foot stake and give the point a location based on that stake plus the distance to the elevation change. In Figure 6-1, a small creek crosses the baseline three times, the first time between stations 0+00 and 1+00. The first stake on the edge of the creek is 50 feet from the 0+00 station, so it's Sta. 0+50.

When the stakes are set, the staking party runs a set of levels on the stakes. They can read the actual elevations, using a benchmark, or simply assign the beginning stake (0+00) an arbitrary value, such as 100.00. Then they shoot the elevation of the rest of the stakes and assign them an elevation that's above, below, or the same as the first stake.

After the field work is done, they take the distances and elevations back to the office and plot them on graph paper. This sheet is called a plan and profile sheet. Figure 6-2 shows a typical example.

On a road that shows a left and right profile as well as a centerline profile, the staking crew draws a cross section perpendicular to the centerline of the road at each station. From each stake along the centerline, they measure out to the right or left (or to both sides) far enough to get past the limits of the project. They may go even farther where there are possible drainage problems. Then they measure the elevation at those points. In most cases they don't place stakes there; they just record the distance from the center stake, and the elevation. Then they return to the office and plot the information on a cross section sheet (see Figure 6-5).

Finally, the designers lay out the finished, or proposed elevations. Then they plot the finished elevations onto the cross section sheets that already show existing elevations. The result typically looks like Figure 6-3. This figure shows cross section views from

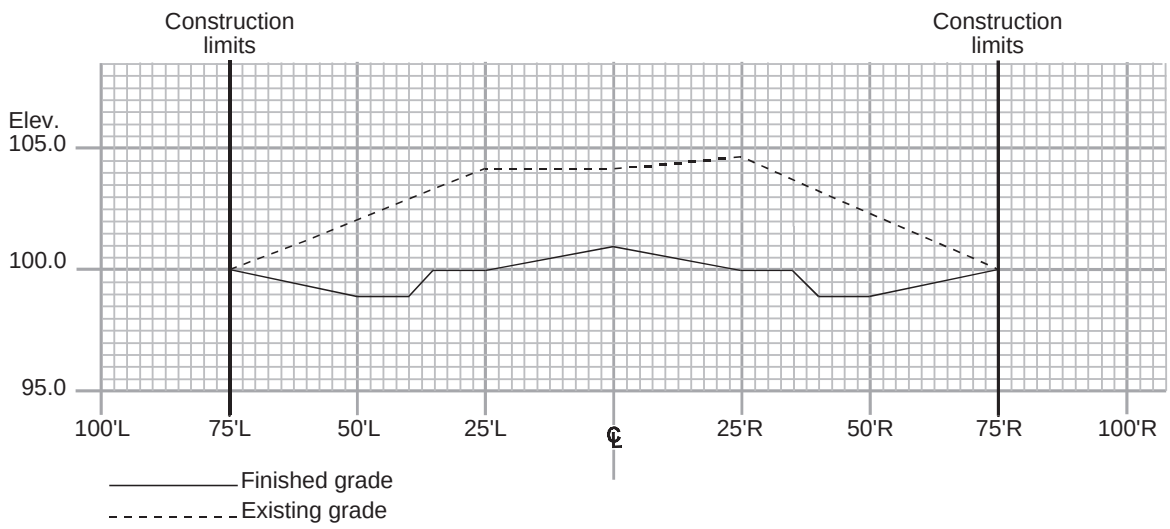


Figure 6-5
Cross section sheet, highway project

two stations with existing and finished grades plotted. To make the difference between them very clear, two kinds of lines appear in Figure 6-3. The broken line plots existing elevation, and a solid line shows the proposed elevation.

When the cross section sheets are finished, you're ready to begin calculating the amount of dirt you'll have to move. As you can see, each cross section shows an enclosed area, bounded on one side by the existing ground line, and on the other by the proposed ground line. The first step in figuring the quantities is to find the area of each cross section. Once you've measured the cross section areas, multiply by the distance between the stations to find the volume of cut or fill required for that portion of the road. Remember that volume equals the area times the length or distance.

Using Graph Paper to Measure Areas

In the absence of more sophisticated measuring tools, you can use graph paper to measure an area. Since the scale used to draw a site plan can vary, keep graph paper with various subdivisions per square inch in your office. Figure 6-6 shows types of commercially available graph paper recommended for various plan scales.

For example, to measure an area drawn at a scale of 1 inch equals 40 feet, place graph paper printed with four divisions per inch over the drawing and count the squares within the area you're measuring. For each square counted, you'd have 100 square feet of plan area. Each square inch of graph paper would equal 1,600 square feet of plan area. Purchase graph paper that's thin enough to see through. You can also have a print shop print graph paper onto transparent plastic sheets.

Plan Scale (Foot/Inch)	Graph Paper Recommended (Divisions/Inch)	Linear Foot (Plan) per Division	Square Foot (Plan) per Square
10	10	1	1
20	20	1	1
30	6	5	25
40	4	10	100
40	8	5	25
50	5	100	10
60	6	10	100
100	10	10	100

Figure 6-6
Graph paper

Taking Off Roadwork with only a Centerline Profile

I've seen roadwork projects that had only a road *template* — a typical road cross section and centerline profile. There's only one way to do a take-off on such a project. Measure the cut and fill areas given at the centerline separately, then multiply the totals by the road width from shoulder to shoulder to obtain cubic yard totals for the cut and fill. Divide your totals by 27 to get the cubic yards of cut and fill required for the road. It's impossible to create an accurate take-off with so little information, but many engineers create roadwork projects like this.

Taking Off Roadwork with only Left, Right and Centerline Profiles

Some roadwork projects show a centerline profile, as well as profiles down left and right road shoulders of the road. To determine the volumes of work required for a road when you're given left, right and centerline profiles, first measure all cut areas along the left shoulder and all cut areas along the right shoulder of the road. Then measure the cut areas along the centerline of the road, total them, and multiply the centerline areas by 2. Multiply the sum of all cut areas (shoulders and centerline) by the shoulder-to-shoulder road width, and divide the total by 4 to obtain the total cubic feet of cut. Again, divide that answer by 27 to convert the total to cubic yards of cut between shoulders.

Repeat these steps, measuring the fill areas, to obtain the cubic yards of fill required between the shoulders. With either the centerline or three-profile projects, you must also consider topsoil stripped and respread, as well as the thickness of the asphalt and base material, to produce an accurate take-off.

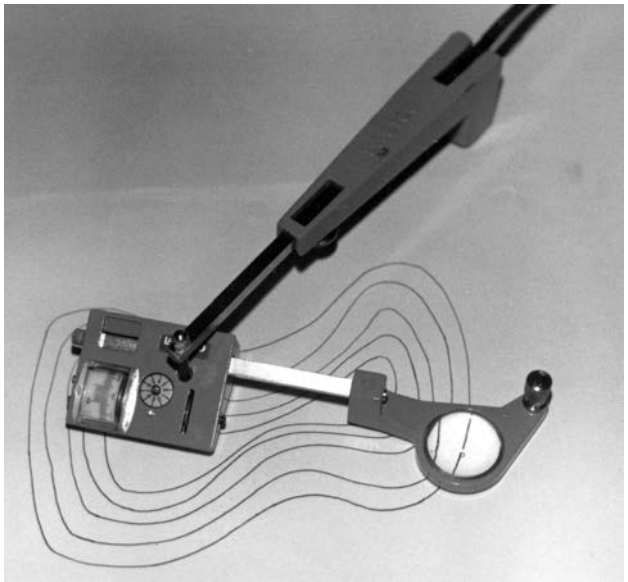


Figure 6-7
Polar compensating planimeter

Because of all of the steps required to produce a take-off for these sections, I believe the cross section method is the most accurate way to take-off roadwork quantities. We'll look at that next.

Cross Section Method

A cross section drawing like the one in Figure 6-5 shows what the road would look like if it were sliced open across its width. To find the volume to be cut, we'll start by finding the end area for a section. There are several ways to calculate this area. I'll show you three methods: first using a planimeter, then a measuring strip, and last, the arc method. The most accurate calculations use the polar planimeter — also known as a buggy.

End Area Calculations Using a Planimeter

Besides digitizers and graph paper, you can use a polar compensating planimeter to determine plan areas. The planimeter is a drafting tool commonly used by engineers and estimators to measure the area of irregularly-shaped regions. See Figure 6-7. A polar planimeter consists of two arms and a movable carriage that links the arms. The pole arm ends in a sharp, weighted point that's called the anchor point. The second, or tracing arm has a stylus or point at the end used to trace the area's outline. The carriage also contains a roller mounted on a drum. The drum's circumference is a scale, also called a read disc, dividing the drum into 100 parts. As you trace around the boundaries of the area, the roller follows and the number of revolutions made by the roller registers on the read disc. The standard ratio of roller revolutions to read disc is 10:1.

Let's look at how to properly use a planimeter. I recommend covering your work surface, whether it's wood, steel or a plastic laminate, with a sheet of cardboard. The anchor point tip is quite sharp, and easily leaves holes in wood. On a hard surface, like steel or plastic, the cardboard will protect the anchor point. Trying to use a planimeter on hard surfaces may bend or even break the anchor point. A bent anchor point will produce incorrect readings, and a broken one results in an unusable instrument.

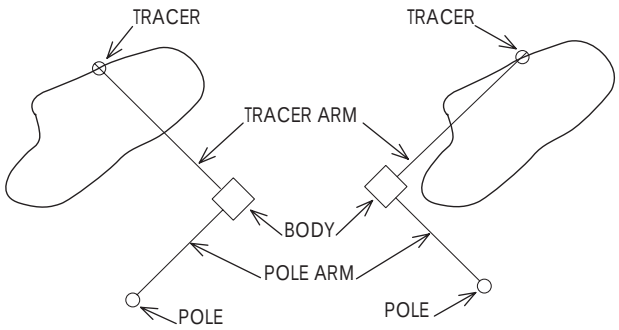


Figure 6-8
Planimeter tracing technique

Spread the plan or map out so it lies absolutely flat. Make certain the sheet has no wrinkles or buckles anywhere. Once the sheet is perfectly flat, keep it that way by taping it to the cardboard.

Use the following guideline to position the planimeter anchor point:

1. Place the anchor point outside of the area to be measured;
2. Place the anchor point to allow tracing of the entire area perimeter.

If the area is too large to cover in one sweep of the planimeter, divide it into several smaller areas that you can cover in one pass. Then add the results together.

Choose a starting point that's easy to remember. Set the roller vernier to zero, or record its current reading. Begin tracing the outline of the area. Work your way around the area perimeter, moving clockwise, until you're back at your starting point. Follow the boundary lines carefully and closely. Any deviation adds an error to your result. To offset the effect of any imperfection in your first pass, I generally recommend doing the tracing step twice; the first time with the tracer arm to the right of the pole arm, and the second time with the tracer arm to the left of the pole arm. The pole should remain in the same position throughout both tracings. See Figure 6-8. Add the readouts and divide by 2 to determine the average.

The Planimeter Constant

Most instruments have a planimeter constant of 10.00 square inches. This means that when the main disc reading is 1.00, the area is 10 square inches. Some instruments give readings in metric measure, and others have different scales, but the procedure is the same. This constant value is usually printed on the instrument itself, and in the instruction book that comes with the planimeter.

If you don't know the constant for the instrument you're using, here's how you can find it. Lay out an area of known value. Since most planimeters have a constant of 10 square inches, use a 2-inch by 5-inch area. Run the planimeter around this 10-square inch area and you should read 1.0 on the disc.

If you don't, you can recalibrate the instrument by finding the new constant. If you run around the area and come up with a figure of 0.910 instead of 1.0, use the following formula to find the new constant.

Where:

C = planimeter constant
A = area
N = final planimeter reading

C = A ÷ N

C = 10 square inches ÷ 0.910

C = 10.989 square inches

A variety of planimeter styles, both mechanical and electronic, are available at engineering supply stores.

The precise method for converting planimeter readouts of plan areas will vary depending on the type of planimeter. But keep in mind that they only measure area. You have to multiply by the depth to convert to volume figures.

Finding the Area

To find the area from the planimeter reading, use this formula:

Area = C (planimeter constant) × N (final planimeter reading)

Let's look at a brief example. Assume the roller of a fixed-arm planimeter with a constant of 10.00 is set at zero (0). After following the perimeter clockwise, the reading is 2.55. If the planimeter wasn't set back to zero, you'd have to subtract the previous reading from the new reading (2.55 – previous reading) when you finish.

The formula for area is:

Area = C × N
= 10.00 × (2.55 – 0)
= 25.5 square inches

The scaled off area is 25.5 square inches.

End Area Calculations Using a Measuring Strip

There's a faster way to find the area of a profile drawing when you need a "ballpark" quantity of cut and fill for a project. Simply create a measuring strip out of a piece of clear plastic, 1½ to 2 inches wide and 18 to 24 inches long. Choose a transparent plastic that you can write on with permanent ink. Draw two lines, 1 inch apart, vertically down the length of the strip. Then draw a centerline through the strip that you'll use

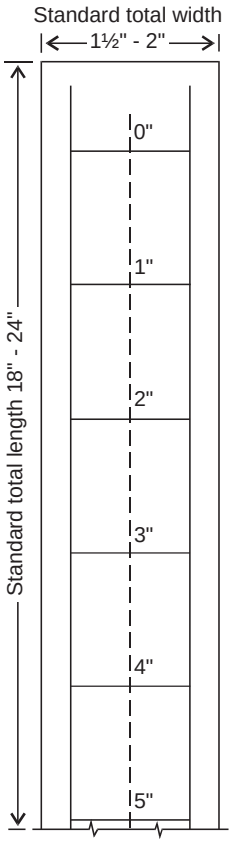


Figure 6-9
A measuring strip

to measure vertical distances on the profile drawing. Mark off 1-inch increments horizontally starting with zero at the top of the measuring strip. You'll end up with a strip of 1-inch squares with a line down the center, as shown in Figure 6-9. Your measuring strip will be a tool you can use on many projects.

Before measuring with the strip, use a pencil to draw vertical lines on the profile sheet, 1 inch apart from left to right. Start your lines at the left end of the profile drawing, where the work begins. You can see the vertical lines on the profile sheet in Figure 6-10. We'll refer to the areas between these vertical lines as *vertical regions* of the profile.

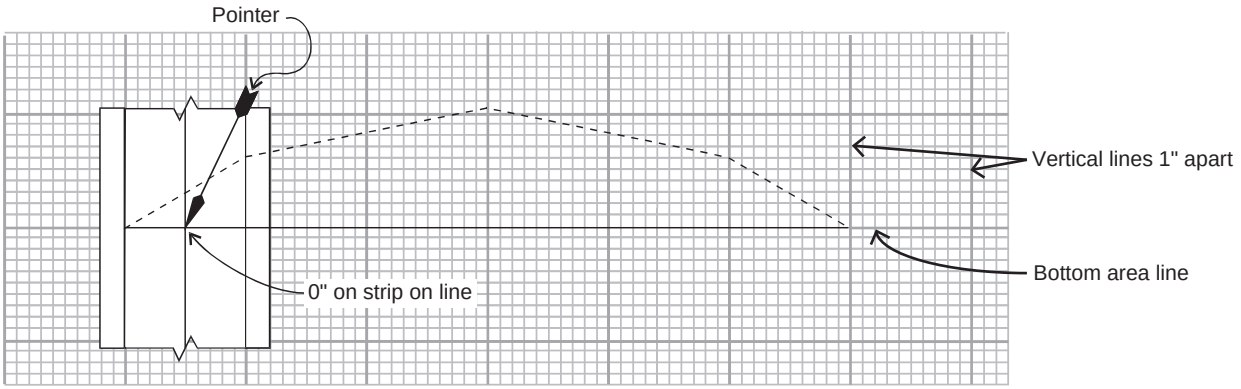
Lay the measuring strip over the first vertical region of the profile drawing, lining up the left edge of the measuring strip with the left vertical line. See Figure 6-10, Step 1. Make sure the horizontal zero-inch line on the strip aligns with the bottom surface of the area to be measured. To begin measuring, place the point of a sharp instrument, such as a pin or a drafting divider, where the centerline on your measuring strip intersects the zero line. Then move the strip up the drawing until the pointer is on the top line of the area you're measuring within the first vertical region. Hold the strip steady and move the pointer back to the bottom area line (Step 2). Carefully move the strip over 1 inch to the right, and repeat Step 2 in the second vertical region. Repeat Steps 2 and 3 until you reach the end of the vertical regions along the area line that you're measuring (Step 4).

When you're ready to read your measurement, lay your measuring strip beside a drafting ruler and read the last point you marked with your pointer. The result will be a cumulative total of all the vertical lengths of the vertical regions of the profile. Since each region measured is 1 inch wide and the total vertical length was measured in inches, the total length measured is equal the area of the profile expressed in square inches. Figure 6-10, Step 5 shows a reading of 4.0 square inches.

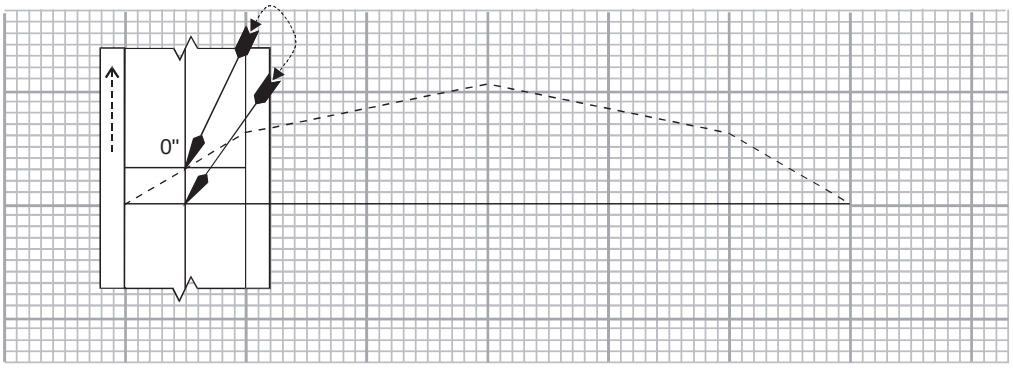
Using this method, you're simply building a running total of the square inches of the end area. With a little practice, you can read right off the profile sheets, without having to use the measuring strip. When using a measuring strip, as in all take-offs, be sure to keep cut and fill measurements separate.

End Area Calculations Using the Arc Section

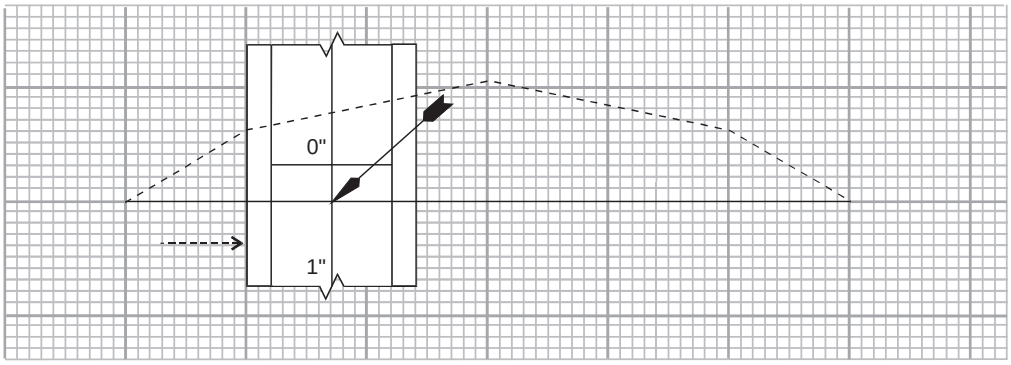
A third method, the arc section, is similar to the measuring strip because you measure each 1 inch of horizontal area and build a cumulative total. Figure 6-11 shows a cross section worked up this way. You divide each whole or partial 1-inch section in half with a vertical line that goes through both the existing and proposed profile. Then



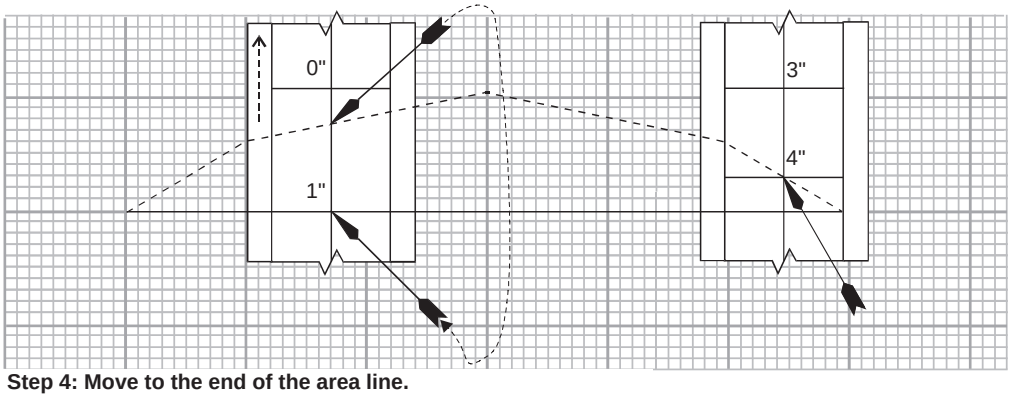
Step 1: Place pointer on zero line.



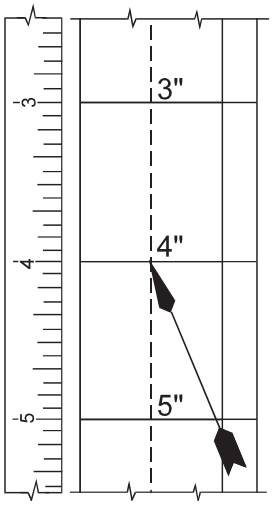
Step 2: Slide strip up to area line, then move pointer back to bottom line.



Step 3: Move measuring strip over 1" and repeat step 2.



Step 4: Move to the end of the area line.



Step 5: Read the last pointer point from a ruler held next to the strip. The reading here is 4.0 inches.

Figure 6-10
Using the measuring strip

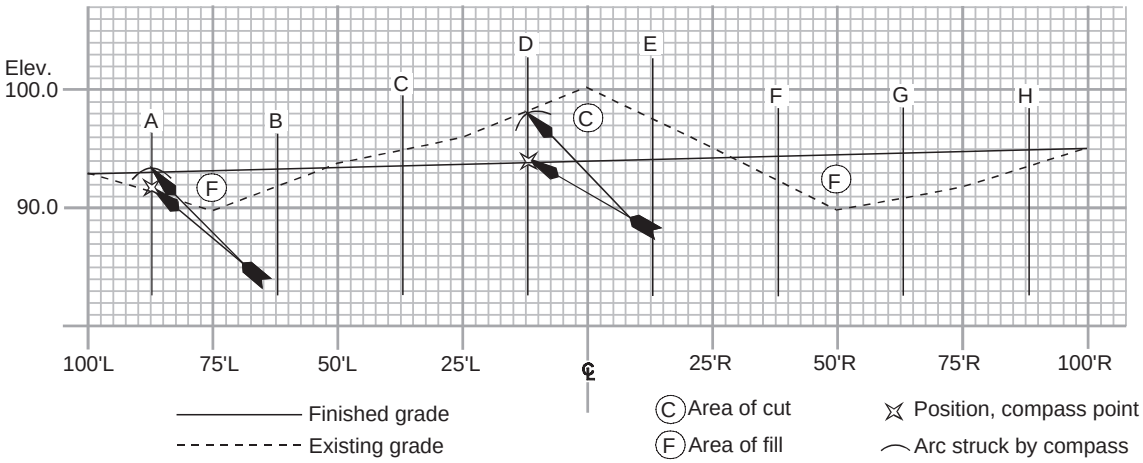


Figure 6-11
Using the arc section

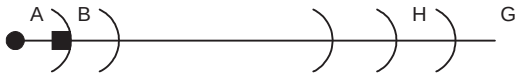
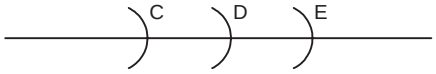
Station name		Inches	Constant	Cut	Fill
Sta. 1+00		F 1.45	1		1.45
Sta.					
Sta.					
Sta. 1+00		0.69	1	0.69	
Sta.					
Sta.					

Figure 6-12
Arc section take-off worksheet

label each of these division lines with a letter (A, B, C, and so on) as shown in Figure 6-11. Put the point of a drawing compass on the bottom line where it intersects the division line. Set the compass to strike an arc that runs through the point where the division line and the top line intersect. Then strike this arc. Let's suppose that we just struck arc A in Figure 6-11. Before we strike arc B we need to make a copy of arc A on a worksheet. My worksheet appears in Figure 6-12.

For the time being, set the compass aside, and be careful not to change its setting. Let's take a look at the worksheet first. Then we'll cover the nuts and bolts of copying arcs from the cross section sheet onto this worksheet.

There are four main points to note when you look at the worksheet in Figure 6-12.

1. Sta. 1+00 appears twice on the worksheet to separate fill areas (top half) from cut areas (bottom half).
2. Just to the right of Sta. 1+00 is a line with several arcs marked on it. We'll call it the measuring line.
3. All arcs on the worksheet intersect the measuring line.
4. The name of an arc stays the same when it's copied from a cross section sheet onto a worksheet.

Using the worksheet is easy. Start by filling in the station name. Since the first arc we're copying is A, the station name is Sta. 1+00. Next retrieve the compass, place its point on the far left end of the measuring line (marked by a filled circle in Figure 6-12), and strike a copy of arc A that crosses the measuring line.

Now we'll go back to the cross section sheet and strike arc B. When we add a copy of arc B to the worksheet we'll use a slightly different process. Here's why. Arc B, like arc A, is from a fill area, as well as being from the same station. That means you add arc B to the same measuring line as arc A. To add arc B, place the compass point on the intersection of arc A and the measuring line. (In Figure 6-12 this point's marked with a filled square.) Then go ahead and strike the arc and label it B.

To copy the cut arcs, C, D, and E, follow the same steps. However, this time you'll use the Sta. 1+00 measuring line that's in the bottom half of Figure 6-12.

When you've finished marking arcs, use a drafting scale or ruler to measure from the beginning of the line to the last arc, then record this length on the worksheet under Inches and again under either Cut or Fill. Each measuring line represents the total square feet of either the cut or fill on the job. In our example, the scale is 1 vertical inch equals 10 feet and 1 horizontal inch equals 25 feet. So each square inch equals 250 square feet ($10 \times 25 = 250$). There are 1.45 square inches of fill, or 362.5 square feet ($1.45 \times 250 = 362.5$).

Notice the column headed Constant in Figure 6-12. This is the width of the area that each arc measures. In this example, the constant is 1 inch. In relatively flat areas, you could use a wider constant.

You may need to use several of the lines on the worksheet to finish all the areas. And make sure you keep the cut and fill sections separate. Notice that the cut and fill sections are labeled on Figure 6-11.

Both the arc section and measuring strip method are just approximations, not accurate take-offs. They're based on the assumption that the slope of a particular section will be roughly equal on both sides of the centerline of that section. Look at Figure 6-13. The area of triangle A is equal to the area of triangle B. Measuring along the centerline is good enough. But if the slope in triangle B is steep and the slope of triangle A is shallow, measuring along the centerline isn't going to be very accurate. Fortunately, slopes are usually more or less uniform and small errors tend to cancel out.

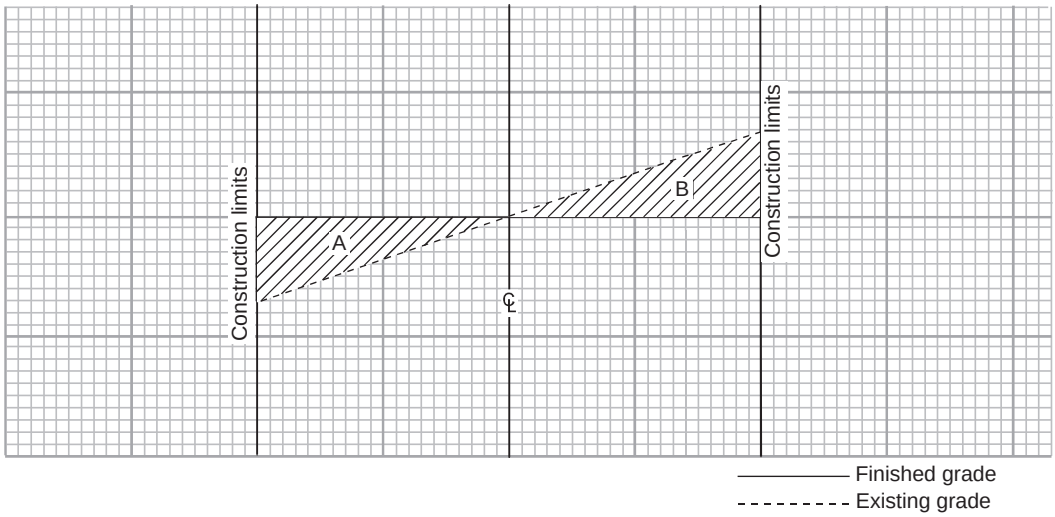


Figure 6-13
Dividing an even slope with a centerline to form two triangles with equal areas

Calculating the Scale Factor

You now know three methods for calculating the end area of a cross section. The next step is to convert area on paper into actual area and then convert that into cubic yards of earthwork. Remember, the planimeter and the measuring strip or arc methods measure only the paper area. To convert them to actual areas, you need to multiply the square inches of end area by the scale factor. Here's the formula:

Where:

V scale = the vertical scale given on the plan

H scale = the horizontal scale given on the plan

Scale factor = V scale × H scale

You apply this scale factor to each square inch of end area of a cross section. For example, assume you've measured a cut area with a planimeter reading of 2.95 square inches taken from a cross section that has a vertical scale of 1 inch = 5 feet and a horizontal scale of 1 inch = 25 feet. To calculate the scale factor for this cross section:

Scale factor = V scale × H scale

= 5 × 25

= 125

To find the area of cut or fill, multiply the scale factor by the number of square inches measured. If the scale factor is 125 and we measured an end area of 2.95 square inches, the actual area is:

125 × 2.95 SI = 368.75 SF

Converting to Volume

We're finally ready to use all of this information to work up the actual cubic yards of earthwork required between cross sections. We'll always use cubic yards to calculate volumes and excavation costs for earthwork.

Cubic measure is length times the width times the depth of an area. So far, in our take-off we've been working in two dimensions, width and depth, in order to find the square feet of area. To make the conversion to cubic measure, we need to know the distance (length) from one cross section to the next.

We'll calculate the volume for a site by breaking the task into many small measurements, and then adding or subtracting them to get the final figure.

Earlier in this chapter, we talked about how the surveyors choose the stations for cross sections throughout the site: They take them at regular intervals, as well as at locations where there are significant changes in the ground slope. That helps make our calculations more accurate. For volume measurements, we'll start by calculating the area of each cross section separately, totaling them, and then dividing the sum by 2 to find the average area. Here's the formula:

Where:

EA1 = the end area of one cross section

EA2 = the end area of the next cross section

Average Area = EA1 + EA2 ÷ 2

After we've calculated the average area for two consecutive cross sections, we'll multiply the average area by the distance between the cross sections.

In Figure 6-14, let's suppose that Sta. 1+00 has a fill area of 206.0 square feet. Sta. 1+65 has a fill area of 400.0 square feet. Then the average area of both stations is:

Average Area = EA1 + EA2 ÷ 2

= 206 + 400 ÷ 2

= 303 SF

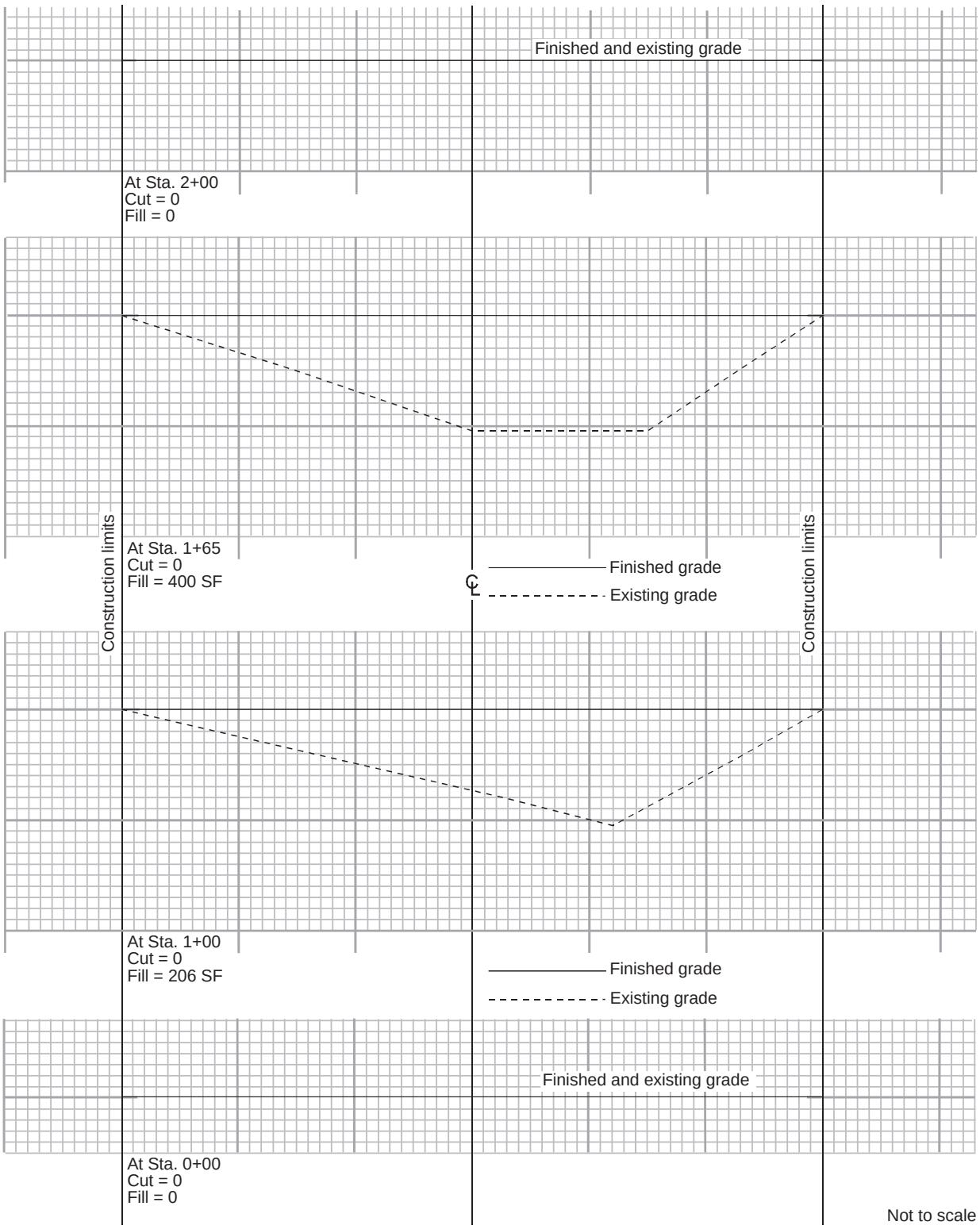


Figure 6-14
Calculating an average volume between two stations

The volume of fill between the stations (in cubic yards) is:

Volume (CY) = 303 SF × 65 ft ÷ 27
= 19,695 ÷ 27
= 729.44 CY

When dealing with excavation quantities, round the volume off to whole numbers, or 729 cubic yards.

You can either convert to cubic yards as you compute each pair of stations, or wait until you get a total volume for the entire project, then convert that to cubic yards. The math is pretty involved, so I think it's easier and safer to calculate the volumes between each pair of stations in cubic yards.

Beginning and Ending Stations

Designers usually want to make a smooth transition from the surrounding ground elevation to the finished project. That means they try not to have any earthwork at the beginning and ending stations. You'll seldom see any calculations for the volumes between end stations and their adjacent stations. Let's call these regions RAW (regions absent of work) regions. By studying the site plan, you can often determine if the volume of work required in a RAW region will have the shape of a wedge, or pyramid. If it's a wedge, the volume of work required in the region will be equal to the station area times the station spacing divided by 2. But if it's a pyramid, the volume of work will be equal to the station area times the station spacing divided by 3. See Figure 6-15.

Let's say the only area data of a RAW region is 400 square feet and the station interval is 100 feet. The volume of a wedge-shape solid would be:

Volume (CY) = (400 SF × 100 ft ÷ 2) ÷ 27
= 20,000 cu. ft. ÷ 27
= 741 CY

Using the same data given above, the volume of a pyramid-shaped solid would be:

Volume (CY) = (400 SF × 100 ft ÷ 3) ÷ 27
= 16,667 cu. ft. ÷ 27
= 247 CY

The volume of the pyramid-shaped solid is 1/3 of the wedge. When in doubt about the exact shape of a RAW region, err on the side of caution and assume it's a wedge.

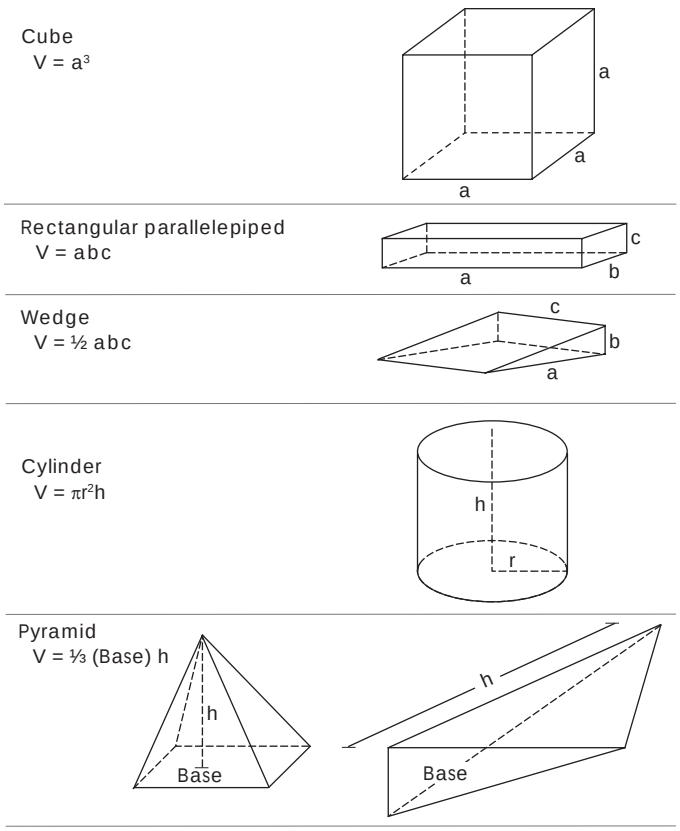


Figure 6-15
Volumes of solids

A Practical Example

Figure 6-16 shows a series of cross sections from a total of six stations. Each cross section shows areas of both cut and fill. The project is a parking lot located on hilly terrain. The end areas of the cross sections have been calculated with a planimeter. We'll use these end areas, and the scale factor derived in Figure 6-16 (see the bottom of worksheet 2, page 2), to calculate total earthwork quantities for the project. The quantity sheet, shown in Figure 6-17, records and summarizes my calculations.

Mass Diagrams

If you intend to make a living building roads, learning how to plot and use mass diagrams will save you time and money. Mass diagrams, also known as *mass haul diagrams*, indicate where to move cut material (excavation) and place it as fill (embankment). To get a feel for what mass diagrams do, imagine yourself walking down the road site, carrying a bucket and a shovel. In regions requiring cut, you remove dirt and place it in the bucket. In regions requiring fill, you shovel dirt out of the bucket and onto the site. A mass diagram is a graph showing how much dirt you have in your bucket at various points along the road. In other words, mass diagrams show you which stations require import and which stations require export — and how much. This helps you select the optimum locations for your borrow pits or dumps. Mass diagrams also illustrate the average haul distance for excavation, and help define which equipment will be most efficient to use within each haul zone.

To create a mass diagram, you'll need to determine excavation and embankment volumes along the length of the road. In our example, we'll use the cross sections shown in Figure 6-18. Dashed lines represent existing grades and solid lines the proposed grades.

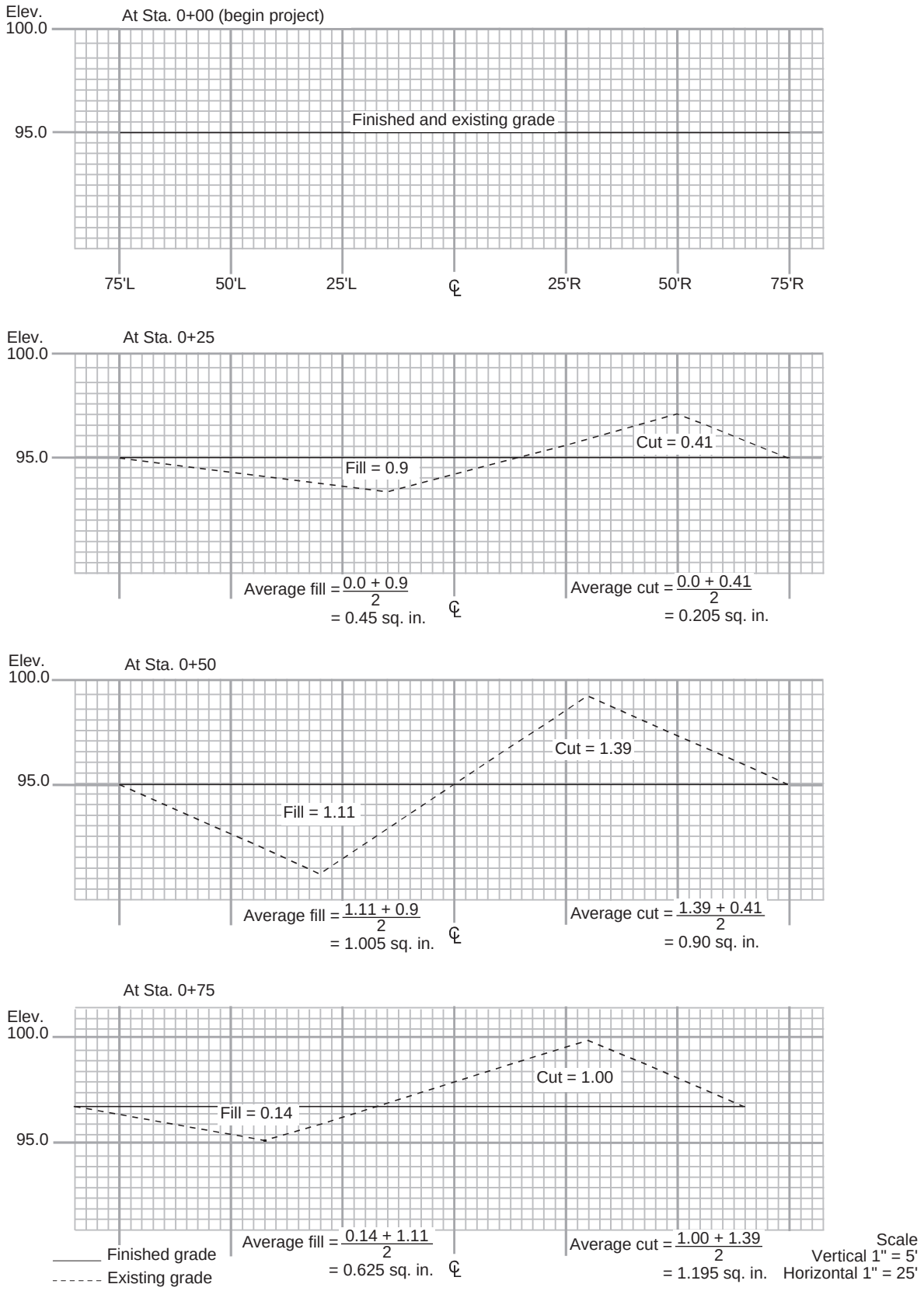
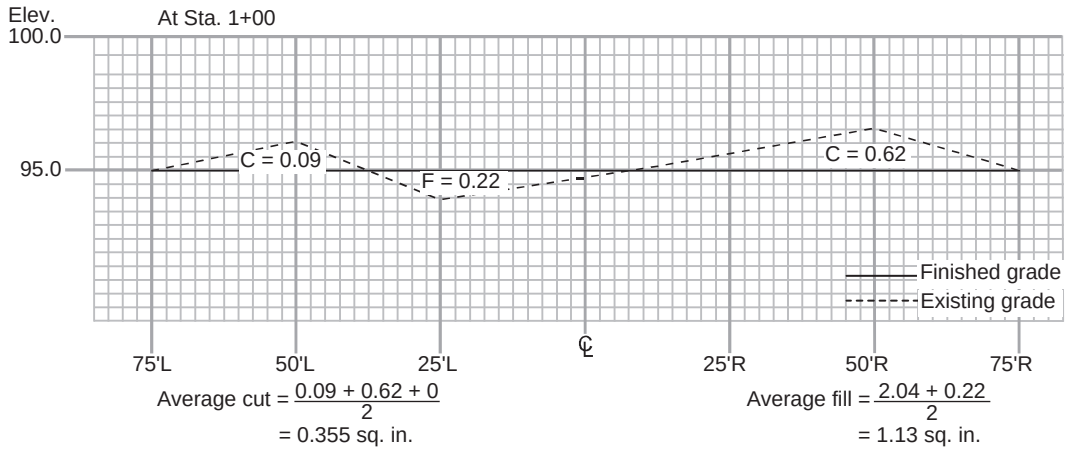
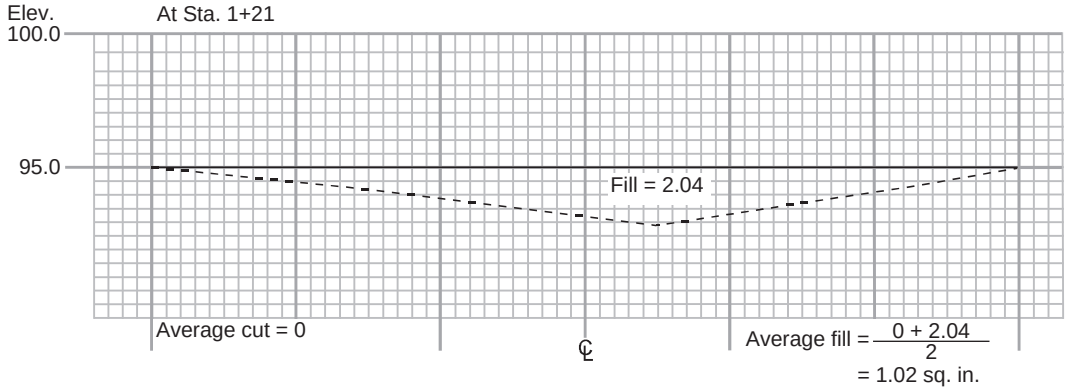


Figure 6-16
Cross section worksheet 1



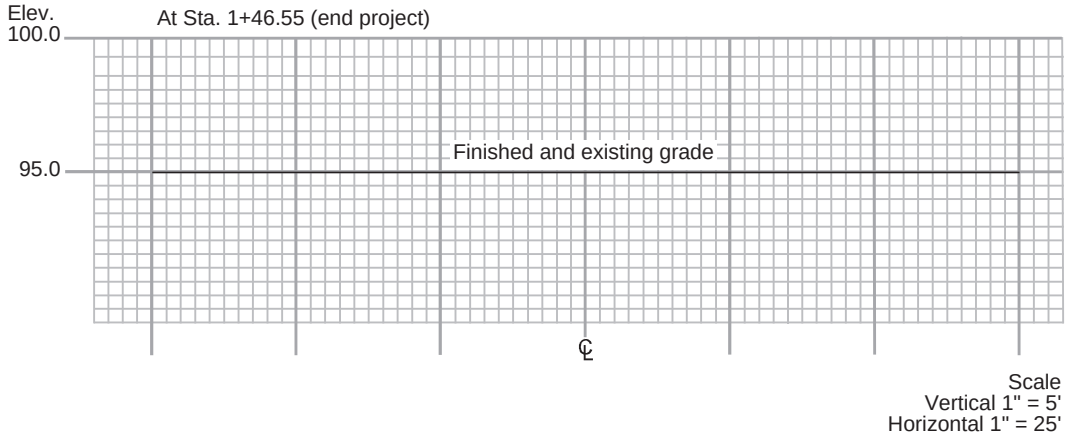
Average cut = $\frac{0.09 + 0.62 + 0}{2}$
= 0.355 sq. in.

Average fill = $\frac{2.04 + 0.22}{2}$
= 1.13 sq. in.



Average cut = 0

Average fill = $\frac{0 + 2.04}{2}$
= 1.02 sq. in.



Average fill and cut calculations between Sta. 0+75 (previous page) and Sta. 1+00

Average fill = $\frac{0.22 + 0.14}{2}$
= 0.18 sq. in.

Average cut = $\frac{0.62 + 1.00}{2}$
= 0.81 sq. in.

Scale factor calculation

V scale : 1" = 5'
H scale : 1" = 25'

Scale factor = *V scale x H scale*
Scale factor = 5 x 25
= 125

Figure 6-16 (continued)
Cross section worksheet 2

Quantities Take-off Sheet

Project: City lot #000-A **Location:** 123 A St. Anytown **Owner:** James Smith

Estimate prepared by: D. Burch **Date:** 10/10/2014 **Checked by:** Charles A. Rogers

Take-off method: Polar planimeter **Sheet:** 1 of 1

1st sta.	2nd sta.	Distance 1st sta. to 2nd sta. (feet)	Cut AEA* (sq. in.)	Fill AEA* (sq. in.)	Scale factor**	Total area cut (SF)	Total area fill (SF)	Volume cut (CY)	Volume fill (CY)
0+00	0+00	0			125				
0+00	0+25	25	0.205	0.45	125	25.63	56.25	23.73	52.08
0+25	0+50	25	0.90	1.005	125	112.5	125.63	104.17	116.32
0+50	0+75	25	1.195	0.625	125	149.38	78.13	138.32	72.34
0+75	1+00	25	0.81	0.18	125	101.25	22.5	93.75	20.83
1+00	1+21	21	0.355	1.13	125	44.38	141.25	34.52	109.86
1+21	1+46.55	25.55	0	1.02	125		127.5		120.65
1+46.55	1+46.55	0			125				
Totals		146.55	3.465	4.41		433.14	551.26	394.49	492.06

Notes: * AEA = average end area, for calculations see Figure 6-16.
** For scale factor calculations, see Figure 6-16.

Figure 6-17
Quantities take-off sheet

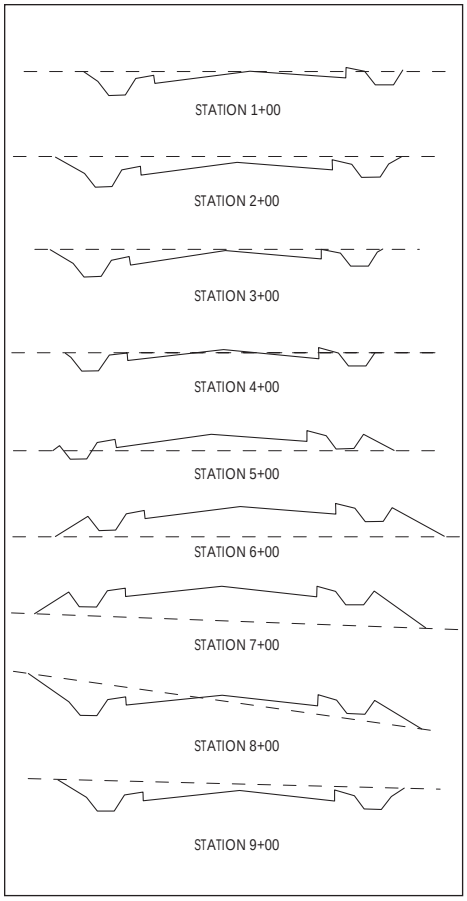


Figure 6-18
Road cross sections

You can tell that Station 1+00 through Station 4+00 primarily require cutting. On the other hand, Station 5+00 through 7+00 require a considerable amount of fill. Station 8+00 requires equal amounts of cut and fill, and Station 9+00 needs only cutting. Stations 0+00 and 10+00, at the start and end of the project, aren't included in the cross sections, since existing and proposed grades are identical at each of these stations. Excavation and embankment volumes for Stations 1+00 through 9+00 are shown in Figure 6-19. Also note the 10 percent soil-shrinkage allowance for embankments.

To calculate the required excavation between Stations 4+00 and 5+00, multiply the average square footage of cut area for the two stations (14 + 2 = 16 ÷ 2 = 8 SF) by the length between the stations (100 feet). That comes to 800 cubic feet, or 30 cubic yards. To determine embankment totals between stations, use the same average end area method and apply the "SF Fill with Shrinkage" column's figures to assess soil compaction. So, for Stations 4+00 and 5+00, you would use the increased 10 percent swell factor for your fill calculation: 42 + 1 = 43 ÷ 2 = 21.5 square feet. Multiply that by 100 feet to get 2150 cubic feet, or 80 cubic yards of embankment.

Next, calculate the net excavation volumes. Subtract the embankment volume from the excavation volume at each station. If there's more excavation than embankment, your net volume will be a positive number. If there's more embankment than excavation, the net volume will be a negative number. For example, the span between Stations 4+00 and 5+00 calls for 30 cubic yards of excavation and 80 cubic yards of embankment. Subtract 80 from 30, and you get negative 50. The second from last column in Figure 6-19 shows net excavation volumes between Station 0+00 and 10+00.

Using my bucket and shovel analogy, think of *positive* net excavation as filling the bucket, and *negative* net excavation as shoveling dirt out of the bucket.

Once you have net excavation volumes between stations, you can calculate cumulative excavation volumes. Cumulative volume, shown in the last column of Figure 6-19, is the hypothetical amount of dirt in your bucket between two adjacent stations.

Station	SF Cut	SF Fill	SF Fill with Shrinkage 10%	CY Excavation	CY Embankment	Net CY Excavation (+) Embankment (-)	Cumulative Volume (Mass Diagram Ordinate)
0+00	0	0	0				
				39	2	37	37
1+00	21	1	1				
				128	2	126	163
2+00	48	0	0				
				156	0	156	319
3+00	36	0	0				
				93	2	91	410
4+00	14	1	1				
				30	80	-50	360
5+00	2	38	42				
				4	278	-274	86
6+00	0	98	108				
				0	424	-424	-338
7+00	0	110	121				
				44	269	-225	-563
8+00	24	22	24				
				130	44	86	-477
9+00	46	0	0				
				85	0	85	-392
10+00	0	0	0				

Figure 6-19
Excavation and embankment volumes between stations

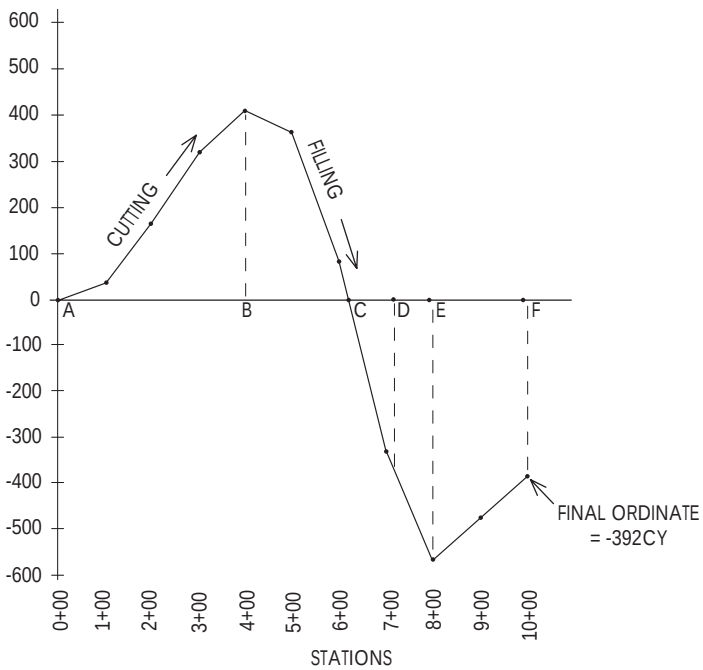


Figure 6-20
Mass diagram

Cumulative volume between Station 0+00 and 1+00 is 37 (39 minus 2) cubic yards. To calculate cumulative volume for each successive interval, add its net excavation volume to the previous interval's cumulative total. For example, in the interval between Station 1+00 and 2+00, you'd add 126 to 37 to get 163 cubic yards.

Cumulative totals give us the ordinates we'll use to plot points on the mass diagram. Ordinates represent vertical distance from the horizontal axis to the point on the graph. For instance, the cumulative volume between Stations 4+00 and 5+00 is 360 cubic yards. Directly above the Station 4+00 and 5+00 interval in Figure 6-20 you'll notice a point corresponding to 360 cubic yards.

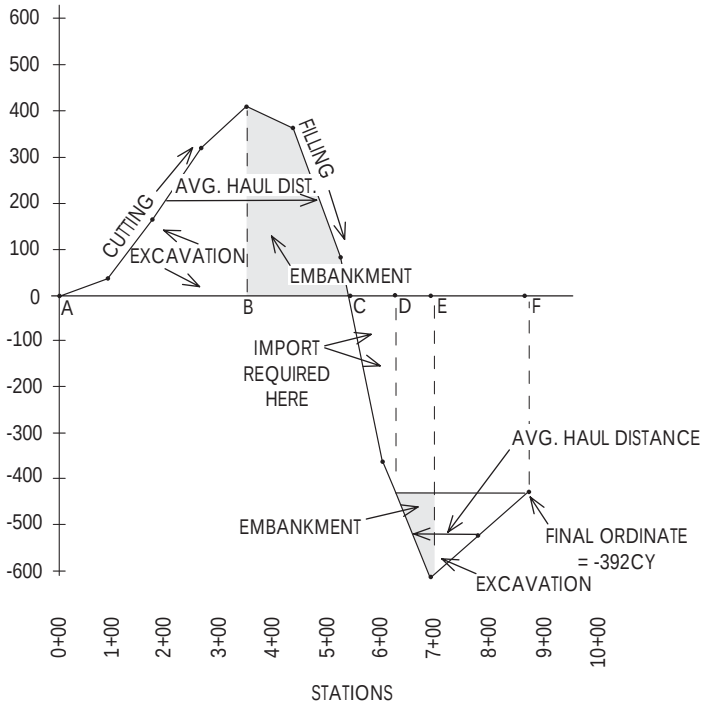


Figure 6-21
Excavation, embankment, import and average haul distances

When excavation volume exceeds embankment volume between two stations, the mass diagram curve rises. When embankment volume exceeds excavation volume between two stations, the curve goes down. The excavation between Stations 0+00 and 4+25 (Points A and B) balances the embankment between Stations 4+25 and 6+50 (Points B and C). This means that all of the excavation between Stations 0+00 and 4+25 can be used for embankment required between Stations 4+25 and 6+50. At Point C (6+50), our hypothetical bucket will be empty.

Beyond Point C, we're at a deficit, and you can see from the final ordinate (-392), that we'll never break even. We need to import 392 cubic yards to finish the job. However, the excavation between Stations 8+00 and 10+00 (Points E and F) can be used for embankment between Stations 7+40 and 8+00 (Points D and E). All that's left to account for now is the distance between Stations 6+50 and 7+40 (Points C and D) — and that's where the import should be deposited.

Points A, C, D, and F on the diagram are called balance points because they form bookends to balanced regions. By the same token, Lines AC and DF are called *balance lines*. Points where the diagram switches from ascending to descending (Point B), or vice versa (Point E), are called *grade points*.

Mass diagrams also help you to determine average haul distances. In each balanced region, locate the midpoint on the curve between the excavation-side balance point and grade point. In our example, the midpoint between Balance Point A (0+00) and Grade Point B (4+25) is 2+12.50. The midpoint between Balance Point F (10+00) and Grade Point E (8+00) is 9+00. From the points at which those distances (2+12.50 and 9+00) intersect the curve, draw a horizontal line in the direction of the hauling. Figure 6-21 illustrates the average haul distances, haul direction, and other relevant details.

Since mass diagrams contain so much useful information in a tidy visual package, they can also help you select the appropriate equipment for various job zones. Based on the haul distances indicated in our diagram, a scraper, loader, and dozer would be a good equipment mix for this job, as shown in Figure 6-22.

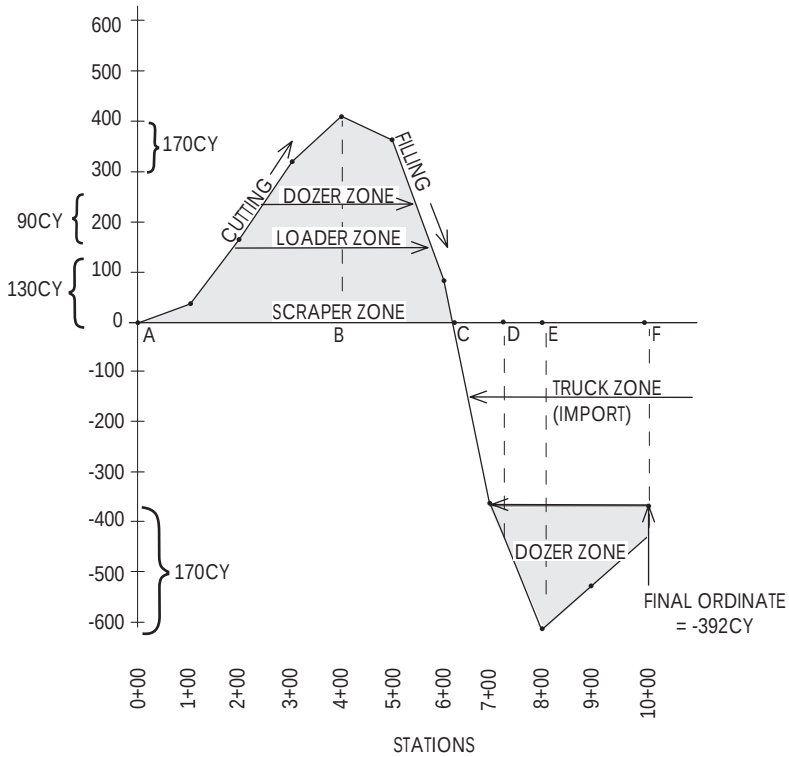


Figure 6-22
Equipment zones

By dividing the job into equipment zones based on haul distance, we also get an estimate of the volume each piece of equipment needs to carry. You'll see in Figure 6-22 that the division between scraper and loader zones occurs around the 130 cubic yard mark on the vertical axis. We'll use scrapers to move approximately 130 cubic yards of dirt from the area between Stations 0+00 and 2+00 to the area between Stations 6+00 and 6+50. Then we'll use loaders to move 90 (220 minus 130) cubic yards between Stations 2+00 and 2+50 to an area between Stations 5+60 and 6+00.

We have two dozer zones, one on the left and one on the right side of the diagram. We'll use dozers to move approximately 170 cubic yards between Stations 2+50 and 4+20 to an area between Stations 4+20 and 5+40. We'll also use them to move roughly 170 cubic yards between Stations 8+00 and 10+00 to an area between Stations 7+20 and 8+00. All of the import will need to be trucked onto the site.

In the second half of this book, I'll provide more detail on equipment choices, including recommendations based on haul distance.

7

Irregular Regions & Odd Areas

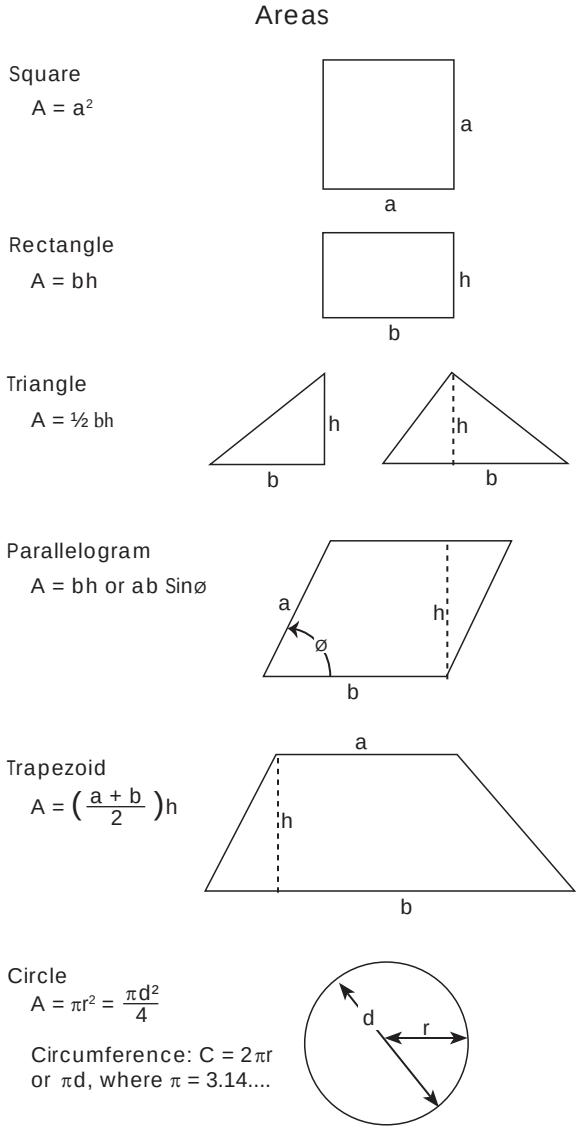


Figure 7-1
Areas

Up to this point, we've only worked with areas that had simple shapes. That makes their area easy to calculate. Unfortunately, most sites you'll work with won't be nice squares or rectangles — they'll be odd-shaped. I've encountered oval (elliptical) and circular shapes, for instance in large planters. Figure 7-1 shows formulas for calculating the area of various shapes.

Jobsites with odd shapes usually also have other challenges, including sharp changes in grade or in contour direction. These conditions make it difficult to find the area by the usual methods. But no matter how irregular the site, you'll always be able to find its area by breaking it down into simple shapes.

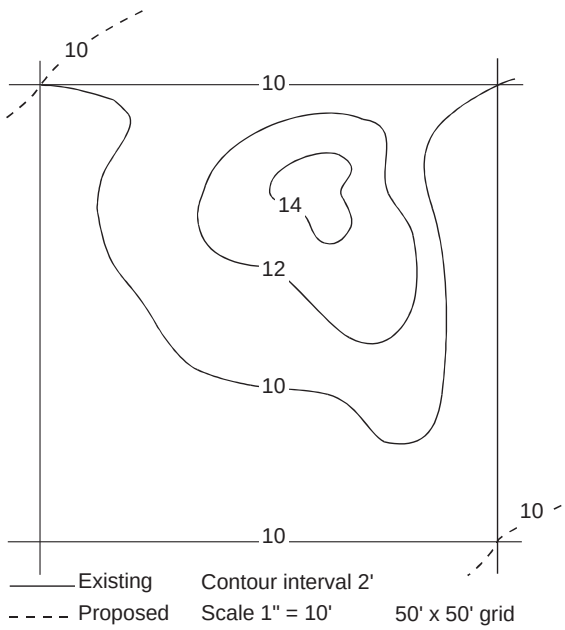


Figure 7-2
A grid square with the same elevation at all four corners

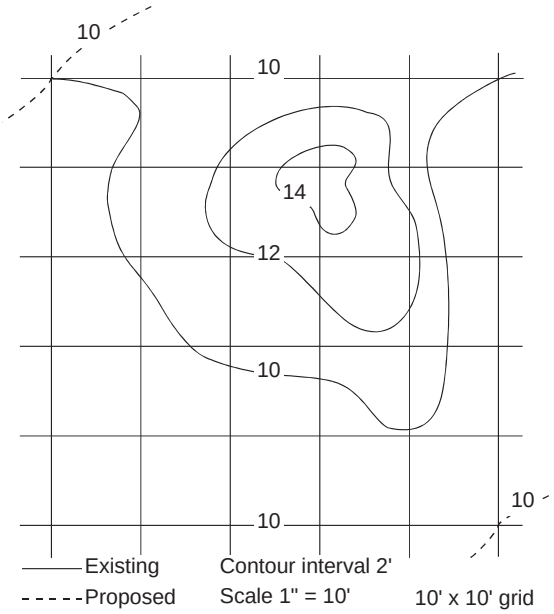


Figure 7-3
Figure 7-2 with a smaller grid

In this chapter you'll learn several different ways to calculate the area of an irregular shape. To find these areas, you'll need to use a few mathematical formulas which may look a little unfamiliar. But don't let them put you off. After just a little practice and a few calculations, you'll find they're not so difficult.

We'll begin by looking at Figure 7-2. If you look only at the corner elevations, it seems there's no earthwork needed here. All four corners of the grid square have the same elevation. But that's not the whole story. What about the contour lines inside the grid square? They tell you there's a 4-foot-high mound inside the grid square. If the job specs include leveling this area, you need to know the volume of this mound.

Here are four ways of finding the volume of the mound:

1. Use a planimeter, as discussed in the last chapter.
2. Subdivide your grid system by breaking it into smaller squares, as shown in Figure 7-3. We discussed this method in previous chapters.
3. Use compensating lines to approximate the shape's outline and to break it down into simpler shapes made up of straight lines.
4. Use an odd-shaped grid system or the multiplane method. You can use any geometric shape for a grid system — if you also know how to calculate its area.

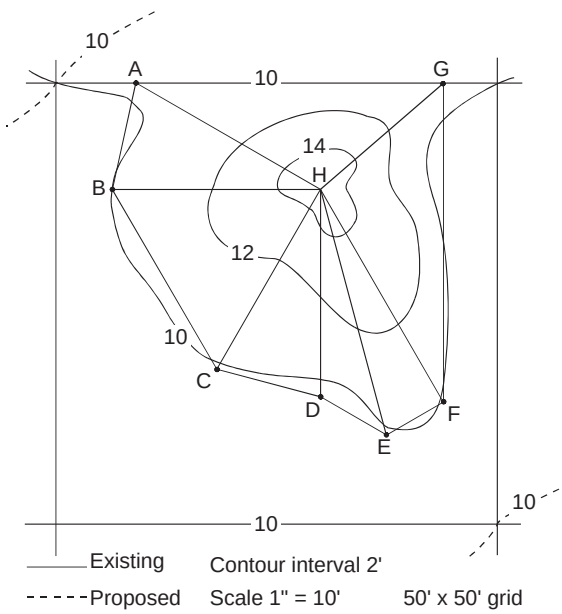


Figure 7-4
Add the compensating lines to Figure 7-2 to divide the mound into seven oblique triangles

In this chapter we'll learn how to use both the compensating line method and the multiplane method. Let's start with the compensating line method.

Finding Area Using Compensating Lines

What's a compensating line? The compensating line of a curved line is just a straight line that's as close as possible to the curved line. To make a compensating line from any curved line, you take points along the curved line and connect them with straight lines. If the curved line doesn't turn very much, you can replace it with a long straight line. If it makes a sharp turn, you'll need a shorter straight line.

In Figure 7-4 we've put compensating lines around the 10 foot contour line. If a section of the contour line doesn't have many turns, or if they're very gradual, we've used fairly long compensating lines. Two good examples are lines AG and GF in Figure 7-4. Where there are many turns, or very sharp turns, in the contour line, the compensating lines are shorter, like line EF. The accuracy of your area and volume estimates depends on how closely your compensating lines follow the contour line.

After drawing the compensating lines, mark a point in the middle of the highest elevation contour. In Figure 7-4 it's point H at the center of the 14-foot contour. Connect each end of each compensating line to the center point. This divides the mound into seven triangles. We'll figure out the area of each of these triangles and add the areas together to find the total area of the elevated grid contour.

All seven of the triangles in Figure 7-4 are oblique triangles; they have no angles that measure exactly 90 degrees. Triangles that include a 90-degree angle are right triangles. Here's the formula you use to find the area of an oblique triangle:

Area = ½(base × height)

Now let's define height and base. The height of an oblique triangle is the length of a perpendicular line drawn from one angle to the opposite side. The base is the side of

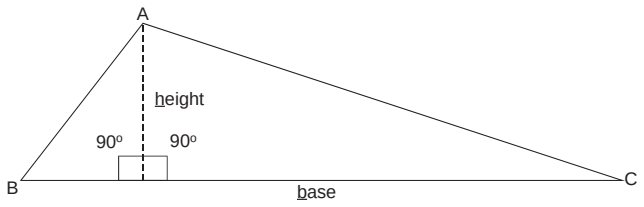


Figure 7-5
Finding the base and height dimensions in an oblique triangle

the triangle that forms a 90-degree angle with that perpendicular line. Take a look now at the oblique triangle ABC in Figure 7-5. Notice that the dashed line from angle A forms two 90-degree angles with side BC. The dashed line is the height and side BC is the base. Why isn't side AB the base? Although you can draw a line from angle C to side AB, that line won't be perpendicular to side AB. This is also true for the line you could draw from angle B to side AC. There's only one possible height and base in any oblique triangle.

Now let's calculate the area for the seven oblique triangles in Figure 7-4. The dimensions you'll need are shown in Figure 7-6. Try doing the calculations for all the triangles except EHF, and check them against my worksheet in Figure 7-6.

What about EHF? We'll use a different method to find its area. That's because it's difficult to draw an accurate perpendicular in such a narrow triangle. The method we'll use to find the area of EHF works with just the measured lengths of the triangle's sides. Here are the formulas we'll use to find the area of EHF:

$$S = (EH + FH + EF) \div 2$$

$$R = \sqrt{[(S - EH) \times (S - FH) \times (S - EF)] \div S}$$

$$\text{Area} = R \times S$$

Compared to the single formula we used earlier, this looks terribly complicated. It really isn't as bad as it looks. But I'm sure you can see why I didn't calculate the areas for all seven triangles this way. You'll find all three of these formulas, as well as the math, in the area calculations worksheet for triangle EHF shown in Figure 7-7 (on page 157).

Look at the last calculation in Figure 7-6. The *Total area* is the sum of the areas of all seven triangles. That comes to 1,251 after rounding.

Finding Volume Using Total Area and Average Depth

To find the average depth, try thinking of the mound as a big meringue pie. Imagine you cut the pie in pieces along the lines in Figure 7-4. Figure 7-8 (on page 158) shows a piece cut out along the lines of triangle BHC.

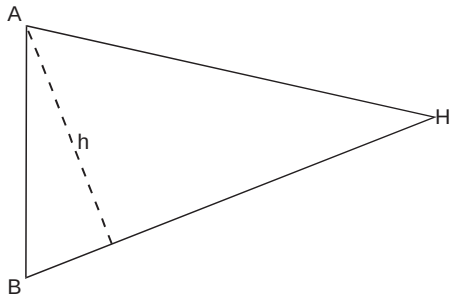
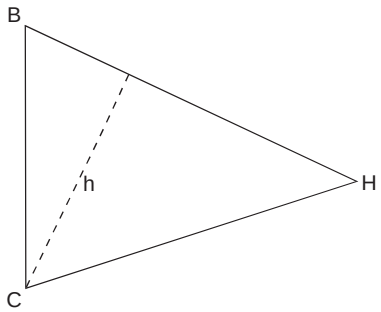
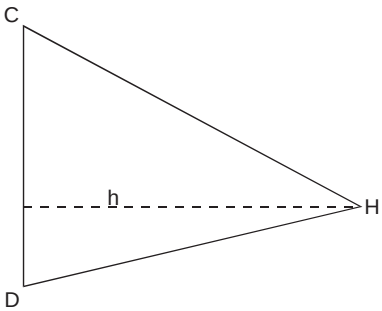
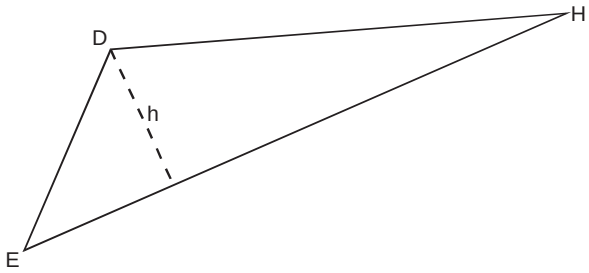
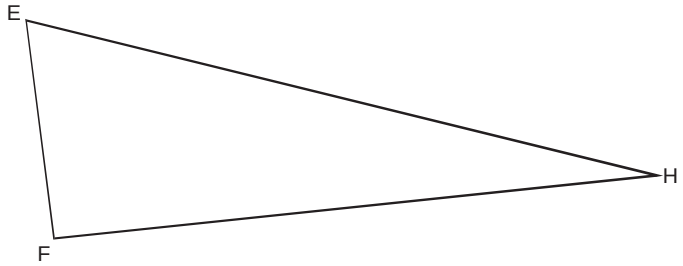
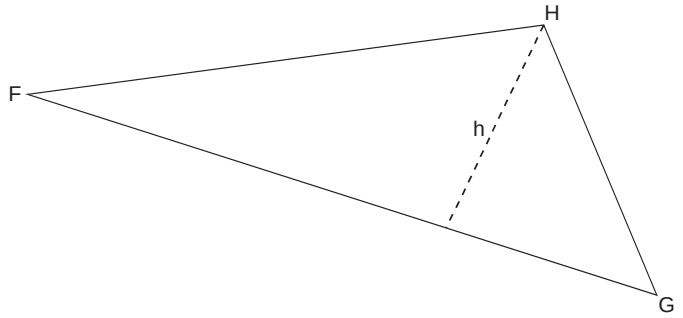
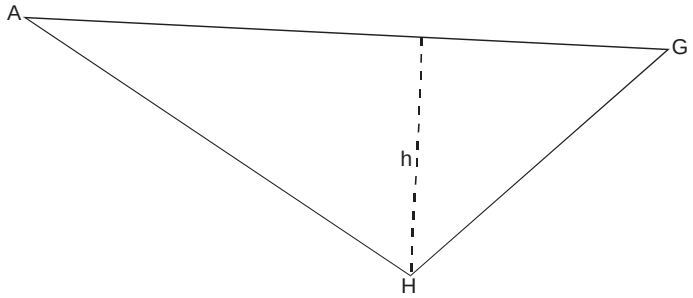
Triangle: AHB 	BH = b	26	**Area = ½(b x h)** (26 x 14) ÷ 2 364 ÷ 2 182
	AH	25	
	AB	15	
	h	14	
Triangle: BHC 	BH = b	26	**Area = ½(b x h)** (26 x 17) ÷ 2 442 ÷ 2 221
	BC	18	
	CH	24	
	h	17	
Triangle: CHD 	CD = b	17	**Area = ½(b x h)** (17 x 22) ÷ 2 374 ÷ 2 187
	CH	24	
	DH	22	
	h	22	
Triangle: DHE 	EH = b	29	**Area = ½(b x h)** (29 x 7.5) ÷ 2 217.5 ÷ 2 108.75
	DE	11	
	DH	22	
	h	7.5	

Figure 7-6
Worksheet — areas of oblique triangles

Triangle: EHF 	EH	29	**See Figure 7-7 for area calculations** 83.79
	FH	28	
	EF	6	
Triangle: FHG 	FG = b	36	**Area = ½(b x h)** (36 x 14) ÷ 2 504 ÷ 2 252
	FH	28	
	GH	18	
	h	14	
Triangle: AHG 	AG = b	36	**Area = ½(b x h)** (36 x 12) ÷ 2 432 ÷ 2 216
	AH	25	
	GH	18	
	h	12	

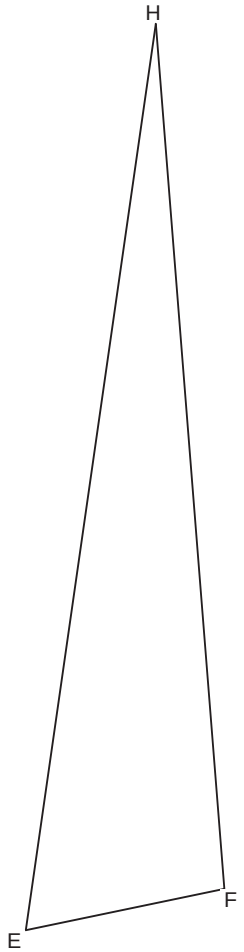
Total area: = 182 + 221 + 187 + 108.75 + 83.79 + 252 + 216
= 1,250.54
(round to 1,251)

Volume: = (1,251 x 2) ÷ 27
= 2,502 ÷ 27
= 92.67 CY
(round to 93 CY)

Figure 7-6 (continued)
Worksheet — areas of oblique triangles

Calculation Sheet

Project: Sample **Date:** 4/22



$$S = (EH + FH + EF) \div 2$$

$$R = \sqrt{[(S - EH) \times (S - FH) \times (S - EF)] \div S}$$

$$Area = R \times S$$

$$EH = 29$$

$$FH = 28$$

$$EF = 6$$

$$S = (29 + 28 + 6) \div 2$$

$$= 63 \div 2$$

$$= 31.5$$

$$R = \sqrt{[(31.5 - 29) \times (31.5 - 28) \times (31.5 - 6)] \div 31.5}$$

$$= \sqrt{[2.5 \times 3.5 \times 25.5] \div 31.5}$$

$$= \sqrt{223.125 \div 31.5}$$

$$= \sqrt{7.0833}$$

$$= 2.66$$

$$Area = 2.66 \times 31.5$$

$$= 83.79 \text{ SF}$$

Conclusion:

Figure 7-7
Alternate method of area calculation using oblique triangle EHF as the example

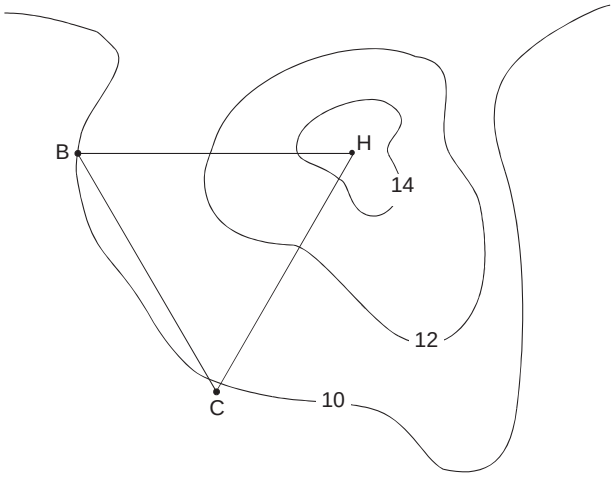


Figure 7-8
Triangle BHC

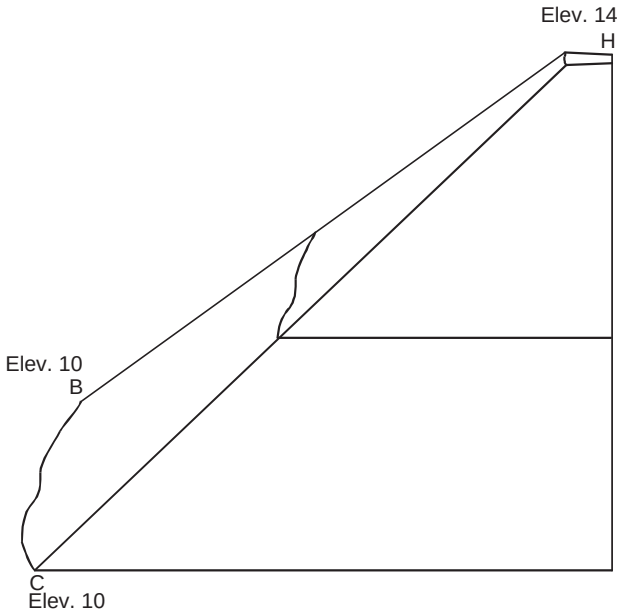


Figure 7-9
Triangle BHC "removed" to find average depth

If you take the piece out, it'll look like Figure 7-9. Let's use this figure to see how to find the average depth of this piece of the mound. The topo map shows that the mound slopes evenly on all sides. That means we only need to find average depth once. Points B and C have the same elevation, 10 feet. At point H the elevation is 14 feet. Here's the math:

$$\text{Average depth} = (14 - 10) \div 2$$
$$= 4 \div 2$$
$$= 2 \text{ feet}$$

This, plus the total area of the triangles (calculated at 1,251 square feet, see Figure 7-6), is all the data we need to find the volume of the mound using this formula:

$$\text{Volume (CY)} = (\text{Average depth} \times \text{Total area}) \div 27$$

$$\text{Volume (CY)} = (2 \times 1{,}251) \div 27$$
$$= 2{,}502 \div 27$$
$$= 92.67 \text{ CY}$$

We'll round that off and call the volume of the mound 93 cubic yards.

Finding Volume Using Compensating Lines with a Coordinate System

Another way to find the area of an irregular shape combines compensating lines with a coordinate system. Land surveyors often use this method. Again, it may seem difficult, especially the mathematical formula you use, so we'll go through it step-by-step.

Step 1

Trace the boundaries of the area in question from the original topo map or scaled site plan onto graph paper. Be careful to choose graph paper that has the same scale as the scale used on your topo map or plan. Figure 7-10 A (on page 161) shows an example — my tracing of the 10-foot contour line from Figure 7-2. The scale in that figure was 1" = 10'.

Now let's suppose you have the following three sizes of graph paper:

1" = 5 squares

1" = 8 squares

1" = 10 squares

Which graph paper should you use? Here's a hint. There's only one wrong answer. The most obvious answer is paper with 10 squares to the inch. It makes a perfect match with the scale used in Figure 7-2. If you make the tracing onto this size graph paper, one square equals 1 foot. The other right answer is to make the tracing on paper with five squares to the inch. Then each square would equal 2 feet. In Figure 7-10 A, I used five squares to the inch.

Step 2

Now we'll add two reference lines, one horizontal and one vertical, to the tracing (lines 0, 0). Figure 7-10 A shows the usual placement for the reference lines. But notice that I said this is the "usual" placement. That means you're free to change their locations to suit the situation or yourself.

Step 3

Next we'll add unit divisions to the reference lines and label the major divisions. Always label the zero on both reference lines. Since one square equals 2 feet, five squares equal 10 feet. That's the major division used for the graphs in Figure 7-10 A, Figure 7-11 (on page 164) and Figure 7-12 (on page 165).

Step 4

Now add compensating lines to the tracing of the 10-foot contour. Mark a point each time the direction of the compensating lines change. Then label the points using any system that makes sense to you. I prefer to use letters to avoid any chance of confusion. Here's the only rule: Name the points in order. Start with whatever point you like. Move around the contour in whichever direction you like, naming points until you're back at the start point. In Figure 7-10 A, I ended up with a total of seven points labeled A through G, going counter-clockwise around the contour line.

Step 5

Go back to your first point (in Figure 7-10 A that's point A) and draw a horizontal line from point A to the vertical reference line. My line (the dashed line) meets the vertical reference line right at the major division labeled 50. Let's call that intersection Av (A's vertical coordinate). So Av equals 50 feet.

I like to use solid lines for the reference lines and a dashed line to connect points and reference lines. That style's used in the graphs shown in Figures 7-10 A, 7-11 and 7-12. You can differentiate these lines any way you like. Drawing all the lines you add with colored pencils is another method.

Let's return to point A now and add another line. This time we'll draw a vertical line from point A to the horizontal reference line. Label the intersection Ah (A's horizontal coordinate). Notice that Ah falls on the second division to the right of 10. We know that each division is 2 feet, so Ah equals 10 + 4, or 14 feet.

Repeat this process, drawing lines from each point to both reference lines, working your way around the contour line point by point, until you return to your starting point.

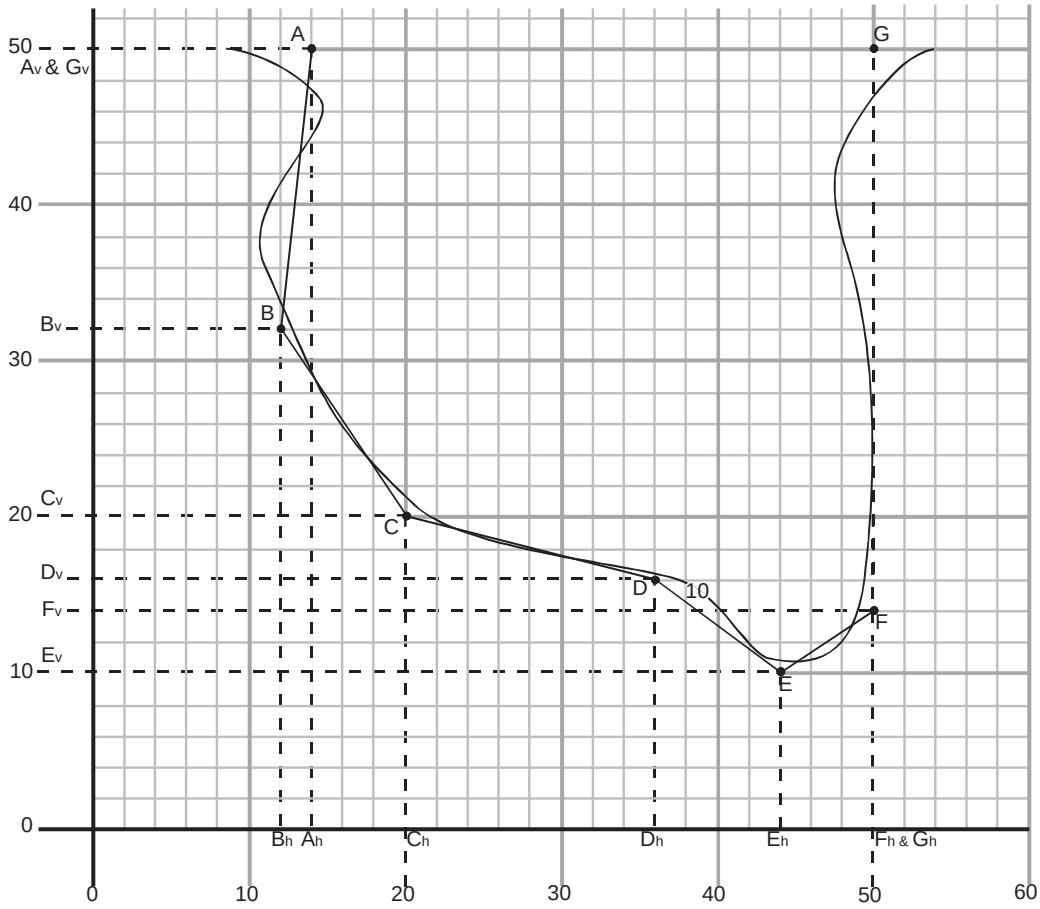
Step 6

We're ready now to move from the graph section in Figure 7-10 to the worksheet (Figure 7-10 B). The worksheet's divided into three sections: Scaled distance, Formula, and Calculations. Use the first section to record horizontal and vertical values for each point as you read them off the scaled reference lines.

The second section gives the formula you use to find the area in square feet.

$$\text{Area (SF)} = [(Nv \times N{+}1h) + (N{+}1v \times N{+}2h) + \ldots (N + Nv \times Nh) - (Nh \times N{+}1v) - (N{+}1h \times N{+}2v) - \ldots (N + Nh \times Nv)] \div 2$$

A. The 10-foot contour line with compensating lines and reference lines



B. Worksheet and area calculations for the 10-foot contour line

Scaled distance

Point	A	B	C	D	E	F	G	
h (scale distance)	14	12	20	36	44	50	50	
v (scale distance)	50	32	20	16	10	14	50	

Formula

Area (SF) = $[(N_v \times N + 1_h) + (N + 1_v \times N + 2_h) + \ldots (N + N_v \times N_h) - (N_h \times N + 1_v) - (N + 1_h \times N + 2_v) - \ldots (N + N_h \times N_v)] \div 2$

Calculations

Area (SF) = [(50 x 12) + (32 x 20) + (20 x 36) + (16 x 44) + (10 x 50) + (14 x 50) + (50 x 14) - (14 x 32) - (12 x 20) - (20 x 16) - (36 x 10) - (44 x 14) - (50 x 50) - (50 x 50)] ÷ 2

= [600 + 640 + 720 + 704 + 500 + 700 + 700 - 448 - 240 - 320 - 360 - 616 - 2,500 - 2,500] ÷ 2

= -2,420 ÷ 2 (ignore the minus sign)

= -1,210 SF (ignore the minus sign)

Figure 7-10
Finding volume by the coordinate system using the 10-foot contour line

At first glance this formula may look like a lot of gibberish. But don't give up. Read through the following definitions and the formula starts to make a lot more sense.

N = the first in series of variables

Nh = horizontal coordinate of a variable

Nv = vertical coordinate of a variable

N+1 = the next variable in a series of variables

N+1h = the horizontal coordinate of the next variable in a series

N+1v = the vertical coordinate of the next variable in a series

N+2 = the third variable in a series

... = continues the sequence within a series of variables

N+N = the final variable in a series of infinite length

To use this formula, break it down into smaller, more manageable parts. That's the purpose of the parentheses ( ) and brackets [ ] already included in the formula. Here's what they tell you to do:

1. Do the multiplication first. Each multiplication operation is enclosed by a set of parentheses ( ).
2. Look for the brackets next. They set off a long string of addition and subtraction that you do in sequence.
3. Finally, do the division.

Now take a look at the Calculations section in Figure 7-10 B to see the formula in action. The first two lines are a single long equation. There just isn't enough room to string it all out on a single line. Where did this huge equation come from? It's the result when you replace the variables in the formula with the actual horizontal and vertical distances for each point. That's easy to do in just one step, after a bit of practice. But you're new at this, so we'll do the replacement in two parts. Breaking this step into two parts means I can show you exactly where every number in the equation comes from. First we'll replace all of the N's in the formula with actual point references for the 10-foot contour line. Here's the result:

$$\begin{aligned}\text{Area (SF)} = [&(Av \times Bh) + (Bv \times Ch) + (Cv \times Dh) + (Dv \times Eh) + (Ev \times Fh)\\ &+ (Fv \times Gh) + (Gv \times Ah) - (Ah \times Bv) - (Bh \times Cv) - (Ch \times Dv)\\ &- (Dh \times Ev) - (Eh \times Fv) - (Fh \times Gv) - (Gh \times Av)] \div 2\end{aligned}$$

Next we'll replace all the point references with the corresponding horizontal or vertical distance recorded in the Scaled distance section of the worksheet. Here's the result for the 10-foot contour line:

$$\text{Area (SF)} = [(50 \times 12) + (32 \times 20) + (20 \times 36) + (16 \times 44) + (10 \times 50) + (14 \times 50) + (50 \times 14) - (14 \times 32) - (12 \times 20) - (20 \times 16) - (36 \times 10) - (44 \times 14) - (50 \times 50) - (50 \times 50)] \div 2$$

Now simply work through the math. First, within each set of parenthesis do all the multiplication. Second, do the string of additions and subtractions within the brackets. If the result is a negative number, as it is in Figure 7-10 B, just ignore the minus sign. Third, divide the result by 2. The resulting number is the area inside the contour line. For the 10-foot contour line in Figure 7-10 B, the area comes out to 1,210 square feet.

Step 7

Repeat the first six steps for each contour line. In the case of the mound in Figure 7-2, there are two more contour lines. Figures 7-11 and 7-12 (on pages 164 and 165) show the calculations for the 12- and 14-foot contour lines. Their areas are 412 and 61.5 square feet, respectively.

We'll use the area within each of the three contour lines and the average end area method to calculate volume.

Step 8

Find the average area between adjacent contour lines. In the case of our sample mound there are two average areas to calculate. First, the average of the areas within the 10-foot and 12-foot contour lines:

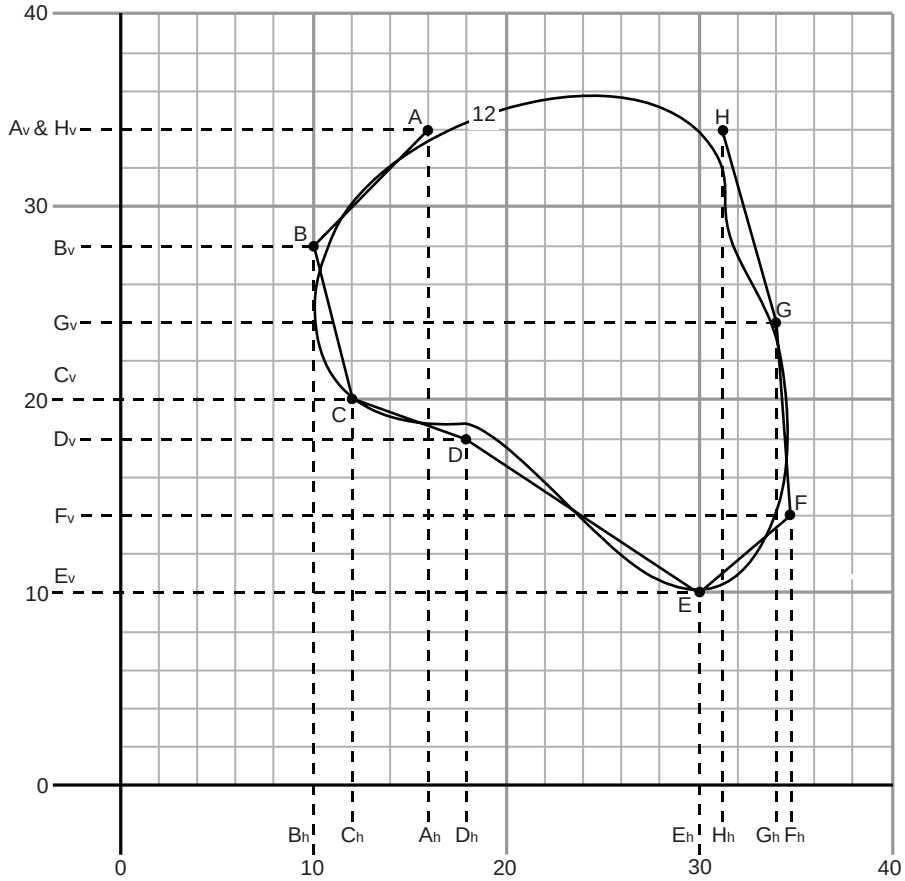
$$\begin{aligned}\text{Average area} &= (1{,}210 + 412) \div 2\\ &= 1{,}622 \div 2\\ &= 811 \text{ SF}\end{aligned}$$

And second, the average of the areas within the 12-foot and 14-foot contour lines:

$$\begin{aligned}\text{Average area} &= (412 + 61.5) \div 2\\ &= 473.5 \div 2\\ &= 236.75 \text{ SF}\end{aligned}$$

*(**Step 9** and **Step 10** continued on page 166.)*

A. The 12-foot contour line with compensating lines and reference lines



B. Worksheet and area calculations for the 12-foot contour line

Scaled distance

Point	A	B	C	D	E	F	G	H
h (scale distance)	16	10	12	18	30	35	34	31
v (scale distance)	34	28	20	18	10	14	24	34

Formula

Area (SF) = $[(N_v \times N + 1_h) + (N + 1_v \times N + 2_h) + \ldots (N + N_v \times N_h) - (N_h \times N + 1_v) - (N + 1_h \times N + 2_v) - \ldots (N + N_h \times N_v)] \div 2$

Calculations

Area (SF = [(34 x 10) + (28 x 12) + (20 x 18) + (18 x 30) + (10 x 35) + (14 x 34) + (24 x 31) + (34 x 16)
- (16 x 28) - (10 x 20) - (12 x 18) - (18 x 10) - (30 x 14) - (35 x 24) - (34 x 34) - (31 x 34)] ÷ 2

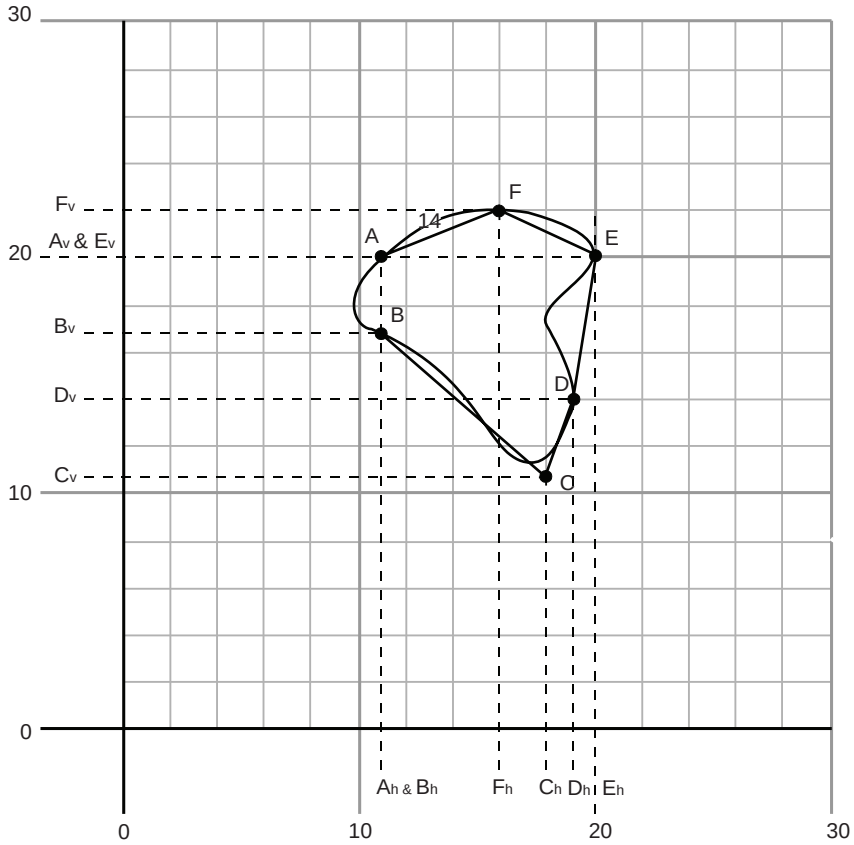
= [340 + 336 + 360 + 540 + 350 + 476 + 744 + 544 - 448 - 200 - 216 - 180 - 420 - 840 - 1156 - 1054] ÷ 2

= -824 ÷ 2 (ignore the minus sign)

= -412 SF (ignore the minus sign)

Figure 7-11
Using the 12-foot contour line

A. The 14-foot contour line with compensating lines and reference lines



B. Worksheet and area calculations for the 14-foot contour line

Scaled distance

Point	A	B	C	D	E	F		
h (scale distance)	11	11	18	19	20	16		
v (scale distance)	20	17	11	14	20	22		

Formula

Area (SF) = $[(N_v \times N + 1_h) + (N + 1_v \times N + 2_h) + \ldots (N + N_v \times N_h) - (N_h \times N + 1_v) - (N + 1_h \times N + 2_v) - \ldots (N + N_h \times N_v)] \div 2$

Calculations

Area (SF = [(20 x 11) + (17 x 18) + (11 x 19) + (14 x 20) + (20 x 16) + (22 x 11) - (11 x 17) - (11 x 11) - (18 x 14) - (19 x 20) - (20 x 22) - (16 x 20)] ÷ 2

= [220 + 306 + 209 + 280 + 320 + 242 - 187 - 121 - 252 - 380 - 440 - 320] ÷ 2

= -123 ÷ 2 (ignore the minus sign)

= -61.5 SF (ignore the minus sign)

Figure 7-12
Using the 14-foot contour line

Step 9

Multiply the average areas by depth and divide by 27 to find volume in cubic yards. Depth equals the contour interval, and that's 2 feet for our sample mound. Here's the math for the volume between the 10-foot and 12-foot contour lines:

Volume (CY) = (811 × 2) ÷ 27

= 1,622 ÷ 27

= 60.07 CY (round to 60 CY)

Next find the volume between the 12-foot and 14-foot contour lines:

Volume (CY) = (236.75 × 2) ÷ 27

= 473.5 ÷ 27

= 17.54 CY (round to 18 CY)

Step 10

To find the total volume, simply find the sum of the volumes. Our sample mound's total volume for the area between the 10-foot and the 14-foot contour lines is 78 cubic yards (60 + 18 = 78).

This volume assumes that above the 14-foot contour line the mound is more or less flat. If this is true, it's safe to leave it out of your estimate. The volume of material is too small to have an effect on your estimate. But suppose the slope of the mound continues upward from the 14-foot contour line (without reaching the 16-foot contour line)? In that case, it's wise to include this area in your volume estimate.

Let's use the sample mound and see how you find a volume for an area like this using the average end area method. Above the 14-foot contour line, the next contour line, if there were one, would be at 16 feet. Since there isn't a 16-foot contour line, the area inside is zero. We already know the area inside the 14-foot contour line is 61.5 SF. Assuming a depth of 1 foot, find the volume of the area above the 14-foot contour line:

Average area = (61.5 + 0) ÷ 2

= 61.5 ÷ 2

= 30.75 SF

Volume (CY) = (30.75 × 1) ÷ 27

= 30.75 ÷ 27

= 1.1 CY

We'll round that off to 1 cubic yard and add it to our earlier total. The adjusted total volume of the mound is 79 cubic yards.

You'll notice that there's a fairly large difference in the volume of the mound using the two methods. The first thing to remember is that any method is only as accurate as the placement of the points. The more points you use at even small changes of direction, the more accurate the results. Keep this in mind when you're choosing which method to use. First, you have to decide how accurate you need the results to be. Sometimes you're just looking for a ballpark figure. That would be close enough if you're looking for a borrow pit along the project. You don't need a high degree of accuracy to find if a certain area contains the amount of material you need. But if you're working with a small area where drainage or site size restrictions are involved, you need to be more accurate.

Either of the two methods might be the better choice in certain situations. I prefer the compensating line method when the direction changes aren't close together and there's room to draw the compensating lines and interior triangles. When the work area is smaller, or the contour lines make drastic and frequent direction changes, the coordinate system is better.

Finding Volume Using the Trapezoidal Rule

Imagine trying to find the volume of an area with lots of twists and turns using compensating lines. If you drew a new line and a triangle for each small curve, you'd soon have too many to deal with. For a very irregular shape, that method is just too cumbersome to be practical. Instead, you can use the Trapezoidal Rule to find the area of this sort of irregular shape.

To use this method, you begin by dividing the area into strips of equal width. Then measure the length of each strip. The strips' lengths vary with the shape of the area. Then you use the following formula to solve for area in square feet.

Where:

d is the width of each piece

y_0 is the length of the first line

y_n is the length of the last line

y_1 is the length of the second line

y_2 is the length of the third line

y_{n-1} is the length of the next-to-last line

n is the number of pieces

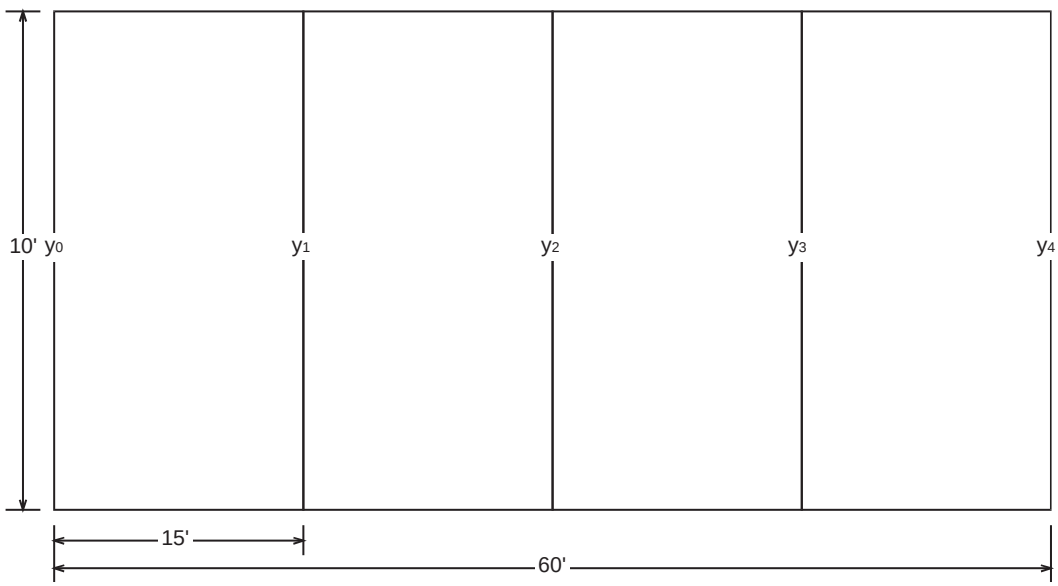


Figure 7-13
Using the Trapezoidal Rule

$$\text{Area (SF)} = d \times [½ \times (y_0 + y_n) + y_1 + y_2 + y_3 + \ldots y_{n-1}]$$

Let's work through two examples to see how to do this, beginning with the rectangle shown in Figure 7-13. First we'll divide the rectangle into four strips of equal width. Each strip is 15 feet wide. We won't measure the strips because we know they're all 10 feet long. So in Figure 7-13, n equals 4, d equals 15, and y equals 10:

$$\begin{aligned}\text{Area (SF)} &= 15 \times [½ \times (10 + 10) + 10 + 10 + 10] \\ &= 15 \times [½ \times 20] + 10 + 10 + 10 \\ &= 15 \times 10 + 30 \\ &= 15 \times 40 \\ &= 600 \text{ SF}\end{aligned}$$

For the second example, we'll use a situation that's a bit more realistic. Take a look at Figure 7-14. This topographic map shows a small lake that's surrounded by a 4-foot-high berm. The lake has a uniform depth of 3 feet and the owner wants the lake filled in and leveled off. The owner wants the berm material used for the fill.

We'll have to do several calculations to find out if the berm contains enough material:

- the volume of the lake
- the volume of the earthen berm
- the difference between these two volumes

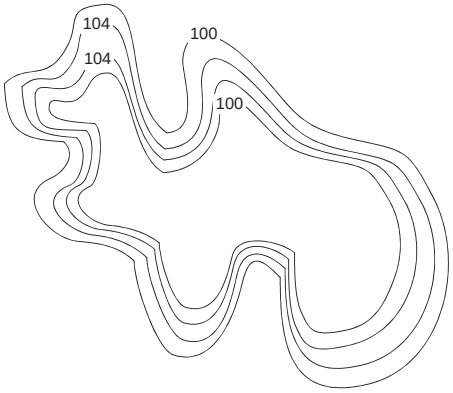


Figure 7-14
Topographic map of a small lake surrounded by a 4-foot-high berm

But before we start, there's a point I want to make about Figure 7-14. You'll notice that Figure 7-14 has two 100-foot contour lines and two 104-foot contour lines. It's very important for us to know which 100-foot or 104-foot contour line is which. In this example I've accomplished this by calling the inner 100- and 104-foot contour lines (the contour lines associated with the lake and located inside of the berm) inside contour lines. Meanwhile, the outer 100- and 104-foot contour lines (the contour lines associated with the berm and located outside of the lake) are outside contour lines. Clearly, there are many other ways to differentiate the two sets of contour lines from one another. Your main goal is to know, at a glance and beyond any doubt, exactly which contour line you're working with in each worksheet or contour line tracing. Experiment and find a system that works for you and then stick with it.

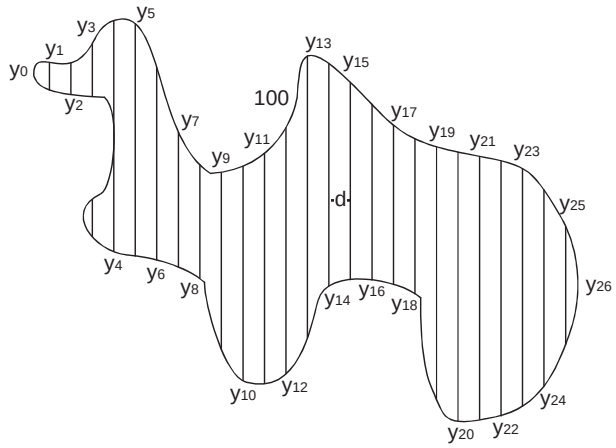
Getting back to Figure 7-14, let's see how you use the Trapezoidal Rule to find the area each contour line encloses. Work with one contour line at a time, repeating these six steps for each contour line:

1. Trace the contour line, noting the scale used.
2. Divide the area into labeled strips of equal width.
3. Record the standard width you use for the strips.
4. Measure the length of each strip.
5. Record these lengths on the worksheet.
6. Use the Trapezoidal Rule to calculate the area.

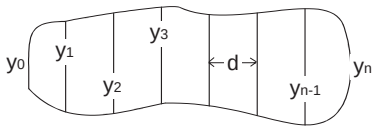
Now let's try out the steps by finding the area of the inside 100-foot contour line. This contour line also represents the surface area of the lake. We'll use the traced copy of the inside 100-foot contour line at the top of Figure 7-15 for steps 1 through 4. Then we'll use the worksheet below for steps 5 and 6. Use Figure 7-16 to follow along with the area calculations for the inside 104-foot contour line. For the outside 104-foot contour, use Figure 7-17. Then for the outside 100-foot contour, use Figure 7-18.

The diagram in Figure 7-15 is already divided into 27 labeled lines. At the lower left, you'll find the scale, the value of d and the name of the contour line. Now take a look at lines y_3 and y_4. Notice what makes these two lines different from the other lines? They both consist of two pieces. Whenever a line has multiple parts, you measure the length of each part. Record each part's length on your worksheet and find their sum. You'll use their total length in the equation and calculations.

Finding the Area of the Inside 100-foot Contour Line



Scale 1" = 50'
d = 10'
Inside 100' contour



y_0 = First line
y_n = Last line {y_{26}}
y_{n-1} = Next to last line {y_{25}}
d = Distance between lines {10'}

Trapezoidal Rule

Area = d x [½ x (y_o + y_n) + y_1 + y_2 + y_3 + ...y_{n-1}]

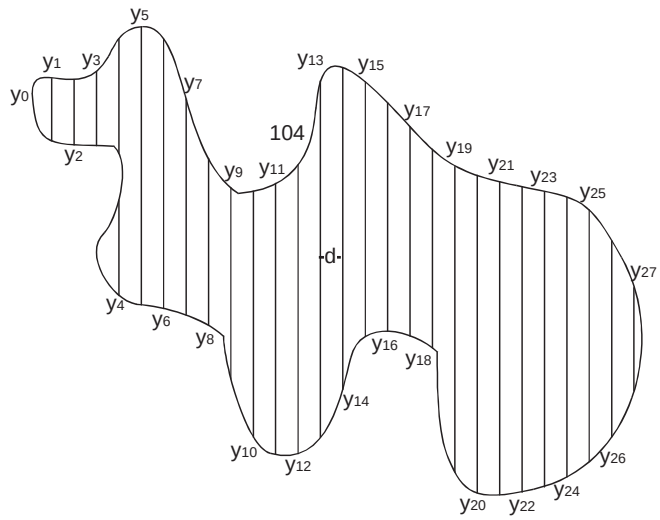
Line number	**y_0**	**y_1**	**y_2**	**y_3**	**y_4**	**y_5**
Scale distance	6	23	27	30 + 28 = 58	40 + 50 = 90	133
Line number	**y_6**	**y_7**	**y_8**	**y_9**	**y_{10}**	**y_{11}**
Scale distance	80	62	55	55	64	112
Line number	**y_{12}**	**y_{13}**	**y_{14}**	**y_{15}**	**y_{16}**	**y_{17}**
Scale distance	126	145	116	86	64	57
Line number	**y_{18}**	**y_{19}**	**y_{20}**	**y_{21}**	**y_{22}**	**y_{23}**
Scale distance	59	67	75	133	132	124
Line number	**y_{24}**	**y_{25}**	**y_{26}**			
Scale distance	110	83	22			

Calculations for: inside 100' contour line

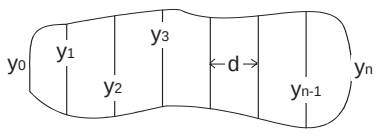
Area = 10 x [½ x (6 + 22) + 23 + 27 + 58 + 90 + 133 + 80 + 62 + 55 + 55 + 64 + 112 + 126 + 145 + 116 + 86 + 64 + 57 + 59 + 67 + 75 + 133 + 132 + 124 + 110 + 83]
= 10 x [½ x (6 + 22) + 2,136]
= 10 x [½ x 28 + 2,136]
= 10 x [14 + 2,136]
= 10 x 2,150
= 21,500 SF

Figure 7-15
Trapezoidal Rule worksheet and area calculations for the *inside* 100-foot contour line

Finding the Area of the Inside 104-foot Contour Line



Scale 1" = 50'
d = 10'
Inside 104' contour



y_0 = First line
y_n = Last line {y_{27}}
y_{n-1} = Next to last line {y_{26}}
d = Distance between lines {10'}

Trapezoidal Rule

Area = d x [½ x (y_o + y_n) + y_1 + y_2 + y_3 + ...y_{n-1}]

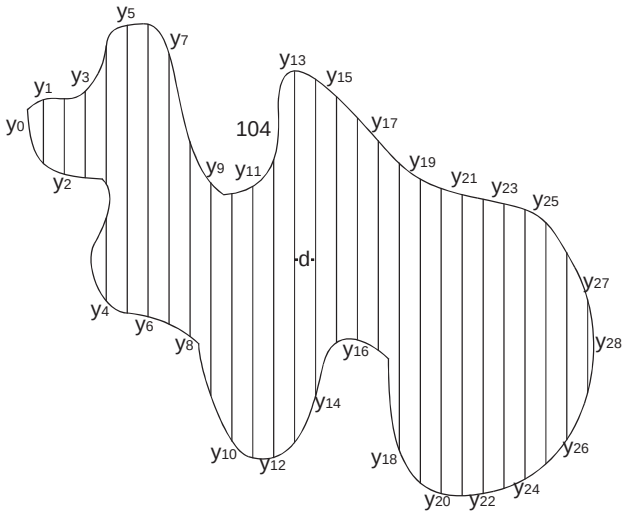
Line number	**y_0**	**y_1**	**y_2**	**y_3**	**y_4**	**y_5**
Scale distance	8	29	36	40 + 30 = 70	45 + 49 = 94	150
Line number	**y_6**	**y_7**	**y_8**	**y_9**	**y_{10}**	**y_{11}**
Scale distance	150	100	75	70	72	125
Line number	**y_{12}**	**y_{13}**	**y_{14}**	**y_{15}**	**y_{16}**	**y_{17}**
Scale distance	168	175	166	140	102	75
Line number	**y_{18}**	**y_{19}**	**y_{20}**	**y_{21}**	**y_{22}**	**y_{23}**
Scale distance	72	75	78	144	146	145
Line number	**y_{24}**	**y_{25}**	**y_{26}**	**y_{27}**		
Scale distance	137	124	101	39		

Calculations for: inside 104' contour line

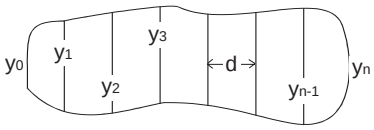
Area = 10 x [½ x (8 + 39) + 29 + 36 + 70 + 94 + 150 + 150 + 100 + 75 + 70 + 72 + 125 + 168 + 175 + 166 + 140 + 102 + 75 + 72 + 75 + 78 + 144 + 146 + 145 + 137 + 124 + 101]
= 10 x [½ x (8 + 39) + 2,819]
= 10 x [½ x 47 + 2,819]
= 10 x [23.5 + 2,819]
= 10 x 2,842.5
= 28,425 SF

Figure 7-16
Trapezoidal Rule worksheet and area calculations for the *inside* 104-foot contour line

Finding the Area of the Outside 104-foot Contour Line



Scale 1" = 50'
d = 10'
Outside 104' contour



y_0 = First line
y_n = Last line {y_{28}}
y_{n-1} = Next to last line {y_{27}}
d = Distance between lines {10'}

Trapezoidal Rule

Area = d x [½ x (y_o + y_n) + y_1 + y_2 + y_3 + ...y_{n-1}]

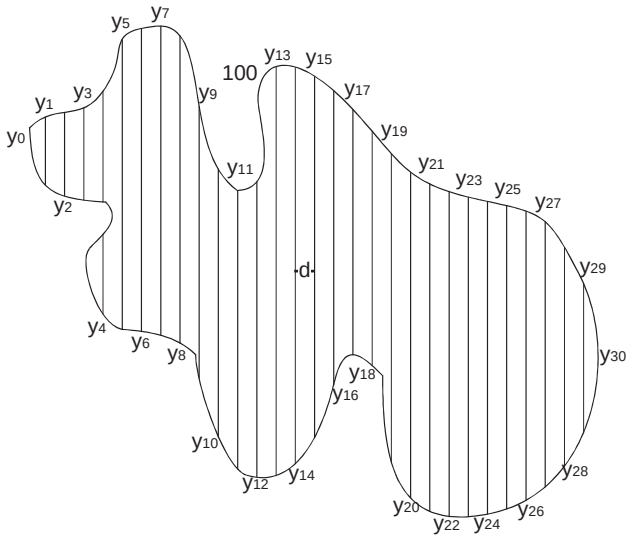
Line number	**y_0**	**y_1**	**y_2**	**y_3**	**y_4**	**y_5**
Scale distance	8	34	42	50+35=85	90+33=123	159
Line number	**y_6**	**y_7**	**y_8**	**y_9**	**y_{10}**	**y_{11}**
Scale distance	164	158	109	82	86	140
Line number	**y_{12}**	**y_{13}**	**y_{14}**	**y_{15}**	**y_{16}**	**y_{17}**
Scale distance	179	188	186	172	144	108
Line number	**y_{18}**	**y_{19}**	**y_{20}**	**y_{21}**	**y_{22}**	**y_{23}**
Scale distance	89	88	124	155	158	157
Line number	**y_{24}**	**y_{25}**	**y_{26}**	**y_{27}**	**y_{28}**	
Scale distance	153	145	128	101	23	

Calculations for: outside 104' contour line

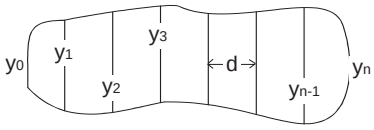
Area = 10 x [½ x (8 + 23) + 34 + 42 + 85 + 123 + 159 + 164 + 158 + 109 + 82 + 86 + 140 + 179 + 188
+ 186 + 172 + 144 + 108 + 89 + 88 + 124 + 155 + 158 + 157 + 153 + 145 + 128 + 101]
= 10 x [½ x (8 + 23) + 3,457]
= 10 x [½ x 31 + 3,457]
= 10 x [15.5 + 3,457]
= 10 x 3,472.5
= 34,725 SF

Figure 7-17
Trapezoidal Rule worksheet and area calculations for the *outside* 104-foot contour line

Finding the Area of the Outside 100-foot Contour Line



Scale 1" = 50'
d = 10'
Outside 100' contour



y_0 = First line
y_n = Last line {y_{30}}
y_{n-1} = Next to last line {y_{29}}
d = Distance between lines {10'}

Trapezoidal Rule

Area = d x [½ x (y_o + y_n) + y_1 + y_2 + y_3 + ...y_{n-1}]

Line number	**y_0**	**y_1**	**y_2**	**y_3**	**y_4**	**y_5**	**y_6**
Scale distance	11	40	50	58+32=90	94+35=129	165	174
Line number	**y_7**	**y_8**	**y_9**	**y_{10}**	**y_{11}**	**y_{12}**	**y_{13}**
Scale distance	175	168	142	109	151	171	177
Line number	**y_{14}**	**y_{15}**	**y_{16}**	**y_{17}**	**y_{18}**	**y_{19}**	**y_{20}**
Scale distance	200	197	185	168	145	117	136
Line number	**y_{21}**	**y_{22}**	**y_{23}**	**y_{24}**	**y_{25}**	**y_{26}**	**y_{27}**
Scale distance	164	168	172	171	168	160	145
Line number	**y_{28}**	**y_{29}**	**y_{30}**				
Scale distance	126	99	30				

Calculations for: outside 100' contour line

Area = 10 x [½ x (11 + 30) + 40 + 50 + 90 + 129 + 165 + 174 + 175 + 168 + 142 + 109 + 151 + 171 + 177 + 200 + 197 + 185 + 168 + 145 + 117 + 136 + 164 + 168 + 172 + 171 + 168 + 160 + 145 + 126 + 99]
= 10 x [½ x (11 + 30) + 4,262]
= 10 x [½ x 41 + 4,262]
= 10 x [20.5 + 4,262]
= 10 x 4,282.5
= 42,825 SF

Figure 7-18
Trapezoidal Rule worksheet and area calculations for the *outside* 100-foot contour line

Avoiding the Trapezoidal Rule's Biggest Pitfall

The area calculations for the Trapezoidal Rule are all quite simple. But that doesn't mean the rule is foolproof. Be careful not to use the length of *yn* (the last line) twice in the area calculations. Back at the very beginning of the formula you average the lengths of the first and last lines. Don't forget that. It's surprisingly easy to forget and then here's what happens. You'll plug *yn* in, for the second time, at the very end of the equation. Fortunately, there's an easy way to check your work for this error and all it takes is one quick glance. Compare the last number in the addition string with the length you recorded for *yn*. Are the two numbers the same? If *yn* and *yn – 1* really are the same length, that's okay. But if they're not, and you plugged in the number in error, then this quick check just saved you from counting the same line twice.

Figure 7-19 shows all the math used to find the lake and the berm volumes. In the last section of Figure 7-19, Fill volume excess (+) / shortfall (–), notice that there's a shortfall of 343 cubic yards. Obviously, you can't complete the job using only the material in the berm. Finding 343 cubic yards of compatible fill material and importing it takes time and costs you money. Be sure to consider and include this type of shortfall cost in your estimates. That way you'll never end up holding the bag.

Coming up, in Chapter 8, we'll look at how to use shrink/swell factors to make your earthwork estimates even more accurate.

Calculation Sheet

Project: Jones job **Date:** 4-20

Areas:
Inside 100' contour (see Figure 7-15): 21,500 SF
Inside 104' contour (see Figure 7-16): 28,425 SF
Outside 104' contour (see Figure 7-17): 34,725 SF
Outside 100' contour (see Figure 7-18): 42,825 SF

Lake volume:

Volume (CY) = (area inside 100' contour x depth) ÷ 27
= (21,500 x 3) ÷ 27
= 64,500 ÷ 27
= 2,388.9 CY

Berm volume:

Volume (CY) = ({[(area 100_o + area 104_o) ÷ 2] x depth} ÷ 27) - ({[(area 100_i + area 104_i) ÷ 2] x depth} 27)

Where: 100_o = outside 100' contour
104_o = outside 104' contour
100_i = inside 100' contour
104_i = inside 104' contour

= ({[(42,825 + 34,725) ÷ 2] x 4} ÷ 27) - ({[(21,500 + 28,425) ÷ 2] x 4} ÷ 27)
= ({[77,550 ÷ 2] x 4} ÷ 27) - ({[49,925 ÷ 2] x 4} ÷ 27)
= ({38,775 x 4} ÷ 27) - ({24,962.5 x 4} ÷ 27)
= (155,100 ÷ 27) - (99,850 ÷ 27)
= 5,744.4 - 3,698.1
= 2,046.3 CY

Fill volume excess (+) / shortfall (-):

Volume (CY) = berm volume - lake volume
= 2,046.3 - 2,388.9
= -343 CY

Conclusion:

Figure 7-19
Volume calculations for the small lake

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8

Using Shrink & Swell Factors

At the end of the last chapter, I mentioned that you need shrink and swell factors to make your estimates more accurate. That's because a given quantity of soil has no constant volume. Add moisture and the soil swells, expanding in volume. Soil volume also increases when it's loosened or disturbed by excavation. Conversely, the soil volume shrinks or contracts when you apply pressure to compact the fill. Actual shrink and swell factors consider the combined effect of:

- moisture content
- density (compact versus loose)
- soil type

We'll begin this chapter with a quick look at soil states and volume measurement. Then we'll move on to some practical examples of when and how to apply shrink/swell factors in your estimates. Next we'll look at how you link soil volume to equipment use and load factors. The chapter finishes up with a look at an alternate method of deriving shrink/swell factors from the soil's weight in different states.

Soil States and Their Units of Measure

It's understood within the construction field that soils have three distinct states. Let's take a look at the different soil states and how you measure them.

- **Bank material** — Undisturbed soil; that is, soil in its natural state and location. You measure the volume of bank material in units called bank cubic yards, or BCY for short.
- **Loose material** — Soil that's no longer in its natural state or location. This soil's loosened through digging, turning or some other excavation process. As a result, the soil volume expands. You measure the volume of loose material in loose cubic yards, or LCY.
- **Compacted material** — Soil that's removed from its natural state or location, placed elsewhere, and then compacted. This process occurs in nature as well as the result of excavation. Compaction reduces the soil's volume relative to its loose-state volume. You measure compacted soil in units of compacted cubic yards, or CCY.

Changes in Soil State

If you've ever dug a hole to plant a tree or shrub, you've already worked with soil in all three states. Before you began digging, you're standing on *bank state material*. First you dig the planting hole, piling the dirt off to one side as you dig. That mound of freshly turned earth is *loose state material*. Then you place the root ball in the hole and replace most of the soil you removed. Finally you finish the job by tamping down the earth or watering it in. That's compaction. All of the soil you put back into the hole is *compacted state material*.

There's one more point I want to make before ending the gardening lesson. Remember that pile of leftover dirt you still had after you filled that hole? You probably wrote it off as being replaced by the root ball, but that's not the whole story. What if you dug the hole but then you changed your mind. Instead of planting a tree, you just filled the hole right back up again. You'd still have a pile of left-over dirt. Most soil won't compact back down to its bank state volume right away. It takes time and natural weathering to return soil to its original bank state. Figure 8-1 provides a visual concept of the three states of soil and its volume change during excavation.

Using Shrink/Swell Factors in Earthwork Estimates

Before you can figure out how much soil you'll need for a particular job, you need to know how much that soil will swell or shrink. The swell and shrink factors tell you

Bank yards (natural condition) 1 BCY	=	Loose yards (after digging) 1.25 LCY	=	Compacted yards (after compaction) 0.9 CCY

Figure 8-1
The three fundamental states of soil

this. For a specific soil, under specific circumstances, you multiply the volume of the soil by its shrink or swell factor to figure out how much you'll have. Here's an example. Say you have a trench to fill and a stockpile of damp earth. You want to know whether there's enough material in the stockpile to fill the trench. Start by calculating the volumes of both the stockpile and the trench. Then multiply the volume of the stockpile by the correct shrink factor. You need the shrink factor because you'll compact the fill, and compaction reduces the volume of soil.

You'll find that every soil you work with is different. Sending a sample of the soil to a laboratory for testing is the only way to find exact shrink and swell factors. Such testing is standard on large projects, and the results will appear on the plans. On a smaller project, specific shrink/swell factors are rarely available. When the factors aren't provided for a project, use the approximate shrink/swell factors listed in Figure 8-2. Shrink/swell factors are based on ratios that compare soils' weights in each of the three states: bank, loose and compact. You'll notice that the soil types listed in Figure 8-2 are very general. That's why the factors are only approximate.

As we saw in Chapter 3, when we discussed the Proctor test, there are different degrees of compaction. Proctor requirements appear on either the plans or the job specifications. Figure 8-2 takes this into account and lists various levels of compaction in the far right column.

Let's try using Figure 8-2 to find out if there's enough material in that stockpile of damp earth to fill the trench we were discussing. Here are the numbers:

- Stockpile volume = 200 cubic yards
- Trench length = 900 feet
- Trench width = 3 feet
- Trench depth = 2 feet
- Compaction required = 100 percent Standard Proctor

Soil type & moisture level	Swell factor	Shrink factor	Compaction requirements
Dry sand	1.13	1.00	BCY
Dry sand	1.32	0.83	95% S.P.
Dry sand	1.39	0.77	100% S.P.
Dry sand	1.38	0.78	95% M.P.
Dry sand	1.45	0.72	100% M.P.
Damp sand	1.13	1.00	BCY
Damp sand	1.16	0.98	95% S.P.
Damp sand	1.22	0.93	100% S.P.
Damp sand	1.21	0.94	95% M.P.
Damp sand	1.27	0.88	100% M.P.
Damp gravel	1.14	1.00	BCY
Damp gravel	1.23	0.93	95% S.P.
Damp gravel	1.29	0.87	100% S.P.
Damp gravel	1.32	0.84	95% M.P.
Damp gravel	1.39	0.78	100% M.P.
Dry clay	1.31	1.00	BCY
Dry clay	1.18	NA	85% S.P.
Dry clay	1.25	NA	90% S.P.
Dry clay	1.39	0.94	100% S.P.
Dry clay	1.39	0.94	90% M.P.
Dry clay	1.54	0.82	100% M.P.
Dry dirt	1.32	1.00	BCY
Dry dirt	1.31	1.00	85% S.P.
Dry dirt	1.39	0.95	90% S.P.
Dry dirt	1.54	0.83	100% S.P.
Dry dirt	1.45	0.90	90% M.P.
Dry dirt	1.61	0.78	100% M.P.
Damp dirt	1.28	1.00	BCY
Damp dirt	1.17	NA	85% S.P.
Damp dirt	1.23	NA	90% S.P.
Damp dirt	1.37	0.93	100% S.P.
Damp dirt	1.29	1.00	90% M.P.
Damp dirt	1.43	0.89	100% M.P.
BCY = bank cubic yards S.P. = Standard Proctor M.P. = Modified Proctor NA = areas where the bank material has a greater density than required for the compacted material			

Figure 8-2
Approximate conversion factors for soil swell and shrinkage

We'll begin by calculating the trench volume in cubic yards. Here's the formula and the math:

Volume (CY) = (Length × Width × Depth) ÷ 27

Volume (CY) = (900 × 3 × 2) ÷ 27
= 5,400 ÷ 27
= 200 CY

The stockpile and the trench have the very same volume — 200 cubic yards. So all's well, right? Not quite. You have 200 LCY of fill, but you need 200 CCY at 100 percent Standard Proctor. Now let's find out how much material you really have in that stockpile.

Step 1:

Find the shrink factor for damp dirt compacted to 100 percent Standard Proctor in Figure 8-2. The answer is 0.93.

Step 2:

To find the post-compaction volume of the stockpile, multiply its loose volume (200 LCY) by the shrink factor (0.93):

200 × 0.93 = 186 CCY

There isn't enough material in the stockpile to do the job. You're short by a total of 14 CCY. You'll need to bring that material in from elsewhere. Be sure that any bid you submit includes these costs.

Ground Loss

During project setup and topsoil stripping operations, heavy equipment traversing the site will compact the soil significantly. This compaction is called *ground loss*. Because it occurs before mass cut and fill operations, you should calculate ground loss separately from the compaction that occurs during mass earthmoving operations. In other words, adjust for ground loss *before* making earthmoving calculations for the site. Also keep in mind that ground loss only affects fill volumes. In areas requiring cut, the removal process will disturb the dirt and cause it to swell to its original volume.

The best predictor for how much ground loss you'll experience is the original land surface condition. In dense, rocky soil, you may get hardly any ground loss, while a plowed field might subside 4 inches or more. Figure 8-3 shows anticipated ground loss subsidence depths for various surface conditions.

Original Surface Condition	Depth of Subsidence (feet)
Plowed field	0.25 to 0.35
Sandy desert	0.30 to 0.45
Disturbed, but not plowed; light traffic prior to move-on	0.15 to 0.20
Disturbed, but not plowed; heavy traffic prior to move-on	0.10 to 0.15
Traversed by heavy construction equipment prior to move-on	Insignificant
Rocky soil	Insignificant

Figure 8-3
Ground loss subsidence ranges

Estimating the Number of Haul Trips

Shrink/swell factors have other useful applications. You use them, for example, to figure how many trips it takes to move a given amount of material from one location to another. Let's see how to do it. Here's what you know:

- Material type: sand
- Material condition: damp
- Total quantity: 1,000 CCY
- Required compaction: 95 percent Standard Proctor
- Per trip haulage capacity: 10 LCY

Note: Always measure hauling capacities in loose cubic yards. Also, this list omits two factors, time and resistance. We'll cover both factors later, in Chapter 13.

Step 1:

Turn back to Figure 8-2 and find the correct swell factor for damp sand at 95 percent Standard Proctor. The answer is 1.16.

Step 2:

To convert this volume into loose cubic yards, multiply the total quantity (1,000 CCY) by the swell factor (1.16):

1,000 CCY × 1.16 = 1,160 LCY

Step 3:

To find the total number of trips, divide total volume in loose cubic yards by the vehicle's capacity:

1,160 LCY ÷ 10 LCY per trip = 116 trips

Material type & moisture level	Pounds per BCY	Pounds per LCY
Clay, natural	2,950	2,130
Clay, dry	2,290	1,940
Clay, wet	2,620	2,220
Common earth, dry	2,620	2,100
Common earth, wet	3,380	2,700
Limestone	4,400	2,620
Sand, dry and loose	2,690	2,400
Sand, wet and packed	3,490	3,120
Note: These weights assume that soils are monotypic, 100% one soil type. Accurate weights for actual soils (a mix of several different soil types) are determined through laboratory testing. The tests cover particle size and distribution, exact moisture content and level of compaction.		

Figure 8-4
Approximate weights of various materials in bank state and loose state

Using Material Weights to Customize Shrink/Swell Factors

As I mentioned earlier, shrink/swell factors are partly based on the weight of soils in different states expressed as a ratio. Figure 8-4 is a list of approximate weights for a variety of common materials with different moisture and compaction levels. You can use the following formulas with the weights to find approximate shrink and swell factors:

Approximate shrink factor = Loose state weight ÷ Bank state weight

Approximate swell factor = Bank state weight ÷ Loose state weight

Remember, these are only approximate. If you need more precise data and it's not provided in the plans or specs, contact a soils engineer. If you choose to calculate your own shrink/swell factors, I strongly recommend obtaining accurate weights for local soils. Contact either the State Department of Transportation or a municipal, county or state planning or engineering agency to get that information.

Using Soil Weights to Calculate Equipment Load Factors

Let's use the data in Figure 8-4 to determine the load factors for the types of soil you'll be working with. Look at the weight ranges for common materials in the table. At the high end is *Sand, wet and packed* with a weight of 3,120 pounds per LCY (far right column). The low end is: Clay, dry at 1,940 pounds per LCY. You can see that a single loose cubic yard, depending on the material, differs in weight by as much as 1,180 pounds.

Equipment capacity charts simply state a volume in loose cubic yards. They don't take weight differences into account. That's your job. Fortunately, load factors make

it easy. Suppose you need to move 43 LCY of natural clay and the stated capacity of the scraper you're using is 12 LCY. How many trips will it take? If you simply divide the total volume by the scraper's capacity, ignoring the load factor, you'll overload the scraper. First you need to find and apply the correct load factor, then calculate the number of trips you need to make.

Step 1:

Find the load factor using this formula:

Load factor = Pounds/LCY ÷ Pounds/BCY

Step 2:

Find these weights for natural clay in Figure 8-4, plug them into the formula and here's the result:

Load factor = 2,130 ÷ 2,960

= 0.72

Step 3:

To apply the load factor, multiply the scraper's basic capacity (12 LCY) by the load factor (0.72). Here's the math:

12 LCY × 0.72 = 8.6 LCY

The result, 8.6 LCY, is the volume of natural clay that's equal in weight to the scraper's listed capacity of 12 LCY.

Step 4:

Find the actual number of haul trips by dividing the total volume (43 LCY) by the scraper's modified capacity (8.6 LCY):

43 LCY ÷ 8.6 LCY = 5

The biggest problem with determining the load factor of a soil is determining the weight of the in-place material. The only practical way to do this yourself is to excavate a portion of the bank material with a hand shovel and weigh it. Then line the hole with plastic wrap and fill the hole with water from a container of known volume. Knowing both the weight and volume of the material excavated, you can determine the density of the soil in terms of weight per bank cubic yard. (We discussed this method of density testing back in Chapter 3.)

Pay Yards

It's important that you understand shrink/swell factors and the three soil states we've covered in this chapter. We'll refer to them throughout the rest of the book.

There's one more important use for this information and that's in calculating pay yards. That's the basis for your pay as an earthwork contractor. Pay yards are usually — but not always — measured in bank cubic yards, or cubic yard bank measure (CYBM). But they can also be measured in cubic yard truck measure (CYTM). To be sure, check the plans or specifications. If the bid sheet doesn't show pay yards in BCY, it's up to you to make sure that your estimate does. A simple note can prevent a nasty surprise at the end of the job. If the bid form just indicates cubic yards (CY), or the specifications don't have a Measurement and Payment section, the engineer needs to clarify his intentions and issue a formal addendum stating how the excavation and embankment will be monitored for payment.

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9

Topsoil, Slopes & Ditches

In this chapter we'll focus on three important topics that every earthwork estimator must understand — the special requirements for topsoil, slopes, and ditches. Let's begin with topsoil. Topsoil is so important that you'll treat it differently from all the rest of the soil on a jobsite.

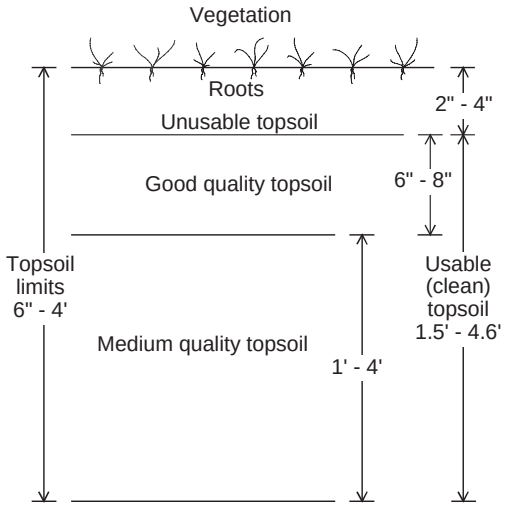


Figure 9-1
Topsoil layers

Dealing with Topsoil

Topsoil is naturally rich in plant nutrients. New material (like leaves, grass and twigs) is always being added. Over time, this organic material decomposes, adding nutrients to the topsoil and making it fertile. Topsoil is ideal for growing lawns and gardens.

Natural topsoil depths vary widely. In the U.S., for example, topsoil depths range from an inch or two in the arid Southwest to over 2 feet in the Midwestern states.

Figure 9-1 shows the layers that make up topsoil. At the very top is a layer with live vegetation. The next layer includes live root systems and the most recent organic material. This layer is between 4 and 6 inches deep and it's the layer that's richest in plant nutrients. Unfortunately, the roots, seeds, and debris that are also in this layer make it unsuitable for you to use either as topsoil or fill.

The next layer is the topsoil that's left after you strip off the root layer. This is clean topsoil — it doesn't contain any roots, seeds or debris. Clean topsoil is valuable. Job specs cover which parts of a site you strip and what you do with the stripped topsoil. Typically, clean topsoil is stockpiled onsite and replaced after construction. Unusable topsoil is often disposed of offsite. If the specs require hauling offsite, find the nearest disposal location before working up an estimate. This may involve more mileage than you want to absorb as a cost.

An earthwork contractor's final task at most jobsites is respreading topsoil. Make sure you have enough on hand when the time comes. Be aware that you may need to bring in additional topsoil. Remember the top 2 to 4 inches of topsoil that you can't use? You may need to replace that now with clean topsoil. Don't get caught by surprise. Always read job specs carefully and completely, then plan ahead. Good topsoil is never cheap or easy to find.

From time to time, not often, you'll have more clean topsoil than you need. Offer to sell the excess to homeowners or small contractors. This can add up to a nice bonus on top of your normal profit on a job.

When stockpiling clean topsoil, take the time to choose your location carefully. Here are a few guidelines:

- Chose a site that's as far away from active work as possible. This helps keep the stockpile from getting scattered about and compacted by equipment.
- Avoid low-lying areas that puddle or may flood. You don't want your soil washed away.
- Control weeds by disking or with a short-term chemical herbicide.

In regions where good, fertile topsoil is scarce, some contractors will haul all of the root-filled topsoil to their lot. They then use a front-end loader to load the soil into a machine with vibrating steel slats, set at an incline, which separates the roots from the clean topsoil. The result is two separate piles: one of good topsoil and one of unusable topsoil. The good material is stored on the lot for future use or sale, and the bad material is hauled to the dump.

Finding the Volume of Topsoil

Because you treat (and bid) topsoil separately, it's smart to track topsoil quantities separately. Remember, most topsoil you remove gets replaced. You replace topsoil in its loose (uncompacted) state. The only way to do that is by hand. That's why cubic yards of topsoil are often the most expensive cubic yards in an estimate.

The designer or engineer usually chooses the limits of topsoil work on a project. Standard practice is to strip topsoil to about 5 feet beyond the sides of a building and about 1 foot beyond the limits of roadways.

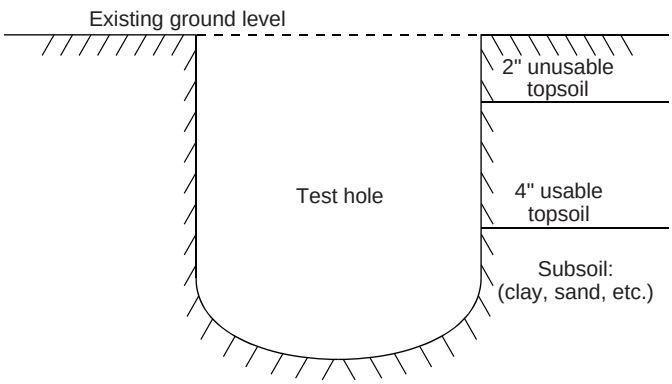


Figure 9-2
Typical topsoil sample test hole

Look for a note on the plans that shows topsoil depth at the building site. If you don't find one, visit the site and make a personal inspection. Use a shovel to remove several plugs of soil, each from a different part of the jobsite. Figure 9-2 shows a profile view of a typical topsoil sample. The unusable topsoil zone extends from the surface down to the ends of the living root systems. Use the average length of all the roots, not the longest or shortest ones, to estimate how much soil you'll have to strip off. It's usually from 2 to 4 inches.

Here's a practical example of how you deal with topsoil, and how you calculate topsoil quantities. We'll use the site plan in Figure 9-3 and the following two items from the job specs.

1. Earthwork contractor shall strip the top 6 inches of soil from the entire site. The earthwork contractor shall remove said topsoil in the two layers as described and disposition them as follows:

   Upper 2 inches of topsoil — remove from site for disposal

   Lower 4 inches of topsoil — stockpile on site

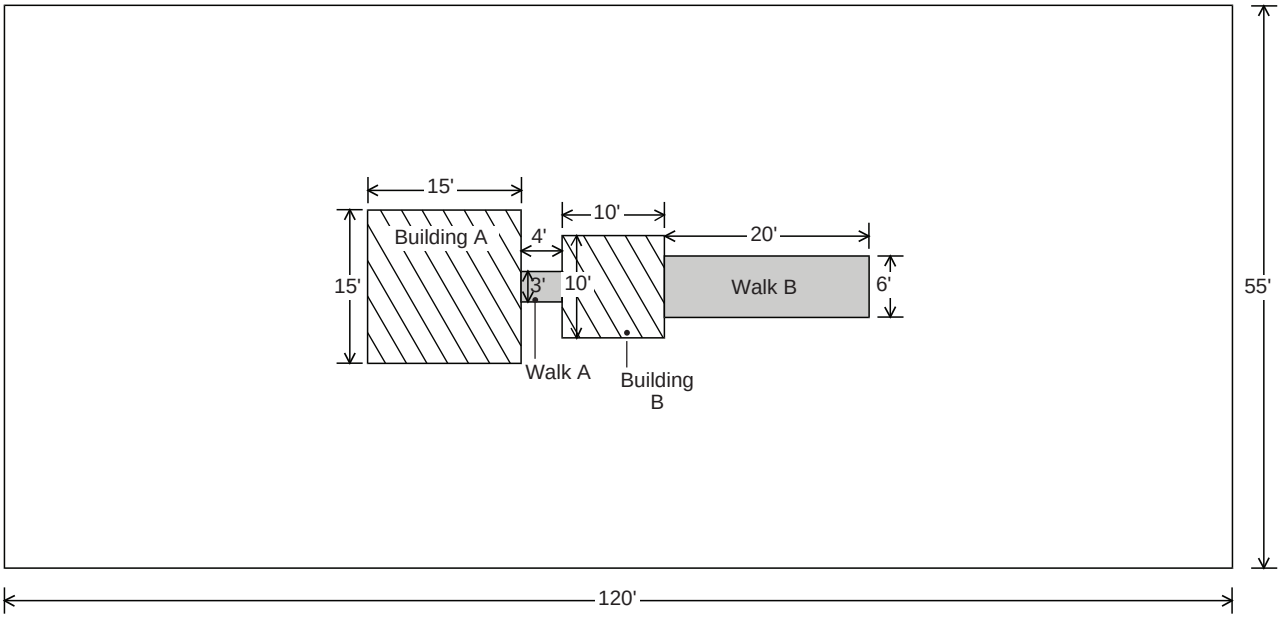


Figure 9-3
Site plan for sample topsoil calculations

2. On completion of construction, the earthwork contractor shall respread topsoil to a depth of 6 inches over all uncovered areas of the site.

We need to know two volumes — stripped topsoil and replaced topsoil. Using these specs, the site plan (Figure 9-3) and basic math, let's look at how to find these volumes.

Finding the Volume of the Stripped Topsoil

According to the specs, we strip topsoil from the entire site, so we'll begin by finding the area of the jobsite in square feet.

Area (SF) = Length × Width

= 120 × 55

= 6,600 SF

You'll recall that the specs divided stripped topsoil into two categories. The upper 2 inches are discarded and the remaining 4 inches are stockpiled. We'll calculate their volumes separately in cubic yards using this formula:

Volume (CY) = [Area (SF) × Depth (feet)] ÷ 27

Let's start with the discarded topsoil volume. Here's what we know:

- Area = 6,600 SF
- Depth = 2 inches, or 0.17 feet (2 ÷ 12 = 0.17)

And here's the rest of the math:

Volume (CY) = (6,600 × 0.17) ÷ 27

= 1,122 ÷ 27

= 41.55 CY

We'll round that off to 42 CY.

You find stockpiled topsoil's volume exactly the same way. The area is the same as for the discarded topsoil but the depth is different. Don't forget to convert the depth, 4 inches, into feet, 0.33 (4 ÷ 12 = 0.33). Here's the rest of this volume calculation:

Volume (CY) = (6,600 × 0.33) ÷ 27

= 2,178 ÷ 27

= 80.66 CY

We'll call that 81 CY.

The total volume of stripped topsoil is the sum of the two volumes we just found.

Total volume of stripped topsoil (CY): 42 + 81 = 123 CY

Finding Replacement Topsoil Volume

First we need to know how many square feet of the site we'll be replacing topsoil on. That's equal to the difference between the site area and the sum of the area of the structures. We already know the site area is 6,600 SF. Now let's find the total area covered by structures, working structure by structure.

Building A

Area = 15 × 15

= 225 SF

Building B

Area = 10 × 10

= 100 SF

Walkway A

Area = 4 × 3

= 12 SF

Walkway B

Area = 20 × 6

= 120 SF

The total structure area equals the sum of all structure areas.

Total structures area (SF): 225 + 100 + 12 + 120 = 457 SF

The difference between the site area and the total structures' area is the total area to be respread with topsoil. Plug in the areas we found for Figure 9-3, and here's the math:

Area (SF) = 6,600 – 457

= 6,143 SF

Lift thickness (inches)	Sq. Ft. of surface area/C.Y.	S.Y. of surface area/C.Y.
1	324	36.00
2	162	18.00
3	108	12.00
4	81	9.00
5	65	7.22
6	54	6.00
7	46	5.11
8	41	4.56
9	36	4.00
10	32	3.56
12	27	3.00
14	23	2.56
16	20	2.22
18	18	2.00
20	16	1.78
22	15	1.67
24	14	1.56

Figure 9-4
Surface area per cubic yard

Next we'll find the replaced topsoil's volume in cubic yards using this formula:

$$\text{Volume (CY)} = (\text{Area} \times \text{Depth}) \div 27$$

From the job specs we know that the depth is 6 inches, or 0.5 feet, and here's the rest of the math:

$$\begin{aligned}\text{Volume (CY)} &= (6{,}143 \times 0.5) \div 27\\ &= 3{,}071.5 \div 27\\ &= 113.76 \text{ CY}\end{aligned}$$

After rounding off to full cubic yards, it turns out that this job requires 114 cubic yards of replacement topsoil. Compare that volume with the volume in the stockpile, and you'll see there's a shortfall of 33 CY (114 – 81 = 33).

You can use the information in Figure 9-4 to estimate the surface area that can be covered by topsoil in different thicknesses.

Balancing Topsoil Stripped with Topsoil Replaced

Since volume is expressed as:

$$\text{Volume} = \text{Area} \times \text{Depth}$$

We can determine the depth of topsoil replaced in order to get a topsoil balance by:

$$\text{Depth of Topsoil Replaced} = \frac{\text{Volume of Topsoil Stripped (cf)}}{\text{Respread Area}}$$

For example, let's say you've stripped 1,000 cubic yards of topsoil and would like to respread it over a 15,000 square foot area. First, multiply the cubic yards of topsoil by 27 to find the cubic feet, then divide by the respread area. The depth of topsoil replaced will be:

Depth = (1,000 CY × 27) ÷ 15,000

= 27,000 ÷ 15,000

= 1.8 feet

Sometimes, the depth of topsoil respread required to achieve a topsoil balance exceeds the depth allowed by the designer. You can determine the maximum allowable volume of topsoil replaced by:

Volume of Allowable Topsoil Replaced = Maximum Depth Allowed × Respread Area

For example, if the maximum allowable depth of topsoil replaced in the previous example is 1 foot, the maximum volume of topsoil replaced is:

Volume of Topsoil Replaced = 1 ft × 15,000 SF

= 15,000 cf ÷ 27

= 556 CY

Calculating Net Volumes for Earthwork

The existing ground level is your reference for measuring contour lines, plan lines, and typical profiles. That reference disappears along with the stripped topsoil and changes your working elevation. As a result, the original contour map no longer applies. The engineer often doesn't know the actual depth of the topsoil, but you do, so the conversion's up to you. You can use the following formulas to find the actual depth and volume of earth moved.

Cut Areas

In areas involving cutting, you have to remove topsoil, cut the earth down to grade, and then replace topsoil to the specified depth. We'll use Figure 9-5 and this formula to find the total depth of cut:

Net cut depth (feet) = Plan depth – Topsoil out (TO) + Topsoil in (TI)

Where:

- Line A-A = existing grade before removing topsoil
- Line B-B = strip grade after removing topsoil

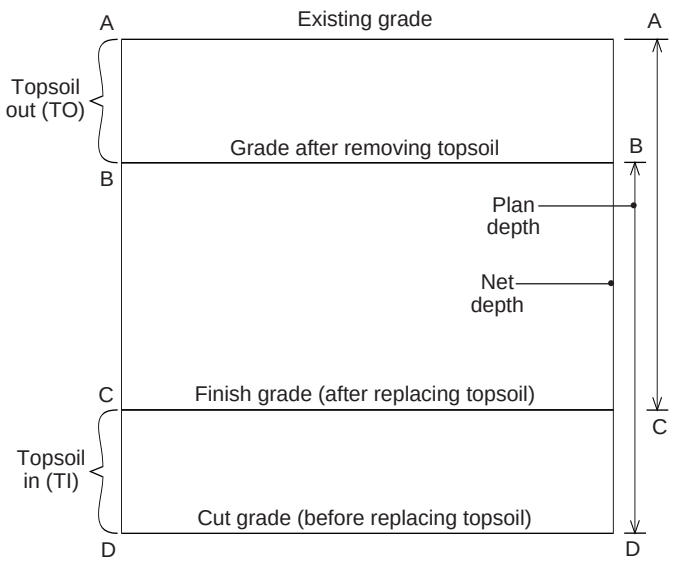


Figure 9-5
Calculating net cut depth

- Line C-C = finished grade after replacing topsoil
- Line D-D = cut grade before replacing topsoil
- Plan depth = existing elevation (line A-A) – finished elevation (line C-C)
- TO = topsoil strip depth (topsoil out)
- TI = topsoil replace depth (topsoil in)

Most site plans you work with show only the existing grade (line A-A) and the finish grade (line C-C). That makes it easy to find plan depth. I strongly recommend that you always use net depth, instead of plan depth, in calculating earthwork volumes.

Figure 9-6 demonstrates a simple way to understand how stripping and respreading topsoil affects earthwork quantities.

Fill Areas

You calculate total fill depths using almost the same steps as for total cut depth. We'll use the cross-section view of a fill area, shown in Figure 9-7, as the sample job. And here's the formula we'll use to find total fill depth:

Net fill depth (feet) = Plan depth + TO – TI

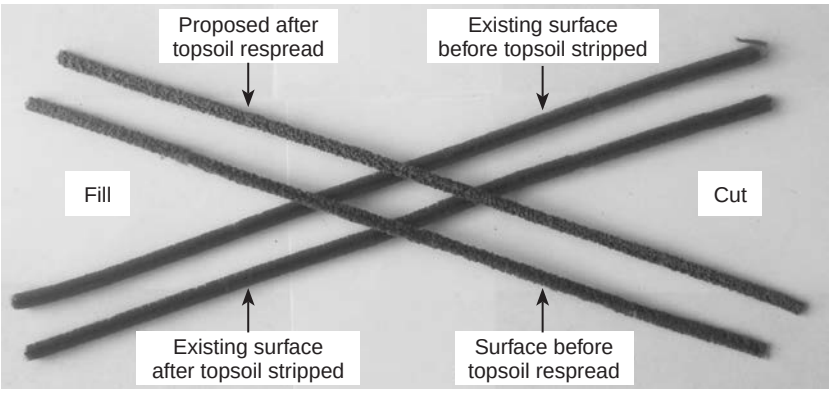


Figure 9-6
Stripping and respreading topsoil

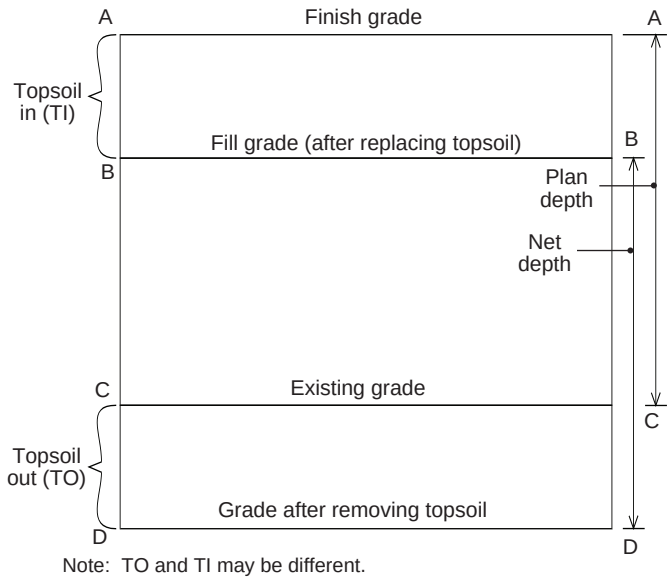


Figure 9-7
Calculating net fill depth

Where:

- Line A-A = finished grade after replacing topsoil
- Line B-B = fill grade before replacing topsoil
- Line C-C = existing grade before removing topsoil
- Line D-D = cut grade after removing topsoil
- Plan depth = finished elevation (line A-A) – existing elevation (line C-C)
- TO = topsoil strip depth (topsoil out)
- TI = topsoil replace depth (topsoil in)

Areas Combining Cut and Fill

On projects that combine cut and fill, I recommend making the calculations on two worksheets. Put all of your cut calculations on one worksheet and all of your fill calculations on a second worksheet. Separate worksheets are the best and easiest way to be sure you never mix up these two volumes.

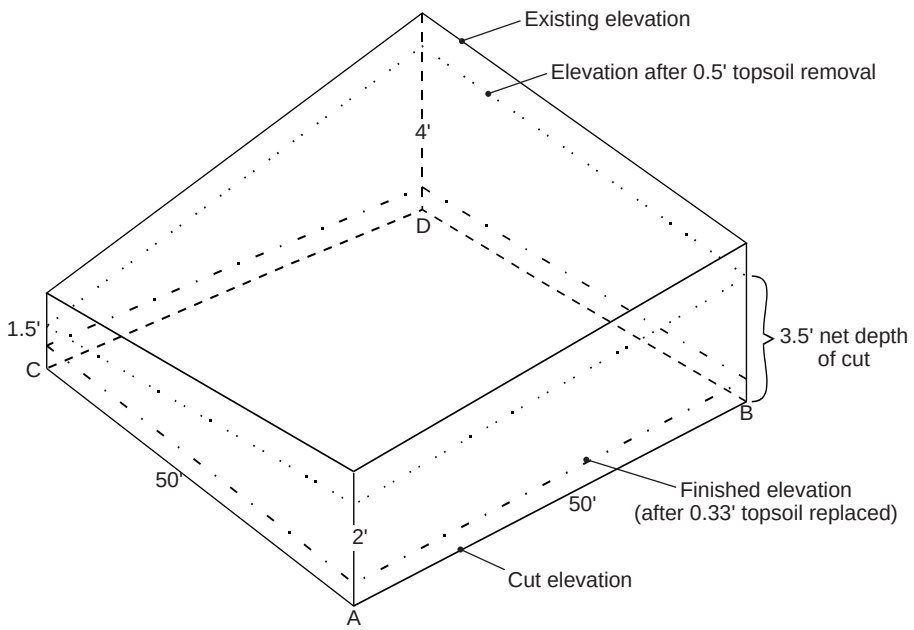


Figure 9-8
Calculating net cut area

Let's try out these formulas using the cut area shown in Figure 9-8 as our example. We'll find the net cut depth using these specs for topsoil depths:

- At project's start — strip to a depth of 6 inches (0.5 feet).
- At project's completion — replace to a depth of 4 inches (0.33 feet).

Step 1 Find average cut:

Average cut = (4 + 3.5 + 2 + 1.5) ÷ 4

= 11 ÷ 4

= 2.75 feet

Step 2 Calculate net cut depth:

Net cut depth (feet) = 2.75 – 0.5 + 0.33

= 2.58 feet

Step 3 Calculate net cut volume:

Net cut volume (CY) = (2.58 × 50 × 50) ÷ 27

= 6,450 ÷ 27

= 238.89 CY

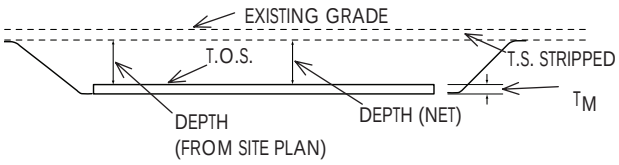


Figure 9-9
Net cut requirement, factoring in the slab

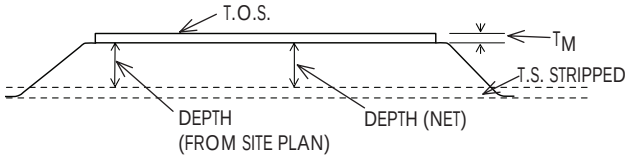


Figure 9-10
Net fill requirement, factoring in the slab

Cut and Fill Areas Under Surface Structures

You use similar formulas to calculate the cut and fill under surface structures, such as sidewalks, paved ditches, and roadways. The formulas you'll use look just the same, however, the meanings of *plan difference, TO*, and *TI* are a little different here, as you'll see. We'll start off with the formulas.

Formula for finding total cut under a surface structure:

Total cut = Plan difference + TI – TO

Formula for finding total fill under a surface structure:

Total fill = Plan difference + TO – TI

Where:

- Plan difference = Change in elevation between proposed and existing grades
- TO = Topsoil strip depth (topsoil out)
- TI = Construction material (concrete, asphalt, or other) depth

Figures 9-9 and 9-10 show how stripping and respreading topsoil affects earthwork quantities beneath a structure area. TM represents the thickness of the material, in this case, the slab.

Slopes and Slope Lines

A *slope line* is a straight line connecting two points. Engineers and designers use slope lines to indicate gradual slopes between finished elevations onsite and existing elevations of undisturbed soil adjacent to the building site. The correct slope is very important to drainage.

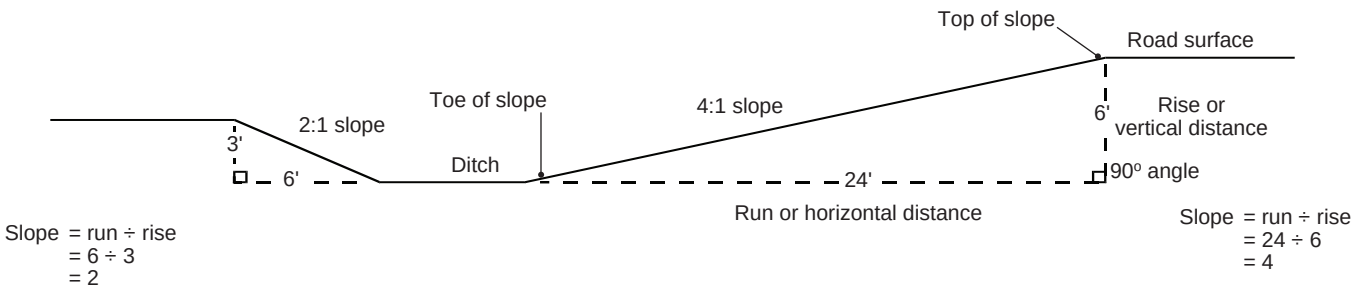


Figure 9-11
Calculating slope

There's an easy and inexpensive way to determine ground slope. You can place a bubble level and tape measure on a sloping surface. Since slope is defined as horizontal distance (or foot of run) to vertical rise, mark the level at 12 inches from one end. To determine the slope, center the bubble in the level, then place a tape measure vertically so that it's lined up with your 12-inch mark on the up-slope end of the level. Next, read the drop from the bottom of the level to the ground. If, for instance, you read 4 inches on the tape, the ground rises (or falls) 4 inches (0.33 feet) for each foot of run. To convert the slope from inches of rise to linear feet of run, divide the rise (expressed as a decimal) into one foot of run. For example, if the ground slopes 4 inches in 1 foot of run, the slope of the ground is 1 foot divided by 0.33 feet, which equals 3. That means for each 3 feet of run you have 1 foot of rise, or a 3:1 slope.

Figure 9-11 shows a slope line connecting the top of a roadway to the bottom of a ditch. One name for the point where a slope and the roadway meet is *top of slope*. The slope meets the bottom of the ditch at the *toe of slope*. The slope here is 4:1. This is a simple ratio. It means that there's 1 foot of vertical climb for each 4 feet of horizontal distance. If the slope is 4:1 and the total vertical fall is 6 feet, then the toe of slope is 24 feet, measured horizontally from the top of the slope.

You can also use the words *run* and *rise* to describe a slope. The *run* is the horizontal distance. The *rise* is the vertical distance. When the run is 4 feet and the rise is 1 foot, the slope is 4:1.

Here's a note of caution: When you're reading plans, you may see a slope labeled 1:4. Don't plow ahead assuming that the designer wants a slope with 4 feet of rise for every 1 foot of run. A slope of 1:4 is very steep — about the same as the roof on an A-frame house. Soil isn't stable at that angle. If you see a slope indicated as 1:4, it's a good bet the designer actually meant a 4:1 slope. It's very easy to reverse the numbers as you write them down. If you have any doubts, check with the designer.

Most slopes you work with range between 5:1 and 2:1. The steepest slope I've ever encountered was 1:1. That's 1 foot of run in 1 foot of rise, which is equal to a 45-degree angle.

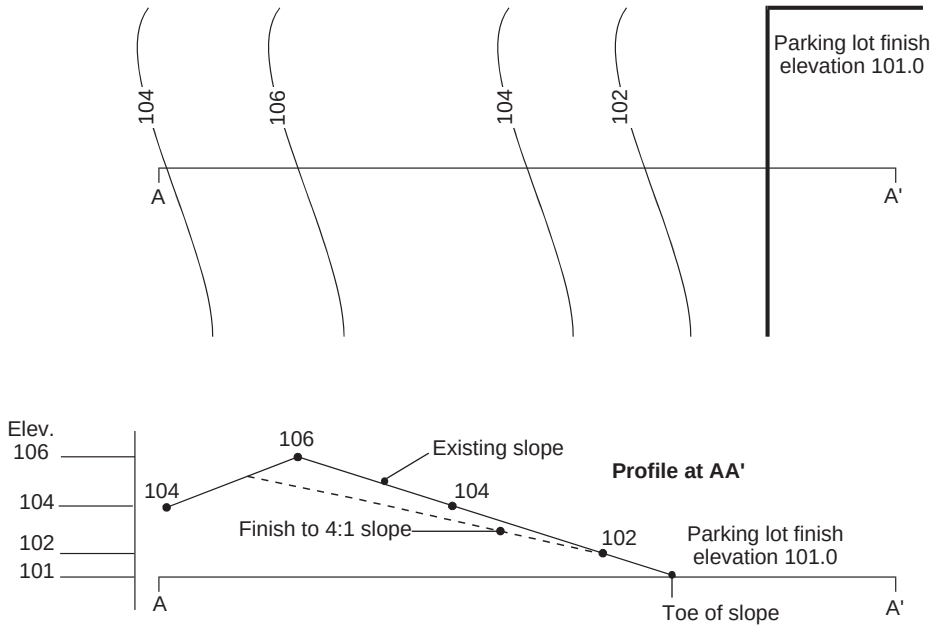


Figure 9-12
Calculating net cut depth

Designers have to consider several factors when planning slopes. First, the owners must be able to maintain the slope. Using a mowing machine isn't safe on any slope over 2:1. Second, drainage is easier to control with slopes in the 5:1 to 2:1 range. The water will run on these slopes uniformly. A good ground cover will protect 5:1 to 2:1 slopes. On steeper or flatter slopes, water will either run too fast and erode the slope, or won't drain fast enough. Water backs up and puddles on a slope that's less than 5:1.

You'll often work with drawings similar to the plan and profile sheet shown in Figure 9-12. The sheet includes a note from the project engineer that simply says the finish grade from the parking lot edge to the existing ground line is to be a 4:1 slope.

Let's move on now to your next task, calculating the topsoil volume you'll need to build that slope.

Calculating Topsoil Volume for a Sloped Area

A slope line like the one in Figure 9-13 connects two points with known elevations. Of course, the amount of slope affects how much topsoil you'll have to remove and replace. The slope line (field distance) is longer than the horizontal distance (plan distance) between the two points. You need to know the field distance before you can estimate the volume of topsoil.

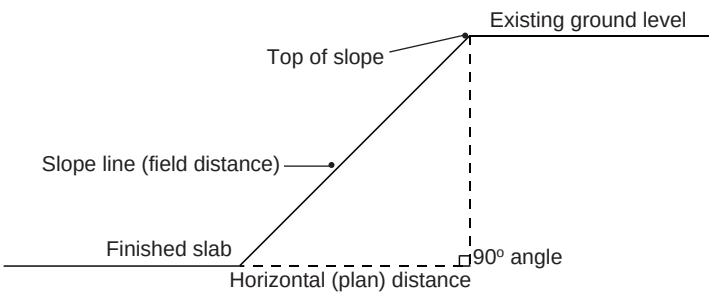


Figure 9-13
Side view of a sloped area

Slope	Length of slope = horizontal distance x %
6:1	1%
5:1	2%
4:1	3%
3:1	5%
2:1	12%
1:1	41%

Figure 9-14
Table used to estimate the length of a slope line

You could calculate the actual length of the slope line, but there's a faster way. Professional estimators use charts like the one shown in Figure 9-14. To find the field distance for a known slope simply multiply the horizontal distance by the percentage you look up in Figure 9-14.

Let's go through an example to show how this works. We'll use the retaining wall project shown in Figure 9-15. The specs call for finishing the slope shown in the section view with a 4-inch-thick layer of topsoil. We'll find the volume of topsoil needed in just four easy steps.

Step 1 Find the slope:

Slope = Run (horizontal distance) ÷ Rise (vertical distance)

Slope = 20 ÷ 5
= 4

The slope in Figure 9-15 is 4:1.

Step 2 Find the percentage increase for the slope:

Using the table in Figure 9-14, the slope is 3 percent.

Step 3 Find the field distance or slope length:

Field distance/slope length (feet) = Horizontal/plan distance × Increase factor

Field distance/slope length (feet) = 20 × 1.03 (3%)
= 20.6 feet

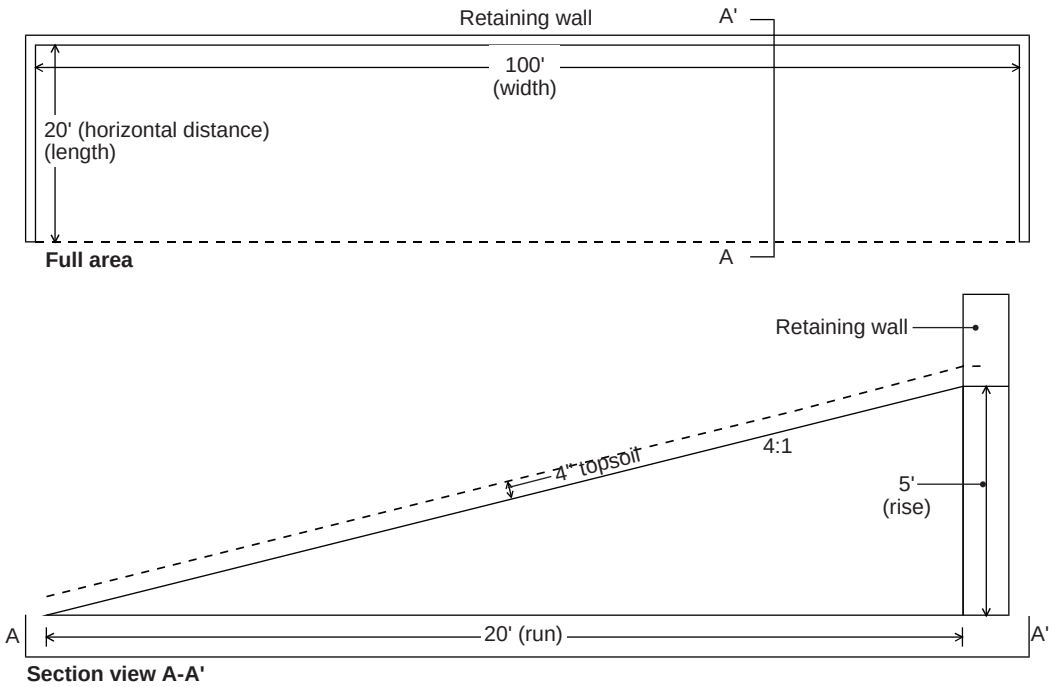


Figure 9-15
Calculating topsoil volume for a slope

Step 4 Calculate the topsoil volume in cubic yards:

Volume (CY) = (Slope length × Slope width × Topsoil depth) ÷ 27

Volume (CY) = (20.6 × 100 × 0.33) ÷ 27

= 679.8 ÷ 27

= 25.18 CY

Slope Lines for Drainage

The finished slope requirements for a roadway or a parking lot appear on the plans, but follow a different format. Instead of a ratio like 4:1, the slope is a fractional part of a foot per linear foot of surface. For example, most roads are higher (crowned) along their centerline. The usual slope is $^{3}/_{8}$-inch per foot. For example, on a standard two-lane road that's 12 feet wide, the centerline elevation is $4^{1}/_{2}$ inches higher than at the road edges. Other ways of measuring slopes like these include tenths of a foot, inches and fractions of inches. Other names for this kind of slope include: *drain slope, cross slope,* and *superelevation*.

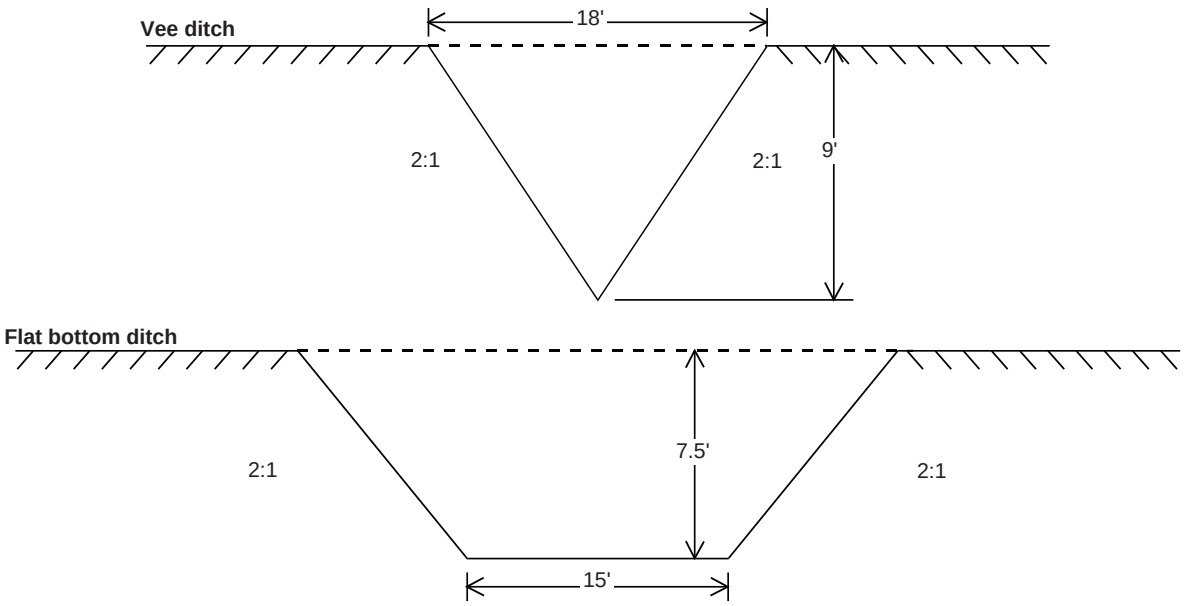


Figure 9-16
Section views of vee and flat-bottom ditches

Estimating Trenches

For estimating purposes, there are two types of trenches:

- drainage channels that carry water away from buildings
- utility line trenches for sewer, water, phone, and other utility lines

We'll look at both types of trench, starting with drainage channels.

Drainage Channels

The grade or incline of a drainage channel controls and conducts runoff. The channel shape and size depend on the expected runoff volume. Speed of runoff determines the type of lining material.

There are two common types of drainage channels, vee ditches and flat-bottom ditches. Figure 9-16 shows examples of both types. You use a vee ditch to supply drainage for relatively small volumes of water. If you expect a larger volume of water, you'd use a flat-bottom ditch. The estimated runoff volume determines the width of the ditch's flat bottom, typically 2 to 10 feet.

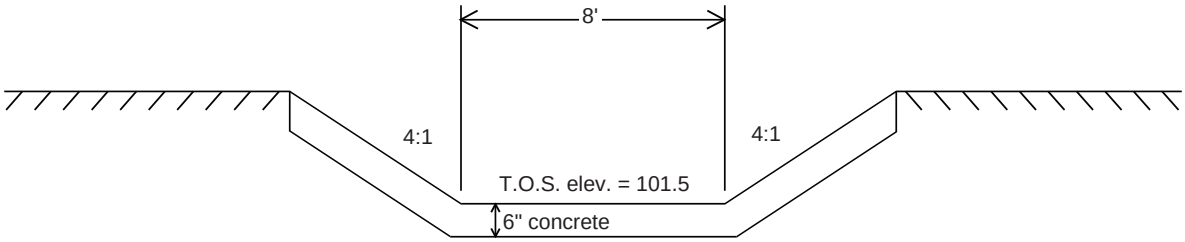


Figure 9-17
Concrete-lined flat-bottom ditch, section view

Figure 9-18
The Gradall excavator

Fast runoff combined with heavy volume call for sealing or lining the trench with concrete so it's protected from erosion. Figure 9-17 shows a concrete-lined flat-bottom ditch. Notice the elevation note included in Figure 9-17: T.O.S. = 101.5. The abbreviation T.O.S. in the figure stands for top of slab. This is often the only elevation that's supplied on the plans. There are two important points I want to make here. First, be careful not to confuse "top of slab" T.O.S. with "toe of slope," also T.O.S. Second, if the plans only give a T.O.S. elevation, it's up to you to calculate the excavation volumes from the top of slab down. For example, in Figure 9-17, total excavation depth includes, at the very least, the slab thickness, 6 inches, plus the depth of any bedding placed under the concrete.

When you price out the labor for a project that has a trench, be aware that a vee trench is more expensive to install than a flat-bottom trench. There's less excavation involved, but much of it will be by hand and not machine. Always keep in mind that on any earthwork project, the price to do the work doesn't necessarily depend on the amount of earth moved, but the method used to move it.

Gradalls

A Gradall excavator is a unique piece of excavation and trenching equipment. The Gradall has a straight, telescoping hydraulic boom mounted on a turntable at the rear end of a truck. See Figure 9-18. It's normally used for cutting, cleaning and grading roadside ditches. The Gradall's boom allows it to safely work under high lines and other overhead obstructions, as well as working over areas too soft or too steep to support

Courtesy of Shoring.com

Figure 9-19
Trench box

heavy equipment. It can also be used for excavating basements, septic tanks and vertical-faced ditches. The Gradall can be equipped with a blade for pushing soil or a ripper for loosening pavement and hardpan. It can also be used as a crane.

Sloping Trenches for Safety

Years ago, contractors installing sewer, water, and other utility lines simply dug trenches the same width as their backhoe bucket, or only as wide as necessary. The trouble was that the ditch walls had no support. The walls sometimes caved in and workmen were killed. This led state and federal agencies to set safety standards. Now, any trench over 5 feet deep must have sloped sides or use trench boxes for support.

A trench box has two sides made of solid metal plate. You can rent or lease them in a variety of sizes. Select trench boxes with a width slightly less than the width of your trench and a bit longer than a standard section of the pipe you're installing. See Figure 9-19.

Many utility line contractors prefer to slope the trench sides instead of using shoring boxes. The amount of slope needed for safety depends on the trench depth and soil conditions. Figure 9-20 lists soil types, with their average safe slopes.

Soil type	Slope
Sand	3:1
Loam	3:1
Sand / clay (mixture)	2:1
Clay	1:1
Warning: The slopes in this table are averages. Base all jobsite slope calculations on actual field conditions and the results of onsite soil testing.	

Figure 9-20
Soil types and their average maximum safe slope

Be very careful when estimating earthwork for trenches. Good judgment is essential if you're going to make any money on the job. Don't count on the plans or specs to mention sloped trenches. You probably won't find any guidelines on the degree of slope to use. However, your local OSHA office should be able to supply the exact requirements.

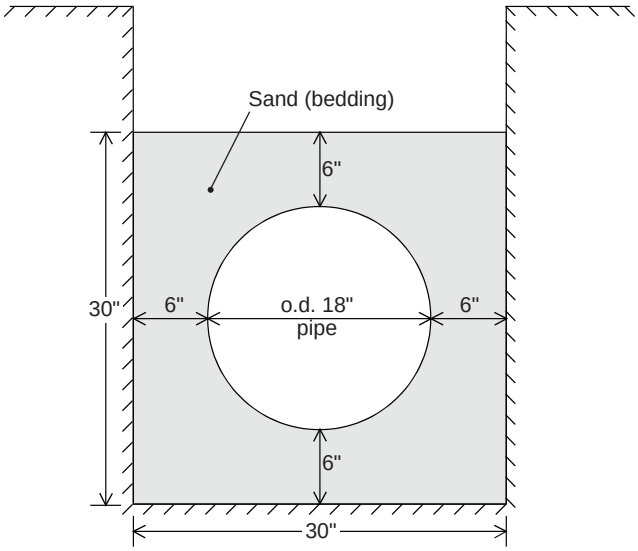


Figure 9-21
Excavation required for pipe and bedding

Utility Trenches

Estimating excavation volumes for utility line trenches is a bit more complicated than drainage channels. We'll start by looking at the three factors that determine trench width:

- the material placed in the trench
- the excavation equipment
- the overcut required

Material Placed in the Trench

If you're trenching for 18-inch-diameter pipe, you don't need a 48-inch-wide trench. Here's the rule of thumb I use:

Trench width (feet) = Pipe width + Workspace to place bedding material and backfill

Most plans for utility trenches require bedding. Bedding is a layer of material that surrounds a pipe, cushioning it during laying and backfilling. Common bedding materials include sand, gravel, and concrete.

Take a look at Figure 9-21. It shows an 18-inch-diameter water line laid in a trench. Notice that the figure also shows a 6-inch-thick bedding of sand surrounding the pipe on four sides. If you only consider the material placed in the trench, how wide is this trench? That's easy. Just add the pipe diameter to the depth of the bedding on both sides.

Trench width (inches) = 18 + 6 + 6
= 30 inches

Remember that this width of 30 inches only considers what's placed in the trench, and that the depth of the material placed in the trench (depth of the bedding plus the pipe diameter) also equals 30 inches.

How much bedding material will you use per linear foot of pipe in Figure 9-21? Simply calculate the filled area (pipe plus bedding), then deduct the area of the pipe.

The pipe is a circle and here's the formula for the area of a circle:

$$\text{Area (SF)} = \pi \times r^2$$

The area of the pipe equals pi (π) times the pipe radius squared (r^2).

Where:

pi (π) = 3.1416

Radius (r) = 9 inches or 0.75^2 feet

$$\begin{aligned}\text{Area (SF)} &= 3.1416 \times 0.75^2 \\ &= 3.1416 \times 0.5625 \\ &= 1.77 \text{ SF}\end{aligned}$$

Find the area of the fill using this formula:

$$\text{Area (SF)} = \text{Width} \times \text{Depth}$$

Plugging in the values from Figure 9-21 we find:

$$\begin{aligned}\text{Area (SF)} &= 2.5 \text{ ft} \times 2.5 \text{ ft} \\ &= 6.25 \text{ SF}\end{aligned}$$

To find the area of bedding material used per linear foot of pipe we'll use this formula:

$$\text{Area (SF/foot of pipe)} = \text{Filled area} - \text{Pipe area}$$

And here's the math for this example:

$$\begin{aligned}\text{Area (SF/foot of pipe)} &= 6.25 - 1.77 \\ &= 4.48 \text{ SF/foot of pipe}\end{aligned}$$

To find the volume of bedding material you'd use for this job you need to know the length of the trench. We'll say it's 75 feet long. Now we'll calculate the bedding material volume in cubic yards. Here's the formula:

Volume (CY) = (Area × Length) ÷ 27

And here's the math for our example:

Volume (CY) = (4.48 × 75) ÷ 27

= 336 ÷ 27

= 12.44 CY

Here's a pitfall to watch out for in utility line trenching. Sometimes the plans only show the flowline elevation for pipe run. Any time you see only a flowline elevation on the plans, ask yourself this question: Does the elevation include the pipe wall thickness or not? Here's why that's important. Pipes have various wall thicknesses. Some have 2-inch-thick walls, some are as much as 6 inches thick. It makes a big difference in your estimate of total excavated volume. Here's a quick example that demonstrates my point.

Assume the trench is 5 feet wide, 20,000 feet long and the pipe has walls 6-inches thick (0.5 foot). How big is the error (in cubic yards) when you don't consider pipe wall thickness?

Volume (CY) = (0.5 × 5 × 20,000) ÷ 27

= 50,000 ÷ 27

= 1,851.85 CY

You wouldn't get paid for this work, since the pay items are figured on the flow line of the pipe.

Some utility lines are set in concrete. How do you find the volume of the concrete? You use the same formulas as we just used to find the volume for bedding material.

When utility lines cross heavily-traveled streets or highways, open trenches aren't allowed. Instead, you have to bore a passageway through the ground, line the boring with encasement pipe, and then run the utility line inside. Encasement pipes are typically much larger than what's run inside.

Utility lines inside an encasement pipe lack support. Filling the void between the two pipes with a dense material provides support. The most typical fillers are sand and concrete. How much sand or concrete does it take to do the job? Find the difference between the areas of the two pipes. Then multiply the result by the length of the encasement. Let's try an example, using Figure 9-22.

Figure 9-22 shows a 45-foot-long section of 18-inch-diameter waterline installed inside a 48-inch-diameter encasement pipe. Solve for the areas of both circles using the formula:

Area = πr^2

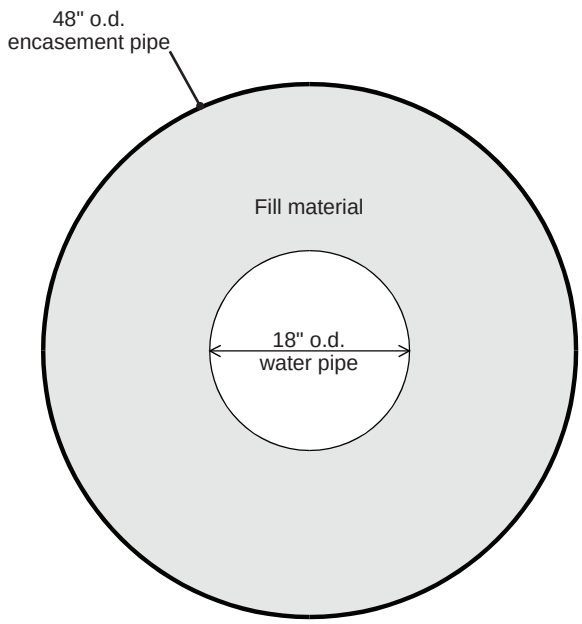


Figure 9-22
Calculating fill volume inside encasement pipe

The encasement pipe's area is 12.57 SF. The area of the waterline is 1.77 SF. Here's the rest of the math:

Volume (CY) = [(12.57 – 1.77) × 45] ÷ 27
= [10.8 × 45] ÷ 27
= 486 ÷ 27
= 18 CY

Excavation Equipment

The excavation equipment you use is also a factor in determining trench width. Buckets on most excavating equipment have widths of 12, 18, 24, 30, 36, or 48 inches. Let's say the trench material width is 32 inches. You can then assume that the bucket used will be at least 36 inches wide.

Overcut

The wider the trench is, the easier it is to work inside. Most earthwork contractors prefer to work with a wider trench, but extra excavation that's not in the specs or required for safety isn't always paid work. What does this have to do with your estimate? It means you have to track the overcut quantities separate from quantities that are pay items.

We'll use the manhole shown in Figure 9-23 as our example. According to the plans, this is a cast-in-place 48-inch-diameter, 7-foot-deep manhole. The contract limits pay items to the same dimensions as the finished structure. That means you're paid to excavate a hole that's the same size as the finished manhole (48 inches across and 7 feet deep). Let's find the payable total excavated volume first.

Volume (CY) = (Depth × Area of one end of the manhole) ÷ 27

Where:

- Depth = 7 feet
- Area one end of manhole = πr^2
- π = 3.1416
- r = 2 feet

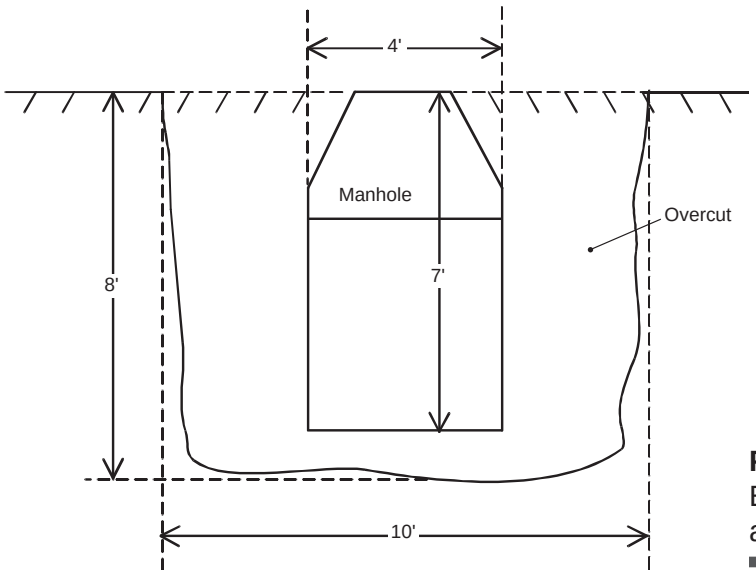


Figure 9-23
Estimating excavation and overcut volumes

Here's the math for the area calculation:

$$\text{Area (SF)} = 3.1416 \times 2^2$$
$$= 12.57 \text{ SF}$$

Next, you calculate excavation volume in cubic yards:

$$\text{Volume (CY)} = (7 \times 12.57) \div 27$$
$$= 87.99 \div 27$$
$$= 3.26 \text{ CY}$$

That's the excavation volume you'll be paid for, but reality demands a lot more excavation. There's no room in this size excavation for the workers who form, pour and strip the forms from the manhole. In Figure 9-23, the dashed lines show the actual excavation outline and dimensions. You calculate this volume the same way as the paid volume.

$$\text{Volume (CY)} = (\text{Depth} \times \text{Area one end}) \div 27$$

Where:

- Depth = 8 feet
- Area one end = πr^2
- $\pi = 3.1416$
- r = 5 feet

Courtesy of Shoring.com

Figure 9-24
Manhole shield

And here's the math:

$$\text{Area (SF)} = 3.1416 \times 5^2$$
$$= 78.54 \text{ SF}$$

Next you calculate the excavation volume in cubic yards:

$$\text{Volume (CY)} = (8 \times 78.54) \div 27$$
$$= 628.32 \div 27$$
$$= 23.27 \text{ CY}$$

Now let's look at what this means in dollars and cents. The total excavated volume comes to about 23 CY. But in terms of pay items, the total is only 3 CY. The 20 CY difference is *overcut*.

Make it a point to include a clause in your standard contract allowing payment for overcut. Then be sure to calculate and include overcut in your bid. Sometimes you'll have to be flexible about this clause. You'll probably have to negotiate. Perhaps offer a lower rate for overcut if that's what it takes to get the job, but try not to work for free.

Another item to consider when estimating manhole excavation is safety. When you have to install a deep manhole in a crowded space, you'll probably have to use a manhole shield to protect your workers. Don't forget to include that cost as well. Figure 9-24 shows a manhole shield.

Get Organized, Stay Organized

Every estimate must be checked. You'll save time here by being organized. Clearly identify each calculation, keep separate steps separate, and always finish the task before moving ahead. Good organization and consistency are the key to accurate, professional estimating.

10

Basements, Footings, Grade Beams & Piers

In this chapter I'll explain how to estimate excavation for basements, footings, and piers. We'll break the project down into logical steps to help eliminate (or at least reduce) the possibility of errors and omissions. The best estimators are both consistent and systematic. They follow the same procedures and use the same methods on every estimate. Develop good estimating habits, and you'll produce more good estimates.

Estimating Basement Excavation Quantities

Although the examples and calculations in this chapter are for basement excavation, the concepts and processes also apply in many other types of work. You use the same estimating procedure to estimate holding tanks, wells, lift stations, or any type of underground structure.

At first glance, it would seem that estimating basements should be a snap. Volume equals length times width times depth, right? Well, yes and no. That will get you the volume inside the basement walls. But there's more to excavation for basements than just the basement itself. How much extra working room do you need outside the basement walls? How much will you have to slope the side walls? How big will the equipment ramp have to be? Every basement excavation job will include complications like these.

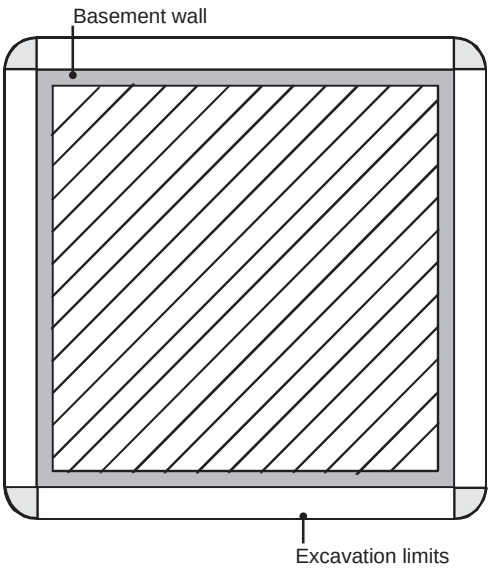


Figure 10-1
Calculating the volume of excavation

The Slope You Select

I've already explained that it's not safe to work in an excavation with vertical walls. Most types of soil are unstable at steep angles. Even firm soil can't be counted on to remain vertical in wet weather. So we'll nearly always have to slope the sides of basement excavations.

Figure 10-1 shows a square basement. The area beyond the basement walls that isn't shaded has to be sloped back away from the pit during construction. When construction is finished and the concrete in the basement walls has set, this sloped area will be backfilled and compacted.

Generally the excavation contractor determines the angle of slope at the basement perimeter. Steeper slopes require less excavation but may not be safe in some types of soil. More gradual slopes make it easier to get in and out of the pit, but require more excavation.

You'll recall from Chapter 9 that run is the horizontal dimension of a slope and rise the vertical dimension. The run and rise are usually expressed as a ratio. A ratio consists of two numbers separated by a colon. Slopes written as ratios list the run first and the rise second. The most common value for rise is 1. Typical values for run range from 1 to 4.

Let's look at some examples. A 1:1 slope rises 1 foot in height for each foot of length. That works out to a 45-degree slope. A 4:1 slope is a very shallow slope. It rises only 1 foot in height over a 4-foot length. A 1:4 slope, meanwhile, is rather steep. It rises 4 feet in height for each foot of length. You'll rarely excavate a slope steeper than 1:4. A slope that's any steeper is unstable and unsafe.

The slope you select depends on the type of soil, safety considerations, the surrounding work space, and the construction methods being used. The table in Figure 9-20, in the previous chapter, shows average maximum safe slopes for different soil types. Generally, a slope of 2:1 is safe for a sand/clay mixture, but you have to consider what other factors may come into play.

If your jobsite includes more than one soil type, always use the slope, or angle of repose, that's recommended for the *least-stable* soil. For example, let's say the site has sand underneath a layer of clay. What slope do you use for the entire project? Sand is less stable than clay, and looking at the table in Figure 9-20, we find that a 3:1 slope is recommended for sand.

Here's something else to think about when you're choosing the slope for a basement excavation. What kind of concrete pour is planned for the footings, walls, and slab? The

reach of the chute on a transit mix truck is between 15 and 18 feet. If the trucks can't get that close to the forms, they can't pour direct from the chute. The more gradual you make the slope, the further away the trucks have to park from the forms. For example, given a 2:1 slope and a depth of 10 feet, trucks won't be able to pour directly from the chute. The run of this slope comes to 20 feet (2 times 10) and that's too far to reach with most chutes. You'll have to build a ramp for the trucks or place the concrete by pump, or with a bucket. These are all expensive solutions.

Finding Volume — Outside Basement Walls

Once we know the run and rise of a slope, the total rise in feet, and the length of the slope, we can use triangles to calculate volumes. We'll start by finding the volume of the sloped area outside of the basement walls in Figure 10-1 — the area without shading. Notice that the area with no shading excludes all four of the corners. Later on in this chapter we'll cover how to find the volume of these corner areas.

In Figure 10-2 you see a cut-away partial view of a basement excavation. Notice that I said *partial*. Figure 10-2 shows only the excavation work done outside of the basement walls. The width of the footing (2 feet) is a dimension that appears on most plan sheets. However, the width of the work space (3 feet in Figure 10-2) isn't typically shown on plans. That's because the amount of work space is up to you. Workers from many different trades use this work space. First in line are the workers who'll build the forms for the basement walls. Later, workers installing DWV and HVAC and electrical lines will also use this space. How much work space you allow depends on:

- the type of concrete forms
- the total excavation depth
- the number and type of utility lines
- the soil conditions

My rule of thumb is to allow no less than 3 feet and no more than 5 feet of work space. Of course, you can adjust that to fit the circumstances and the needs of your fellow subcontractors.

Before we start on the volume calculations, I want to mention the basement wall footings. It's likely that footing excavation work isn't included as a part of the basement excavation. However, I recommend that you follow the industry practice and include footing excavation in the general excavation category. We'll assume that's been done here in our example.

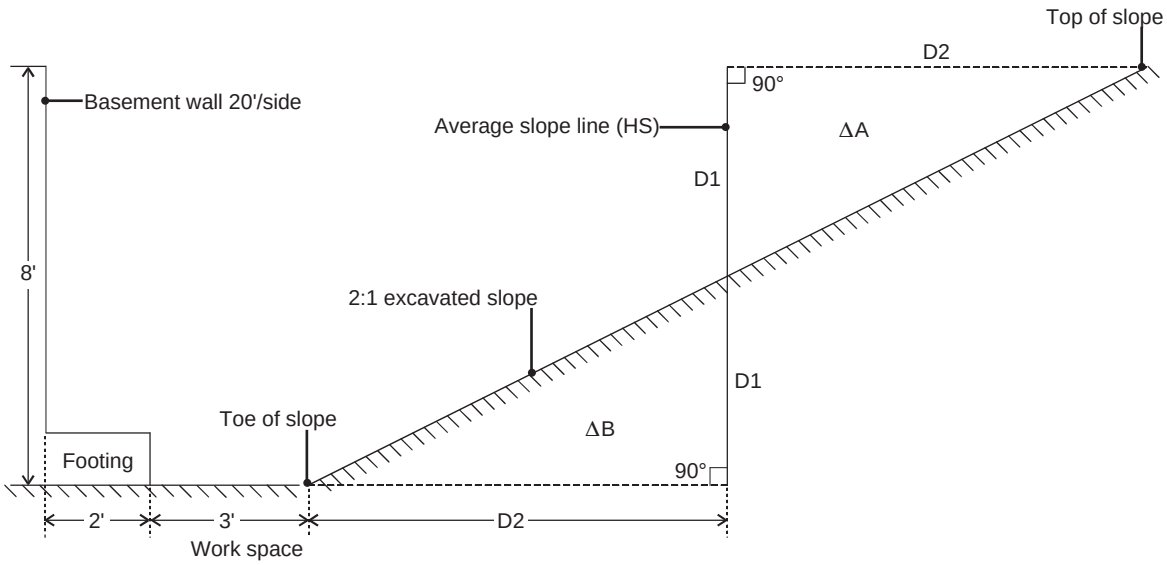


Figure 10-2
Using an average slope line

Using the Average or Half-Slope Line and Equivalent Area to Calculate Basement Excavation Volume

To make slope calculations easier, estimators usually draw a vertical line down the midpoint of the slope. This is called the average slope line or half-slope line (HS for short). The average slope line in Figure 10-2 is the line labeled D1. Line D1 intersects the slope exactly at its horizontal midpoint.

The two dashed lines in Figure 10-2 marked D2 extend the existing and proposed ground levels to intersect with line D1. Notice that the lines D1, D2 and the excavated slope line form a pair of right triangles. We'll call them triangle A and triangle B.

The triangles also have the same length hypotenuse. That's the excavated slope line side of each triangle. Right triangles with the same hypotenuse are identical. That means that the area and volume of triangles A and B are also identical. This simple fact makes calculating the excavated area and volume much easier. I'll explain how it works using Figure 10-3. In Figure 10-3, triangles A and B are identical. Therefore, replacing triangle A with triangle B has no effect on the total volume. However, this substitution does change the shape of the region we're working with. Compare Figure 10-2 with Figure 10-3 and the effect is obvious. What was an irregular region in Figure 10-2 becomes, in Figure 10-3, a regular, shaded, rectangle labeled equivalent area.

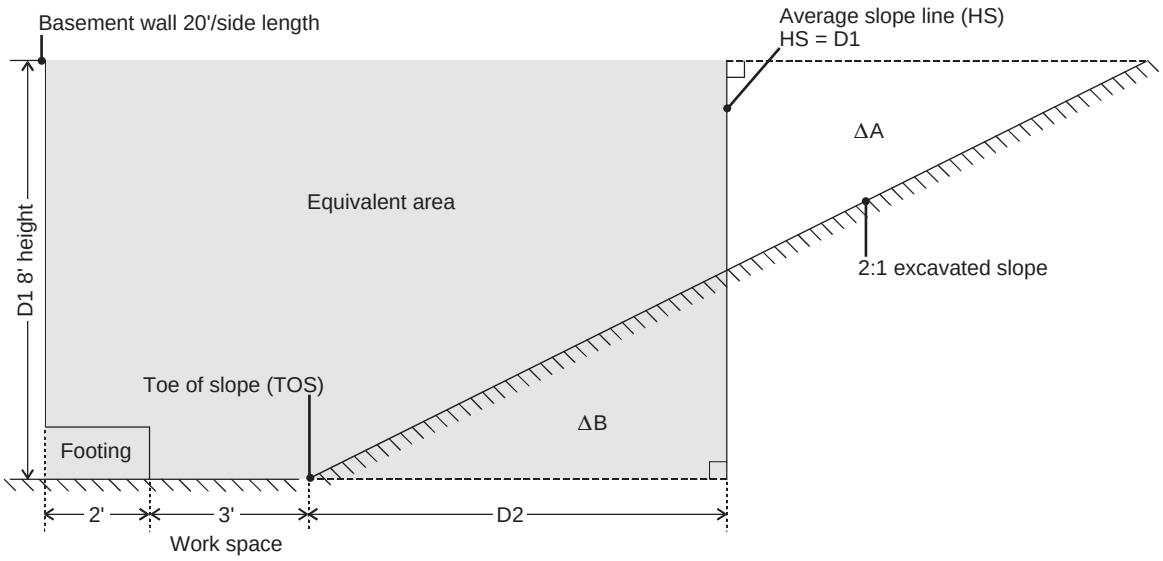


Figure 10-3
Using equivalent area

You already know how to find the volume of a rectangle:

Volume = Length × Width × Height

Here are the values for the variables in Figure 10-3:

- Length – one side of the basement = 20 feet
- Height – wall height, including footing = D1 or 8 feet
- Width – total horizontal distance from outside face of the basement wall to the average slope line, or the sum of the footing width (2 feet), the work space width (3 feet), plus D2.

Obviously, we can't go any further without finding the length of line D2. D2 is the horizontal distance measured from the toe of the slope, or TOS, to the half-slope line, or HS. Now let's see how you find its length.

Finding Toe of Slope to Half Slope — TOS to HS

This horizontal distance is equal to half the slope's total run, or:

TOS to HS = Total run ÷ 2

The total run of a slope equals:

Total run = Total rise × (run ÷ rise)

I believe in learning by doing, so let's try these formulas out with a couple of examples.

Example 1

Let's say the run to rise ratio is 1:1 and the total rise is 8 feet. What is the TOS to HS distance?

Step 1 — Calculate total run:

Total run = Total rise × (run ÷ rise)
= 8 × (1 ÷ 1)
= 8 feet

Step 2 — Calculate TOS to HS distance:

TOS to HS = Total run ÷ 2
= 8 ÷ 2
= 4 feet

Example 2 (based on Figure 10-3)

The run to rise ratio is 2:1, the total rise is 8 feet, and D2 = TOS to HS distance. Repeat the steps used in Example 1 to find the length of D2.

Step 1 — Calculate total run:

Total run = 8 × (2 ÷ 1)
= 16 feet

Step 2 — Calculate length of D2:

D2 = TOS to HS distance
= 16 ÷ 2
= 8 feet

Finding Width for the Equivalent Area

You recall that the width is the sum of: footing width, work space width and D2. Figure 10-3 supplies the first two values and we just found D2. Now find their sum.

Width = 2 + 3 + 8

= 13 feet

Calculating Volume by Equivalent Area

We now know the dimensions of the Equivalent area in Figure 10-3. They are:

- Length = 20 feet
- Width = 13 feet
- Height = 8 feet

Use the following formula to find its volume in cubic yards:

Volume (CY) = (Length × Width × Height) ÷ 27

Volume (CY) = (20 × 13 × 8) ÷ 27

= 2,080 ÷ 27

= 77 CY

Basement Wall Dimensions

Before we go any further, let's stop for a bit to take a look at something that's tripped up many an earthwork estimator. Did you know that there are three ways to show basement wall dimensions? All three are legitimate, and all three are widely used in the construction business. The three ways are:

1. Inside wall line to inside wall line
2. Outside wall line to outside wall line
3. Center of wall line to center of wall line

Figure 10-4 shows three plan views of the same part of a basement wall. In all three I've marked the same dimension, the length of the wall. But each time I get a different result. Why is this? Simple, I used a different dimensioning system each time.

It's up to you, as an earthwork estimator, to study the project plans and figure out the dimensioning system that's been used on the plans. Let's take a close look at each system, starting at the top of Figure 10-4.

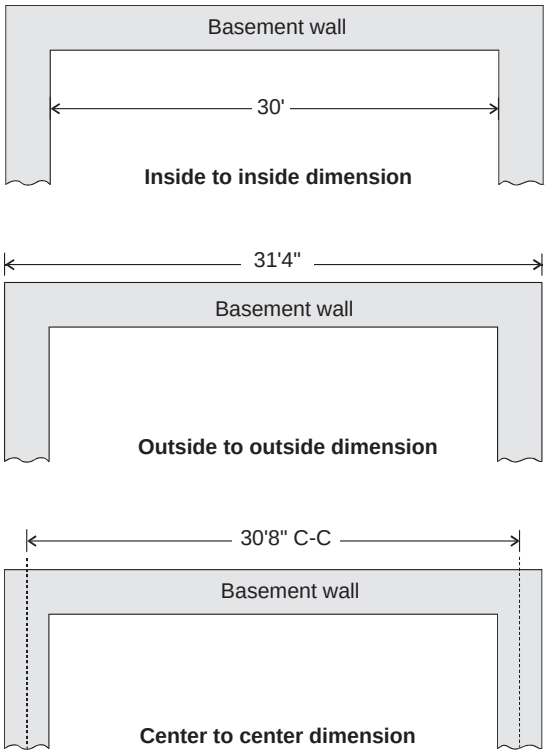


Figure 10-4
Dimensional systems

Inside wall line to inside wall line

This system is typically used for interior dimensions. Measurements are from the inside face of one wall to the inside face of the opposite wall. In this dimensional system, wall thickness isn't a factor that's considered at all.

Outside wall line to outside wall line

This system is typically used for exterior dimensions. Measurements are from the outside surface of one wall to the outside surface of the opposite wall. The resulting dimensions include the thickness of both walls.

Center of wall line to center of wall line

It's easy to tell when this system's used on a set of plans. You'll see C-C written alongside the measuring line. That stands for center to center. Measurements are from the center of one wall to the center of the opposite wall. The resulting dimension includes the width of one wall (half the width for each of two walls equals the width of one wall).

Unless basement plans use outside-to-outside dimensions, you'll need to adjust two dimensions, length and width, by the thickness of the wall or walls before you calculate the excavation volume. Think a few inches won't make much difference in an excavation that's 40 feet across? It adds up faster than you think. Let's say you're estimating the excavation volume for a basement with these dimensions:

- Area = 30 feet x 40 feet
- Height = 8 feet
- Wall thickness = 8 inches

These are inside-to-inside dimensions, but you assume they're outside-to-outside dimensions. Your estimate will be short by almost 28 cubic yards. We'll assume a conservative cost of, say, $3 per yard. Multiply it out and you'll find that you've made an $84 mistake. That comes right off your profit. So it really does pay to be sure that you're working with the right dimensions.

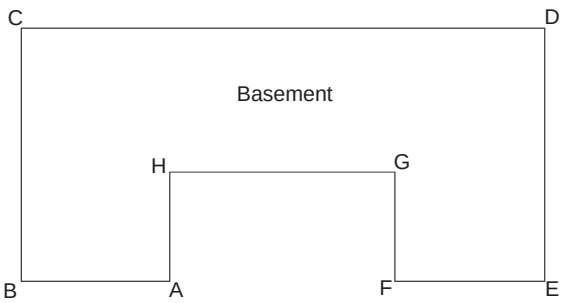


Figure 10-5
Plan view of a basement with two inside corners, G and H, and six outside corners, A, B, C, D, E and F

Inside vs. Outside Corners

Up to this point all the basements we've dealt with had four walls and four corners. As Figure 10-5 shows, basements sometimes have offsets and setbacks. Also note that the basement in Figure 10-5 has two types of corners — outside corners and inside corners. The outside corners are: A, B, C, D, E, and F. The inside corners are G and H.

Here's a simple rule for basements with square corners. The number of outside corners is always four more than the number of inside corners. Put that as a formula, and it's:

Number outside corners – Number inside corners = 4

In Figure 10-6 you'll find four basement plans with inside and outside corners that prove this formula.

Look back at Figure 10-1. Remember that we talked about excavating the sloped areas outside the walls, but ignored the volume in the shaded areas at the corners. Now let's pick up the volume at those corners.

Figure 10-7 A is a plan view of a portion of a basement wall. Notice that one inside corner and one outside corner are shown. Arrows point down the slope toward the basement. Both the inside and outside corners are rounded and sloped toward the basement pit. It's easy to see that you'll do a lot more excavation for outside corners than you will for inside corners. How much more? Let's find out. You'll be glad to know that it won't take a separate calculation for each corner. There's an easier way.

Finding Corner Volumes — the Easy Way

At inside corners there's less material to remove. At outside corners, there's more material to remove. Luckily, these two amounts cancel out one for one. Remember the rule about corners? You always have four more outside corners than inside corners. You only need to calculate the volume of those four outside corners.

How do you go about finding the volume of four sloped outside corners? It's easier than you think. Suppose you joined all four corners together at the deepest point. What you'd have is an upside-down cone. The height of the cone is equal to the height of the basement wall. The formula for the volume of a cone is:

Volume (CY) = [$^1/_3$(Base area × Height)] ÷ 27

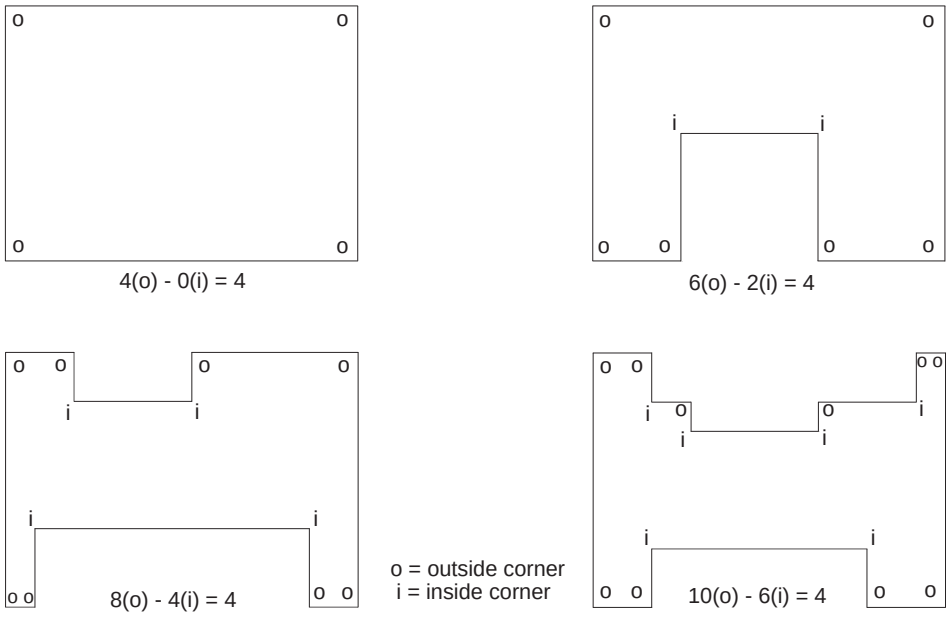


Figure 10-6
Basements with square corners always have four more outside corners than inside corners

The base of a cone is a circle, and the formula for the area of a circle is:

Base area = πr^2

But what is the radius of this circle? Take another look at Figure 10-7 B. In the shaded corner areas, a straight line drawn from point C out to the excavation limit line is a radius. It's equal to 2 times the TOS to HS distance.

Now let's find the volume of the cone shown in Figure 10-7 B. Assuming that the walls are 8 feet high and the slope is 2:1, the radius represented by the line CB would be 16 feet. You can use the following formulas to find the radius, then solve for the volume of the cone:

TOS to HS = Total run ÷ 2

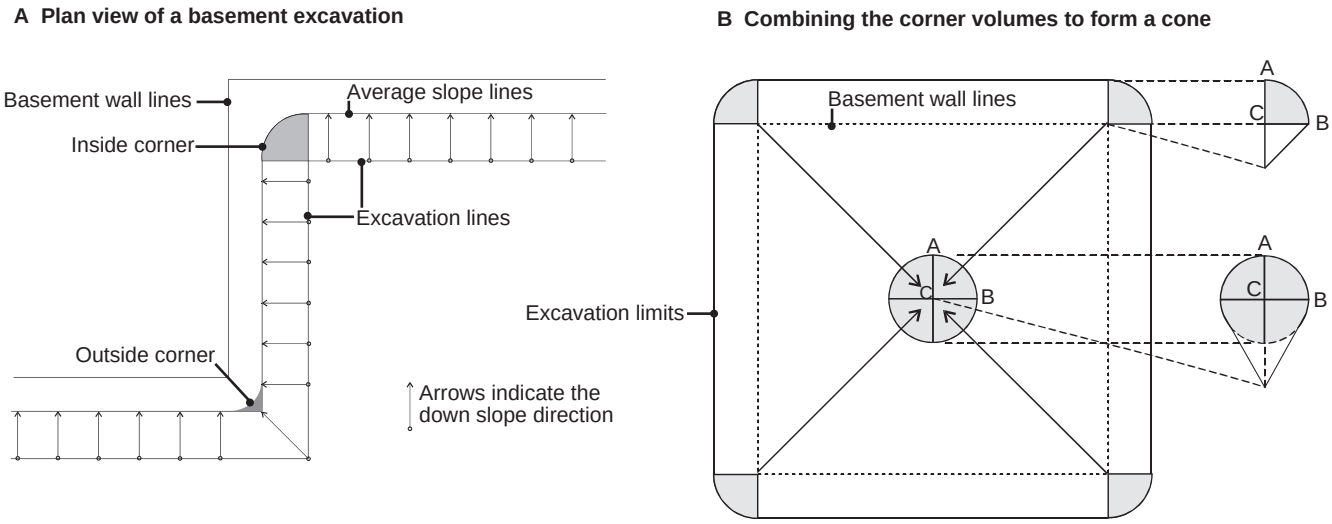
Total run = Total rise × (run ÷ rise)

Radius = TOS to HS × 2

Step 1 — Calculate total run:

Total run = 8 × (2 ÷ 1)

= 16 feet



Base area = πr^2 radius = 2 × TOS to HS Volume (CY) = $\left(\frac{\text{base area} \times \text{height}}{3}\right) \div 27$

Figure 10-7
Calculating corner volume

Step 2 — Calculate TOS to HS distance:

TOS to HS = 16 ÷ 2

= 8 feet

Step 3 — Find the length of the radius CB:

CB = 8 × 2

= 16 feet

Step 4 — Find the volume of the cone in cubic yards:

Volume (CY) = $[{}^{1}/_{3}\,(3.1416 \times 16^2 \times 8)] \div 27$

= $[0.333 \times (3.1416 \times 256 \times 8)] \div 27$

= $(0.333 \times 6{,}434) \div 27$

= 2,142.5 ÷ 27

= 79 CY (rounded)

Calculating the Total Volume for Basement Excavation

I recommend that you keep volume estimates inside the basement walls separate from volume estimates outside the basement walls. The soil you remove from inside the basement walls will have to be spread out over the site or hauled away. We'll call the material you remove from inside the basement walls the V-in. We'll call the material you remove from outside the basement walls the V-out. The outside material will be stockpiled and used as backfill when construction's complete. Figure 10-8 is a plan view of a basement excavation showing both the V-in and the V-out.

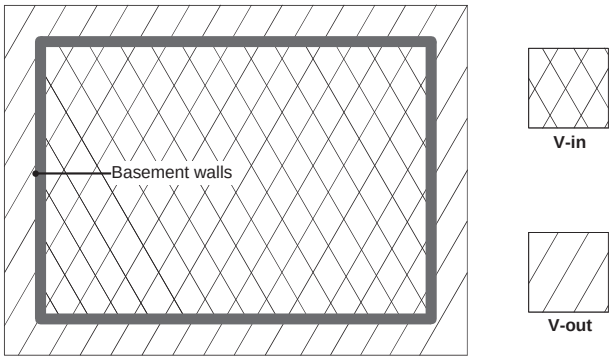


Figure 10-8
V-in and V-out portions of a basement excavation

As we saw in Chapter 9, backfill work involves extra steps. Backfill requires not only compacting but also some hand work. If you don't want to do that extra work for free, you'll take my advice — calculate, estimate and bid V-out volumes separately.

Finding Volumes for Vertical Wall Basement Excavations

While most basement excavations have sloped sides, it's possible to find basement excavations with vertical walls. See Figure 10-9. Some soils are capable of standing vertically, at least for a while. Suppose the jobsite's hemmed in with other buildings, and the surrounding buildings all have basements that are just as deep as your basement? In a case like this, you don't have any choice. You have to excavate vertical walls. You calculate total volume for vertical walls a bit differently.

Figuring Total Volume, V-Out and V-In

When the walls are vertical, you use this formula to find V-out in cubic yards:

V-out (CY) = Total volume (CY) – V-in (CY)

Here's the formula you use to find V-in volume in cubic yards — don't forget to use outside to outside dimensions:

V-in (CY) = ({Basement} Length × Width × Depth) ÷ 27

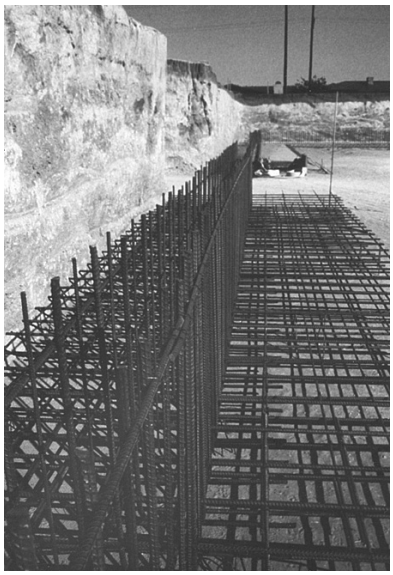


Figure 10-9
Basement with vertical walls

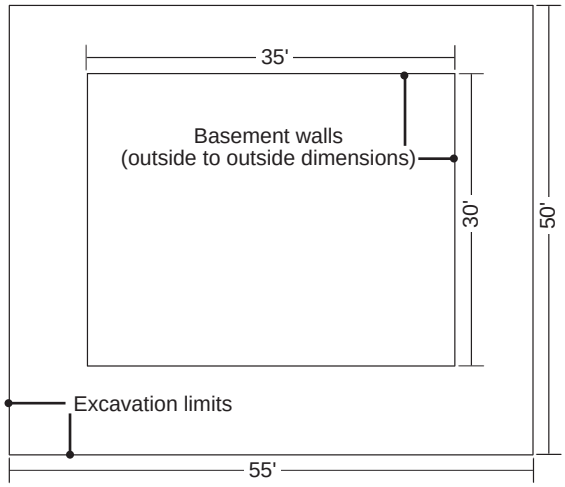


Figure 10-10
Site plan for a sample basement excavation

And the formula for total volume in cubic yards is:

Total volume (CY) = ({Excavation} Length × Width × Depth) ÷ 27

Let's do a simple example. Figure 10-10 is a site plan for a basement. The excavation depth is 8 feet and the specs list both the basement wall line and the excavation limit line as verticals. We'll use the formulas just given to find three volumes for this excavation: V-in, total volume, and V-out. Figure 10-11 is a Quantities Take-Off Sheet for basement excavation volume. Notice that I round off both the total volume and the V-in volume before I subtract to find the V-out volume. This is a common practice in earthwork estimating. The small difference in volume isn't significant.

Finding Volumes for Sloping Wall Basement Excavations

Now we'll calculate the volumes for a basement excavation with sloping sides. Here's an important tip. Always find the V-out volume first, then figure the V-in volume, then add to find total volume. Make sure you follow this sequence for a basement including setbacks or offsets.

For this example we'll use Figure 10-12, the plan view, plus a detail view showing the equivalent area for a basement excavation.

Quantities Take-off Sheet

Project: Sample basement **Date:**

Quantities for: Excavation **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:**

Volume type	Length (ft)	Width (ft)	Depth (ft)	Volume (CF)	Volume (CY)	Misc.
Total	55	50	8	22,000	814.81	
V-in	35	30	8	8,400	311.11	
V-out*	—	—	—	—	504.00	

Note:
*V-out volume = Total volume - V-in volume
= 815-311
= 504 CY

Figure 10-11
Worksheet for sample basement excavation volume calculations

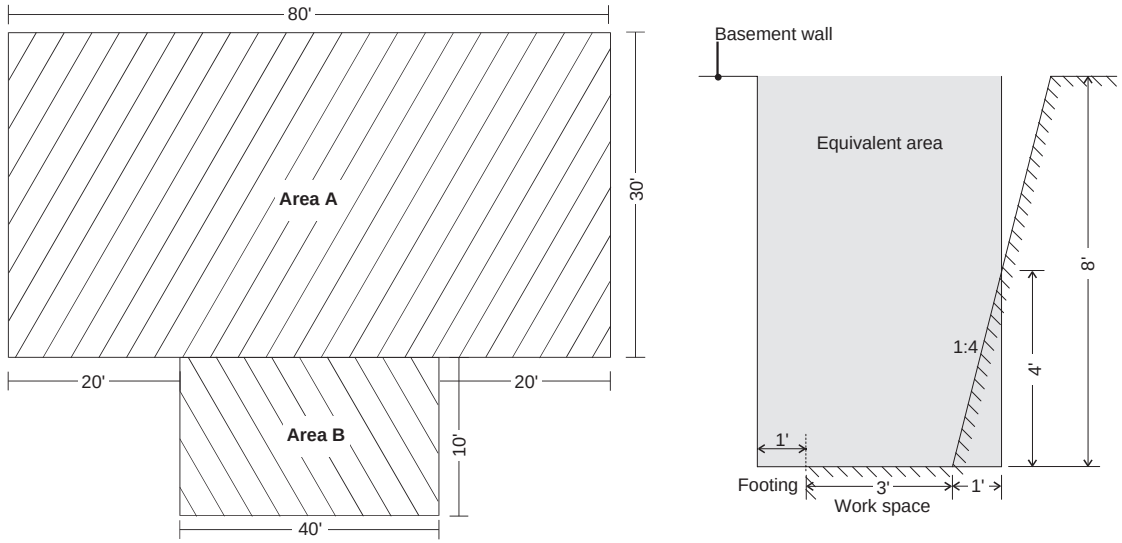


Figure 10-12
Calculating the volume of a sloping wall basement excavation

Let's start off with a few dimensions.

- Wall height = 8 feet
- Wall length = 240 feet
  Wall length is the sum of the lengths of all the basement walls:
  30 + 80 + 30 + 20 + 10 + 40 + 10 + 20 = 240
- Width of equivalent area = 5 feet
  That's the sum of: outside footing width, work space and TOS to HS distance:
  1 + 3 + 1 = 5

Figuring Total Volume, V-Out and V-In

Here are the formulas we'll use to find V-out volume in cubic yards:

V-out (CY) = (Wall length × Equivalent area) ÷ 27

Equivalent area (SF) = Width × Height
= 5 × 8
= 40 SF

V-out (CY) = (240 × 40) ÷ 27
= 9,600 ÷ 27
= 355.56 CY

Next we'll find the corner volume in cubic yards with this formula:

Corner volume (CY) = $[(\pi r^2 \times \text{Height}) \div 3] \div 27$

Where:

- $\pi = 3.1416$
- r (the radius of the cone's base) = 1 foot
- Height = 8 feet

$$\begin{aligned}\text{Corner volume (CY)} &= [(3.1416 \times 1^2 \times 8) \div 3] \div 27\\ &= (25.13 \div 3) \div 27\\ &= 8.38 \div 27\\ &= 0.31 \text{ CY}\end{aligned}$$

You complete the V-out calculations using this formula:

V-out, total (CY) = V-out + Corner volume

$$\begin{aligned}\text{V-out, total (CY)} &= 355.56 + 0.31\\ &= 355.87 \text{ CY}\end{aligned}$$

To calculate the inside volume, the V-in, we first divide the basement space into two regular rectangles. In the plan view in Figure 10-12 they're labeled Area A and Area B.

The dimensions and areas of these two rectangles are:

- Area A = 80 × 30 = 2,400 SF
- Area B = 10 × 40 = 400 SF

You use this formula to find V-in in cubic yards:

V-in (CY) = [(Area A + Area B) × Depth] ÷ 27

$$\begin{aligned}\text{V-in} &= [(2{,}400 + 400) \times 8] \div 27\\ &= (2{,}800 \times 8) \div 27\\ &= 22{,}400 \div 27\\ &= 829.63 \text{ CY}\end{aligned}$$

To find total excavation volume in cubic yards, round both the V-out and the V-in to full cubic yards and find their sum.

Total excavation volume (CY) = V-out (full CY) + V-in (full CY)

Total excavation volume (CY) = 356 + 830

= 1,186 CY

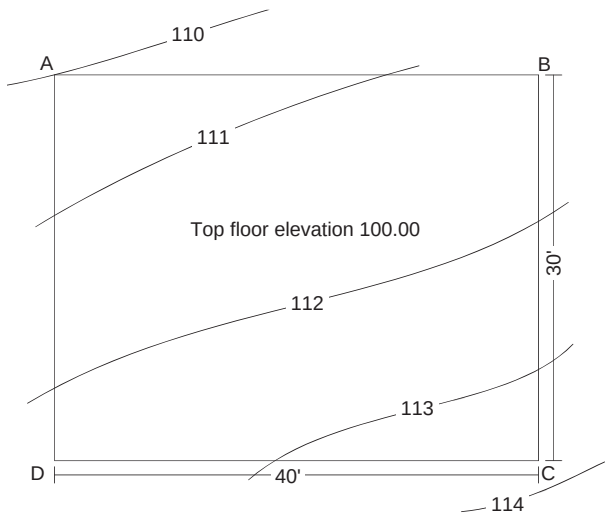


Figure 10-13
Finding the "real" excavation depth for a basement

Basement Excavation Depths

Be careful to determine the correct depth for basement excavations. Check the indicated depth of the basement on the plans, the existing ground lines, the topsoil depth (both in the surrounding area and under the basement slab), and the floor slab depth.

Assume Figure 10-13 shows four basement corners, and the contours show existing elevations. Suppose the specs give a finished elevation for the basement slab's top of 100.00 feet. What's the excavation volume?

In Chapter 5 you learned to use a grid system in an area take-off from a topo map. Using that method, find the basement corner depths in Figure 10-13 and then subtract the top-of-slab elevation (100.00).

- Point A = Elevation 110.00 – 100.00 = 10.00 feet
- Point B = Elevation 111.35 – 100.00 = 11.35 feet
- Point C = Elevation 113.70 – 100.00 = 13.70 feet
- Point D = Elevation 112.20 – 100.00 = 12.20 feet

Find the average depth using the values you found above.

Average depth = (10.00 + 11.35 + 13.70 + 12.20) ÷ 4

= 47.25 ÷ 4

= 11.81 feet

We haven't made any allowance for topsoil that's to be stripped, or for topsoil that's replaced later, or for the thickness of the slab. Let's assign values to each of these factors and then see how to incorporate them into excavation depth.

Assume the following:

- Slab thickness = 6 inches (add)
- Stripped topsoil depth = 8 inches (subtract)
- Replaced topsoil depth = 4 inches (add)

We'll convert these values from inches to feet (divide by 12), work through the addition and subtraction, and apply the result to the average depth we already calculated. The result is the real depth of the excavation shown in Figure 10-13.

$$\begin{aligned}\text{Real depth} &= 11.81 + [(6 + 4 - 8) \div 12] \\ &= 11.81 + (2 \div 12) \\ &= 11.81 + 0.17 \\ &= 11.98 \text{ feet}\end{aligned}$$

To find the excavation volume in cubic yards you multiply the real depth by the area of the basement and divide by 27. Here's how it works for this example:

$$\begin{aligned}\text{Area} &= 30 \times 40 \\ &= 1{,}200 \text{ SF}\end{aligned}$$

$$\begin{aligned}\text{Basement excavation volume} &= (1{,}200 \times 11.98) \div 27 \\ &= 14{,}376 \div 27 \\ &= 532.44 \text{ CY}\end{aligned}$$

Here's something else to remember as you work with basement excavation volumes. Many basements are built with their walls extending 1 to 2 feet above the finished grade. This reduces the excavation depth by the same amount. This information appears on the plans. So, check your plans carefully.

Sample Basement Estimate

To test your understanding of these calculations, figure the excavation volume for the basement shown in Figure 10-14. Figure 10-15 is a detail showing the V-out region with the average slope line. Base all your calculations on the data given in these two figures, and the job specifications on page 233. I recommend that you work all the way through your estimate. Then check it against my work, shown in Figures 10-16, 10-17 and 10-18.

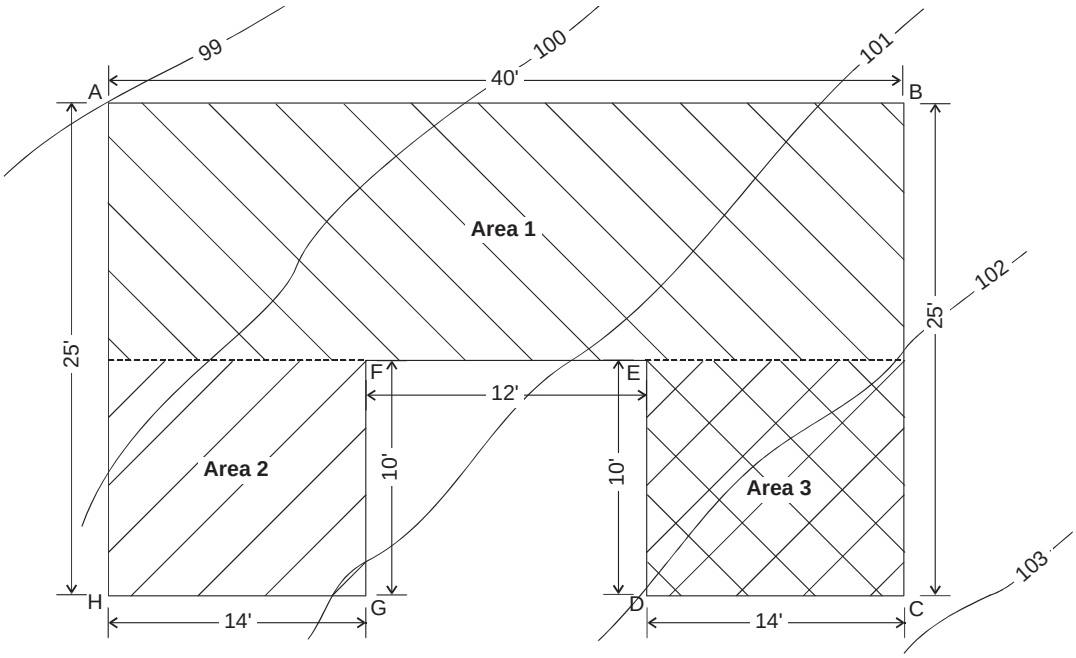


Figure 10-14
Plan view of the sample basement with existing contour lines

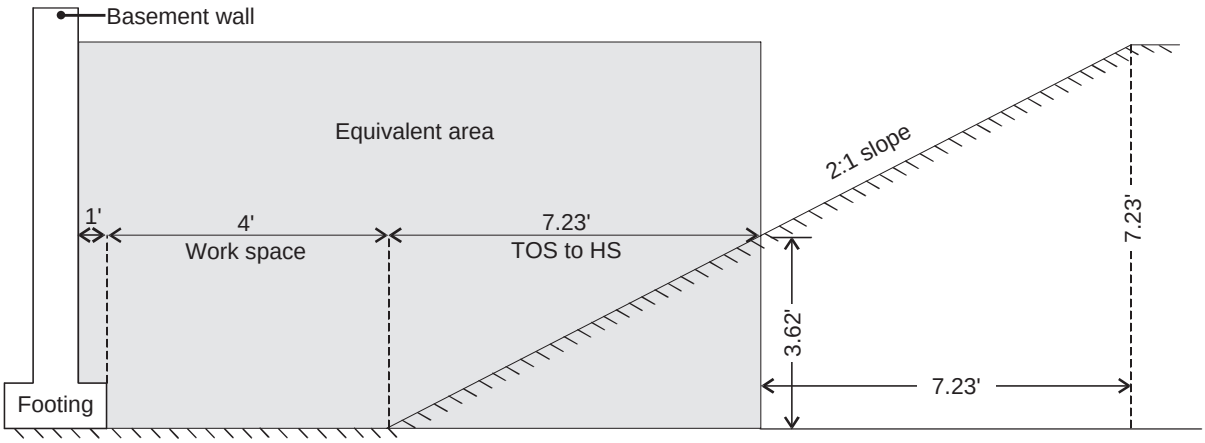


Figure 10-15
Average slope line detail for sample basement estimate

Quantities Take-off Sheet

Project: Sample estimate **Date:**

Quantities for: Determine real depth **Sheet** 1 **of** 3

By: **Checked:** **Misc:**

Point	1 Elev.	2 Elev.	C.I.	Measured distance	Point elevation	Depth (point elev. - top slab elev. 94.0')
A	99	100	1	0.0	99.0	5.0
B	101	102	1	0.2	101.2	7.2
C	102	103	1	0.85	102.85	8.85
D	102	103	1	0.0	102.0	8.0
E	101	102	1	0.3	101.3	7.3
F	100	101	1	0.5	100.5	6.5
G	101	102	1	0.15	101.15	7.15
H	100	101	1	0.45	100.45	6.45
					Total	56.45

Note:

Average = 56.45 ÷ 8
= 7.06

$$\text{Real depth} = 7.06 + \left(\frac{8\ (\text{slab}) + 4\ (\text{replace topsoil}) - 10\ (\text{strip topsoil})}{12}\right)$$

= 7.06 + 0.17
= 7.23'

Figure 10-16
Take-off sheet calculating average and real depth for sample project

Calculation Sheet

Project: Sample Estimate **Date:**_____

V-out, walls (CY) = $\frac{\text{perimeter x area}}{27}$

Perimeter = AB + BC + CD + DE + EF + FG + GH + HA (See Figure 10-14)
= 40 + 25 + 14 + 10 + 12 + 10 + 14 + 25
= 150'

Area (SF) = width x depth

Depth = 7.23' (See Figure 10-16)

Width = footing + work space + TOS to HS (see Figure 10-15)
= 1 + 4 + 7.23
= 12.23'

Area = 12.23 x 7.23
= 88.4 SF

V-out, walls (CY) = $\frac{150 \times 88.4}{27}$
= 13,260
= 491.1 CY

V-out, corners (CY) = $\frac{{}^{1}/_{3}\pi r^2 \times h}{27}$

π = 3.1416
r = 2 x TOS to HS (see Figure 10-15)
= 2 x 7.23 = 14.46'

V-out, corners (CY) = $\frac{0.33 \times (3.1416 \times 14.46^2 \times 7.23)}{27}$

= $\frac{0.333 \times (3.1416 \times 209.09 \times 7.23)}{27}$

= $\frac{1{,}581.49}{27}$

= 58.6 CY

Total V-out (CY) = V-out, walls + V-out, corners
= 491.1 + 58.6
= 549.7 CY

Conclusion

Figure 10-17
Calculating V-out for the sample project

Quantities Take-off Sheet

Project: Sample estimate **Date:**

Quantities for: V-in & Total **Sheet** 3 **of** 3

By: **Checked:** **Misc:**

Area	Length (ft)	Width (ft)	Depth (ft)	Volume CF	Volume CY	
1	40	15	7.23	4,338.0	160.67	
2	10	14	7.23	1,012.2	37.49	
3	10	14	7.23	1,012.2	37.49	
				Total V-in	235.65	

Note:
Total volume (CY) = Total V-in + Total V-out
= 235.65 + 549.7
= 785.35 CY

Figure 10-18
Calculating V-in and total volume for the sample project

Here are the job specifications:

- Soil type is a sand/clay mix
- Strip topsoil depth = 10 inches
- Replace topsoil depth = 4 inches
- Wall height = 8 feet
- Basement slab thickness = 8 inches
- Elevation, at top of slab = 94.0 feet
- Footing width (outside the basement wall) = 1 foot
- Workspace = 4 feet

Step 1 — Determine the depth:

Using the grid square take-off method, find the elevations for points A through H. Subtract the top of slab elevation (94.0 feet) from each to find the excavation depth. Then find the average depth for points A through H.

Calculate real depth from average depth by adding 12 inches (8 inches for the floor thickness and 4 inches for topsoil replaced) and subtracting 10 inches (for topsoil removal). The correct result for real depth is 7.23 feet. If you get a different number, check your figures against mine (Figure 10-16).

Step 2 — Find the equivalent area:

Let's find a safe slope for this job. Checking again the average maximum safe slope table in Figure 9-20 in Chapter 9, we find that 2:1 is safe for a sand/clay mixture. We see that Figure 10-15 shows slope profile at 2:1. We also know that the total rise is 7.23 feet. That means the total run equals 14.46 feet ([7.23 × 2] ÷ 1 = 14.46) and the TOS to HS distance is 7.23 feet (14.46 ÷ 2 = 7.23).

Before we can find the equivalent area, we need to know the total width. Figure 10-15 has all the data you need. The outside footing is 1 foot. The work space is 4 feet, and the TOS to HS is 7.23 feet. Add these together to arrive at a total width of 12.23 feet. Now let's calculate the equivalent area in square feet. Simply multiply the total width (12.23 feet) by the average depth (7.23 feet).

$$\text{Equivalent area (SF)} = 12.23 \times 7.23$$
$$= 88.4 \text{ SF}$$

Step 3 — Calculate V-out:

Figure 10-14 includes the lengths of all the basement walls. Their sum is the total wall length. You use total wall length and the equivalent area to find wall V-out in cubic yards. Next you find corner V-out in cubic yards. Finally, you find the sum of wall and corner V-outs, and that's your total V-out. The correct answer is 549.7 cubic yards. See Figure 10-17 to review the math.

Step 4 — Determine V-in:

First, you divide this irregular shape into three regular rectangles. They appear in Figure 10-14 labeled as Area 1, Area 2 and Area 3. Find the volume of each rectangle in cubic yards. The sum of these three volumes is the total V-in in cubic yards. The answer is 235.65 cubic yards. Figure 10-18 shows my math.

Step 5 — Figure total volume:

Find the total volume by adding V-out to V-in. Total excavation volume for this project is 785.35 cubic yards. My calculations appear in Figure 10-18.

A Shortcut for Calculating Basement Excavation

The math required to determine basement excavation can be simplified if there's no work space required between the basement shell and the toe of the slope. This is possible if the outside face of the footing is flush with the outside of the basement shell, and the soil is stable enough that you won't have to worry about slides, as in Figure 10-19. In such a situation, the total excavation volume will be:

Total volume = Shell length + Distance (toe to top of slope) × Shell width + Distance (toe to top of slope)

Using the information in Figure 10-19, let's calculate the total volume of excavation (in cubic yards) for the basement in Figure 10-20:

Basement volume (CY) = 100 × 140 × 10
= 140,000 cu. ft. ÷ 27
= 5,185 CY

Shell volume (CY) = 80 × 120 × 10
= 96,000 cu. ft. ÷ 27
= 3,556 CY

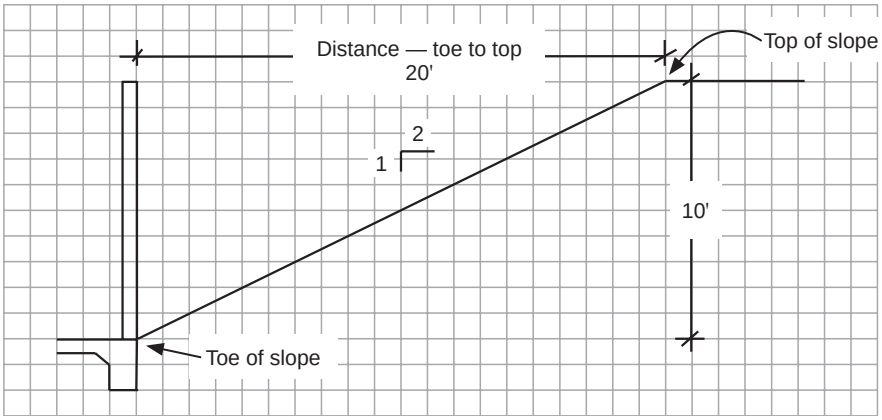


Figure 10-19
Basement section

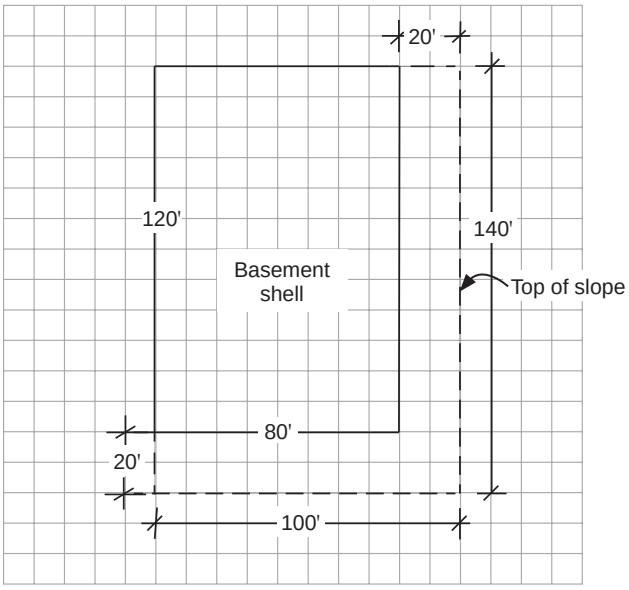


Figure 10-20
Basement plan

The volume outside the shell will be:

Volume out (CY) = Basement volume – Shell volume

= 5,185 CY – 3,556 CY

= 1,629 CY

Test Hole	Depth to Top of Rock	Thickness of Rock
1	4 feet	3 feet
2	1 foot	4 feet
3	5 feet	3 feet
4	8 feet	2 feet

Figure 10-21
Test-hole data

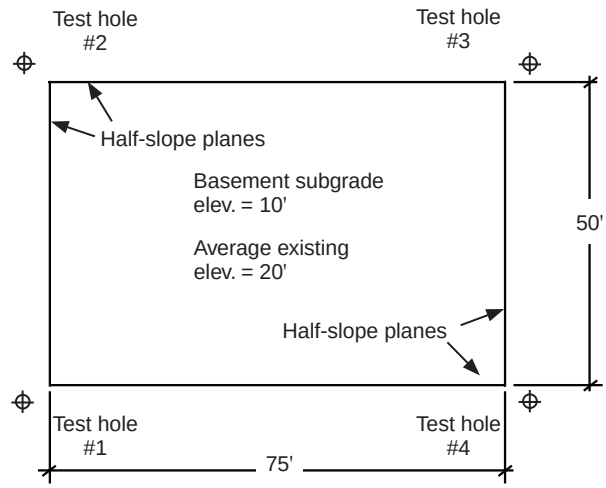


Figure 10-22
Soil borings for excavation

Excavating a Basement with Dissimilar Soils

So far in this chapter, we've discussed excavating basements with homogeneous soils. This is usually the case, but not always. You may find many types of soil and/or rock within an excavation. This is a vitally important consideration, because a variation in soil type will affect:

- the safe bank slope (including total volume of excavation)
- production rates (total project time and costs)
- amounts of soil swell (and the total number of haul trips required to export the spoil)
- the types of equipment you need to excavate the material

You'll need to account separately for the quantities of each type of material you anticipate, since a different unit price will apply to each type of material excavated.

Given the test-hole data in Figure 10-21, let's determine the volume of each type of material we anticipate to be excavated in the basement diagrammed in Figure 10-22. Assume that the overall dimensions given are from half-slope plane to half-slope plane, and that the soils above and below the layer of rock are common earth and clay, respectively.

The test-hole data indicates an excavation with a three-dimensional view as diagrammed in Figure 10-23.

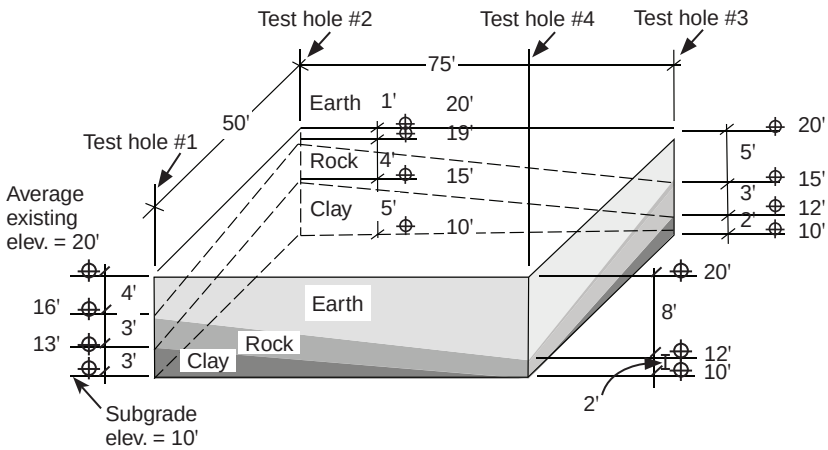


Figure 10-23
Three-dimensional view of basement excavation

The volume of any given bed of material is:

V (any bed) = Length × Width × Average bed thickness

V (any bed) = 75 × 50 × 10

= 37,500 cu. ft. ÷ 27

= 1,389 CY

We know that we will be excavating a total of 1,389 cubic yards of rock, common earth and clay. Now let's determine how much of each type of material we're going to be dealing with.

So, the volume of clay is:

V (clay) = 75 × 50 × [(3 + 5 + 2 + 0) ÷ 4]

= 3,750 sq. ft. × 2.5 ft.

= 9,375 cu. ft. ÷ 27

= 347 CY

The volume of rock is:

V (rock) = 3,750 sq. ft. × [(3 + 4 + 3 + 2) ÷ 4]

= 3,750 sq. ft. × 3 ft.

= 11,250 cu. ft. ÷ 27

= 417 CY

And, the volume of earth is:

V (earth) = 3,750 sq. ft. × [(4 + 1 + 5 + 8) ÷ 4]
= 3,750 sq. ft. × 4.5 ft.
= 16,875 cu. ft. ÷ 27
= 625 CY

Your total volume should match the sum of the materials:

Total volume = V (clay) + V (rock) + V (earth)
= 347 CY + 417 CY + 625 CY
= 1,389 CY

In this example, we had the good fortune of being given test holes at the corners of the basement. This is seldom the case, and solving the problem without a good earthwork computer program involves higher, complicated mathematics, including triple integration (calculus) or matrix theory.

Sheet Piling

When working on steep excavations, one very effective way to reduce over-excavation and dewatering, as well as create a safe working environment, is to surround the proposed excavation with sheet piles. Sheet piling is especially useful when the excavation is in a restricted space, such as a basement excavation. This type of work should be done by a specialty contractor — one who installs walls designed by a professional engineer.

Sheet piling is usually driven into the ground using impact or vibratory hammers. Impact hammers can be air, hydraulic or diesel. Vibratory hammers use vibration, as well as hammer weight to drive the piling into the soil. In soft material, you can also use a hammer that pushes the panels into the soil, thus reducing impact noise and vibration. The entire wall is formed by driving the panels in a sequential operation so that the adjacent panel edges are interlocked.

Sheet piles used in this kind of work are usually black or galvanized steel. Each panel is Z-shaped. When two panels are connected, they form a corrugation, adding to the strength of the wall system. The interlocking edges (*interlocks*) also strengthen the system, as well as forming a rigid barrier for earth and water. If the panel interlocks are cold-rolled, a small amount of water seepage can occur, but with hot-rolled interlocks, the system is virtually watertight. Also, a hot-rolled system maintains its shape better during installation than a cold-rolled system does.

Steel sheet piling is available in lengths from 15 through 70 feet, with the 40-foot panel the most widely used. They are manufactured in 12, 10, 8 and 7-gauge thicknesses.

Steel panels are heavy, so the trucking costs are high. You can normally load only 10 full 40-foot-long panels onto a truck before it reaches its weight limit.

Sheet piling systems are available as free-standing (*cantilevered*) units, or they can be reinforced with I-beams or hydraulic rams (*whalers*), as well as cross beams. In a cantilevered wall, one third of the panel length should lie beneath the bottom of the proposed excavation. In a reinforced system, at least 7 feet of the panel should lie beneath the bottom of the excavation.

Sheet piling has many advantages:

- The systems are available at a relatively low cost.
- Steel piles displace soils, rather than remove it, so adjacent structures are unaffected by soil movement.
- The systems have excellent stability, even in earthquake zones.
- Sheets can be removed and reused on other projects.
- Topography and ground water have little effect on the installation.
- The panels have a long service life.
- You can adjust the pile length by welding or bolting panels together.

There are also some disadvantages to sheet piling:

- They don't work well in stiff clay or soils containing boulders.
- The noise and vibration during their installation can cause a local disturbance, as well as causing adjacent property to settle.

Estimating Ramps

On a basement job, you'll usually have to cut a ramp to move excavation equipment in and out of the pit. The location, size, and material of this ramp affect the excavation quantities. But most estimators don't actually estimate the volume of the ramp. The only purpose of a ramp is to provide temporary access to the pit. It increases efficiency and more than pays for itself in time saved.

However, you may have to estimate ramp excavation occasionally. So I'll explain the estimating procedure. The mathematics required to make a close technical estimate of an equipment ramp is beyond the scope of this book. And it's highly unlikely that you'll

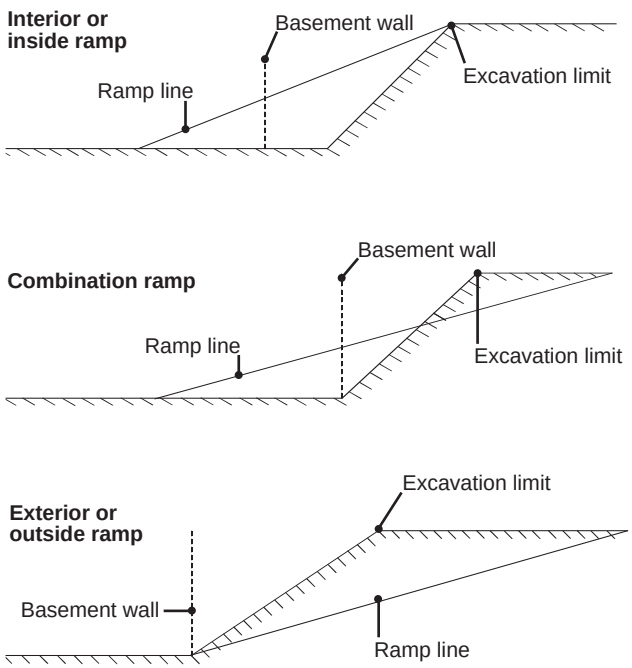


Figure 10-24
Three kinds of ramps

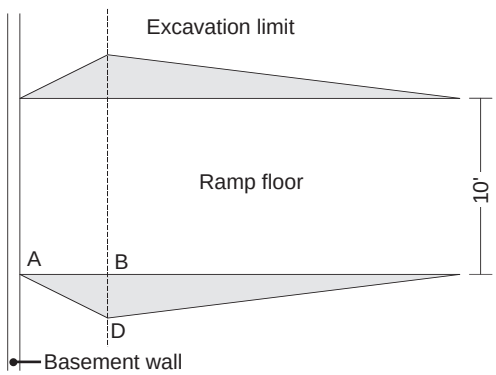


Figure 10-25
Plan view of outside ramp

ever need to make exact calculations for a ramp anyway. Rather than provide details you'll never use, I'll explain an easy way to get results that are acceptable for most, if not all, purposes.

Ramps are classified by their location relative to the outside limits of the basement wall. They are interior, exterior, or a combination of the two. Figure 10-24 shows each type of ramp. An interior ramp is totally within the limits of the excavation. An exterior ramp is located outside the basement wall and may be as much as 10 feet away from the wall. The combination ramp is both inside and outside the excavation area. The type of ramp determines the quantities and placement procedure — and, of course, the cost.

An interior ramp is the most expensive and the least desirable. The excavation equipment has to work around the ramp until all the wall work is done except the wall area that falls within the ramp. At that point, it takes hand work or a backhoe to remove the ramp. Don't use an interior ramp if space is available outside the basement.

An outside ramp is the least expensive because no part of it has to be removed before the walls are completed. Of course, the ramp has to be backfilled and compacted when basement excavation is finished. Note the outside ramp shown in Figure 10-25 (plan view) and Figure 10-26 (elevation view). We'll use triangle area formulas to calculate ramp volumes based on both right and oblique triangles.

The two shaded areas in Figure 10-25 are the sloping embankment along the sides of the ramp. I recommend that you ignore the soil volume moved in this area. The formulas for calculating this embankment are complex and the volumes are small. To compensate for ignoring the volume in the shaded areas, we'll be a little more generous in calculating volumes in other areas.

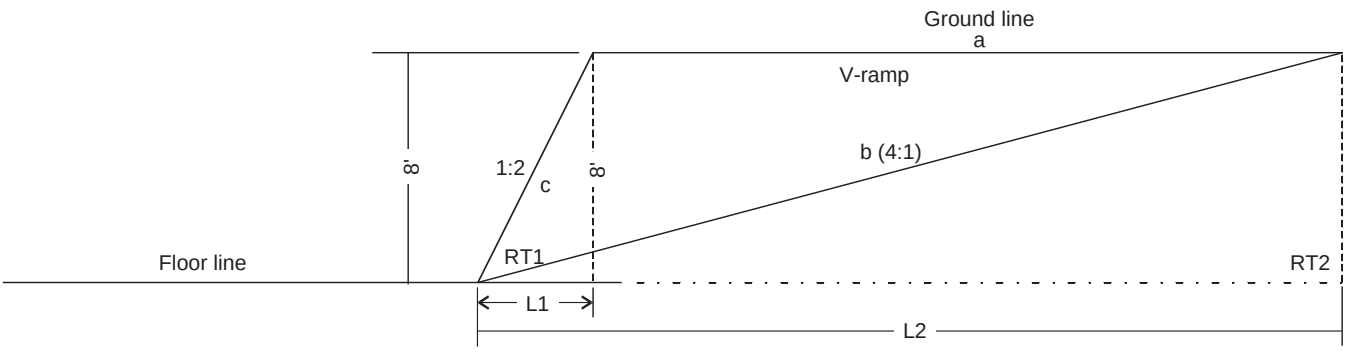


Figure 10-26
Elevation view of outside ramp

Look at Figure 10-26. The oblique triangle labeled V-ramp defines the volume of earth to be moved for this ramp. You use three formulas to find the area of an oblique triangle:

$$A = r \times s$$

Where:

$$r = \sqrt{[(s - a) \times (s - b) \times (s - c)] \div s}$$

and

$$s = \tfrac{1}{2} \times (a + b + c)$$

To find the area of the V-ramp triangle, we need to know the lengths of the three sides: a, b, and c. Remember that the V-ramp triangle isn't a right triangle, so we can't use the Pythagorean theorem to find the lengths of the sides.

However, Figure 10-26 does include two right triangles, labeled RT1 and RT2. Notice that the hypotenuse of RT1 is the same as side c in the V-ramp triangle and that the hypotenuse of RT2 is the same as side b in the V-ramp triangle.

Now, what do we know about triangles RT1 and RT2?

We know that the height of triangle RT1 is 8 feet. That's the same as the excavation depth. We also know that the slope of the hypotenuse of RT1 is 1:2. That means for each 1 foot of run, the slope rise is 2 feet. So if the rise is 8 feet, the run must be 4 feet. The run is the same as length L1. So L1 is 4 feet. Write 4 feet in beside L1 on Figure 10-26.

The Pythagorean theorem says:

> The square of the hypotenuse of a right triangle equals the sum of the squares of the other two sides.

In this case, the square of side c equals the square of 8 feet plus the square of 4 feet. The actual length of side c is the square root of the result.

$$c^2 = 8^2 + 4^2$$
$$= 64 + 16$$
$$= 80$$

$$c = \sqrt{80}$$
$$= 8.94 \text{ feet}$$

We'll round 8.94 feet to 9 feet and pencil 9 feet in by side c in Figure 10-26.

Now let's find the length of side b of the V-ramp triangle. This side is the hypotenuse of triangle RT2. It's also the horizontal length of the ramp floor. You get to determine this length. It should be as short as possible to save on space and yardage, but long enough so the workers and their equipment can use it easily. Let's assume a slope of 4:1 for the ramp, 4 feet of run for each 1 foot of rise. So, for the rise of 8 feet, the run is 32 feet. Mark 32 feet by line L2 in Figure 10-26.

Now let's use the Pythagorean theorem again to find the length of side b:

$$b^2 = 32^2 + 8^2$$
$$= 1{,}024 + 64$$
$$= 1{,}088$$

$$b = \sqrt{1{,}088}$$
$$= 32.98 \text{ feet}$$

We'll round that to 33 feet and pencil 33 feet in by side b in Figure 10-26.

And we can just subtract to find the length of side a:

$$a = L2 - L1$$
$$= 33 - 4$$
$$= 29 \text{ feet}$$

We now know the lengths of all three sides of the V-ramp oblique triangle:

- a = 29 feet
- b = 33 feet
- c = 9 feet

Use the following formulas to figure the area:

$$A = r \times s$$

$$r = \sqrt{\{[(s - a) \times (s - b) \times (s - c)] \div s\}}$$

$$s = ½ \times (a + b + c)$$

Now, plug in our known lengths:

$$s = ½ (29 + 33 + 9)$$
$$= ½ \times 71$$
$$= 35.5$$

$$r = \sqrt{\{[(35.5 - 29) \times (35.5 - 33) \times (35.5 - 9)] \div 35.5\}}$$
$$= \sqrt{[(6.5 \times 2.5 \times 26.5) \div 35.5]}$$
$$= \sqrt{(430.6 \div 35.5)}$$
$$= \sqrt{12.13}$$
$$= 3.5$$

$$A = 3.5 \times 35.5$$
$$= 124.3 \text{ SF}$$

We'll round that off and call the area 124 square feet.

The area of the V-ramp oblique triangle in Figure 10-26 is 124 square feet. According to Figure 10-25, the ramp is 10 feet wide. Now find the ramp volume in cubic yards.

$$\text{Volume (CY)} = (124 \times 10) \div 27$$
$$= 1{,}240 \div 27$$
$$= 45.93 \text{ CY rounded to 46 CY}$$

You don't have to estimate interior ramps because all the soil is within the excavation area. It's already calculated as part of the V-in and V-out. You can calculate combination ramps by constructing working triangles as we did in Figure 10-26. But only calculate the part of the ramp that's outside the excavation limit line.

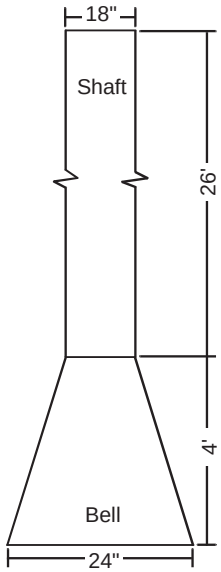


Figure 10-27
Finding the volume of a pier shaft and bell

Grade Beams and Piers

When difficult soils or load problems mean that normal footings can't support the foundation, grade beams (or grade beams and piers) provide the needed support. Piers are drilled into the ground below the grade beam and poured with concrete. The weight of the grade beam will bear on the piers. Sometimes a belled footing is needed at the bottom of the pier to distribute the weight over a broader area. Figure 10-27 shows a pier shaft and a bell. The shafts are drilled with an auger bit, and bells are reamed with a *belling tool* — a bit with hinged leaves that open to clear a wider diameter near the bottom of the hole.

Working with piers is very specialized work. Most excavation contractors don't try to do it themselves. They hire subcontractors who have the special equipment required, like the pier drilling truck shown in Figure 10-28. But even if you don't do the work, you may have to calculate the volume of the holes so the subcontractor bidding the job can figure the volume of soil he has to haul off the site.

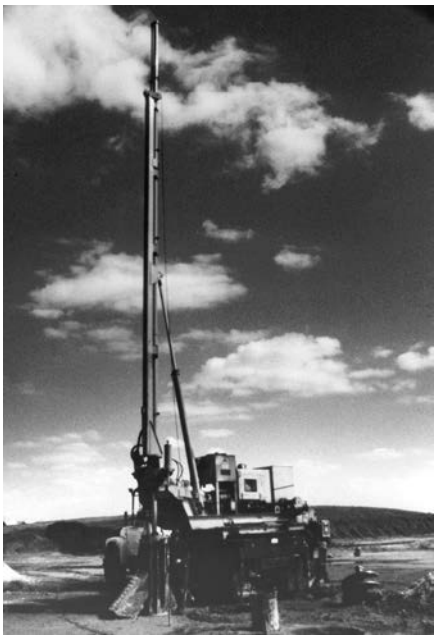


Figure 10-28
Pier-drilling truck

The pier subgrade elevation will be shown on the plans at a depth where the designer believes adequate bearing soil exists. However, the actual depth of suitable bearing soil may be different. That's why contractors are usually required to submit, as part of the bidding documents, a list of cost additions and deductions per linear foot of pier. In this situation, the contractor basically signs a stipulated sum contract with a unit price rider. The amount charged for additional excavation will include the contractor's overhead and profit. Any amount deducted for less-than-anticipated excavation, however, should be net costs only. In other words, the unit price deduction won't include overhead and profit. That's because, regardless of whether less-than-expected excavation occurs, there are costs for maintaining and submitting records of the drilling. The owner should still be liable for those costs.

Calculating the Shaft Volume

Suppose you need to figure out the volume of a pier shaft and bell, like the one in Figure 10-27. The shaft is 18 inches in diameter and 26 feet deep. The bell's base diameter is 24 inches and its depth is 4 feet.

To calculate the volume of the shaft, multiply the area of an end of the shaft by its length. For a shaft diameter of 18 inches (or 1.5 feet), the radius is 0.75 feet.

$$\text{Area} = \pi r^2$$

$$\begin{aligned}\text{Area (SF)} &= 3.1416 \times 0.75^2 \\ &= 3.1416 \times 0.56 \\ &= 1.76 \text{ SF}\end{aligned}$$

$$\text{Shaft volume (CY)} = (\text{Area} \times \text{Depth}) \div 27$$

$$\begin{aligned}\text{Volume (CY)} &= (1.76 \times 26) \div 27 \\ &= 45.76 \div 27 \\ &= 1.7 \text{ CY}\end{aligned}$$

Calculating the Bell Volume

To estimate the volume of the bell, calculate the area of the top and bottom circles of the bell. Add the two together and divide by 2 to find the average area. Then multiply by the depth of the bell. We already know the area of the top circle is 1.76 square feet. Let's figure the area of the bottom circle. The radius of the bottom circle is 1 foot (one-half of 24 inches).

$$\begin{aligned}\text{Area of bottom circle} &= 3.1416 \times 1^2 \\ &= 3.1416\end{aligned}$$

$$\begin{aligned}\text{Average area} &= (3.1416 + 1.76) \div 2 \\ &= 4.9 \div 2 \\ &= 2.45 \text{ SF}\end{aligned}$$

$$\begin{aligned}\text{Bell volume} &= (2.45 \times 4) \div 27 \\ &= 9.8 \div 27 \\ &= 0.36 \text{ CY}\end{aligned}$$

Shaft Diameter	Cubic Feet of Soil Excavated per L.F. of Shaft	Diameter-Feet of Soil Excavated per L.F. of Shaft
12″	0.79	1.00
14″	1.07	1.17
16″	1.41	1.34
18″	1.77	1.50
20″	2.18	1.67
22″	2.64	1.83
24″	3.14	2.00
26″	3.69	2.17
28″	4.28	2.34
30″	4.91	2.50
36″	7.07	3.00
42″	9.62	3.50
48″	12.56	4.00
54″	15.90	4.50
60″	19.64	5.00

Figure 10-29
Pier shaft drilling data

Total volume of shaft and bell:

Volume = 1.7 + 0.36

= 2.06 CY

Unless it's specified by the designer, the diameter and depth of the bell will usually be determined by the size of the contractor's drill rig.

Another Method of Calculating Pier-Drilling Volumes

Pier drillers usually charge by the diameter-foot for drilling the pier shaft. Smaller shafts (less than 24 inches in diameter) carry a higher drilling unit price than shafts with a larger diameter, so you'll need to account for them separately. Figure 10-29 shows cubic-foot and diameter-foot factors per linear foot of shaft excavation.

To determine the diameter-feet of soil excavated from a pier shaft, multiply the appropriate diameter-feet factor (based on shaft diameter) by the shaft depth. For example, 1.83 is the diameter-foot factor for a 22-inch-diameter shaft. If the shaft is 12 feet deep, then the total soil excavation is 1.83 × 12 = 21.96, rounded to 22 diameter feet.

If a pier consists of a shaft only, the soil excavation volume equals shaft depth times the appropriate cubic-foot factor shown in Figure 10-29. The factors really just represent the area of a circle of the given diameter — recall that the area of a circle is pi (3.14) times radius (½ diameter) squared. Take, for example, a shaft with a 48-inch (4-foot) diameter. The radius squared (2^2) equals 4 feet. Multiplying 3.14 by 4, we get 12.56, which confirms the factor shown in the table. You can use this method to calculate your own cubic-foot factors for shaft diameters that aren't listed in the table. Be sure to convert shaft diameter measurement into feet when performing the calculation.

Bells

Bell reaming is priced by the cubic foot of excavated soil. Figure 10-30 lists cubic-foot bell excavation volumes. The figures represent only the bell's net soil volume. In

Dia. of Bell	Net Volume in the Bell												
	Diameter of Shaft												
	16″	18″	20″	22″	24″	26″	28″	30″	36″	42″	48″	54″	60″
20″	0.5	0.2											
22″	0.9	0.6	0.3										
24″	1.4	1.0	0.6	0.3									
26″	1.9	1.4	1.1	0.7									
28″	2.6	2.1	1.6	1.2									
30″	3.4	2.8	2.3	1.7	1.3	0.8	0.2						
32″	4.3	3.7	3.1	2.5	1.9	1.3	0.8						
34″	5.3	4.6	4.0	3.3	2.7	2.0	1.4						
36″	6.4	5.7	5.0	4.3	3.5	2.8	2.2	1.5					
38″	7.6	7.0	6.2	5.4	4.6	3.8	3.1	2.3	0.5				
40″	9.1	8.0	7.2	6.3	5.5	4.6	3.7	2.9	0.8				
42″	10.7	9.8	8.9	8.0	7.1	6.2	5.2	4.3	1.9				
44″	12.4	11.5	10.5	9.5	8.5	7.5	6.5	5.5	2.7	0.5			
46″	14.3	13.3	12.3	11.2	10.1	9.0	7.9	6.9	3.8	1.2			
48″	16.3	15.3	14.2	13.1	12.0	10.8	9.6	8.4	4.8	2.1			
50″	18.6	17.5	16.3	15.1	13.9	12.6	11.4	10.1	6.4	3.1	0.6		
52″	21.0	19.9	18.6	17.4	16.1	14.7	13.4	12.0	8.0	4.3	1.4		
54″	23.6	22.3	21.1	19.8	18.4	17.0	15.6	14.1	9.7	5.7	2.4		
56″	26.3	25.1	23.8	22.4	20.9	19.5	18.0	16.4	11.7	7.3	3.5		
58″	29.3	28.0	26.7	25.2	23.7	22.1	20.5	18.9	14.3	9.1	4.9		
60″	32.5	31.1	29.7	28.2	26.6	25.0	23.4	21.6	16.3	11.1	6.5	2.7	
62″		35.0	33.0	31.4	29.7	28.0	26.2	24.4	18.3	13.3	8.2	3.9	
64″		38.0	36.5	34.8	33.1	31.3	29.4	27.5	21.6	15.7	10.3	5.5	
66″		41.8	40.2	38.5	36.7	34.8	32.9	30.9	24.7	18.4	12.8	7.2	3.3
68″		45.8	44.2	42.4	40.5	38.5	36.5	34.4	27.8	21.3	15.0	9.1	4.4
70″		50.1	48.3	46.5	44.6	42.5	40.4	38.2	31.3	24.4	17.6	11.4	6.0
72″		54.6	52.8	50.8	48.8	46.7	44.5	42.2	35.1	27.7	20.5	13.8	8.0
74″		59.3	57.5	55.4	53.3	51.2	48.9	46.5	39.1	31.3	23.7	16.5	10.1
78″		69.4	67.6	65.5	63.2	60.8	58.4	55.8	47.7	39.3	30.9	22.7	15.1
84″		87.0	84.8	82.4	80.0	77.4	74.6	71.8	62.8	53.2	43.6	34.0	24.9
90″								90.4	80.5	69.8	58.8	47.8	37.1
96″								111.8	100.8	89.1	76.8	64.3	52.1
102″									124.1	111.2	97.7	83.8	60.8
108″									150.6	136.6	121.8	106.5	90.9
114″									180.4	165.3	149.2	132.4	115.1
120″									213.5	197.3	179.8	161.7	142.8
126″									250.2	232.9	214.2	194.5	174.1
132″									290.6	272.2	252.3	231.2	209.0
138″									334.7	315.6	294.3	271.8	248.0
144″									383.6	362.5	340.4	316.4	291.2

Figure 10-30
Net bell volumes

other words, they don't include soil volume from the pier shaft that forms the center of the bell.

To calculate total belled pier excavation volume, add the total shaft volume to the net bell volume. Let's say you need to calculate total soil volume displacement of a belled pier that's 18 feet deep with a 24-inch shaft diameter and a 60-inch bell diameter. The shaft volume equals 3.14 (from Figure 10-29) times 18, which comes to 56.5 cubic feet. The net bell volume (using the table in Figure 10-30) is 26.6 cubic feet. The combined total (56.5 + 26.6) equals 83.1 cubic feet, or 3 cubic yards.

Figuring the volume of piers, shafts, bells, grade beams, and footings is complex work. Make it easier and reduce the chance of errors by splitting the area into simple, regular parts. Then calculate each area and volume as a separate step. Finally, add the parts to find the whole. Work systematically. Be consistent. Be well organized. Keep your work neat and tidy so it's easy to check, both for you and for another estimator. That's the key to consistently accurate excavation estimates.

11

All About Spoil & Borrow

In this chapter we'll define spoil and borrow and learn how to calculate the volume of each. On many jobs you'll need an accurate estimate of how much soil has to be hauled in or hauled away and how much it'll cost. That makes this topic one that's very important to any excavation estimator.

Spoil is any excavated material that can't be used on the project. This is excavated material that you have to remove from the site. Borrow is material that you need to bring to the site in order to complete the job. Your source for borrow material is the borrow pit.

Obviously, you want to avoid spoil and borrow whenever possible. A balanced job has all the fill that's needed available onsite. And when the job's complete, there's no spoil to haul away. The easiest, least expensive and most profitable excavation jobs involve neither borrow nor spoil.

Sometimes you can avoid borrow and spoil by temporarily stockpiling material onsite or close by during construction. Then, you can use it later for backfill when construction is finished. Carefully calculate the amount of material that's stored and how much space you need for it. You'll find instructions for calculating stockpile area later in this chapter.

Underlying Costs of Spoil and Borrow

If you can't avoid importing soil, ask yourself the following three questions at the start of your estimate:

1. What borrow pit is closest to this jobsite?
2. Is the borrow pit material compatible with the onsite material?
3. What are the costs of moving the material?

Obviously, your costs depend on how you answer each of those questions. So we'll take the time for a closer look.

Locations — Borrow Pit vs. Jobsite

The closer the borrow pit is to your jobsite, the better off you are. First, the closer your jobsite is to the borrow pit, the fewer miles of hauling you pay for. Second, the closer the jobsite and the borrow pit, the better your chances for a good material match.

Obviously, the fewer miles you haul borrow material, the lower your costs. The same is true when you're hauling spoil. Other cost factors include traffic loads, and street and bridge conditions.

Borrow material should always be as similar as possible to onsite material. On some projects a good match between the two soils is very important. You may need a test by a soils engineer to make sure that the borrow meets design standards. Check the plans and specifications to see who provides and pays for this testing. More often than not, tests like this are done at the expense of the excavation contractor.

Spoil Disposal

You also have to consider soil type when you're dealing with spoil. Suppose your spoil is rich, high-quality topsoil. Good topsoil's a valuable commodity, as we saw earlier in Chapter 9. Someone will want it. Not only that, they'll pay you for it — and for your time, too. That's the good news.

Unfortunately, most spoil isn't high-grade topsoil. Instead it's material such as rock, muck or clay, and miscellaneous debris. There just isn't a lot of demand for material like this. Sometimes it's a problem finding a disposal site that's close enough to be practical. Here are a few tips to try if you run into trouble along these lines. Your local building department keeps public records listing all the excavation projects still in the approval stage. Check this list. Are any of the projects close to your jobsite? Does the paperwork

show that they'll need fill? You're likely to have just what they need. Keep an eye out for private party ads looking for fill dirt or offering to accept fill. If none of these pan out, you'll have to use the nearest legal dump site that accepts spoil. Obviously, it's to your advantage to dispose of spoil as close to the jobsite as possible and reduce those hauling costs.

Interim Spoil

Not all spoil necessarily remains spoil. Material you remove from a site temporarily is called interim spoil. It's taken from a jobsite during construction and then brought back later to complete the project. You use interim spoil only when there's no other choice. For example, say the jobsite's very small, or has extreme topography such as steep slopes or deep ravines. In those cases, interim spoil is the only answer. Interim spoil is unique, expensive, and something to avoid — because you handle it twice.

Spoil and Borrow Volume Calculations

You find the total volume of spoil on a project using the following formula:

Total spoil vol. (CY) = [Total cut vol. – (Total backfill vol. + Total fill vol.)] × Swell factor

Let's say that your spoil material is moist sand and you already know these volumes:

- Cut = 500 CY
- Fill = 200 CY
- Backfill = 150 CY

Here's the math for spoil volume in cubic yards:

Total spoil volume (CY) = 500 – (200 + 150)
= 500 – 350
= 150 CY

Looking back at Figure 8-2 in Chapter 8, you'll find the swell factor for moist sand is 1.13:

Total spoil volume (LCY) = 150 × 1.13
= 169.5 LCY

Before we move on, here are two excellent reasons for always using loose cubic yards for spoil volume.

1. It reminds you to use swell and shrink factors.
2. If you subcontract haulage, the bids are sure to be per LCY.

If you get a negative value for spoil, it means there's no spoil to haul off. In fact, you don't have enough material to do the backfill and fill work called for in the plans. That means it's time for you to locate a borrow pit. Project engineers and designers do their best to minimize borrow amounts. But despite all efforts to avoid borrow, some jobs still require imported material. We'll talk more about balancing cut and fill volumes in the next chapter.

The subject of shrink and swell factors is covered in detail in Chapter 8, so we won't go into it again here. There are two types of stockpiles that require special consideration when it comes to applying shrink and swell factors: interim spoil stockpiles and topsoil stockpiles. We'll look at each of these special situations in depth.

Interim Spoil Stockpiles

Interim spoil, you recall, receives extra handling. First, you excavate it onsite. Second, you stockpile it offsite. Third, you bring it back onsite for use. At step one and step two you're working with loose state material, so you apply the swell factor. Normally, the volume of an interim spoil stockpile doesn't change between the second and third steps. However, there are three exceptions. Here are the exceptions and how to deal with each of them:

1. Material stockpiled for more than three months. Settling changes the state of stockpiled material. You now have a stockpile of compact material. Recalculate the volume in compact cubic yards, applying the correct shrink factor.
2. Material stockpiled unprotected through the rainy season. You'll lose an unknown quantity of material via water erosion and they'll be a change in the moisture content of the material. Recalculate the volume and apply the right swell factor for the moisture level.
3. Material that's sold to another party. Don't cheat yourself; recalculate the stockpile's volume and apply the appropriate shrink or swell factor.

There are special rules for applying shrink and swell factors to stockpiles of topsoil.

- ➤ Apply only the swell factor to topsoil-out volumes.
- ➤ Apply only the shrink factor to topsoil-in volumes.

Balancing Two Separate Jobsites

You can balance two separate jobsites by using the following equation:

Change in depth = Net import (or export) × 27 ÷ Total site areas

Let's look at an example. Assume that Job 1 requires an import of 10,000 CY and Job 2 requires an export of 4,000 CY. Also assume Job 1 has an area of 20,000 square feet and Job 2 has an area of 16,000 square feet. The net import is 6,000 CY (10,000 CY – 4,000 CY). The total site area is 36,000 square feet (20,000 + 16,000). Therefore, the proposed elevations throughout both sites must be changed by:

Change in depth = 6,000 CY × 27 ÷ 36,000 SF

= 4.5 feet

Since both projects require a net import, the fill is less than the cut. So, to balance the sites, each site must be lowered by 4.5 feet.

Calculating the Volume of a Stockpile

Figure 11-1 shows the same stockpile of loose soil in several different views. We'll use this stockpile to introduce the procedures you use to find stockpile volume. First, divide the stockpile into three sections, as shown in Figure 11-1 A. The middle section is the prism shown in Figure 11-1 C. The two end sections, meanwhile, combine to form the cone shown in Figure 11-1 D.

Finding the Volume of the Middle Section

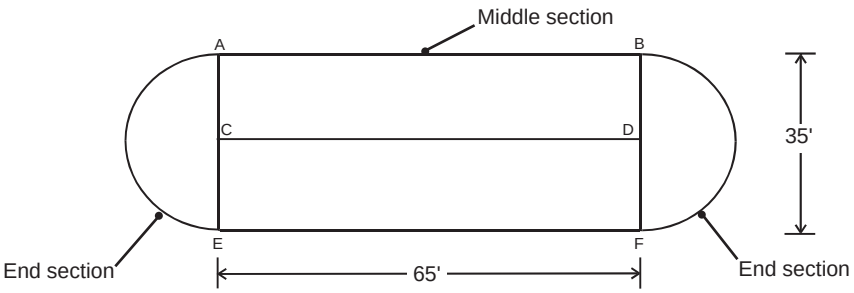
The middle section is the prism ABCDEF shown in Figure 11-1 C. The volume of a prism equals its end area times its length. The ends of a prism are triangles, like triangle ACE in Figure 11-1 C. Here's the formula you use to find its area:

Area = ½ × (base × height)

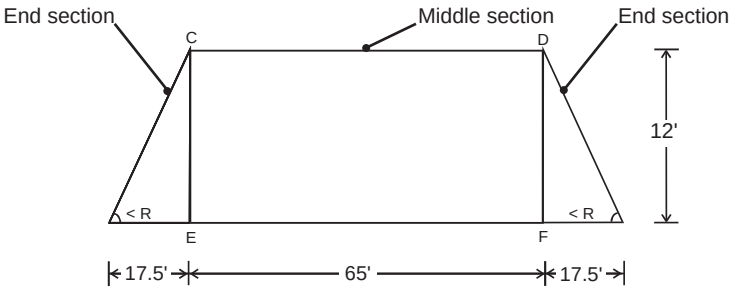
Area triangle ACE = ½ × (35 × 12)

= ½ × 420

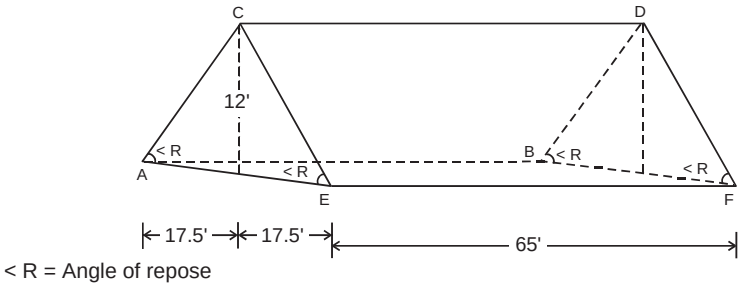
= 210 SF



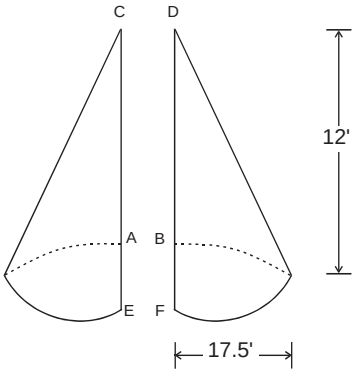
A. Top view



B. Front view



C. Middle section - prism



D. Combined end sections

Figure 11-1
Four views of a sample stockpile

Next we'll find the prism's volume in cubic feet. Multiply the end area (210 SF) by the prism's length (65 feet):

Prism volume (CF) = 210 × 65

= 13,650 CF

Finding the Volume of the Combined End Sections

Now let's find the volume of the two end sections. Remember, if we lump them together they form the cone in Figure 11-1 D. We'll find the volume of the whole cone using a diameter of 35 feet and a height of 12 feet. You'll recall that a circle's radius is half its diameter. But do you also recall the formulas we use to find the volume of an upside-down cone? Here they are:

Volume (CF) = $^1/_2$ × (base area × height)

Base area (SF) = πr^2

Now, plug in the values for the cone shown in Figure 11-1 D:

Base area = 3.1416×17.5^2

= 3.1416 × 306.25

= 962.12 SF

Next, you find the volume in cubic feet:

Volume = $^1/_3$ × (962.12 × 12)

= $^1/_3$ × 11,545.44

= 3,848.48 CF

Here's the formula to find the total volume of the stockpile in Figure 11-1 A in cubic yards:

Volume (CY) = (Prism volume + Cone volume) ÷ 27

Plug in the volumes for the prism and the cone that we've just calculated:

Total volume (CY) = (13,650 + 3,848.48) ÷ 27

= 17,498.48 ÷ 27

= 648.09 CY

Finding the Volume of a Stockpile of Unknown Height

Suppose you have to estimate the volume of a stockpile and you don't know how high the stockpile is. The easy part of the job is to measure the width and length of the stockpile. The hard part is finding the height of the pile.

When you dump or pile loose soil, it forms a peak at the top and slopes outward on all sides. The angle between the side of a stockpile and the ground is called the *angle of repose*. It's usually between 20 degrees (for very loose material such as muck) and 40 degrees (for firm material such as dry loam). Add more material to a stockpile and the angle of repose remains the same. Most of the added material slides down the sides of the pile. The base grows broader, while the height increases only slightly. No matter how much material you add, the angle of repose stays the same. And because the angle of repose is constant, we can use it to calculate the stockpile's height.

The Reverse Angle Method

We'll use the reverse angle method to find the stockpile height. To use this method you'll need a 100-foot tape, a standard carpenter's square and a plumb bob on a line. You use the 100-foot tape to measure the lengths of the stockpile's sides and ends. Then you use the carpenter's square and the plumb bob to determine angles.

Figure 11-2 A is a top view of our sample stockpile. Figures 11-2 B through 11-2 D are detail views of the same stockpile. We'll go through finding its height step by step.

Step 1 — Set up the carpenter's square:

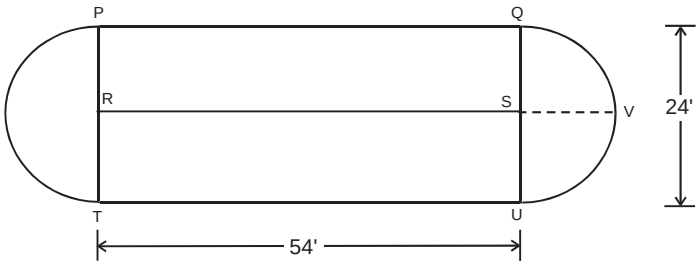
Stand the carpenter's square beside the stockpile, as shown in Figure 11-2, with the long leg horizontal and the short leg vertical. The bottom corner of the square's long leg should just touch the side of the stockpile, point X in Figure 11-2 B. It's important for the long leg of the square to be parallel to the ground and as level as possible. You can check this by resting a bubble level along the top edge of the square's long leg. The square is level when you center the bubble.

Step 2 — Set up the plumb bob:

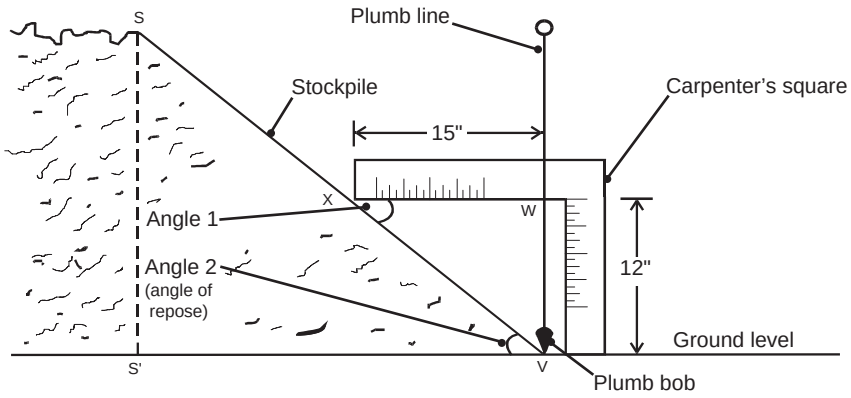
Hold the plumb line in front of the long leg of the square. Suspend the plumb bob so that its tip just clears the ground. Position the tip right over the point where the stockpile meets the ground; point V in Figure 11-2 B.

Step 3 — Find the tangent of the reverse angle:

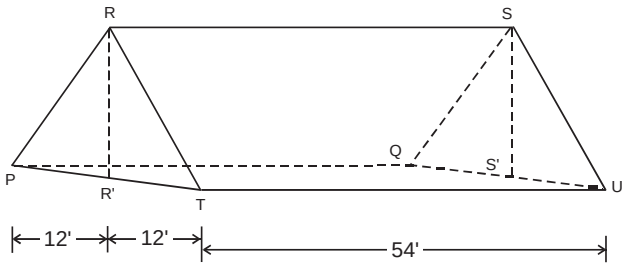
The plumb line crosses the long leg of the square at point W in Figure 11-2 B. Record the distance from the end of the leg to the plumb line. In Figure 11-2 B this distance is line XW and it's 15 inches long.



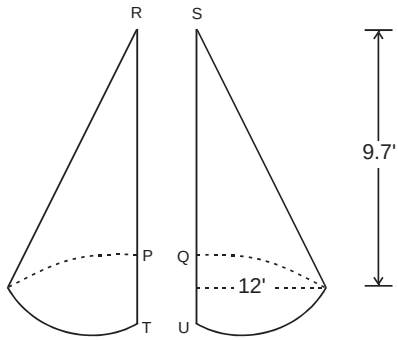
A. Top view



B. Setup for finding a reverse angle



C. Prism - middle section



D. Combined end sections

Figure 11-2
Finding the volume of a stockpile of unknown height

The short leg on a standard carpenter's square is 12 inches long. Check your square just to be sure that it's a standard square. Remember to use the inside scale for this measurement, not the outside scale. In Figure 11-2 B the short leg of the square and line WV both equal 12 inches.

You now know the lengths of two sides of triangle VWX in Figure 11-2 B. The ratio of the lengths of these two sides, XW and WV, is a mathematical function. It's called the tangent of an angle. Here's the formula:

Tangent of angle = Length of angle's opposite side ÷ Length of angle's adjacent side

In Figure 11-2 B, for Angle 1 the opposite side is line WV and the adjacent side is line XW. So, plug in the values we found for those two sides:

Tangent of Angle 1 = WV ÷ XW
= 12 ÷ 15
= 0.8

Now you can use that to find the angle of repose.

Step 4 — Find the angle of repose:

Once you know the tangent of an angle, it's easy to find the angle that produces that tangent. Figure 11-3 is a list of tangents for angles ranging from 20 to 40 degrees. These are the angles you're most likely to need when calculating stockpile volumes. Here's how it works. Find the tangent listed in Figure 11-3 that's closest to the tangent value we just found for Angle 1 (0.8). The closest listed tangent in Figure 11-3 is 0.80978. To find the angle for this tangent, read across to the angle column. A tangent of 0.80978 is formed by a 39-degree angle. Therefore, Angle 1 measures about 39 degrees.

We know that the top of the carpenter's square and the ground are parallel. So Angle 1 and Angle 2 are identical angles. We also know that Angle 2 is the stockpile's angle of repose. So the angle of repose is 39 degrees. But we're not finished yet. Remember we still need to find the stockpile height and volume.

Step 5 — Calculate height from the angle of repose:

Let's identify Angle 2's opposite and adjacent sides using Figure 11-2 B. Angle 2's opposite side is the broken line SS^1. Line SS^1 is also the stockpile height. Angle 2's adjacent side is line S^1V. We know the length of S^1V is half the width of the stockpile, or 12 feet (24 ÷ 2 = 12).

How do we find the length of SS^1? We'll use the tangent function.

Tangent of angle = Length of angle's opposite side ÷ Length of angle's adjacent side

Degrees	Tangent	Degrees	Tangent
20	.36397	31	.60086
21	.38386	32	.62487
22	.40403	33	.64941
23	.42447	34	.67451
24	.44523	35	.70021
25	.46631	36	.72654
26	.48773	37	.75355
27	.50953	38	.78129
28	.53171	39	.80978
29	.55431	40	.83910
30	.57735		

Figure 11-3
Tangents for angle of repose

We know the tangent for Angle 2 is 0.80978. We also know that the length of Angle 2's adjacent side is 12 feet. What we want to find is the length of the opposite side, so we'll rewrite the tangent function as follows:

Length of angle's opposite side = Tangent of angle × Length of angle's adjacent side

Now you just plug in the values:

$$\text{Length of } SS^1 = 0.80978 \times 12$$
$$= 9.7 \text{ feet}$$

Step 6 — Calculate the total volume:

Here's your chance to try out the procedures and formulas introduced at the beginning of this chapter. Using the data from Figure 11-2 and the preceding five steps, find the volume of the stockpile in cubic yards. After you've finished, compare your result with that shown in Figure 11-4.

Forces that Influence the Angle of Repose

As we have seen, the angle of repose is the angle between the ground and the surface of the pile. Most soils will hold a 30- to 45-degree maximum angle of repose.

Gravity is the primary force which causes a soil pile to spread. Surface-to-surface contact between aggregates causes friction, which works against the gravity that prevents a soil pile from spreading. On a per-unit volume basis, finer aggregates have

Calculation Sheet

Project:_____ Date:_____

Stockpile vol. (CY) = (prism vol. + cone vol.) ÷ 27

Prism vol. (CF) = end area x length
End area (SF) = ½ (base x height)
Prism (see Figure 11-2C)
End area = area of triangle PRT (see Figure 11-2C)
Prism length = 54'
Base ΔPRT is side PT
PT = 24'
Height ΔPRT = 9.7'
End area = ½ (24 x 9.7)
= ½ x 232.8
= 116.4 SF
Prism vol. = 116.4 x 54
= 6,285.6 CF

Cone vol. (CF) = ⅓ (base area x height)
Base area (SF) = πr^2
Cone (see Figure 11-2D)
Height = 9.7'
π = 3.1416
r = 12'
Base area = 3.1416×12^2
= 3.1416 x 144
= 452.4 SF
Cone vol. = ⅓ (452.4 x 9.7)
= ⅓ x 4,388.28
= 1,462.76 CF

$$\text{Stockpile vol. (CY)} = \frac{6{,}285.6 + 1{,}462.76}{27}$$

$$= \frac{7{,}748.36}{27}$$

$$= 287 \text{ CY}$$

Conclusion

Figure 11-4
Calculations sheet for sample stockpile volume

greater surface-to-surface contact area than coarse aggregates. Here are some general rules regarding soil-pile behavior for coarse-grained aggregates (gravels and sands) of comparable size:

- Large aggregate will spread more than smaller aggregate, and therefore have a lower angle of repose.
- All other things being equal, heavier aggregate will spread more than lighter aggregate.
- Rounded or smooth aggregate will spread more than angular-shaped aggregate.
- The higher the water content, the more the soil pile will spread.
- The farther the aggregate is dropped, the more the soil pile will spread.
- Poorly-graded aggregate will spread more than well-graded aggregate. Well-graded aggregate contains an even distribution of particle sizes that help create friction between the particles.

Calculating Volume for a Stockpile of Set Area

The space available for a stockpile location on most jobsites is limited. That means you'll often want to know how much material you can expect to stockpile in that space. A stockpile that spills over into another contractor's workspace won't make you any friends on the jobsite. And don't forget to leave yourself the workspace you'll need — which will depend on the type of equipment you use.

In Figure 11-5 A, you see a plan view for a stockpile. The dimensions, after allowing for workspace, are 30 feet wide by 70 feet long. Now, let's say that the angle of repose for the soil is 40 degrees. Find how much soil you can pile here using the tangent function and Figures 11-3, 11-5 A and 11-5 B.

Step 1 — Calculate the height:

Turn to Figure 11-3 and find the tangent for a 40-degree angle. The tangent is 0.83910. The length of the adjacent side is half the stockpile width (see Figure 11-5 A). The adjacent side is 15 feet (30 ÷ 2 = 15). The side opposite this angle is also the height dimension for the stockpile. Rewrite the tangent function to solve for the length of the angle's opposite side:

Length of angle's opposite side = Tangent of angle × Length of angle's adjacent side

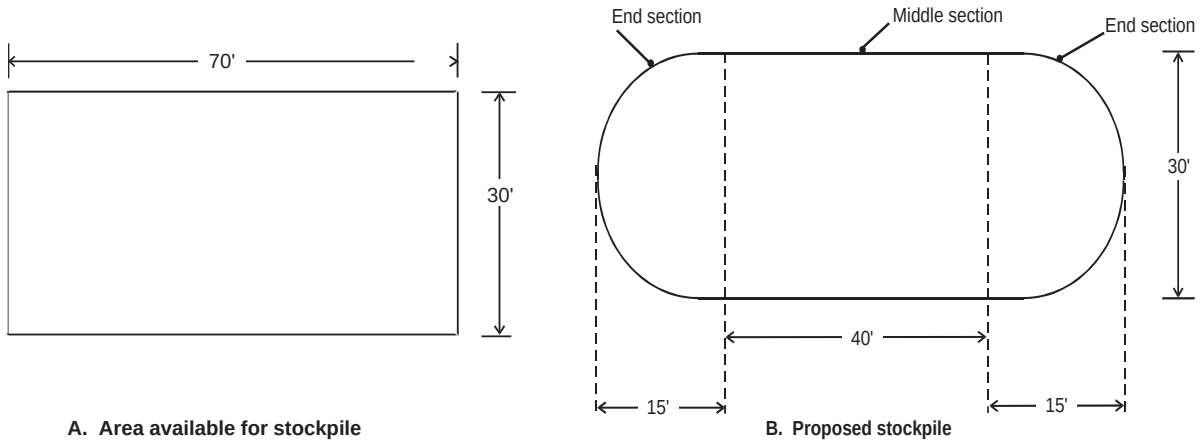


Figure 11-5
Calculating maximum stockpile volume in available area

Plug in the known values for the tangent of the angle and the length of the adjacent side. Here's the math:

Stockpile height (feet) = 0.83910 × 15

= 12.6 feet

Step 2 — Calculate the prism volume:

You use the dimensions from Figure 11-5 B, the height you found in Step 1, and these formulas:

Volume (CY) = (End area × Length) ÷ 27

End area (SF) = ½ × (Base × Height)

The prism length is 40 feet. Find the area for one end of the prism. This is a triangle 12.6 feet high with a 30-foot base. So the end area is:

End area (SF) = ½ × (30 × 12.6)

= ½ × 378

= 189 SF

Next you find the triangle's volume in cubic yards:

Volume (CY) = (189 × 40) ÷ 27

= 7,560 ÷ 27

= 280 CY

Step 3 — Calculate the cone volume:

Combine the two end sections of the stockpile and you have a cone. Use this formula to find the cone's volume in cubic yards.

$$\text{Volume (CY)} = [1/3 \times (\text{Area of base} \times \text{Height})] \div 27$$

The height is 12.6 feet (see **Step 1**). The base of a cone is a circle, and the area of the circle equals πr^2. So:

$$\begin{aligned}\text{Area of base} &= 3.1416 \times 15^2 \\ &= 3.1416 \times 225 \\ &= 706.86 \text{ SF (rounded to 706.9 SF)}\end{aligned}$$

And the volume of the cone is:

$$\begin{aligned}\text{Volume (CY)} &= [1/3 \times (706.9 \times 12.6)] \div 27 \\ &= [1/3 \times 8{,}906.94] \div 27 \\ &= 2{,}968.98 \div 27 \\ &= 109.96 \text{ CY}\end{aligned}$$

Step 4 — Calculate the total volume:

Just add the prism volume and the cone volume to find the total volume.

$$\begin{aligned}\text{Volume (CY)} &= 280 + 109.96 \\ &= 389.96 \text{ CY}\end{aligned}$$

We'll round that off and call it 390 cubic yards. That's the maximum possible volume of this soil that you could stockpile in the area shown in Figure 11-5 A. But there's one last calculation to make. You still need to convert the stockpile volume into loose cubic yards by applying the correct swell factor.

In the next chapter, I'll describe how engineers and estimators use balance points to "balance" the cut and fill. On an ideal job, you don't have either spoil or borrow — because cut and fill balance exactly. You won't see a job like that every day. But it's always the goal.

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12

Balance Points, Centers of Mass & Haul Distances

Both engineers and estimators use the words balance point, but to each, these words mean something entirely different. To an engineer, the *balance point* is an imaginary line where the cut on one side of the line is equal to the fill on the other side of the line. Engineers try to plan earthwork so the volume of cut matches (balances with) the fill volume. But excavation estimators know that cutting and filling soil isn't an exact science, so what's planned as a balanced job may not work out that way. They have a different understanding of a balance point.

Balance Points to an Excavation Estimator

To the excavation estimator, the balance point is midway between the cut and the fill. A very simple example is shown along the Profile 2 line in Figure 12-1. The cut volume and the fill volume are identical. That's not going to happen in real life, but for the purpose of this explanation, let's say it is. Later in this chapter we'll look at some complex cut and fill jobs, where the cut and fill volumes aren't equal. For now, I'll use Profile 2 in Figure 12-1 to define three concepts important to any earthwork estimator: *center of mass, haul distance* and *balance point*. We'll start with the center of mass.

Figure 12-1 has two centers of mass. The center of mass for the cut area is line A-A. The center of mass for the fill area is line B-B. The distance separating these two centers of mass, measured along Profile 2, is the haul distance. The midpoint on Profile 2, between lines A-A and B-B, is the balance point.

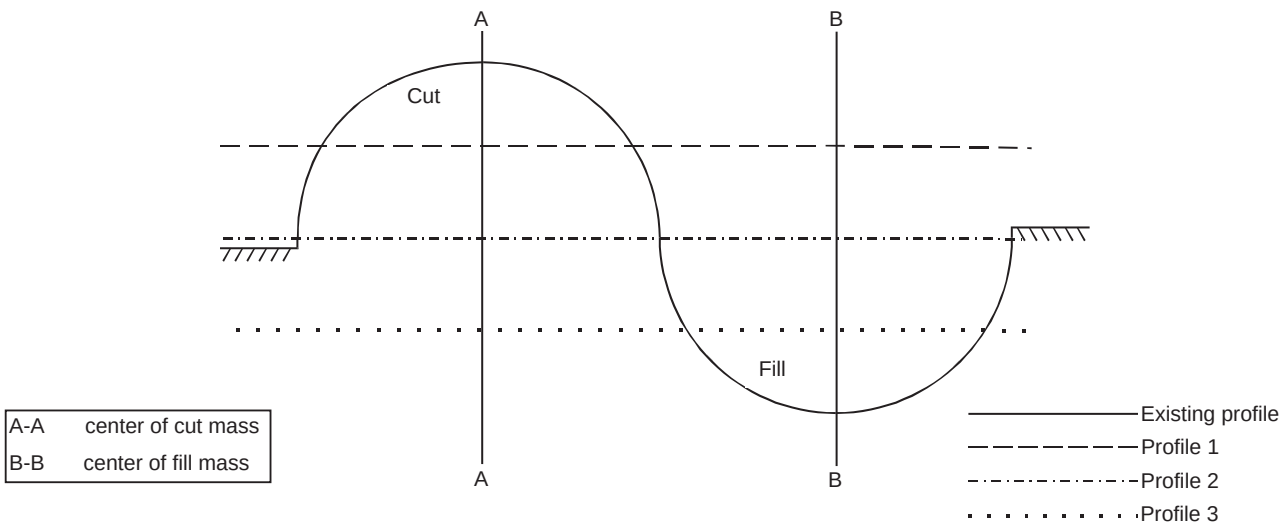


Figure 12-1
A simple example of balancing cut and fill

Why are these concepts so important? Because you can't find your haul distance unless you know the locations of both centers of mass. The balance point tells you how far you'll have to move the soil. And you use the haul distance to determine your round trip, or cycle time, per load. Basically, the greater the haul distance, the greater your cost.

In this chapter, you'll learn how excavation estimators find balance points, and you'll get to practice that skill by calculating average haul distance for a sample project.

Balance Points to an Engineer

An engineer determines the finish grade, or grades, that appear on the project plans using arbitrary balance points. Let's look at how balance points work using a pair of examples. We'll start by taking another look at Figure 12-1.

This profile shows the existing profile plus three possible finish profiles for a project. Notice how much alike the cut and fill areas are in shape and size. If you compare the three proposed profiles using their different proportions of cut and fill volume, here's what you find:

Profile 1: Small cut volume versus very large fill volume.

Profile 2: Cut and fill volume are about equal.

Profile 3: Very large cut volume versus small fill volume.

Obviously the best finish grade for the project shown in Figure 12-1 is Profile 2. In this case that's a pretty simple choice. But in reality it's never that straightforward.

Figure 12-2 shows a more realistic example. It's a profile view of a one-mile section from a larger project. There are three profiles shown in Figure 12-2: the existing profile and two proposed finish profiles. The shapes of the cut and fill areas aren't symmetrical and the cut and fill volumes aren't equal for either finish profile.

Now let's compare the two proposed profiles. Profile 1 is a level surface with a single elevation. Profile 2 slopes in from both ends toward the center, providing drainage for the site. Profile 1 requires a much larger volume of fill material than you'll have onsite from the cuts. Finishing the job would mean importing a large volume of fill from an offsite borrow pit. Profile 2 requires a smaller volume of imported fill, and with careful planning, comes close to balancing. Profile 2 has another advantage — a shorter haul distance. The lowest elevations for Profile 2 roughly match the lowest existing elevations.

Engineers understand how important carefully planned profiles are and do their best to balance the job and shorten haul distances. But no matter what the engineer has done or failed to do, make sure your plans use the minimum possible haul distance.

Reducing Haul Distances

There are two types of costs in every excavation job: the cost of loading soil and the cost of moving soil once it's loaded. The cost of loading soil will be about the same for every contractor using equipment appropriate for the job. But the cost of hauling soil will be lower for the contractor who's able to reduce the average haul distance. Any money you save by reducing the average haul distance adds to your profit on the job. Good planning can maximize both equipment productivity and profit.

In Figure 12-2 I've used the capital letters, A, B, C and D to label the cut areas, and lower case letters, *a, b, c* and *d* for the fill areas. How would you plan this job? Well, you might start at cut A and move to fill *a*. Then you'd move to cut B and use part of this material to finish fill *a*, and the rest to start on fill *b*. Then you'd move on to cut area C and so on. I suppose that would work. And many contractors tackle the problem that way, working from left to right or north to south, finishing one area and then moving on to the next.

But your equipment access to the section shown in Figure 12-2 is at cut C. You have to begin work at the center and move toward the ends. Which way do you fill from cut C? Does the material go into fill *b* or fill *c*? And, if fill *c*, how much goes into *c* before you start filling at *b*?

Here's what happens if you don't plan this, or any job, carefully. You end up hauling a lot of fill a mile or more from cut area A to fill *d*. That's the expensive way to do cut and fill work.

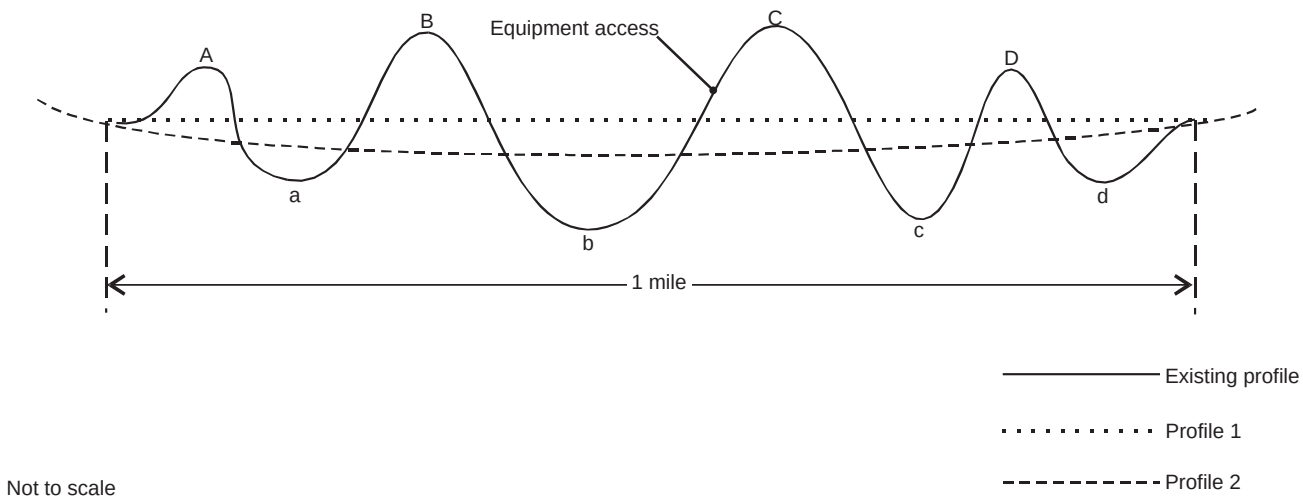


Figure 12-2
A more complex example of balancing cut and fill

Let's work though two examples. The only difference between these two examples is the location of the borrow pit. Both assume the following:

- The finish profile will be Profile 2 in Figure 12-2.
- Volumes of cut and fill are listed in Figure 12-3.
- The swell/shrink factor is 1.14.

Example 1

Assume the borrow pit lies between cut areas C and D in Figure 12-2. Here's a five-step plan for this job.

Step 1 — Fill area *a*:

You need a total of 3,500 cubic yards of material here. Use 1,000 cubic yards from cut area A plus 2,500 cubic yards from cut area B for a total of 3,500 cubic yards. You have 500 cubic yards left from cut area B.

Step 2 — Fill area *b*:

Here you need a total of 8,000 cubic yards of material. Use the 500 cubic yards you have left from cut area B, plus all 7,000 cubic yards from cut area C, plus 500 cubic yards from cut area D for a total of 8,000 cubic yards. You have 700 cubic yards left from cut area D.

Cut Areas	Volume (CY)
Area ***A***	1,000
Area ***B***	3,000
Area ***C***	7,000
Area ***D***	1,200
Total cut	**12,200**

Fill Areas	Volume (CY)
Area ***a***	3,500
Area ***b***	8,000
Area ***c***	9,000
Area ***d***	1,700
Total fill	**22,200**

Figure 12-3
Cut and fill volumes for the sample project shown in Figure 12-2

Step 3 — Fill area *d*:

This fill area requires a total of 1,700 cubic yards of material. You have 700 cubic yards of material from cut D left to use. Fill area d is short 1,000 cubic yards. This material comes from the borrow pit.

Step 4 — Fill area *c*:

The total volume of fill needed here is 9,000 cubic yards. All of this material comes from the borrow pit.

Step 5 — Finishing fill areas *c* and *d*:

You need another 10,000 cubic yards (1,000 + 9,000) of material. Apply the shrink factor, 1.14, to arrive at the total borrow volume of 11,400 compact cubic yards.

Under this plan, the fill areas where you need the borrow material are the closest to the borrow pit and the result is minimum haul distance.

Example 2

Assume the borrow pit lies to the left of cut area A in Figure 12-2. Here's our plan for this job.

Let's start by supposing that you ignore the change in the borrow pit's location. You decide you'll just use the same plan as for Example 1. Here's what happens. To finish the job in fill areas *d* and *c*, you'll end up hauling borrow material from one end of the project to the other! Not a very efficient way to do the job, is it?

There's a better way to plan this job. Let's see how, using the volumes listed in Figure 12-3.

Step 1 — Fill area *d*:

We'll start by using all 1,200 cubic yards from cut area D plus 500 cubic yards from cut area C for fill area *d*.

Step 2 — Fill area *c*:

For fill area *c* you need 9,000 cubic yards. Combine the leftover 6,500 cubic yards from cut area C with 2,500 cubic yards from cut area B.

Step 3 — Fill area *b*:

That brings you to fill area *b*, where you need 8,000 cubic yards. Use the 500 cubic yards you still have left from cut area B, plus 1,000 cubic yards from cut area A, to start on fill area *b*. The remaining 6,500 cubic yards you need to finish fill area b comes from the borrow pit.

Step 4 — Fill area *a*:

And don't forget fill area *a*, where you need 3,500 cubic yards. This material will also come from the borrow pit.

Step 5 — Finishing fill areas *b* and *a*:

Total borrow, after applying the shrink factor of 1.14, is 11,400 compact cubic yards, just as in Example 1. But by carefully planning the cut and fill, you wind up with the two fill areas using borrowed material as close as possible to the borrow pit. That means the minimum haul distance — and the minimum cost.

Always try to find a way to minimize haul distance. A little creative thinking sometimes helps. Here's an example of what I mean. Take another look at fill area *d* and cut area D in Example 1. Remember, the borrow pit is located between cut areas C and D. That also happens to be the location of fill area *c*. Here's what I'd try in a case like this. I'd go to the project engineer and ask for permission for a temporary overcut of 1,000 cubic yards in cut area D. With this additional material I'll complete not only fill area *b* but also all of fill area *d*. After that I'll bring cut area D back up to grade using material from the borrow pit.

But never carry out a creative solution unless your plan's been approved by the project engineer or manager.

Calculating Haul Distances

To plan cut and fill work, you have to calculate not only the volume to be moved but also the center of the mass. Knowing the center of mass, or CM, you can set balance points. Your balance points don't need to be exact, but the more accurate they are, the more money you'll save on hauling.

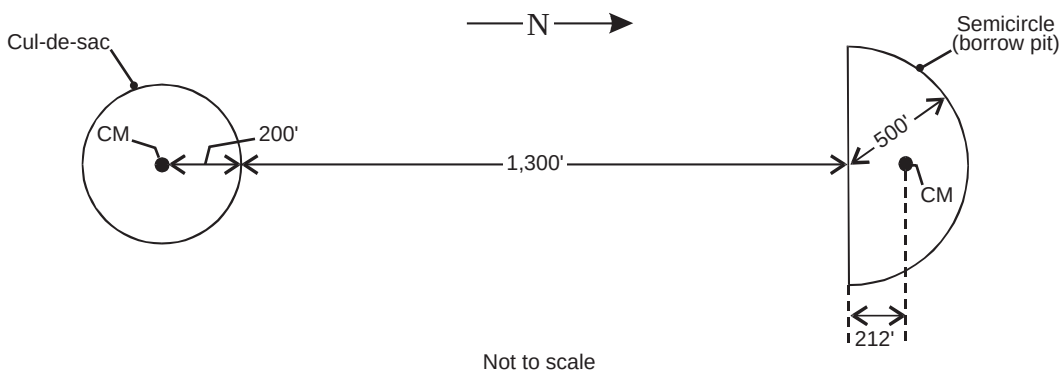


Figure 12-4
Haul distance

To calculate the balance point, you have to know the haul distance. To know the haul distance, you have to know the center of mass. So let's begin by finding the center of mass.

Figure 12-4 shows a typical problem. The contractor will use material from the semicircular area on the north end of the job to build up the cul-de-sac circle on the south end. The haul distance, measured from cul-de-sac edge to semicircle edge, is 1,300 feet. Obviously, not all the soil is excavated at the edge of the semicircle, and it's not all dumped at the edge of the cul-de-sac. Therefore, the actual haul distance on this job is more than 1,300 feet for nearly every load.

We need to find the average haul distance for this project, and that's a three-step process. First, we'll find the distance between the south edge of the semicircle and the north edge of the cul-de-sac. Second, we'll find the distance from the edge to the center of mass, CM in Figure 12-4, for both the semicircle and the circle. Third, the average haul distance equals the sum of three distances: fill area edge to center of mass, plus borrow pit edge to center of mass, plus edge to edge.

Finding the Distance from Edge to Center of Mass

Figure 12-5 lists the formulas we need to calculate the distance from the edge of a circle, semicircle, rectangle or a triangle to the center of mass. These formulas use the following abbreviations:

CM = center of mass	x = distance from center of mass to an edge
r = radius	d = diameter
h = height	w = width
b = base	A-A and B-B = axis drawn through the center of mass

Calculating the Haul Distance for a Circle

Using the circle in Figure 12-4 and the first formula from Figure 12-5, let's find the average haul distance. Notice that the formula used for a circle is very simple.

$$x_a = x_b = d \div 2 = r$$

Because they're radii for the same circle, x_a and x_b are exactly the same length. We know from Figure 12-4 that the radius of the circle is 200 feet. So, for the cul-de-sac end of the job we'll add 200 feet to the haul distance.

Calculating the Haul Distance for a Semicircle

Now let's find the average haul distance for the semicircle in Figure 12-4. We'll use the following formula for a semicircle from Figure 12-5:

$$x_b = 0.424 \times \text{radius}$$

We know the radius for the semicircle from Figure 12-4 is 500 feet so:

$$\begin{aligned} x_b &= 0.424 \times 500 \\ &= 212 \text{ feet} \end{aligned}$$

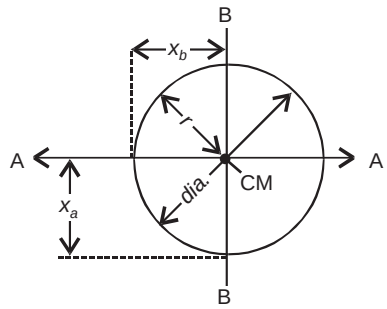
The semicircle adds 212 feet to the edge-to-edge haul distance.

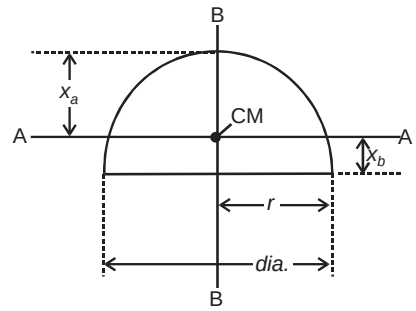
The average haul distance is the sum of the two edge-to-center-of-mass distances plus the edge-to-edge haul distance given in Figure 12-4. Here's the math:

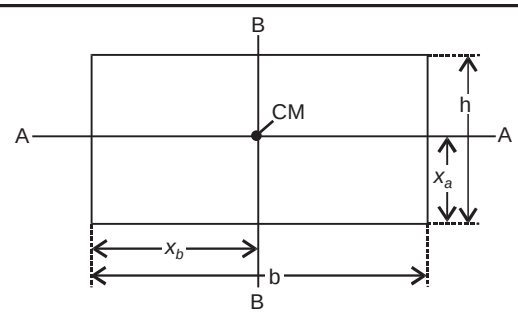
$$\begin{aligned} \text{Average haul distance} &= 1{,}300 + 200 + 212 \\ &= 1{,}712 \text{ feet} \end{aligned}$$

Break-Even Point (BEP)

There are times when you might want to consider whether the initial cost of improving production on a project is worth the expense. For example, let's say you have a project requiring 10,000 cubic yards of export. You could shorten the haul route by building a bridge across a stream, but it will cost $5,000 to build. You've determined the cost per cubic yard using the longer route will be $4.00 per cubic yard, and using the bridge route will be $2.00 per cubic yard. At what point would it be worth the money to build the bridge?

Formula	Circle
$x_a = x_b = \frac{d}{2} = r$	

Formula	Semicircle
$x_a = \frac{d(3p - r)}{6p} = .288d = .576r$ $x_b = \frac{2d}{3p} = .212d = \frac{4r}{3p} = .424r$	

Formula	Rectangle
$x_a = \frac{h}{2}$ $x_b = \frac{b}{2}$	

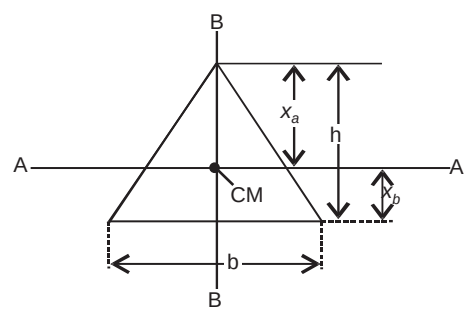
Formula	Triangle
$x_a = \frac{2}{3}h$ $x_b = \frac{1}{3}h$	

Figure 12-5
Formulas for calculating center of mass

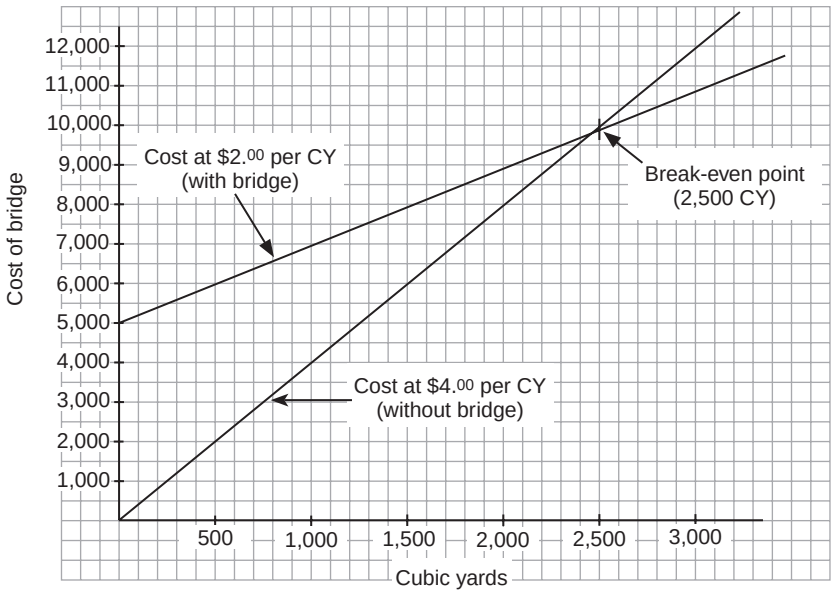


Figure 12-6
Break-even point

To determine the break-even point (BEP), use the following formula:

BEP = Bridge cost ÷ Cost savings per CY

BEP = 5,000 ÷ (4 – 2)

= 5,000 ÷ 2

= 2,500 CY

Since the project requires 10,000 cubic yards of export, building the bridge would save money (see Figure 12-6). Any quantity (cubic yards) below the BEP makes the bridge unfeasible, and any quantity above the BEP makes the bridge worthwhile.

Had the bridge cost $5,000 to build and the cost savings only $0.40 per cubic yard, the BEP would be 5,000 ÷ 0.40 = 12,500 cubic yards. The bridge would unfeasible, since the project requires only 10,000 cubic yards of export.

Finding a Vertical Center of Mass

So far we've assumed that cut and fill depths are uniform throughout each cut and fill area. In reality that's seldom the case. Cuts and fills are deeper in some places and shallower in others. The result is a proportional shift in the location of the center of mass. But if the location of the center of mass changes, so does your average haul distance. This raises two big questions:

1. How do you find the center of mass for an area without a uniform depth?
2. How does it factor into your average haul distance calculations?

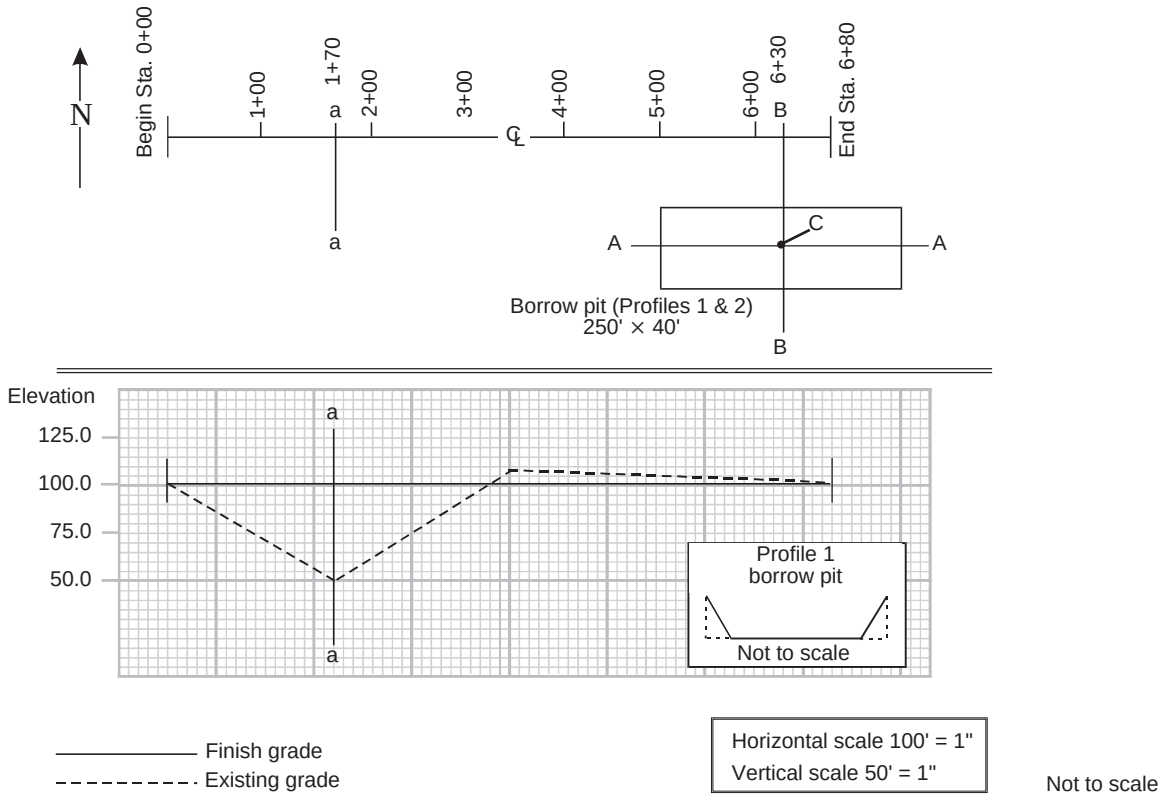


Figure 12-7
Plan and profile sheet for a section of a road project

The best way to answer both questions is with an example. In this example we'll find two different average haul distances. The first average haul distance assumes an area with a uniform depth. The second average haul distance is for an area without a uniform depth. Otherwise it's identical to the first area.

Figure 12-7 is the plan and profile sheet for our sample project, a 680-foot-long section of a road project. Let's take a close look at both parts of Figure 12-7. We'll start at the top of the sheet with the plan view.

The plan view, you remember, is an overhead view of the jobsite. The main features of any plan view are the centerline and a series of measured distances, usually at 100-foot intervals, marked along the length of the centerline. In Figure 12-7, the measured distances start on the left with Sta. 0+00 and end on the right with Sta. 6+80. The station-to-station interval is 100 feet, except for Stations 1+70, 6+30 and 6+80. Why are they different from the rest? Let's find out.

The reason Station 6+80 doesn't follow the rule is easy to explain. Station 6+80 marks the eastern limit of this jobsite. But this won't work as an explanation for the other two remaining stations. Did you notice that Sta. 1+70 and Sta. 6+30 (and none of the others) have alternative names? Station 1+70 is also line *a–a*, and Sta. 6+30 is also line

B–B. As you'll recall from Chapter 6, surveyors don't just mark off the standard 100-foot intervals on a centerline — they also stake important features and significant changes in elevation.

The reason Sta. 1+70 is special is obvious as soon as you look at the profile view in the lower half of Figure 12-7. Station 1+70, or line *a–a*, passes through the lowest point found along the existing elevation, shown with a dashed line. But that's not all. Line *a–a* also divides this fill area, roughly an equilateral triangle, into two equal parts. So line *a–a* is the fill area's center of mass.

Sta. 6+30, or line B–B, also marks one axis for a center of mass. The mass, of course, is the rectangle just south of the centerline at Sta. 6+30 labeled Borrow pit (Profiles 1 & 2). This 250- x 40-foot borrow pit is the source for all the fill material we'll use on this project. Line B–B divides the borrow pit into two equal parts across its width, and line A–A does the same along the borrow pit's length. The point where B–B and A–A cross is labeled C. Line B–B doesn't appear in the profile view in Figure 12-7 because the borrow pit's not located along the road centerline.

Like most plan and profile sheets, Figure 12-7 uses one scale for horizontal dimensions and another scale for vertical dimensions. Plan and profile sheets always list the scales used, and so does Figure 12-7. We'll scale off the dimensions, using the borrow pit dimensions and these scales from Figure 12-7:

- Horizontal scale: 100' = 1"
- Vertical scale: 50' = 1"

Let's start off with the borrow pit width. From the plan view we know that the actual width is 40 feet. What's the equivalent measured plan dimension using the vertical scale? To find out, divide 40 by 50; the answer is 0.8 inch.

Now let's do a reverse calculation. Take a measurement off of the plan sheet and change it back to an actual distance. Suppose you measured the borrow pit's length from the plan view in Figure 12-7, and it measured 2.5 inches long. Using the horizontal scale, what's the borrow pit's actual length in feet? To find out, you just multiply 2.5 by 100. The result is 250 feet.

The distance from the road centerline to the north edge of the borrow pit is next. We measure 0.7 inch, then multiply by 50 to find an actual distance of 35 feet.

Now we'll find the average haul distance for the sample project shown in Figure 12-7, using two different borrow pit profiles: Profile 1 and Profile 2.

Calculating Average Haul Distance for Profile 1

You probably noticed the small profile view of the Profile 1 borrow pit at the lower right of Figure 12-7. But be sure that you also notice the note that says: Not to scale.

Why include this profile view? To show you that it's symmetrically shaped. And that's important because it makes finding its center of mass much easier. Here's how it works. The fact that the sides slope equally allows us to ignore the slope. Instead, we'll proceed as if this borrow pit had a uniform depth and treat it like a simple rectangle. To find this rectangle's center of mass we'll use these formulas from Figure 12-5:

x_a = Width ÷ 2

x_b = Length ÷ 2

You'll find the borrow pit dimensions in Figure 12-7:

- Length = 250 feet
- Width = 40 feet

And here's the math:

x_a = 40 ÷ 2

= 20 feet

x_b = 250 ÷ 2

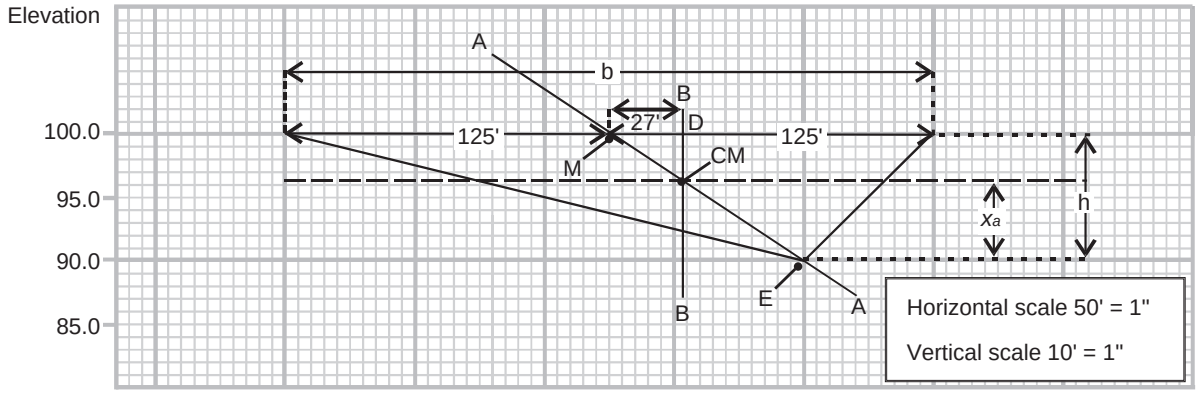
= 125 feet

At the scale used in Figure 12-7, the lines would be 0.8 and 1.25 inches long. Line A–A divides the borrow pit into two equal parts from west to east. Line B–B, meanwhile, divides the borrow pit into two equal parts from north to south. The point labeled C marks the intersection of lines A–A and B–B.

The distance separating Station 1+70 (fill area center) and Station 6+30 (borrow pit center of Profile 1) is 460 feet (630 – 170 = 460). But this is only part of the average haul distance because it's measured along the centerline of the roadway. We need to add on two more distance measurements to find the average haul distance. First, add the distance from the roadway centerline to the edge of the borrow pit. That's 35 feet. Second, add the distance from the edge of the borrow pit to its center of mass. That distance is the same as the value we found earlier for x_a — 20 feet. Add all three distances and the result is the average haul distance for the Profile 1 borrow pit.

Distance from Sta. 1+70 to Sta. 6+30	460 feet
Distance from roadway to edge of borrow pit	35 feet
Distance from edge to center of mass	+ 20 feet
Average haul distance =	515 feet

That takes care of calculating average haul distances for all the symmetrical borrow pits out there. Unfortunately, there aren't many. Most borrow pits don't look like Profile 1. Instead, most borrow pits look a lot more like the one in Profile 2 (see Figure 12-8).



E	apex of triangle & point of lowest elevation = 90.0'	A-A	= axis passing through points E and M
b	triangle base & horizontal baseline, length = 250'	B-B	= axis perpendicular to b & passing through CM
		CM	center of mass
h	triangle height/depth = 10'	x_a	= $^2/_3 \times$ h = 0.667 × 10 = 6.67'
M	midpoint, horizontal baseline = b ÷ 2 = 250 ÷ 2 = 125'	x_b	= $^1/_3 \times$ h = 0.333 × 10 = 3.33'

Not to scale

Figure 12-8
Profile view of borrow pit *Profile 2*

Calculating Average Haul Distance for Profile 2

When you're working with a borrow pit shaped like Profile 2, most of the material comes from the far end of the pit. That means your average haul distance is longer. The big question is, how much longer?

Here's a rundown of what we know about the borrow pit in Figure 12-8:

- Length = 250 feet
- Width = 40 feet
- Depth = 10 feet

Profile 2 is an oblique triangle — it's not symmetrical. In the plan view, Profile 2 and Profile 1 are identical. That means we can skip calculating the following distances for Profile 2:

- Distance from roadway to pit edge = 35 feet
- Distance from pit edge to center of mass = 20 feet
- Distance from Sta. 1+70 to Sta. 6+80 = 460 feet

The cross section's center point and the center of mass aren't the same point. As you might expect, the center of mass for Profile 2 is off-center and nearer to the pit's deepest point. But notice that I said the center of mass is closer to the deepest point.

No matter how irregular a shape is, you can always find its center of mass by using sophisticated mathematics. But lucky for us, there's an easier way. Your results won't be quite as accurate using this method, but they'll be more than adequate for an estimate.

In Figure 12-8, the Profile 2 borrow pit is 250 feet long and 10 feet deep. Now let's find its center of mass.

Step 1 — Find the horizontal midpoint:

The base of the triangle that is the Profile 2 borrow pit is also the horizontal baseline. You find the horizontal midpoint by dividing the length of the base, 250 feet, by 2. The result is 125 feet (250 ÷ 2 = 125). Using the horizontal scale from Figure 12-8, 50' = 1", so 125 feet scales off as 2.5 inches (125 ÷ 50 = 2.5). Measure 2.5 inches in from either end (west or east) along the horizontal baseline and mark this point. In Figure 12-8 I call this point M.

Step 2 — Add line A–A:

Line A–A is an axis that connects the horizontal midpoint, point M, and the deepest point in Profile 2, point E.

Step 3 — Find the vertical midpoint and the vertical baseline:

We'll use the center of mass formulas for right and oblique triangles from Figure 12-5 to locate the vertical midpoint for Profile 2. Here they are:

$$x_a = {}^2/_3 \times h$$

$$x_b = {}^1/_3 \times h$$

The depth of the borrow pit, *h*, is 10 feet.

$$\begin{aligned} x_a &= {}^2/_3 \times 10 \\ &= 0.667 \times 10 \\ &= 6.67 \text{ feet} \end{aligned}$$

At the vertical scale of 10' = 1", that's 0.667 inches (6.67 ÷ 10 = 0.667). In Figure 12-8 the borrow pit's deepest point is point E. You'd measure 0.667 inches up from point E and make a light pencil mark. Then add a second baseline, the vertical baseline, that passes through that point and is parallel to the horizontal baseline, *b*.

Step 4 — Find the actual center of mass:

Line A-A, which passes through and connects points E and M, also intersects the vertical baseline (dashed line) established at the vertical height of x_a. In Figure 12-8, the point where line A-A intersects this line is the actual center of mass for Profile 2. This intersection is the point labeled CM in Figure 12-8.

Step 5 — Find the edge-to-center-of-mass distance:

Draw a perpendicular line that passes through point CM and intersects the horizontal baseline *b*. In Figure 12-8 this is line B-B. Point D marks the intersection of line B-B and the horizontal baseline *b*. The distance between point CM and point D is the distance from the edge to center of mass. In Figure 12-8 the distance between CM and point D measures 0.54 inch, which is 27 feet ($0.54 \times 50 = 27$). So, the center of mass for this borrow pit lies 27 feet east of its horizontal midpoint.

Step 6 — Calculate the average haul distance:

Simply add 27 feet to the 515 total haul distance we calculated for Profile 1, increasing it to 542 feet.

I recommend ignoring the vertical haul distance of 6.67 feet. Like most vertical haul distances, this one's too small to be worth the bother.

In the next chapter we'll look at the costs of doing business as an excavation contractor. Those costs include machine production rates, operating expenses, and owning equipment.

13

Earthmoving Equipment: Productivity Rates and Owning & Operating Costs

Up to this point we've been concentrating on estimating volumes of earthwork. Volume is always important on an earthwork job and it's rarely easy to estimate. But there's more to estimating earthwork than calculating volumes. In this chapter we'll change our focus. We'll look at costs that good estimators never overlook in their estimates.

The costs we'll cover fall into three categories:

- Equipment — purchase or lease costs, maintenance and operation costs
- Labor — costs for wages, insurance, withholding and other taxes
- Overhead — costs for office space, equipment, supplies and onsite expenses

Contracts for earthwork projects are awarded by the competitive bid process. General contractors invite bids from companies that specialize in excavation work. The excavation contractors submit bids based on the project plans and specifications provided by the general contractor. Each bid quotes a dollar cost per cubic yard of material moved. As an estimator, it's your job to work up these bids. That means calculating two different cost totals in dollars per cubic yard for each job. One of these totals comes straight from the amount of material that's moved. The second total covers the costs of doing business as an excavation contractor.

As an excavation estimator you're a member of the contractor's planning team. You'll help decide what personnel and machines to use on each job. One construction company I worked for paired up a field superintendent and an estimator for each project. They worked as a team and developed a coordinated plan of attack for each project. This team not only organized the job but also scheduled the equipment. Projects ran smoothly and on schedule.

Good equipment cost estimates start with good equipment operating cost records. The more performance records you have, the better your chances of developing accurate cost figures to use in bids. If you don't have the records, then you'll have to estimate average annual operating costs. If you have equipment records from past jobs, I strongly recommend using them as the basis for your operating costs. Operating costs based on actual experience are much better and more realistic than any estimate.

Obviously, I don't have your actual equipment costs, so instead I've used my own data in this chapter. And I've included the formulas and factors you need to calculate costs from your own data.

There are three major factors to consider when you develop machine ownership and operating costs: power, speed, and production. This chapter covers all three factors in depth. We'll begin with power.

Machine Power

Each earthmoving machine has only a certain amount of available power. An important part of your job as an earthwork estimator is matching your machine's usable power with your job's power requirements. Usable power is the available power limited by job conditions. Required power is the amount of power it takes to move not only the machine but also its load. If you do work under special conditions, there may be local factors to take into considerations when calculating power, such as thin air at high altitudes. But in most situations, there are just two important factors that determine the amount of power you require: rolling resistance and grade resistance.

Rolling resistance is the force the ground exerts against the machine through its tires, measured in pounds of pull. The machine won't move without enough power to overcome this resistance.

Grade resistance is the force exerted by gravity on a machine as it moves uphill or downhill. This is also measured in pounds. Grade resistance is a dual factor — it acts positively under some conditions and negatively in others. The effect of grade resistance depends on the direction of travel relative to the grade. It's a negative when you travel uphill and a positive when you go downhill.

Rolling Resistance

Forces that affect rolling resistance include friction, maintenance, tire design and inflation.

Here's a rule of thumb for roughly estimating rolling resistance: Rolling resistance equals 40 pounds per ton of weight on bias tires and 30 pounds per ton of weight on radial tires.

Surface type & condition	Rolling resistance factors (lb/ton)*
Concrete or asphalt	40
Hard gravel surface	65
Packed snow	50
Loose snow	90
Packed dirt	100
Loose dirt	150
Loose sand or gravel	200
Soft, muddy dirt	320

*Rolling resistance factors are applicable only when calculating resistance for wheeled equipment.

Figure 13-1
Rolling resistance factors for wheeled machines

This rule of thumb assumes:

- normal maintenance
- a hard, level road surface
- wheeled machines

If either the road surface or equipment falls short of those assumptions, you'll need more power to move each ton.

I'm willing to assume that all of your equipment is well-maintained and in top-notch running condition. But the road conditions are another matter entirely! How many smooth, hard-surface, level roads have you seen lately on jobsites, or anywhere else? There aren't many roads with ideal surfaces in the real world. And that's where rolling resistance (RR) factors come into play. You use RR factors to compensate for all the different variations for less-than-ideal road conditions. You'll find a table of RR factors, based on road surfaces, in Figure 13-1.

Here's how you use RR factors in a formula for rolling resistance:

RR (lb) = Weight on wheels (tons) × RR factor

Remember, you only use RR factors in resistance calculations for wheeled equipment. Why don't RR factors apply to track equipment? Track machines carry their own road surface with them and it's always the same. The machine's tracks are its road surface.

Now let's try out the formula using the RR factors from our table. Suppose you have a 12-ton truck traveling on a level packed-dirt road. We need to find the rolling resistance in pounds. Figure 13-1 shows that a surface of packed dirt has a RR factor of 100. So your values are 12 tons for the weight on the wheels, and 100 for the RR factor.

Here's the calculation:

RR (lb) = 12 × 100

= 1,200 lbs

Now let's change things around a bit. Say that you're running a pull-type scraper behind a wheeled tractor. What does this change mean for the way you'll find the weight on wheels? It means the weight on wheels doesn't include the tractor's weight.

The weight on wheels now consists only of the scraper's weight. This is because the tractor furnishes all of the push or pull pounds needed here. If the tractor's attached to, or it's part of, the scraper, then the weight on wheels is the sum of three weights: tractor, scraper and the load.

Finding Rolling Resistance

How much resistance a machine works against makes a great deal of difference in how much power it takes to do a job. Here's a pair of examples that demonstrate my point.

Example 1

We'll say a wheeled tractor attached to a fully-loaded scraper is moving on a level, packed-dirt road. The wheeled tractor weighs 25,000 pounds. The scraper weighs 23,000 pounds and has a full load of material weighing 21,000 pounds. Using the RR factors in Figure 13-1, find the rolling resistance.

Step 1 — Find weight on wheels (tons):

You recall that the tractor's attached to the scraper, so weight on wheels equals the tractor weight plus the scraper weight plus the load weight. We know what all of these weights are in pounds, but we want the result in tons. Just find the sum of the weights and divide the result by 2,000:

$$\begin{aligned}\text{Weight on wheels (tons)} &= (25{,}000 + 23{,}000 + 21{,}000) \div 2{,}000\\ &= 69{,}000 \div 2{,}000\\ &= 34.5 \text{ tons}\end{aligned}$$

Step 2 — Find rolling resistance (lb):

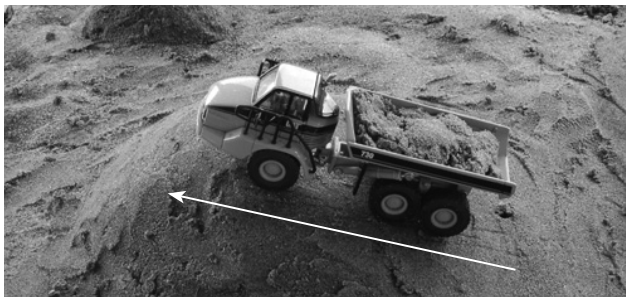
The RR factor for a packed-dirt road is 100, so here's the equation:

$$\begin{aligned}\text{Rolling resistance (lb)} &= 34.5 \times 100\\ &= 3{,}450 \text{ lbs}\end{aligned}$$

Example 2

We'll change just one variable. In this example the road surface is soft, muddy dirt. Everything else is the same as in Example 1. Check Figure 13-1 and you'll find the RR factor for soft, muddy dirt is 320:

$$\begin{aligned}\text{Rolling resistance (lb)} &= 34.5 \times 320\\ &= 11{,}040 \text{ lbs}\end{aligned}$$



Rolling resistance = 10%
Grade resistance = 5%

Effective grade = 15%

Figure 13-2
Uphill grade

Rolling resistance = 10%
Grade resistance = -5%

Effective grade = 5%

Figure 13-3
Downhill grade

That's a 300 percent increase in the rolling resistance! In a case like this, I'd think seriously about using a larger tractor for the job.

Grade Resistance

Grade resistance is the force of gravity on any machine, wheel or track, that's moving on a grade. Let's look at an example of what a 10 percent grade means. Suppose the grade is 10 percent and the horizontal distance you travel is 100 feet. By the time you travel 100 feet horizontally on a 10 percent grade, you'll also gain 10 feet in elevation.

A machine moving uphill must overcome not only grade but also rolling resistance. On level ground there's no grade resistance. When a machine moves downhill, the slope of the grade assists and partly cancels the effect of rolling resistance. You probably won't be surprised to learn that there are three formulas used to find total resistance. You use one formula to find RR traveling uphill (Figure 13-2). If you need to find RR traveling downhill (Figure 13-3), that's a different formula. And the third RR formula is for level travel. In these formulas, TR is short for total resistance, RR is rolling resistance and GR is grade resistance. Here are the formulas:

TR (uphill travel) = RR + GR

TR (level travel) = RR

TR (downhill travel) = RR – GR

Here's a rule of thumb for estimating grade resistance: For every 1 percent of grade, assume 20 pounds grade resistance per ton of vehicle weight.

Turn that into a formula and here's what you get:

GR (lb) = Weight on wheels (tons) × 20 (lb/ton) × % grade

Let's look at an example. Suppose a wheeled scraper with bias tires is traveling up a 6-percent grade on a hard gravel surface. We'll find the rolling resistance, grade resistance and total resistance for this example assuming these weights:

- Wheeled scraper weight is 60,000 pounds
- Load weight is 50,000 pounds

Step 1 — Find weight on wheels (tons):

Weight on wheels (tons) = (60,000 + 50,000) ÷ 2,000
= 110,000 ÷ 2,000
= 55 tons

Step 2 — Find grade resistance (lb):

Use the formula for grade resistance, keeping in mind that this is a 6-percent grade.

Grade resistance (lb) = 55 × 20 × 6
= 6,600 lbs

Step 3 — Find rolling resistance (lb):

Use the RR factors from Figure 13-1 and the following formula:

Rolling resistance (lb) = Weight on wheels (tons) × RR factor

Rolling resistance (lb) = 55 × 65
= 3,575 lbs

Step 4 — Find total resistance (lb):

Using the formula for uphill travel:

TR (lb) = RR + GR

TR (lb) = 3,575 + 6,600
= 10,175 lbs

What's the total resistance if we change the direction of the loaded scraper's travel? Same scraper, same load, same road and same 6-percent grade, but this time we'll use the formula for downhill travel:

TR (lb) = RR - GR

TR (lb) = 3,575 - 6,600

= -3,025 lbs

A negative result means that this is a grade assistance, or pushing force, equal to 3,025 pounds acting on the scraper. To operate this scraper safely you need braking force at least equal to the 3,025 pounds grade assistance.

Available Power

The power available from a machine depends on two factors: horsepower and operating gear speeds. Once you define the conditions, it's easy to find the average operating speed for a machine. Start by calculating resistance using the formulas for total resistance. Then turn to the specification sheet or operating manual for the machine. There you'll find tables and charts listing pulling power for selected gear ranges, ground speeds and braking forces.

Wheel and track machines are both rated in pounds of pull, but there are two different kinds of pull. Track machine pull ratings are in units of drawbar pounds of pull. This means that under certain specific conditions (operating gear, rpm and speed) the machine is able to pull the specified number of pounds on a drawbar.

Wheeled machine ratings are in rim pounds of pull. This is the number of pounds of pull that the wheel rims are designed to withstand before they break traction and slip while propelling the machine forward. Figure 13-4 shows an example of a rimpull chart. Drawbar pull charts for track equipment look much the same, and are used in the same way.

Machine Speed

Machine speed is the second of the three main factors you use in determining operating costs. Machine speed is simply how fast the machine can pull a specified load under certain jobsite conditions. The faster a machine moves, the more material it can move per day. Machine speed depends on two factors, the gear ratio and the number of pounds of pull provided by each gear. To find machine speed you need to know the machine's weight and the total resistance. You use the weight and resistance data with the machine's specification chart to determine machine speed.

		Rimpull (lbs)	
Gear	Speed (mph)	Rated	Maximum
1	2.0	35,000	45,000
2	5.0	18,000	23,000
3	7.0	11,000	18,000
4	8.5	9,000	13,000
5	10.0	7,500	11,000
6	11.0	5,500	9,000
7	11.9	3,500	7,000
8	12.5	1,500	5,000

Figure 13-4
Rimpull chart for a wheeled tractor

Here's how it works. We'll say that the machine is a wheel-type scraper and the total resistance is 8,500 pounds. Using Figure 13-4 as your machine's specification chart, find the machine speed. It says fourth gear provides 9,000 pounds of pull at 8.5 mph. Fifth gear provides 7,500 pounds of pull at 10 mph. Clearly, fifth gear doesn't supply enough pull, so your best choice is to use fourth gear and run the loaded scraper at 8.5 mph. We'll see how you find empty machine speeds and total travel times a little later in this chapter. But first let's look at usable power. Not only is usable power related to available power, it also affects machine speed.

Usable Power

Usable power is simply available power less the power you lose either because of problems with traction or altitude. We'll take a close look at both factors, starting with traction.

Traction

Earthwork estimators define traction as a machine's ability to continue moving forward without the wheels or tracks slipping. When either tracks or tires slip, you lose speed. That's why traction is always a factor whenever you figure a machine's speed or efficiency.

You measure traction in either pounds of pull or pounds of push. There's a direct link between the weight on a machine's drive wheels and the amount of traction. It's physically impossible for a machine to exert a force greater than the weight on its

Surface type and condition	Traction factors	
	Tires	Tracks
Concrete/asphalt	0.90	0.45
Normal dirt, dry	0.55	0.90
Normal dirt, wet	0.45	0.70
Sand, dry	0.20	0.30
Sand, wet	0.40	0.50
Gravel road	0.36	0.50
Snow, packed	0.20	0.27
Ice	0.12	0.12

Figure 13-5
Coefficients of traction

drive wheels. Clearly, it's important to know not only the weight of a machine, but also which are the drive wheels. For example, the drive wheels for a wheeled tractor pulling a wheeled scraper are on the tractor, not on the scraper.

To find out how many pounds of pull really are available (from a specific machine, operating on a specific type of surface), earthwork estimators use coefficients of traction. Figure 13-5 compares the coefficients of the traction of tires and tracks on various types of surfaces. In the chart you'll see that on a concrete or asphalt surface, tires are the best choice. They operate at about 90 percent efficiency. Tracks slip easily on surfaces like concrete and asphalt. According to Figure 13-5, on these surfaces efficiency drops considerably for track machines, which operate at only about 45 percent of total traction.

Now compare tracks to tires when the surface is dry dirt. This time the track machine has the advantage, operating at about 90 percent efficiency. Tires slip easily in dry dirt and their operating efficiency drops to about 55 percent.

The percentage of gross vehicle weight (GVW) on the drive wheels appears on each machine's spec sheet. Use the data from the manufacturer if it's available. Otherwise, use one of the following formulas to calculate weight on the drive wheels.

Track machine pulling wheeled scraper: Weight on drive wheels = 100% GVW

Four-wheeled tractor with attached scraper: Weight on drive wheels = 40% GVW

Two-wheeled tractor with attached scraper: Weight on drive wheels = 60% GVW

Let's try pulling all of these factors and formulas together by finding the rimpull available in pounds. Here's what we know for our example:

- Machine is a two-wheeled tractor with an attached scraper
- Gross vehicle weight is 125,000 pounds
- Travel surface is a hard gravel road

Step 1 — Calculate the weight on the drive wheels:

For a two-wheeled tractor with attached scraper, the weight on the drive wheels equals 60 percent of the gross vehicle weight. Here's the math:

$$\text{Weight on drive wheels (tons)} = (125{,}000 \times 0.6) \div 2{,}000$$
$$= 75{,}000 \div 2{,}000$$
$$= 37.5 \text{ tons}$$

Step 2 — Find the coefficient of traction:

This is a wheeled machine and the travel surface is a hard gravel road. According to Figure 13-5, the coefficient of traction for this combination is 0.36.

Step 3 — Calculate rimpull in pounds:

Here's the formula and the math.

$$\text{Rimpull (lb)} = \text{Weight on drive wheels} \times \text{Coefficient of traction}$$

$$\text{Rimpull (lb)} = 75{,}000 \times 0.36$$
$$= 27{,}000 \text{ lbs}$$

But traction isn't the only factor that determines machine speed. Another factor is altitude.

Altitude

Altitude is a measurement of height above sea level. As altitude increases, atmospheric pressure decreases. And the lower the atmospheric pressure, the less horsepower a machine has. A naturally-aspirated engine (any engine not equipped with a turbocharger) loses about 3 percent horsepower for every 1,000 foot gain in elevation above 3,000 feet. This is a general value and may not be the value for your machines. Refer to your machine's owner manual or your equipment dealer for the individual machine values.

Let's see how it works. Say a machine has a drawbar pull of 8,500 pounds at or below 3,000 feet, and the jobsite elevation is 7,000 feet. What's the actual drawbar pull for this machine at this elevation?

Step 1 — Find the percentage of lost horsepower:

As you now know, you lose 3 percent of your horsepower per 1,000 feet above 3,000 feet. Here's the math for our example:

$$\text{Lost horsepower (\%)} = (7{,}000 - 3{,}000) \times 3\%$$
$$= 4{,}000 \times 3\%$$
$$= 12\%$$

Step 2 — Calculate actual drawbar pull in pounds:

Actual drawbar pull in pounds equals the rated drawbar pull less 12 percent. For our example the math works out like this:

$$\text{Actual drawbar pull (lb)} = 8{,}500 - (8{,}500 \times 12\%)$$
$$= 8{,}500 - 1{,}020$$
$$= 7{,}480 \text{ lbs}$$

Cycle Time

Cycle time is the measurement of how long it takes for a machine to pick up a load, travel to the dump site, dump the load, and make the return trip to the excavation site. One of the primary goals for excavation estimators is finding the shortest possible cycle times for equipment. Here's why. The shorter the cycle time, the more trips made per hour, the more material moved, the more money you make.

Cycle times are the product of two kinds of time: fixed time and variable time. Let's start by defining these two types of time.

Fixed Time

Fixed time refers to a group of operations including loading, dumping and maneuvering that, assuming similar conditions, take the same amount of time to accomplish from one job to the next. Manufacturers of earthmoving equipment often include estimates for fixed time in their equipment manuals. But, as you might expect, their estimates tend to be optimistic. Perhaps on a perfect jobsite they are accurate. I wouldn't know — I've never been on a perfect jobsite. So instead of using this somewhat unrealistic data, keep your own records. The data you compile by tracking real cycle times are far more meaningful. After all, it applies to your machines, your type of work and your conditions. Cycle times based on your customized fixed times are sure to be more accurate.

Variable Time

Variable time is the amount of time that a machine spends in transit between the loading site and the dumping site. Obviously this changes from job to job. The main factors in determining variable time are:

- Distance, by haul road, separating the loading site from the dumping site

Figure 13-6
Equipment maintenance truck

- Percentage of grade
- Condition of the haul road

To find variable time for a job, clock several runs with a stopwatch and then find their average. Don't forget to count the time required for maintenance, including fuel, lubricants and fluids, as well as air filters. See Figure 13-6.

Cycle times vary from one type of equipment to another, and even from machine to machine and operator to operator. Your selection of machines for a project depends on the jobsite conditions as well as the distance traveled between loading and unloading. As we saw earlier, sometimes wheeled loaders are the best choice. Under different conditions, the best machine for the job may be a track loader.

The sum of the fixed and the variable times is your estimated cycle time for a project. After work starts on a project, make several comparisons by clocking real cycle times and thinking of your estimate as a goal. Say you notice that the cycle times on a project keep rising. That's a tip-off that there's a problem. Cycle times don't rise except when equipment is used inefficiently. Double-check the haul road's layout and condition. It's a good bet it needs maintenance. Many excavation contractors find that it pays, in shorter cycle times, to keep and run a motor grader onsite. The main job of the motor grader? Maintaining the condition of the haul road surface. Here are three goals to keep in mind from start to finish on every job:

- Keep all machines working at full capacity and top efficiency
- Maintain the best possible haul road surface

- Use grades as productively as possible

Now that you know how to find cycle times, it's time we moved on to take a look at machine production and how to calculate productivity.

Machine Production

This is the third and final factor you use to determine owning and operating costs. Here's a simple definition of machine production: The quantity of material transferred between two locations within a specified period of time.

Three major factors determine machine production:

- Material
- Time
- Efficiency

Let me explain how this works with an example.

Finding a Production Rate in Cubic Yards per Hour

Suppose that you've signed a contract that requires moving 25,000 cubic yards of material in two weeks. To finish on schedule, how many cubic yards of material must you move per hour?

Let's assume you have just one machine available for this job, and you'll run it eight hours a day, five days a week. Now it's time for some math.

Step 1 — Finding the total hours:

Eight hours per day, five days a week, for two weeks comes to a total of how many hours?

$$\text{Total hours} = 8 \times 5 \times 2$$
$$= 80 \text{ hours}$$

Step 2 — Finding the production rate in cubic yards per hour:

You want to move 25,000 cubic yards of material in a total of 80 hours.

So how many cubic yards must you move per hour?

Production rate (CY/hr) = 25,000 ÷ 80
= 312.5 CY/hr

Where do you go from here? The next step is to figure out how many machines and men it's going to take to achieve that production rate. But isn't there something wrong here? Ask yourself this question: Would you sign a contract without first doing the math so you'd know what you were promising? I sure wouldn't, and neither should you! I buffaloed you into starting from the wrong end of that job, but in the process you learned something about production rates.

What Production Rates Tell You

Let's take a quick look at what you've learned so far. You know how to calculate material quantities. You also know how to find how long it takes to move a given quantity of material with a specific machine, assuming ideal jobsite conditions.

In the real world, perfect conditions are something you'll never find. Don't forget that you need to allow for that fact in your estimates. On any excavation job, no matter what, you always lose some time and capacity. A good estimate includes an allowance for this fact of life. How? My preferred solution is to always make a slight reduction to my productivity estimate.

Good production data is vital to estimators. It tells you how many machines you need to move the most material, in the least amount of time, for the least cost and therefore, the greatest profit.

Productivity is easy to calculate, but beware of this trap: *If two machines are good, then four machines are twice as good.* It's just not true. More machines don't always equal more productivity. The opposite result is really more likely. Too many machines in too little space can reduce productivity, simply because they're in each other's way. The same is true for equipment size. For instance, I know of a mining company that purchased a very large dump truck to improve production. The only problem was that the truck was so big that no other vehicles could operate on the same road. That was a very expensive mistake.

To find a machine's production rate you need to know its cycle time. Then you calculate production in trips per hour using the following formula:

Machine production (trips/hour) = 60 minutes ÷ Cycle time in minutes

Suppose your cycle time is 6.5 minutes. What's your machine production in trips per hour?

Machine production (trips/hour) = 60 ÷ 6.5

= 9.23 trips/hour

This formula assumes ideal conditions, but we know that's not realistic. Fortunately, the excavation industry recognizes that neither people nor their machines are 100 percent efficient. They analyzed data from thousands of jobs and developed factors that everyone uses.

Project Duration

You can determine the total project duration required for any given task using one of the following formulas:

Project duration (days) = Total quantity of work ÷ Daily production

Project duration (hours) = Total quantity of work ÷ Hourly production

For example, the time required to excavate 60,000 bank cubic yards at a production rate of 300 bank cubic yards per hour will be:

Project duration (hr) = 60,000 BCY ÷ 300 BCY per hour

= 200 hours

Job Efficiency Factors and How to Use Them

An operator stops for a break or a drink of water. A machine breaks down or stalls without warning. Minor delays add up and they happen for all sorts of reasons. That's why people and their machines are never 100 percent efficient. The job efficiency factors in Figure 13-7 take this fact into account. Equipment manufacturers, engineers, designers and construction organizations have developed this data using information gathered over the years. You may wish to develop your own factors.

Efficiency factors make it easy for you to bring your productivity estimates into line with what's realistic and achievable. Let's try out the efficiency factors from Figure 13-7. We'll use the machine production rate of 9.23 trips per hour that we found earlier, and assume all work is done during the daytime. If the machine is track-driven, our efficiency-factor-adjusted production rate is 7.66 trips per hour (9.23 × 0.83 = 7.66). We'll round that off and call it 8 trips/hour. If the machine has rubber tires, then the adjusted production rate is 6.92 trips per hour (9.23 × 0.75 = 6.92) or, rounded, 7 trips per hour.

Now let's see how these figures relate to material volumes. Suppose the capacity of your track machine works out to 100 cubic yards per hour. During the daytime this machine actually moves a total of 83 cubic yards per hour and at night 75 cubic yards per hour.

	Actual productivity	
	Minutes per hour	Factor
Normal day operations		
Track equipment	50	0.83
Wheel equipment	45	0.75
Normal night operations		
Track equipment	45	0.75
Wheel equipment	40	0.67

Figure 13-7
Efficiency factors

The job efficiency factors in Figure 13-7 are averages. They're fairly accurate for most types of equipment. But if the machine's spec sheet includes job efficiency data, use it instead.

Productivity Calculations for a Simple Dirt Job

Let's start by taking a look at Figure 13-8. This is the site plan for our sample project. This is a simple dirt job where we'll move material from a borrow pit to a fill area using two haul roads, road A and road B. The length of each road and the grade percent also appear in Figure 13-8. This time we'll skip calculating the centers of mass for both the fill area and the borrow pit. You'll find them marked on the site plan with the abbreviation CM. Instead we'll begin by taking a close look at the haul roads.

The Haul Roads

Figure 13-8 tells us that haul road A is 1,200 feet long and has a 4 percent grade. Haul road B is 1,750 feet long and has a 2 percent grade. We'll assume that both haul roads are only wide enough for one-way traffic. Now, which haul road should the loaded machines use? Don't make the mistake of thinking it won't make much difference. It makes a lot of difference and that difference will show up in your profit/loss column.

Your best choice for the project in Figure 13-8 is to run the loaded machines on road A and the empty machines on road B. Why? For a start, loaded machines are heavier and travel more slowly than empty machines. Road A is 550 feet shorter than road B.

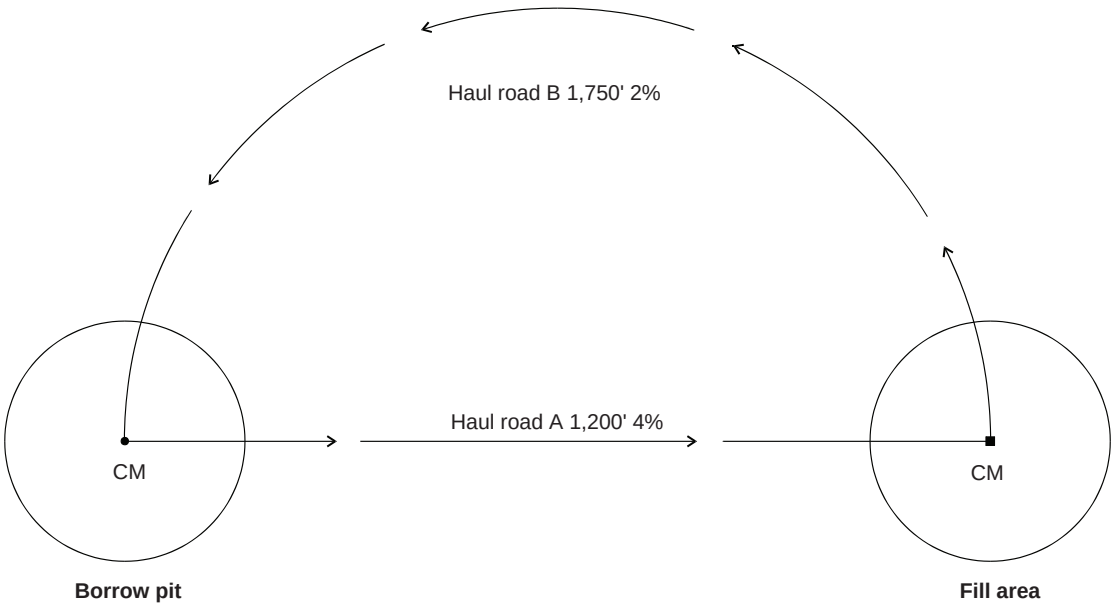


Figure 13-8
Layout of a simple dirt job

That's one reason to run the loaded machines on road A. The second reason is even better. Running the loaded machines on road A is making the most productive use of that 4 percent grade by using it to your advantage. Here's how this works. When you run the loaded machines on road A, the entire trip is downhill. That gives you a positive grade resistance. Now let's set up that sample project.

Sample Project Machine & Haul Road Specifications

Here's all the data we'll need for the sample project calculations:

- Machine type is a two-wheel-drive scraper
- GVW (gross vehicular weight) or empty weight is 45,000 pounds (22.5 tons)
- Rated payload weight is 65,000 pounds (32.5 tons)
- Loaded weight (GVW + Payload weight) is 110,000 pounds (55 tons)
- Rimpull chart — use Figure 13-4
- Length of haul road A (measured from the borrow pit center of mass to the fill area center of mass) is 1,200 feet

- Grade, haul road A is 4 percent
- Grade, haul road B is 2 percent
- Haul road surface type and condition is hard-packed dirt, recently graded
- Rolling resistance factor is 100 (from Figure 13-1)

Let's start with the series of calculations that will add up to our total cycle time. We'll do each of these calculations twice; first for the loaded machines, traveling on road A, and then for the empty machines using road B.

Resistance Calculations

We'll make two separate sets of resistance calculations for this sample project, one for loaded machines and one for the empty machines. Remember these formulas?

GR (lb) = Weight on wheels (tons) × 20 (lb/ton) × % grade

TR (lb) for uphill travel = RR + GR

TR (lb) for level travel = RR

TR (lb) for downhill travel = RR – GR

Where:

TR = Total resistance

RR = Rolling resistance

GR = Grade resistance

Rolling Resistance

We'll start with rolling resistance, using the same formula for both calculations:

RR = Weight on wheels × RR factor

There is a difference, of course, in how you define "weight on wheels." For the loaded machines, "weight on wheels" is the gross vehicular weight plus the payload weight. But for the empty machines, "weight on wheels" is just GVW.

Loaded:

RR = (22.5 + 32.5) × 100

= 55 × 100

= 5,500 lbs

Empty:

RR = 22.5 × 100

= 2,250 lbs

Grade Resistance

Here's the formula for grade resistance:

GR (lb) = Weight (tons) × 20 (lb/ton) × % grade

The loaded machines on road A are assisted by the 4 percent grade. Here's the math:

GR (lb) = 55 × 20 × 4

= 4,400 lbs

Empty machines on road B travel uphill on a 2 percent grade. The grade resistance equals:

GR (lb) = 22.5 × 20 × 2

= 900 lbs

Total Resistance

For the loaded machines in this example you find total resistance using this formula:

TR (lb) = RR – GR

TR (lb) = 5,500 – 4,400

= 1,100 lbs

To find total resistance for the empty machines you use this formula:

TR (lb) = RR + GR

TR (lb) = 2,250 + 900

= 3,150 lbs

Total resistance and rimpull are the same for a wheeled machine like the scraper we're using for this sample job.

Finding Operating Speed and Gear Using a Rimpull Chart

Let's review our rimpull needs for the sample job:

- For the loaded machines we need 1,100 pounds of rimpull
- For the empty machines we need 3,150 pounds of rimpull

We'll use the rimpull chart shown in Figure 13-4 to find the operating speed and gear for the loaded and the empty machines.

Now let's see how this works. In the Rated column, find the number closest to, but not less than, the 1,100 pounds of rimpull we know we need for the loaded machines. That's 1,500 at the bottom of the Rated column. Stay in the bottom row and move across to the Gear column to find the operating gear we'll use. The answer is eighth gear. Now move to the Speed (mph) column to find the machine's speed in miles per hour. The answer is 12.5 miles per hour.

Repeat these steps for the empty machines and check your results against the following list.

- Required rimpull = 3,150 pounds
- Gear = seventh
- Speed = 11.9 mph

Notice anything odd here? Most haul roads, like the roads in Figure 13-8, are less than a mile long. But most specification sheets list speeds in miles per hour, just like Figure 13-4. Let's make these speeds easier to work with by converting them into feet per minute. All you do is multiply the miles per hour by a constant of 88. Here's how it looks as a formula:

$$\text{Feet per minute} = \text{Miles per hour} \times 88$$

Try it out converting the speeds we just found:

$$\text{Loaded speed (feet per minute)} = 12.5 \times 88$$
$$= 1{,}100 \text{ feet per minute}$$

$$\text{Empty speed (feet per minute)} = 11.9 \times 88$$
$$= 1{,}047 \text{ feet per minute}$$

Calculating Travel Times

We know that haul road A is 1,200 feet long. We also know the loaded machine's speed is 1,100 feet per minute. To find the travel time, you just divide distance by the rate of speed.

Loaded travel time (minutes) = 1,200 ÷ 1,100

= 1.10 minutes

Haul road B is 1,750 feet long and the empty machine's speed is 1,047 feet per minute.

Empty travel time (minutes) = 1,750 ÷ 1,047

= 1.67 minutes

The manufacturer's handbooks that come with most loaders include graphs of estimated loaded and unloaded travel times under a variety of conditions. There's no point in duplicating the work, so if the travel time data's included, use it.

Calculating Cycle Time

Cycle time, remember, is variable time plus fixed time. Variable time for the sample project is the sum of loaded travel time plus empty travel time. That comes to 2.77 minutes (1.10 + 1.67 = 2.77). Fixed time for the two-wheel-drive scraper used in the example equals load time (we'll say that's 0.60 minutes) plus dump and maneuver time (0.50 minutes). So fixed time equals 0.60 + 0.50 = 1.10 minutes, and cycle time equals 0.60 + 0.50 + 1.10 + 1.67 = 3.87 minutes.

Calculating Production Rates

The first production rate we'll find for the sample project measures the number of trips per hour. Here's the formula and the math:

Production (trips/hr) = 60 ÷ Minutes per trip

Production (trips/hr) = 60 ÷ 3.87

= 15.50 trips per hour

To find a more realistic production rate we'll apply an efficiency factor as the next step.

We'll use the efficiency factors from Figure 13-7. The machine is wheeled and we'll assume this is a normal day operation. That combination makes the efficiency factor 0.75, or 45 minutes of actual production per hour. So, the actual production rate is 11.62 trips per hour (15.50 × 0.75 = 11.62). We'll round that off and call it 11.5 trips per hour.

You already know the payload size for the machine is 32.5 tons. Now you also know the machine makes 11.5 trips per hour. So how many tons of material will this machine, filled to capacity, move in an hour? To find out, use this formula:

Production rate (tons/hr) = Payload size × Trips per hour

Here's the math for the sample project:

Production rate (tons/hr) = 11.5 × 32.5

= 373.75 tons per hour

If this were an actual job, you would know a lot more than this about the material you're moving. Make it your business to know at least this much about any material:

- Type
- Moisture content
- Swell factor

You need that information to calculate production rates, either in cubic yards per hour (CY/hr) or cubic yards per day (CY/day). Then you use those production rates to figure out how many machines you'll need on the job to move the material efficiently and on schedule. The other factors you'll want to consider include:

- Availability of machines
- Size of the operation
- Number of working days

Equipment Production Rates

On most earthmoving projects the focal point is some type of scraper. But scrapers don't work alone. Other machines either support your scraper units or do other types of work. So now we'll see how to calculate production rates for other common earthmoving machines.

Excavators and Hauling Units

An important consideration regarding trucks is how many hauling units are needed to properly service an excavator. For starters, try to have at least one or two standby units available to replace hauling units that break down. If rented equipment isn't readily available, a rule of thumb is to have one standby unit for every five hauling units in operation.

To calculate the actual truck requirement for a given excavator, divide haul unit cycle time by the load time. *Haul unit cycle time* is the combined time it takes to load, turn, dump, spot and travel.

Since load time is a component of both the numerator (top) and denominator (bottom) of the truck requirement division problem, I'll break it down into simpler terms. Load time depends on truck capacity, bucket capacity and the excavator cycle time.

Here's an example of how to determine the number of haul units for a job. Let's say a 20 LCY truck has a 0.5-hour haul unit cycle time and a 0.046-hour load time. Divide 0.5 by 0.046 to obtain the truck fleet requirement. That comes to 10.9. Rounding up, you'll need 11 trucks.

Interfacing Production Rates of Excavators and Hauling Units

The payload of a dump truck is usually expressed in loose cubic yards. This is because, even if the soil being loaded is excavated from an in-place, natural condition (bank cubic yards, or BCY), by the time the soil is dropped into the truck body, it's in a disturbed, loose condition.

The production rate of an excavator loading a truck is expressed in either loose or bank cubic yards per hour, depending on the physical condition of the soil being excavated. For example, if a dragline is excavating in-place material, its production rate is expressed in bank cubic yards per hour; but if the dragline is loading loose, stockpiled material, the production rate is expressed in loose cubic yards per hour.

As a general rule, the production rate of a loader is expressed in loose cubic yards per hour, whereas the production rate of other equipment normally used for loading a truck (draglines, backhoes, shovels, mass excavators, clamshells, etc.) is expressed both in bank or loose cubic yards per hour.

Since the production rate of an excavator/haul-unit system is dependent upon the production rates of both the excavator and the trucks, we must interface the production rates of both units. Production rate data tables for numerous excavators are based on bank-cubic-yard production, so it's usually easier to express the truck payload in bank cubic yards.

The number of dipper cycles required to fill a truck can be determined by this formula:

Truck capacity dipper cycles = Truck capacity ÷ Excavator capacity

For example, assuming 30-percent swell, determine the number of dipper cycles required for a 2-BCY power shovel to fill a 14-LCY dump truck. Expressed in bank cubic yards, the truck capacity is: 14LCY.

Payload (BCY) = 14 LCY ÷ 1.3 LCY/BCY
= 10.8 BCY

The number of dipper cycles required to fill the truck is:

Dipper cycles = 10.8 BCY ÷ 2 BCY/cycle
= 5.4 (rounded up to 6 cycles)

Pusher Units

Wheeled units that aren't self-loaders need to work with a pusher unit. But how many haul units can one pusher unit efficiently handle? You don't want either the haul units or the pusher unit to sit idle. In this business, wait time is wasted time. Strike a balance between your pusher unit cycle time and the number of haul units per pusher unit. The result is minimum wait time and maximum productivity.

First, you find the cycle time for your pusher unit using this basic formula:

Pusher unit cycle time (min.) = Boost time + Transfer time + Return time + Load time

Use the following industry standardized times for pusher units:

- Boost time + Transfer time = 0.25 minutes
- Return time = 40 percent of load time

Now, simplify the formula as follows:

Pusher unit cycle time (min.) = 0.25 + (1.4 × Load time)

Next, you find the haul unit's cycle time using the same steps as earlier in this chapter. Once you know both the pusher and the haul unit cycle times, you use this formula to find the number of haul units you'll need per pusher unit:

Haul units per pusher unit = Hauling unit cycle time ÷ Pusher unit cycle time

Let's do an example. Suppose the cycle time for the hauling units is 4 minutes and load time for the pusher unit is 0.5 minutes. Here's the math:

$$\begin{aligned}\text{Haul units per pusher unit} &= 4 \div [0.25 + (1.4 \times 0.5)]\\ &= 4 \div [0.25 + 0.7]\\ &= 4 \div 0.95\\ &= 4.21 \text{ haul units per pusher unit}\end{aligned}$$

Haul units are pieces of equipment, so a decimal number doesn't make much sense. We'll round this answer off to the nearest whole number, or four haul units per pusher unit.

Bulldozers

Production rates for bulldozers are complex and involve many variables. Most excavation contractors don't calculate production rates for their bulldozers. Standard practice among excavation contractors is to simply consider the costs of keeping a bulldozer onsite as part of job overhead.

Compactors with front blades now keep the unloading areas smooth on most jobsites. But there's still plenty of dozer work on any jobsite, especially in finish work — working slopes down and dressing them up.

Compactors

There are two types of compactors: sheepsfoot rollers and pneumatic rollers. Compactors of either type both deposit and compact fill material using a standard 6-inch lift. There are many variables to consider in finding compactor production rates.

They include:

- Compactor type
- Material type and moisture content
- Compaction requirements
- Area involved
- Machine speed
- Required number of passes

Compactor type	Average speed (mph)
Self-propelled sheepsfoot roller	5
Self-propelled tamper unit	6
Self-propelled pneumatic roller	7
Sheepsfoot roller pulled by wheeled tractor	7
Sheepsfoot roller pulled by track tractor	4
Sheepsfoot roller pulled by motor grader	12

Figure 13-9
Compactor's average operating speeds

The type of compactor, for instance, determines rolling resistance. Let's compare rolling resistance for the two types of compactors, assuming normal material and 6-inch lifts. For a sheepsfoot roller, rolling resistance is about 500 pounds per ton. For a pneumatic roller, add 10 pounds per ton per inch of compacted material.

Fortunately, there's a shortcut. Just use the following simplified formula:

$$\text{Compactor production rate (CY/hr)} = (W \times S \times L \times 16.3) \div P$$

Where:

- W = width, compacted area (feet)
- S = speed (mph)
- L = lift thickness (compact inches)
- 16.3 = mathematical constant
- P = passes, machine (number required)

Obviously speed (mph) is the shortcut here, but that leaves you with a big question. What is the source for this data? The best source is the specifications sheet for your specific machine. If you don't have that, use Figure 13-9.

Sample Calculation of Compactor Productivity

Now let's try out that formula on a sample problem. Here's all the data we need:

- Compactor type: 15-ton, self-propelled, 12-foot-wide sheepsfoot roller

- Lift thickness: 6-inch lifts
- Number of passes required: 5
- Machine speed: see Figure 13-9

Find the production rate for this compactor. We'll start by matching the formula variables to their values in this example. Here's the result:

- W = 12 feet
- S = 5 mph
- L = 6 inches
- P = 5

Next, simply plug these values into the formula and do the math:

$$\text{Compactor production rate (CY/hr)} = (W \times S \times L \times 16.3) \div P$$

$$\begin{aligned}\text{Compactor production rate (CY/hr)} &= (12 \times 5 \times 6 \times 16.3) \div 5 \\ &= 5{,}868 \div 5 \\ &= 1{,}173.6 \text{ CY/hour}\end{aligned}$$

Motor Graders

Keeping a motor grader onsite is standard practice in the excavation business for all but the smallest projects. On any project, motor graders have two main jobs.

1. Keeping haul roads smooth
2. Leveling all finish grades

Both jobs are critical. But you don't measure or estimate these jobs as volumes. Production rates for motor grader work use the amount of time it takes to complete a task, rather than the volume of material moved.

Typically, a grader makes the same number of passes regardless of the task being done. Here's the standard sequence. The first pass is a cutting pass with the blade set to cut to the depth of the bottom of the deepest ruts or hollows. This requires the lowest gear and speed of all the passes. The second pass, in a higher gear and speed, smoothes out small irregularities and any blade spill left behind by the first pass. The third pass is the finish pass. The gear and speed are either the same or slightly higher than in the second pass.

Calculating Motor Grader Task Times

Let's try a sample problem. Assume the following:

- Total number of passes: 3

- First pass gear: second
- Speed in second gear: 3.1 mph
- Second and third passes gear: third
- Speed in third gear: 4.2 mph
- Length of haul road: 4.1 miles
- Productive minutes per hour: 50
- Efficiency factor: 83 percent

What's the total time for this job? It's the sum of the times for each pass. The time for each pass equals the road length divided by grader speed. Here's the math for the first pass:

$$\text{Pass 1 (hours)} = 4.1 \div 3.1$$
$$= 1.32 \text{ hours}$$

The second and third passes were identical, so we'll combine them here:

$$\text{Pass 2 and 3 (hours)} = (4.1 \div 4.2) \times 2$$
$$= 0.976 \times 2$$
$$= 1.95 \text{ hours}$$

Next add these times together to find total time:

$$\text{Total time (hours)} = 1.32 + 1.95$$
$$= 3.27 \text{ hours}$$

Actual total time equals total time divided by the efficiency factor. Here's the math:

$$\text{Actual total time (hours)} = 3.27 \div 0.83$$
$$= 3.94 \text{ hours}$$

We'll round that off and call it 4 hours.

That's the end of our discussion of production rates for earthmoving equipment. I've limited this discussion to the standard machines that you'll find on almost every earthmoving job. There are other machines, of course, and we'll look at several and see how to calculate their production rates for the sample bid in Chapter 15.

Owning and Operating Costs

Once you've figured the material quantities and machine time required, it's time to consider the hourly cost of owning and operating the equipment. And there's more to these costs than just the purchase price of the machine. Hourly cost has to include the ownership cost, operating cost, and the operator's wages. The wages are easy to calculate — just multiply the hourly wages by the number of operators. Ownership and operating costs are a little more complicated.

Ownership Costs

Ownership costs are a fixed cost because they continue whether or not a machine's working. These are the four components to ownership costs: depreciation, interest, insurance and taxes. We'll take a closer look at these, starting at the top of the list.

Depreciation

Let me make one thing clear at the start. I'm no tax expert. What I call depreciation isn't the same as depreciation in the tax code. That type of depreciation is very complex and beyond my experience. Depreciation, as I use the word in this book, refers only to equipment ownership costs.

You'll agree, I'm sure, that the older a machine is, the less it's worth. Depreciation, to greatly simplify, is a way for you to spread out the purchase price of a machine over its useful lifetime. The useful life span of a machine depends on the working conditions, machine type and the skill of the operator.

The most important is the equipment's operating conditions. For most earthmoving equipment, the standard useful life span is:

- Excellent conditions = 12,000 hours
- Average conditions = 10,000 hours
- Severe conditions = 8,000 hours

To establish a realistic value for a machine at the end of its useful life, I recommend contacting local equipment dealerships. They can quote Blue Book values. Some contractors I know assume the value of a machine at the end of its useful life is zero. This practice artificially inflates hourly operating costs. I recommend using only actual values to calculate hourly operating costs for equipment. Then calculate hourly depreciation using this formula:

Depreciation per hour = Purchase price – Tire value ÷ Estimated useful life span

Most of those variables are familiar. Purchase price is clear enough, and we just covered depreciation and estimated useful life span. But what about tire value? Tires on earthmoving equipment wear out rapidly. Over the useful lifetime of a machine you'll replace the tires many times. Because tire costs are an operating cost, not an ownership cost, deduct their value from the purchase price. When you buy a new machine, obtain the value of all tires from the equipment company and deduct them from the purchase price. For a used machine, either the equipment company or local tire supplier can provide you with the estimated value of the tires.

Interest, Insurance and Taxes

Each machine accounts for a specific percentage of your total costs in each of these three categories. We'll find the sum of the three percentages and use that to calculate ownership costs. In the rest of this chapter I refer to this group as IIT (my shorthand for interest, insurance and taxes). To calculate these hourly costs, find the sum of the percentages of your total annual costs and divide the result by the estimated hours of use per year. Remember that these are yearly costs. That means you should recalculate them annually, using the actual costs and the actual hours of usage. Use the actual costs for the past year to help you estimate the costs for next year.

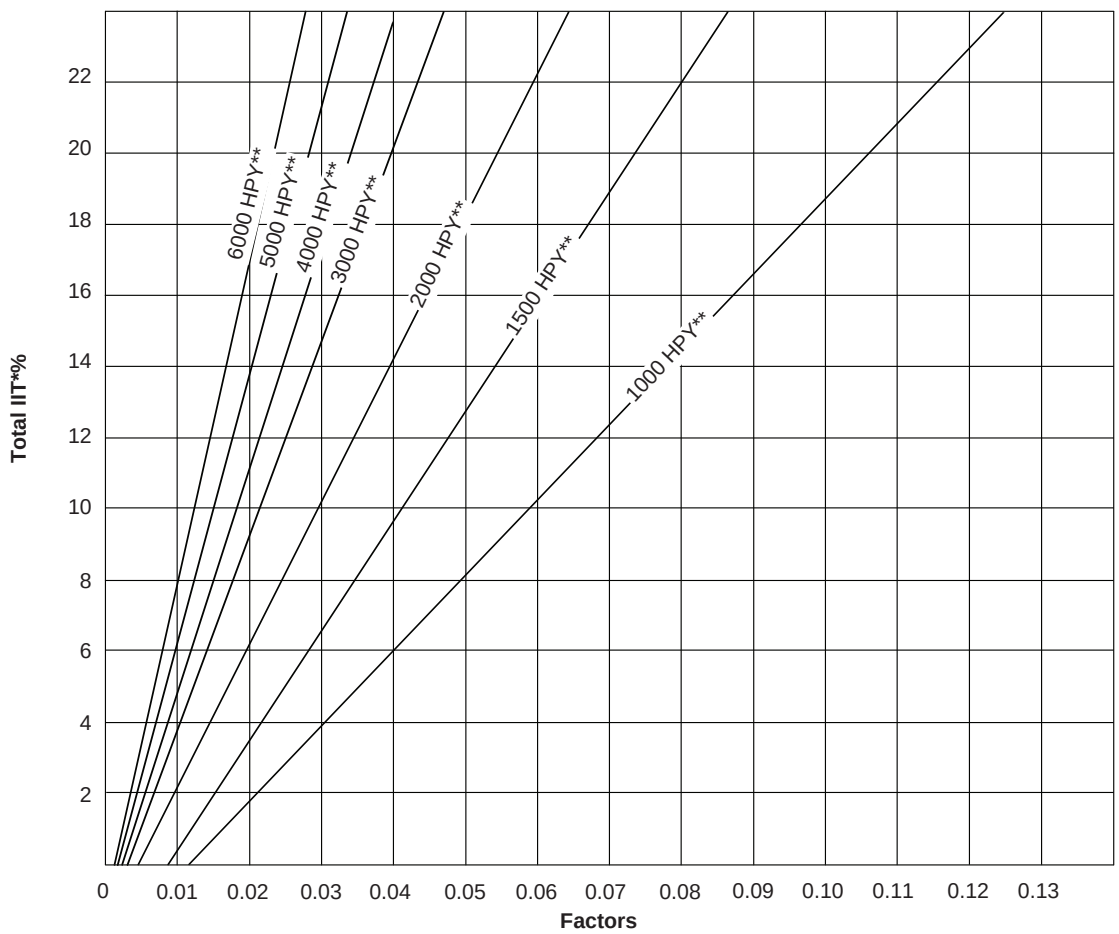
You'll find hourly cost factors helpful in estimating your hourly operating costs. Figure 13-10 is a typical chart. Your equipment company should have a comparable chart for your equipment. To use Figure 13-10 you need to know the following:

- Machine's average hours of usage per year
- Interest rate percentage on machine's purchase loan
- Percentage of total annual insurance costs assigned to the machine
- Your per-machine percentage of total tax paid

Find the sum of the three percentages. Find your result in the vertical scale on the left side of Figure 13-10. Read across and to the right until this horizontal line meets the diagonal line matching your average hours per year usage. Go straight down from that point and read the factor off of the horizontal scale that runs across the bottom of Figure 13-10.

Confused? This example should help. Assume the delivered purchase price for your machine was $75,000 and you use it an average of 3,000 hours per year (HPY for short). These are your rates:

- Interest = 7%
- Insurance = 5%
- Taxes = 4%



*IIT = Interest, insurance and taxes **HPY = hours per year

Figure 13-10
Graph of hourly cost factors for interest, insurance and taxes

Step 1 — Find the sum of the yearly percentages:

7 + 5 + 4 = 16%

Step 2 — Find 16% on the left vertical scale in Figure 13-10.

Step 3 — From 16%, read across to the right, until this line intersects the 3,000 HPY diagonal.

Step 4 — From that intersection, read straight down to the factors scale across the bottom of Figure 13-10.

Step 5 — From that scale, read your IIT factor.

You need the IIT factor to estimate your hourly cost using this formula:

Approximate hourly cost = IIT factor × Delivered price ÷ 1,000

Approximate hourly cost = 0.032 × 75,000 ÷ 1,000
= $2.40 per hour

Operating Costs

Operating costs include fuel and lubricants, tires, and repairs. These all vary depending on how much use the machine gets.

Fuel and Lubricants

I recommend that you keep up-to-date and accurate records of your own costs for fuel and lubricants for each machine. If you don't have this information, use the manufacturer's estimates from your spec sheet or owner's manual. But start keeping records of your own right away. Typically, manufacturer data is overly optimistic. It's better than no data at all, but use it only until you've established your own data.

Tires

Calculating the hourly cost of tires depends on several variables, including type of tire, site conditions and upkeep. Many tire manufacturers can provide estimated service life for their products. Again, you'll have more accurate estimates if you keep good records of tire costs for each machine. Either way, when you've estimated service life hours, here's how to figure estimated hourly cost:

Hourly tire cost = Replacement cost of tires ÷ Estimated service life (hours)

Remember that the replacement cost of tires includes all of the costs for tire replacement. Besides the price of the tires themselves, you also pay for mounting, tubes, and taxes. Another cost you need to consider is the relatively new tire disposal cost. Many states now charge the tire company to dispose of old tires, and they pass this cost on to the consumer. Make sure you know what the fee is and include it in your calculations.

Repairs

Over the life of a machine, the repair cost will probably be higher than the fuel or tire cost. Earthmoving machines work hard in dirty and difficult conditions. Hard usage takes a toll on every machine. Keeping accurate records on individual machines will reveal the machine's repair cost, and provide a guide for deciding when to trade it in for a new model or a bigger unit. If you don't have detailed records, calculate repair costs using this formula:

Repair cost per hour = Repair factor × (Delivered price – Tire cost) ÷ 1,000

Machine type	Operating conditions		
	Excellent Repair factor	Average Repair factor	Severe Repair factor
Wheeled tractor scrapers	0.07	0.09	0.13
Off-highway trucks	0.06	0.08	0.11
Track-drive tractors	0.07	0.09	0.13
Wheeled tractors	0.04	0.06	0.09
Track loaders	0.07	0.09	0.13
Wheeled loaders	0.04	0.06	0.09
Motor graders	0.03	0.05	0.07

Figure 13-11
Repair factors for earthmoving equipment

The repair factor depends on the operating conditions. Figure 13-11 gives you repair factors for different operating conditions.

Figure 13-12 shows a sample ownership and operating cost form for machine equipment.

Calculating the Overhead

Up to now, we've looked at costs directly attributable to a particular machine. But your bid must also cover fixed costs, usually called company overhead. In a larger company, the overhead may be considerable.

Overhead costs include:

- Building and grounds for your shop, storage yard, and office, including all taxes, insurance, and upkeep
- Utilities such as phone, heat, and electricity
- Legal and accounting fees, advertising, office supplies
- Management and support payroll, including withholding taxes, insurance and fringe benefits, for office and shop
- Superintendents and the pickups they use
- Lowboys and tractors for moving equipment

Machine Ownership and Operating Cost Summary

Machine type_____ Company number _____

Purchase date_____ Delivered price_____

Depreciation

Tire replacement cost _____

Location	**Size**	**Quanitity**	**Cost**
Front	_____	_____	_____
Rear	_____	_____	_____
Drive	_____	_____	_____

Delivered price - tire cost _____

Minus resale or trade-in value _____

Net depreciation value _____

Hourly ownership cost

$$\frac{\text{Net depreciated value}}{\text{Depreciation hours}} = _____ = _____$$

Interest (_____%), Insurance (_____%), Taxes (_____%)

Estimated yearly use in hours_____

$$\frac{\text{Factor x price}}{1000} = \frac{\text{x}}{1000} = _____$$

Total ownership cost _____

Hourly operating costs

Fuel price (_____) x use/hour (_____) = _____

Lubricants and filters

Item	**Unit price**	**Used/hour**	**Cost**
Engine	_____	_____	_____
Transmission	_____	_____	_____
Finals	_____	_____	_____
Hyd	_____	_____	_____
Grease	_____	_____	_____
Filters	_____	_____	_____
Other	_____	_____	_____

Total fuel, lubricants and filters _____

Tires

$$\frac{\text{Replacement cost}}{\text{Estimated hours}} = _____ = _____$$

Repairs

$$\frac{\text{Factor x (cost - tires)}}{1{,}000} = \frac{\text{x}}{1000} = _____$$

Other

Total operating cost _____

Operator wages _____

Total owning and operating cost _____

Figure 13-12
Sample machine ownership and operating cost summary

Machine number	O&O cost per hour	Average hours per year	O&O cost per year	Percentage overhead	Term overhead	Overhead cost per hour	Total hourly cost
1	29.82	1,500	44,730.00	30%	33,000.00	22.00	51.82
2	35.01	1,300	45,513.00	30%	33,000.00	25.38	60.39
3	36.22	500	18,110.00	12%	13,200.00	26.40	62.62
4	21.15	2,000	42,300.00	28%	30,800.00	15.40	36.55
		Totals	**150,653.00**	**100%**	**110,000.00**		

Figure 13-13
Total ownership and operation machine costs

The machines that do the actual dirt moving must make enough money per hour to cover company overhead as well as the direct costs of operating the machines.

Begin your estimate of overhead for the coming year by totaling actual overhead for the prior year. Be sure to include all company expenses that weren't the result of taking some particular job. That's your company overhead.

Next, make an estimate of whether overhead will increase or decrease during the coming year. Adjust actual overhead for last year by the estimated percentage of increase or decrease in overhead during the coming year.

Then convert estimated total overhead for the year into a cost per hour for each machine you'll be using during the coming year. There are two accepted methods of doing this.

One is to total the average annual hours for all production machines. Then divide the total overhead cost by the total number of hours. The answer is your average hourly operating cost. This is the easiest method, but not the best. You probably won't use every machine on every project. That's why I recommend the second method — calculating an average hourly operating cost for each individual machine.

Figure 13-13 is the chart I use to compile the cost for each machine. Here's what the column headings mean:

Machine number — is a number you assign to a specific machine. Any numbering system will work.

O&O cost per hour — is the owning and operating cost per hour.

Average hours per year — is either the actual total number of hours that you ran the machine in the previous year, or your estimate of use for the coming year.

O&O cost per year — is the owning and operating cost per hour times the estimated number of hours of use.

Percentage overhead — is the percentage of total machine hours assigned to this specific machine.

Term overhead — is the percent of overhead times the total yearly overhead cost.

Overhead cost per hour — is annual overhead divided by the average hours per year.

Total hourly cost — is the sum of the owning and operating cost per hour and overhead cost per hour.

The numbers in Figure 13-13 are based on my estimate of a total overhead of $110,000 per year.

Adding the Profit

The last dollar amount on your estimate — and probably the most important — is profit. There are almost as many ways to figure profit as there are earthwork contractors. There are two general rules, however.

- First, add the profit to the hourly cost for all "cost plus" bids. That's a project where the owner pays directly for all materials, and pays for the machine on an hourly basis.
- Second, the profit should always be the last item you add to the estimate. Keep that figure separate until the last minute.

Suppliers or subs may change their bid at the last minute, requiring an immediate change in your bid. Also, some area of your bid may be overstated while others may be below actual cost. (This is called loading the bid.)

Bid Price per Cubic Yard

At last we've almost arrived at the figure we've done all these calculations to find — the bid price. This is really a simple formula:

Bid price ($/CY) = Total hourly cost of all machines ÷ Cubic yards in project

In this chapter I've tried to tie together the methods for finding quantities, choosing the type and number of machines, how long the project will last, what it will cost, and how to add overhead and profit. We'll carry this information even farther in the next two chapters, with a practice estimate and a sample bid.

14

A Sample Take-off

If you've followed the instructions provided in the first thirteen chapters of this book, you should be able to estimate most common excavation work. Now, just to test your understanding, I'm going to give you a final exam for this course. But don't worry. This is an open book exam. In fact, to make your task easier, I'm going to offer hints on where to look if you need a little more information on how to do some calculations.

This final exam is broken into two parts. Part one is in this chapter. We'll take-off quantities for a complete project — from start to finish. Figure 14-2 (page 342) is the site plan. To make it easier for you, I've put all the figures together at the end of this chapter. In the next chapter, Chapter 15, we'll use the quantities calculated in this chapter to price the work.

This sample estimate is intended to be as realistic as possible. It's also intended to test your understanding of everything covered in this manual. Figure the quantities. Then compare your answers with my answers. If the answers agree, you're ready to begin estimating your own jobs.

The plan sheets shown in this chapter are much smaller than the plans you'll have for most jobs. That's because, if you're looking at a printed page, they're reduced to fit. Plus, in the printing process, the images may change in size slightly, so what I scaled off the plans shown may not match exactly the plans you're looking at. And if you're viewing this chapter on an electronic device, obviously the plans are sized to fit your screen. In that case, you'll need to print out the plan pages. Use regular 8½ x 11 paper, with 1-inch margins. And be aware that the dimensions you scale off the printout of the plans won't agree exactly with the dimensions in my examples. Just ignore these differences. In most cases they'll be small. The important thing is that you understand the procedure — not that we arrive at exactly the same figures.

For most estimates you'll list each excavation category separately. For example, your estimate will show the number of units and the unit costs for dirt excavation, for rock excavation, for utility line excavation, for backfill, and so on. Since your estimates have to show estimate details, my sample estimate will show all the details.

We'll use several different types of take-off forms to do the calculations. I introduced specialized take-off forms in many of the earlier chapters. We'll use some of these forms in this chapter. But some of the work is best done on plain ruled paper. The paper or form you use is a matter of personal preference, in my opinion. Most professional excavation estimators use printed forms for at least some of their work. But you can do an accurate take-off on any type of paper.

No matter what type of form you use, always show your calculations. That makes checking easier. Every professional estimator I know shows the calculation details on estimates. I recommend that you do the same. If you need to know where some figure came from, all the information should be there on the sheet, readily available for inspection. If you have to make revisions in the estimate, changes are easy if all the calculations are shown. If the calculations are too long to include on the take-off sheet, attach a separate piece of paper.

Nearly every set of plans and specs will include a section titled "General Specifications." That's where you should start reading. So that's where we'll begin this sample estimate.

General Specifications

General specifications will be very similar on most of the jobs you bid. But don't fall asleep while reading the general specs. Any unusual work conditions on a job will be described in the "General Specifications." For example, if you have to maintain traffic movement during the excavation or observe special precautions for environmental reasons, you'll discover that in the general specs section of the bid documents. A few missed words in the general specs can double your cost of doing the work. So stay alert and read every word.

Here are the general specifications for our sample project:

Item 1: Clearing and Grubbing

Due to the small amount of trees and undergrowth, clearing and grubbing will not be a pay item per unit. They will be on a lump sum basis.

Item 2: Soil Testing

The results of the borings and other miscellaneous soil information will be found in the plans. The contractor shall be responsible for any deviation from the results shown.

Topsoil tests indicate a 2-inch-thick layer of deleterious material unsuitable for use. This material must be removed completely from the jobsite. The usable portion of material averages 4 inches. Payment will be based on this figure. Any excess topsoil material will become the property of the contractor, and will be removed from the site.

Item 3: Service Road

The road on the back of the property shall be considered a service road only. Due to the lay of the land and drainage needs, no ditches will be required. The road shall be constructed of 6 inches of Type AB-3 crushed stone.

Item 4: Entrance Drive

The entrance drive shall be constructed of asphaltic concrete over a crushed stone base. Grade and line shall be according to the standard drawings for this area.

Item 5: Parking Lot

The parking lot shall be built to the size and specifications as shown on the general plan and as denoted here. The surface shall be 4 inches of asphaltic concrete over 6 inches of crushed stone base of Type AB-3. The crown of the lot shall be built into the lot using the surface asphalt. The grading shall be within plus or minus 0.10 foot. Contractor shall make the surface drain regardless of finished grade or plan notes.

Item 6: Buildings

Both the office building and the shop building require excavation work. Details for the shop building footing and the office building basement are covered in the standard drawings, and in the plans.

Item 7: Rock Excavation

The contractor may encounter rock during excavation work at certain areas designated on the plans. In such case, the rock shall be excavated to a depth of at least 1 foot below grade line in areas of cut. Suitable material shall then be placed and compacted to bring the area back up to grade. The contractor shall bid this item as anticipated only, at a unit price. Quantities shall be determined as work progresses.

Item 8: Utility Work

Both sanitary and storm sewer lines shall terminate in manholes at the southern property line. All sanitary sewer lines shall be 8-inch cast iron pipe. All storm sewer lines shall be 12-inch corrugated metal pipe. Trench shoring shall be used in excavation of all trenches with a depth of 3 feet or more. Bedding for all lines shall be as per standard drawings.

Doing the Take-off

We'll break the take-off into logical steps, figuring work in the same order it'll be done in the field. That makes topsoil excavation our first topic.

Figuring the Topsoil

First, we'll find the total amount of topsoil to strip from the project to get down to workable material. Second, we'll calculate the amount of topsoil we can store and replace on the site. Third, we'll identify the areas where topsoil will be replaced. Finally, we'll find a place to store topsoil while doing other site work. If you have trouble with any of these calculations, review Chapter 9.

According to the general specifications, the existing site has 6 inches of topsoil. But the top 2 inches includes debris and vegetation that make it unsuitable for use as replacement soil. Figure 14-2 shows the parking lot, two roadways and the location for two buildings. Everything else on site will be covered by topsoil.

Check my calculations in Figure 14-3 to see if you agree. The site measures 340 feet by 240 feet. The 2 inches of unsuitable material total 503.70 CY. This volume has to be hauled away. The next 4 inches of reusable material total 1,007.41 CY. That's the amount of material we'll store, either on or off the site. I know from making the site visit and talking to the owner that this spoil can be stored in the northeast corner of the property during construction. So that's my plan for this job.

How much topsoil will it take to place a 6-inch layer over the area not covered by structures? See my calculations in Figure 14-3. First, I found the site's area, 81,600 SF. Then I found the total area covered by buildings, roads and parking lots, 22,050 SF. Subtract the covered area from the total area and multiply the result by 0.5 to get the total topsoil. Divide that by 27 to find cubic yards of topsoil. The result is 1,102.77 CY. We have 1,007.41 CY in the stockpile (subtract the 4 inches of good topsoil from total topsoil), so we need to truck in an additional 95.36 CY of topsoil. Let's round that off to a total of 96 CY. Figure 14-4 is a summary of my topsoil figures.

Rock Service Road

The specifications call for 6 inches of rock on the service road. Take another look at Figure 14-2. The service road's broken down into three parts, labeled Service road A, Service road B, Service road C. We already found the area for each of these parts in Figure 14-3. The service road won't need any extra compaction because it's all cut. That means you won't need to calculate any extra yardage for undercutting. Now let's find out how many cubic yards of rock we'll need. First, add the three areas

together (see Figure 14-3). Second, multiply the sum of the areas by 0.5. Third, divide that result by 27. I get 120.37 CY of rock for an answer, and Figure 14-5 shows my calculations.

Bidding Rock: Tons or Cubic Yards?

Some estimators bid rock by the ton. Others prefer to estimate rock by the cubic yard. If you want to bid rock by the ton, you'll need to know how much a cubic yard of the rock weighs. The weight varies depending on the kind of rock. For this estimate, we'll use loose limestone rock. One cubic yard of loose limestone weighs 2,800 pounds, or 1.4 tons. So, 120.37 CY of rock at 1.4 tons per cubic yard works out to about 168.5 tons.

Grid Square Take-Off

Figure 14-6 is a contour map of the building site. Dashed lines show existing elevations and solid lines show proposed elevations. Figure 14-7 shows a grid system laid over the contour map. Grid squares are numbered from A to I_1. Each 1¼ -inch grid square represents an area 50 feet by 50 feet on the ground. That makes the map scale 1" to 40'. Check the scale by measuring for yourself. Each grid (except partial squares along the right and lower edge) should measure 1¼ inches by 1¼ inches.

This estimate is fairly simple because nearly all the grids require cut. We'll start by finding the existing elevation for each corner of each grid square. That's a three-step process. First, find and record the elevation of the contour lines on either side of the corner. Second, measure the distance between the two contour lines and from the higher contour line to the corner. Third, using the measurements as a ratio, solve to find the corner elevation. If you need to review all or part of this procedure in greater detail, turn back to Chapter 5.

Scaling Existing Elevations

Let's start by finding the existing elevation at point A-1. That's corner 1 (the northeast corner) of grid square A in Figure 14-7. Notice that corner A-1 is between existing contour lines 100 and 102. So we know that the existing elevation at A-1 is more than 100 and less than 102. How much is corner A-1 above elevation 100? To answer that question we'll measure the distance between contour lines 100 and 102 along a line that passes through corner A-1.

Here's the estimating procedure:

1. Lay your measuring scale on Figure 14-7 so the point of origin (zero) is on contour line 100. The scale should run perpendicular to contour line 100.

2. Slide the end of the scale along contour line 100 until the scale edge runs over the top of corner A-1.

3. Note the distance between contour line 100 and contour line 102.

4. On my scale, the distance between 100 and 102 is 40 units. If you're measuring with an ordinary ruler, you'll get almost exactly 1 inch. (The unit of measure isn't important. Use any measuring system you like. The estimated elevation at A-1 will be nearly the same for any unit of measure.)

5. Then, without moving the scale, note the distance from contour line 100 to corner A-1. I get 7 units. With an ordinary ruler, it's about $^{3}/_{16}$ inch.

Recording Existing Elevations

Now take a look at Figure 14-8. That's my worksheet for existing corner elevations from Figure 14-7. Let's use corner A-1 as an example, and see what sort of data's here and where it comes from:

Location — The name of a specific grid square corner: A-1.

Low elevation — For A-1 it's 100.

High elevation — For A-1 it's 102.

Scale distance — For A-1 it's 7/40, or the measured distance (Low elevation contour to A-1, 7 units, over Low elevation contour to High elevation contour, 40 units).

Contour interval — 2 units.

Add elevation — The Scale distance, converted to a decimal, times the Contour interval. For A-1 it's:

$$7 \div 40 \times 2 = 0.35$$

If you measure in fractions of an inch, the calculation looks like this:

$$^{3}/_{16} \div 1 \times 2.0 = 0.375 \text{ inch}$$

The two answers (0.35 and 0.375) aren't a perfect match, but they're close enough for this type of work.

Point elevation — Low elevation (100.0) plus Add elevation (0.35), or for A-1:

$$100 + 0.35 = 100.35$$

I've used the same procedure to find the existing elevations for the four corners of all 35 grid squares, and recorded the data in Figure 14-8. Work out the rest of the

corner elevations on your own. When you compare your results with mine they should be about the same.

Scaling and Recording Proposed Elevations

Repeat the same process using the proposed elevations, this time comparing your work with my data shown in Figure 14-9.

Calculating Excavation Volumes from the Grid Square Take-off

Once you know existing and proposed elevations at each corner, it's easy to find excavation quantities. Turn to Figure 14-10. This worksheet records the data used to calculate an Average depth for each grid square. Here's how it works using grid square A, and A-1, for our example:

Proposed —Elevations for each Element, or corner, come from the Point elevation column in Figure 14-9. For A-1 it's 100.

Existing — Elevations for each Element come from the Point elevation column in Figure 14-8. For A-1 it's 100.35.

Depth — The Existing minus the Proposed elevations. For A-1:

100.35 – 100 = 0.35

Average depth — This appears right below the grid name. This is a simple average, the sum of the four corner depths divided by the number of corners. In our example, Grid A, it is:

(0.35 + 2.14 + 0.91 + 0) ÷ 4 = 0.85

Before we move on to the next step, take a look at the data and calculations for Grid I_1, and especially note the data in the Depth row. Three of these values are negative numbers. The proposed elevation is greater than the existing elevation, so the depths are negative. Furthermore, the Average depth is also negative. That tells us that Grid I_1 is fill, while the other 34 grid squares are all cuts.

Calculating Average Depth

Turn to Figure 14-11 to see how I use the average depth figures to find excavation volumes for either cut or fill.

Location — The grid square name.

Length and Width — The dimensions for each grid square aren't identical. For example, in Figure 14-7, eleven of the grid squares don't

measure 50 by 50. That's a difference that counts. Always record your data carefully.

Ave. depth — This comes from Figure 14-10.

Vol. cut (CY) and Vol. fill (CY) — These are Length × Width × Ave. depth ÷ 27. You enter the result in the Vol. cut column if it's positive, and in the Vol. fill column if it's negative. Using grid square A, this is how you calculate it:

50 × 50 × 0.85 ÷ 27 = 78.70 CY

Notice that there are three totals listed at the end of Figure 14-11:

Total cut = 13,062.06 CY

Total fill = 53.93 CY

Total spoil = 17,040.65 LCY (in the Note box)

What About Topsoil?

You may have noticed that so far we've ignored topsoil depth in our calculations. Topsoil is removed before any other excavation begins, and it's not replaced until the construction is complete. Most professional excavation estimators work from existing and proposed grade elevations and ignore the depth of the topsoil. Doing that on this job will result in building elevations that are 6 inches lower than you might expect. But it won't change the grid square excavation volumes. Here's why.

Look at Figure 14-12. This is a cut-away view of a grid square. The specs on this job require stripping off 6 inches of topsoil. Assume the finish elevation is 100.0. Now let's calculate the depth of cut in two different ways. The first time (or Case 1), we'll ignore the topsoil. The second time (Case 2), we'll include the topsoil in our calculations by using the elevations identified as Alternate.

Case 1. Ignoring the Topsoil — Depth of the cut at corner 4 equals existing elevation minus proposed elevation, or 102.22 – 100 = 2.22 feet.

Case 2. Considering the Topsoil — Existing depth is 102.22. Removing 6 inches leaves the depth at 101.72. Remember that number. In order to replace 6 inches of topsoil and have the finished grade be 100, we must start by excavating to a depth that's 6 inches below the finished grade. That's 100 minus 0.5, or 99.5. Therefore, the cut at corner 4 equals: existing elevation, 101.72, minus proposed elevation, 99.5, with a result of 2.22 feet.

Case 2 takes more time and math to arrive at exactly the same answer that we found in Case 1. Don't you agree now that it's easier to ignore the topsoil?

On most jobs where you aren't concerned with final building elevations, my advice is to ignore topsoil removed and replaced. That's the procedure we'll follow in this chapter. Make an exception for large areas where topsoil will be removed but not replaced, such as a parking lot.

Entrance Road

A 28-foot-wide driveway runs 125 feet north from the south property line. Figure 14-13 shows this entrance road and proposed contour lines at the site. Figure 14-13 A shows the entrance road in plan and profile views. Figure 14-14 shows a typical section of this entrance road.

Figure 14-15 gives the excavation limits for the entrance road. Using these excavation limits, I created the excavation template shown in Figure 14-16.

Calculating Average End Areas

Take another look at Figures 14-13 and 14-13 A, and compare them. You'll notice that finished roadway elevations follow the profile of the finished contour lines. On most roadway jobs you'll have to average the end areas at each section to figure the excavation volume. On this job, we're in luck because the end areas are nearly identical. As a result we'll only need to calculate the end area once. For the other stations we'll use the same end area figure because it's the average. That saves a whole lot of figuring time.

If necessary, review Chapter 6 to refresh your memory on how to do average end area calculations. No matter which method you use (measuring strip, planimeter or arc section), your answer should match mine. As Figure 14-15 shows, average end area equals 34.1 SF.

To find the excavation volume:

1. Calculate the end area in two places.
2. Add the two end areas together.
3. Divide the sum by 2 to find the average end area.
4. Multiply the result by the distance between the two end areas and you'll have the excavation volume in cubic feet.
5. Divide the result by 27 to change cubic feet to cubic yards.

Let's see how this works with Sta. 0+00 and Sta. 0+18 in Figure 14-13 A. At Sta. 0+00 we only need to meet the existing grade. There's no excavation required, so the end

area equals 0. At Sta. 0+18, however, using the full template, the end area equals 34.1 (see Figure 14-15). That takes care of Step 1. Now for the rest of the math:

0 + 34.1 = 34.1

34.1 ÷ 2 = 17.05

17.05 × 18 = 306.9 CF

306.9 ÷ 27 = 11.37 CY

Let's do one more station calculation, Sta. 0 + 50. Remember, the end area of all the other stations is 34.1.

34.1 + 34.1 = 68.2

68.2 ÷ 2 = 34.1

34.1 × 32 = 1,091.2

1,091.2 ÷ 27 = 40.42 CY

Figure 14-17 summarizes my excavation volume calculations for the five stations (Sta. 0+00, 0+18, 0+50, 1+00 and 1+25) along the entrance road. My rounded-off total for excavation volume, including a 31 percent swell factor, is 192 CY.

Remember, you can use any reasonable distance between these end sections. Once you're out in the field you'll find 100-foot intervals used in very flat areas. However, areas with larger or more frequent changes in elevation use 50- or 25-foot intervals.

Parking Lot

The general specifications require a parking lot made of 4 inches of asphaltic concrete laid over a 6-inch crushed stone base. Add these together to find the total excavation depth, 10 inches.

You'll remember that this site had 6 inches of topsoil. The first 2 inches have been stripped and hauled away. The remaining 4 inches were also stripped, and stockpiled. In the grid square take-off and entrance road calculations, we ignored the topsoil. Anytime you remove and replace topsoil, it has no effect on excavation volumes. But we won't be replacing any topsoil in the parking lot. To include the topsoil in these excavation calculations, I'll subtract topsoil depth from excavation depth to find the additional excavation depth. My answer is 4 inches.

Take a close look at the parking lot area in Figure 14-2. You'll see that I've broken it down into two rectangular parts labeled Parking lot A and Parking lot B. We already know their areas from the calculations shown in Figure 14-3. A's area is 1,750 SF and B's

area is 4,350 SF. Add them together to find the total area, 6,100 SF. Next we'll find total excavation volume for a 4-inch-deep cut over an area measuring 6,100 SF.

(4"÷ 12) × 6,100 SF = 2,033.33 CF

2,033.33 CF ÷ 27 = 75.31 CY

75.31 CY × 1.31 = 98.66 LCY (rounded to 99 LCY)

What About Drainage?

Figure 14-18 shows the parking lot with a break point represented by line (A)(B). This line is the highest point on the lot. Water will drain from this line toward the service road and down to the catch basins. It's hard to excavate such a small slope. Building this sort of slope into the asphaltic surface, however, is easy. So we'll use 4 inches as the excavation depth throughout the parking lot. Later on we'll build the right drainage slope into the asphalt surface.

Sanitary Sewer Lines

Figure 14-19 shows the sanitary sewer system. From the general specifications and the description at the bottom of Figure 14-20, we know that the sanitary sewer lines are 8-inch cast iron pipe. According to the general specifications, we'll have to use a trench box during excavation because the trench is 3 feet deep. So we'll calculate trench volumes using straight sides instead of sloping sides.

Our first job here is to find the volume of material we'll remove from the trenches and manhole areas. Then we'll calculate the volume of rock and concrete needed in the trench and around manholes as well as the backfill needed to finish the job.

Let's begin by examining the plan and profile sheets for this system, shown in Figures 14-21 through 14-24. Each plan and profile sheet has two parts. The top part is a plan view showing general layout and alignment of the line or lines. The bottom part of each sheet contains a profile view of the line. This is a cut-away view of the piping and the manholes.

You'll also find the scale listed near the top of each sheet. You've seen this before in earlier chapters, but if you're new to the business, the scale may look confusing at first glance. This is what's called a dual scale, and it's easy to use once you know how it works. In Figures 14-21 through 14-24 I've used the following scale:

Horizontal: 5 squares = 20'

Vertical: 6 squares = 5'

Why the difference between horizontal and vertical? It allows me to enlarge the sewer lines and related structures, such as manholes, without changing other dimensions.

Your designer needs the extra space here to record inlet and outlet elevations and other data. One last note about dual scales. The plan view scale and the horizontal scale in the profile view should be (but aren't always) the same. Double check; just to be sure.

Sanitary Sewer Line Excavation

The method for finding cubic yards in utility line excavation is quite simple. At each structure, find the difference between the finished contour line at the top and the flowline of the pipe. Add a few inches for undercut of the pipe. Multiply the average depth by the length between the two structures. Multiply by the trench width. Finally, convert the answer to cubic yards.

We'll use a special calculation for the undercut. Most designers illustrate sewer lines as shown in Figures 14-21 through 14-24. They show all lines between manholes with an inlet elevation where the lines enter a manhole, and an outlet elevation where they exit. This elevation is the actual flowline inside the pipe. It doesn't allow for the thickness of the pipe or for 6 inches of bedding material under the pipe. In the example, I've added 6 inches to all depths to allow for bedding material. I've elected to ignore the pipe thickness, since an 8-inch-diameter pipe only adds about ½ inch. Where pipe diameters are larger, you'll probably want to consider the thickness of the pipe walls.

Figures 14-25 through 14-28 show how I calculated average depths for the lines between the manholes. Note the additional 6 inches (+0.5 foot) for the undercut.

Figure 14-29 summarizes the excavation work required for the four lines. The total is 369.86 LCY (rounded to 370 LCY).

Sanitary Sewer Line Backfill

Figure 14-30 is a section view showing the rock backfill to be placed around the pipe. Notice that 6 inches of rock are required over and under the pipe. Add the 8-inch diameter of the pipe and you get a total depth of 20 inches for rock backfill. That's the same as 1.67 feet, a figure we'll use to calculate dirt backfill quantities.

Dirt Backfill

Figure 14-31 shows my calculations for dirt backfill. Numbers in the length, width and average depth columns are the same as for trench excavation and come from Figure 14-29. Rock backfill and the pipe together reduce trench depth a total of 1.67 feet. Here are my calculations for Line 1.

Average depth of 4.70 feet is reduced by 1.67 feet, leaving 3.03 feet. Find the volume by multiplying length times width times depth.

$145 \times 2 \times 3.03 = 878.7$ CF

To find volume in compact cubic yards (CCY), you multiply volume by 1.25 (25 percent shrinkage) and divide by 27.

878.7 CF × 1.25 ÷ 27 = 40.68 CCY

Rock Backfill

Figure 14-32 shows how I calculated rock backfill quantities. Numbers in the length and width columns are the same as for trench excavation and come from Figure 14-29. Depth is 20 inches, or 1.67 feet. Of course, pipe fills a portion of this volume. How much of the 24-inch by 20-inch cross section area does the pipe actually occupy? The pipe's diameter is 8 inches, so the radius is 4 inches. The area of a circle equals pi (3.14) times the radius (4 inches) squared. The result here is square inches. Square feet are easier to work with, so divide by 144 to convert to square feet. Plug in the numbers:

$$A = 3.14 \times 4^2$$
$$= 3.14 \times 16 \text{ SI}$$
$$= 50.24 \text{ SI}$$

$$A = 50.24 \div 144$$
$$= 0.35 \text{ SF}$$

Look at Figure 14-32 and you'll see that same number in the Area of pipe column.

Now, to calculate the rock volume needed for Line 1, multiply the width times depth, then subtract the area of pipe (0.35 SF). Multiply the result by the trench length, and divide that by 27 to get your rock volume in cubic yards. Here's the calculation for Line 1:

$$\text{Rock volume} = W \times D \times L$$
$$= [(2 \times 1.67) - 0.35] \times 145$$
$$= (3.34 - 0.35) \times 145$$
$$= 2.99 \times 145$$
$$= 433.55 \text{ CF}$$

$$\text{Rock volume} = 433.55 \text{ CF} \div 27$$
$$= 16.06 \text{ CY}$$

You'll see 16.06 CY for Line 1 under Rock fill vol. in Figure 14-32. Calculate rock fill volumes for lines 2, 3, and 4 the same way. Finally, total the Rock fill vol. column and round the result to full cubic yards. My total rock fill volume for the four sanitary sewer lines comes to 39 CY.

Developing Manhole Excavation Constants

Next we'll calculate excavation volumes for the three manholes in the sanitary sewer system. Let's start by developing two *SF per foot of depth* area constants. These constants are:

1. The excavation area constant
2. The manhole area constant

Figure 14-33 supplies all the data we need — two diameters and two formulas:

- Pipe diameter is 4 feet
- Excavation diameter is 8 feet
- Formula to find the radius of a circle is: r = diameter ÷ 2
- Formula to find the area of a circle is: area = πr^2
- The value of pi (π) is: 3.14

You can't find the area without knowing the radius, so we'll start there and then move on to calculate the areas. For the manhole I get:

4 ÷ 2 = 2 feet (radius)

$3.14 \times 2^2 = 12.6$ SF area

For the excavation I get:

8 ÷ 2 = 4 feet (radius)

$3.14 \times 4^2 = 50.24$ SF area

Calculating Manhole Excavation Volumes

Now let's see how you use these constants to calculate the manholes' excavation and backfill volumes. You find each manhole's excavation volume by repeating the same six steps. Using manhole No. 1, let's walk through the steps. Figure 14-34 is the worksheet with my results. We'll begin with finding the manhole depth, using the correct plan and profile sheet:

1. Record the outlet, and the finish elevations for the manhole.
2. Subtract the outlet elevation from the finished elevation:
   Elevation difference for No. 1 is 100 – 89.7 = 10.3
3. Elevation difference plus 1 foot is the manhole depth:
   Depth for No. 1 is 11.3

4. Multiply Depth by the excavation area constant:
   Excavation area (SF), or the constant, for No. 1 is 50.24

5. Divide the result by 27:
   Exc. vol. (CY) for No. 1 is 21.03

6. Multiply Exc. vol. (CY) by 1.31:
   Shrink (–) or swell (+) factor for No. 1 is + 1.31

The result for No. 1 is 27.55, the same value you see in the Actual vol. (CY) column in Figure 14-34.

Repeat the same steps for manholes 2 and 3. Total the Actual vol. column and round the result to full cubic yards, as shown in Figure 14-34. I get a total excavation volume for the manholes of 108 LCY.

Calculating Manhole Backfill Volumes

After installing the concrete manholes, the next task is backfill around the structures, and that means another round of volume calculations. My backfill volume calculations are shown in Figure 14-35. Here's an example, using manhole No. 1 and following the column headings shown in Figure 14-35.

Depth: There's no change, so I reuse the data from Figure 14-34. For No. 1 this is 11.3 feet.

Excavation area: The constant from Figure 14-33, 50.24 SF.

Manhole area: The constant from Figure 14-33, 12.6 SF.

Exc. area – MH area: Subtract the manhole area from the excavation area to find the backfill area per foot of depth. For No. 1:

50.24 SF – 12.6 SF = 37.64 SF

Backfill vol. (CF): Multiply backfill area by Depth and the result is backfill volume in cubic feet. For No. 1:

11.3 ft × 37.64 SF = 425.33 CF

Shrink (–) or swell (+) factor: Backfill takes the shrink factor –1.25. So for manhole No. 1, I get:

425.33 CF × 1.25 = 531.66 CCF

Actual vol.: Divide cubic feet of backfill by 27 to convert it to cubic yards.
For No. 1:

531.66 CCF ÷ 27 = 19.69 CCY

Repeat the same calculations for the remaining two manholes. Total the Actual vol. column, and round the result to full cubic yards. I found that the total volume of backfill around the manholes came to 77 CCY. Before we move on, take a look at the Note section at the bottom of Figure 14-35. It says:

108 exc – 77 bkfill = 31 CY spoil

That's my shorthand for 108 CY excavated, less 77 CY replaced as backfill, leaves me with a total of 31 CY of spoil.

Storm Sewer Lines

Enclosed storm sewer systems are an efficient way to provide a concealed drainage system for runoff water in urban areas. In rural areas, open ditch systems serve the same need. Figure 14-36 is a plan view of the enclosed storm sewer system for our sample project. We'll calculate excavation volumes for the storm sewer system by following the same steps we used earlier for the sanitary sewer system.

Storm sewer systems include structures called catch basins. These are precast concrete boxes that have an opening at the top on at least one side. These openings allow surface runoff water to enter the storm sewer system. One of these openings, called a drop, or curb inlet, appears in Figure 14-37. There are two more standard drawings for the storm sewer system. Figure 14-38 shows the excavation limits for the catch basins. Figure 14-39 shows the backfill requirements. Further information about the storm sewer system comes from the General Specifications, including:

1. All lines are 12-inch corrugated metal pipe (CMP)
2. City line tie-in via manhole at south project limit line
3. Trench box required, so trench walls are vertical

Catch Basin Excavation

The plan and profile sheets for the three catch basins, the manhole, and their connecting lines appear in Figures 14-40 through 14-42. Notice that the profile views give inlet and outlet elevations for each catch basin. There's one dimension missing: the catch basin depth. Assume that the bottom of each catch basin is 1 foot lower than its outlet.

Figure 14-43 shows and summarizes excavation calculations for the three catch basins and manhole No. 1.

Elev. diff.: The finished elevation minus outlet elevation. Both elevations appear in Figure 14-40. For catch basin 1 that's:

100 – 98 = 2 feet

Depth: The Elev. diff. plus 1 foot. For catch basin 1:

2 + 1 = 3 feet

Struct. exc. area: The constant we found in Figure 14-38, 36 SF.

Volume: Depth times Struct. exc. area; divide the result by 27 to convert it to cubic yards. Plug in the numbers for catch basin 1:

3 feet × 36 SF = 108 CF

108 CF ÷ 27 = 4 CY

Actual vol.: Volume times the Swell (+) factor, 1.31. For catch basin 1:

4 CY × 1.31 = 5.24 CY

Catch Basin Backfill

Figure 14-44 shows the backfill calculations for the three catch basins and manhole No. 1.

Depth: This repeats the data from Figure 14-43.

Struct. area: The area of the catch basin (see Figure 14-38) or manhole (see Figure 14-33).

Exc. area: This repeats the data from Figure 14-43.

Backfill area: The Exc. area minus Struct. area. Plug in the numbers for catch basin 1 to get:

36 SF – 4 SF = 32 SF

Volume (CY): The Backfill area times Depth; divide the result by 27. For catch basin 1 that's:

32 SF × 3 feet ÷ 27 = 3.56 CY

Actual vol.: The Volume (CY) times the Shrink (–) factor, or 1.25. For catch basin 1:

3.56 × 1.25 = 4.45 CCY

Average Depth Calculations for Storm Sewer Lines

The next step is finding the average excavated depth for each storm sewer line. Figures 14-45 through 14-47 record the calculations for each line. Look at these calculations for storm sewer line 1, which runs from catch basin 1 to catch basin 2. (See Figure 14-40.)

1. Subtract the outlet depth at CB 1 (98.01) from the finish grade at CB 1 (100). The result is 1.99.
2. Subtract the inlet depth at CB 2 (97.01) from the finish grade at CB 1 (100). The result is 2.99.
3. Add 0.5 feet to each for the 6 inches of crushed rock backfill shown in the standard drawing, Figure 14-39.
4. Total the two elevation differences (2.49 + 3.49), and divide by 2. The result (2.99 feet) is the average depth for storm sewer line 1.

Figures 14-46 and 14-47 show the same set of calculations for storm sewer lines 2 and 3 respectively.

Storm Sewer Line Excavation Volumes

Now let's find excavation volumes for each of the three storm sewer lines. My work is summarized in Figure 14-48. Using storm sewer line 1 as our example, let's plug in the numbers:

Length: Line 1 (CB 1 to CB 2) is 42 feet, as shown in Figure 14-40.

Width: 2 feet.

Average depth: 2.99 feet, as computed in Figure 14-45.

Volume: Length times Width times Average depth divided by 27.

(42 × 2 × 2.99) ÷ 27 = 9.3 CY

Actual vol.: Volume times the swell (+) factor + 1.31.

9.3 CY × 1.31 = 12.19 LCY

Take a look at Figure 14-48, and you'll see the same number in the Actual vol. column for Line 1.

Storm Sewer Line Backfill Volumes

Before we can compute the dirt backfill required, we need to know how much of the excavated depth is filled by the pipe and the rock backfill. Figure 14-39, you recall, is the standard drawing showing a section view of the storm sewer after pipe placement. Notice that 6 inches of rock are required over and under the pipe (6 + 6 = 12). Now add the 12-inch diameter of the pipe (12 + 12 = 24). So rock and pipe together fill 24 inches (2 feet) of the total excavated depth.

Dirt Backfill

Figure 14-49 shows the calculations for dirt backfill. The values for Length, Width and Average depth haven't changed, so I'll reuse the data from Figure 14-48. We also know that rock backfill and the pipe reduce the excavation depth by 2 feet. Here are my calculations for Line 1, as an example:

2.99 – 2 = 0.99 foot

42 × 2 × 0.99 = 83.16 CF

83.16 CF ÷ 27 = 3.08 CY

3.08 CY × 1.25 = 3.85 CCY

The result, 3.85 CCY, matches the number you'll see under Actual vol. for Line 1 in Figure 14-49.

Rock Backfill

Figure 14-50 shows how to calculate the rock backfill quantities. The numbers in the Length and Width columns are from Figure 14-48. The Depth is 24 inches, or 2 feet. Of course, the pipe fills a portion of this volume. How much of the 24-inch by 24-inch cross section area does the pipe fill? We know the pipe diameter is 12 inches, so its radius is 6 inches. The area of a circle is π (3.14) × r^2. Substituting the numbers, I get:

$A = 3.14 \times 6^2$

$= 113.04$ SI

A = 113.04 SI ÷ 144 = 0.78 SF

In Figure 14-50 this constant appears in the column headed Area of pipe.

To find the volume of rock needed for fill, multiply Width by Depth. The result's the

excavated area in square feet. Next, subtract the Area of pipe from the excavated area, multiply the answer by the Length, and then divide the result by 27. Here's what my rock fill volume calculations for Line 1 look like:

2 feet × 2 feet = 4 SF

4 SF – 0.78 SF = 3.22 SF

3.22 SF × 42 feet = 135.24 CF

135.24 CF ÷ 27 = 5.01 CY

You'll see that 5.01 appears in the Rock fill vol. column for Line 1 in Figure 14-50. Repeat these calculations for Lines 2 and 3. Then total the Rock fill vol. column and round the result to full cubic yards. As Figure 14-50 shows, the total volume for the rock backfill is 30 CY.

Shop Building Footing

For the shop footing, we need to find three volumes: total excavated volume, rock backfill volume, and dirt backfill volume. Most of the data we'll use in finding these volumes comes from two standard drawings, Figures 14-51 and 14-52. We'll refer to Figure 14-51 for excavation details, and to Figure 14-52 for backfill details. For the shop building's dimensions, refer to Figure 14-2. Remember, all measurements are made to the outside of the footing. If you feel lost at any point, review Chapter 10.

Footing Excavation, V-out

We'll begin with the V-out calculations. V-out for the shop building equals excavation volume plus the total excavated corner volume. To find excavation volume, you use the standard formula:

Volume = L × W × D

Use the shop building's dimensions from Figures 14-2 and 14-51 and divide by 27 to get your answer in cubic yards. The excavation volume comes to:

(240 × 2 × 1) ÷ 27 = 17.8 CY

To find the total excavated corner volume in cubic yards, use this formula:

$(^1/_3\ \pi \times r^2) \times d \times n \div 27$

Where:

pi (π) = 3.1416

corner radius (r) = 1 foot

depth (d) = 1 foot

number of corners (n) = 4

The total corner volume is:

$(0.3333 \times 3.1416 \times 1^2) \times 1 \times 4 \div 27 = 0.16$ CY

The last step is to add the two volumes together:

17.8 CY + 0.16 CY = 17.96 CY

Footing Excavation, V-in

The next volume we'll find is for V-in. Your data comes from Figures 14-2 and 14-51. This is a simple volume calculation:

V-in = (L × W × D) ÷ 27

V-in = (80 × 40 × 1) ÷ 27

= 118.52 CY

Rock Backfill

Next we'll find the backfill volumes. Figure 14-52 shows rock backfill on the V-in side, and dirt backfill on the V-out side. You calculate the two volumes separately, so let's begin with the rock backfill.

Volume for the rock backfill equals V-in minus the volume displaced by two masses of concrete. Let's start with the volume displaced by the 6-inch-thick concrete slab floor. The depth for V-in (Figure 14-51) is 1 foot.

Subtract the slab's depth, 0.5 feet, and the result is the depth of the rock backfill. Here are the revised dimensions: Depth = 0.5 foot, Length = 80 feet, and Width = 40 feet. The second lump of concrete is the footing, but only the portion on the V-in side. (See Figure 14-52.) Calculate this volume using these dimensions from Figure 14-52: Depth = 0.5 foot, Width = 1 foot and Length = 240 feet. After finding these two volumes in cubic yards, subtract the footing volume from the depth-adjusted volume. The result is the rock backfill volume for the shop building footing.

(80 × 40 × 0.5) ÷ 27 = 59.26 CY

(240 × 1 × 0.5) ÷ 27 = 4.44 CY

59.26 – 4.44 = 54.82 CY rock backfill

Dirt Backfill

You find dirt backfill volume by calculating the volume displaced by the footing on the V-out side. Its dimensions (from Figure 14-52) are: Width = 0.5 foot, Depth = 0.5 foot and Length = 240 feet. The volume for dirt backfill equals excavation volume for V-out (17.96 CY from above) minus the volume of the footing.

(240 × 0.5 × 0.5) ÷ 27 = 2.22 CY

17.96 CY – 2.22 CY = 15.74 CY dirt backfill

Spoil Volume

We need one more volume to finish out the shop building footing calculations: the spoil volume. Spoil is the difference between the volume excavated and the volume replaced as dirt backfill. We already calculated both. If you noticed the lack of shrink and swell factors in these calculations, good job! The factors apply to both the excavated and the backfill volumes, except for the rock backfill, so spoil volume is:

17.96 × 1.31 = 23.53

15.74 × 1.25 = 19.68

23.53 CY – 19.68 CY = 3.85 CY of spoil

See Figure 14-53 for my shop building footing calculations: V-out, V-in, rock backfill, and dirt backfill, and Figure 14-54 for shrink and swell factor calculations. These actual volumes, the volume multiplied by the applicable factor, are very important. I don't want to lose track of these figures. I also don't want to waste time searching for them in the forest of numbers and calculations. Here's my solution; I transfer my totals to a worksheet. Figure 14-54 is my worksheet for the shop building footing. This is where I add the shrink or swell factors and round off my results to full cubic yards.

Office Building

The office building has a basement. We need to calculate volumes for V-out, V-in, rock backfill, and dirt backfill. The formulas and sequence of steps are the same as those for the shop building footing. This time we have one standard drawing. Figure 14-55 covers the details for excavation and backfill. Figure 14-2 gives the office building dimensions: length 55 feet and width 50 feet. Try completing the basement volume calculations on your own first. When you're done, or if you hit a snag, read through the step-by-step that follows. Use it to check your work, or jog your memory.

Basement Excavation, V-out

V-out volume is the sum of the excavated volume and the total excavated corner volume. To find the excavated volume you multiply length by width by depth. Here's another way of describing this calculation:

Exc. vol. = Perimeter × Average slope line area × Depth ÷ 27

Perimeter is the same as length or side plus side plus side plus side. Using the dimensions from Figure 14-2 for the office building, we find:

$$50 + 50 + 55 + 55 = 210 \text{ feet}$$

We saw how to find average slope line areas in Chapter 10. As you recall, this is the total width of the V-out multiplied by depth. Total width is the sum of footing width plus work space plus one-half total rise times run divided by rise. Using the data from Figure 14-55 we find:

$$(0.5 + 4 + 1.75) \times 7 = 43.75 \text{ CF}$$

Put the two together and we find that excavated volume comes to:

$$210 \times 43.75 \div 27 = 340.28 \text{ CY}$$

Find the total excavated corner volume in cubic yards using this formula:

$$\text{Corner volume} = (^1/_3\ \pi\ r^2) \times \text{Depth} \times \text{Number of corners} \div 27$$

For pi (π) use 3.1416, corner radius is 3.5 feet, depth is 7 feet, and number of corners is 4.

$$(0.3333 \times 3.1416 \times 3.5^2) \times 7 \times 4 \div 27 = 13.3 \text{ CY}$$

Finish your V-out calculations by adding excavated volume and total corner volume together:

$$340.28 \text{ CY} + 13.3 \text{ CY} = 353.58 \text{ CY}$$

Basement Excavation, V-in

Next we calculate the basement V-in. It's a simple volume calculation because there's no slope or ramp to include. The basement dimensions are: Length = 55 feet, Width = 50 feet, and Depth = 7 feet.

$$55 \times 50 \times 7 \div 27 = 712.96 \text{ CY}$$

When you actually excavate a basement, it's not possible to cut perfect corners. That's not a problem in estimating because an allowance is built into the corner volume calculations. Here's how it works. One of the variables in the formula for finding corner volume is corner radius. The dimension used is the horizontal distance between the toe of the slope to the top of the slope. But, in reality, only half of that horizontal distance is additional yardage. The rest is the built-in allowance.

Basement Backfill Volumes

Now let's find the backfill volumes. Figure 14-55 calls for rock backfill on the V-in side, and dirt backfill on the V-out side. Let's find the rock backfill volume first. Here's your chance to practice what you learned earlier about deducting for a displaced volume. Figure 14-55 includes two pieces of data you'll need:

1. The depth of the rock backfill is the same as the height of the basement footing: 6 inches, or 0.5 feet.
2. The concrete footing fills a 2-foot-wide strip all around the basement perimeter. That's the same as subtracting 2 feet each from the basement length and from the width.

That means you can calculate the rock backfill volume as follows:

(V-in length – 2) × (V-in width – 2) × V-in depth ÷ 27

(55 – 2) × (50 – 2) × 0.5 ÷ 27 = 47.11 CY rock backfill

The basement's dirt backfill volume in cubic yards equals the V-out, after you subtract the volume displaced by concrete. Here are the dimensions (from Figure 14-55) of the concrete footing on the V-out side: Length = 210 feet, Width = 0.5 foot and Depth = 0.5 foot. So, total displaced volume, in cubic yards, equals:

210 × 0.5 × 0.5 ÷ 27 = 1.94 CY

The dirt backfill volume, in cubic yards, equals V-out volume minus displaced volume:

353.58 CY – 1.94 CY = 351.64 CY

See Figure 14-56 for the calculations for the office building basement excavation, and backfill. Then turn to Figure 14-57. This is my worksheet for the basement, showing actual volumes, rounded totals (to full cubic yards), and total spoil.

Summary Sheet

Figure 14-58 is the project summary sheet. It brings all the totals together on one page. We estimate a total of 67 CCY of fill, 19,695 LCY of excavation, 1,005 CCY of backfill, and 291 CY of rock fill. In addition, we'll move 2,614 CY of topsoil. We'll have 18,621 LCY of excess material, or spoil, to remove from the site. Note that dirt backfill quantities are given in compacted cubic yards (CCY) and excavation quantities are in loose cubic yards (LCY).

Calculating volumes for any excavation job is easy if you break the project into small tasks and solve each in sequence. Take it a step at a time, work systematically and show all your work. That's the key to accurate excavation estimates.

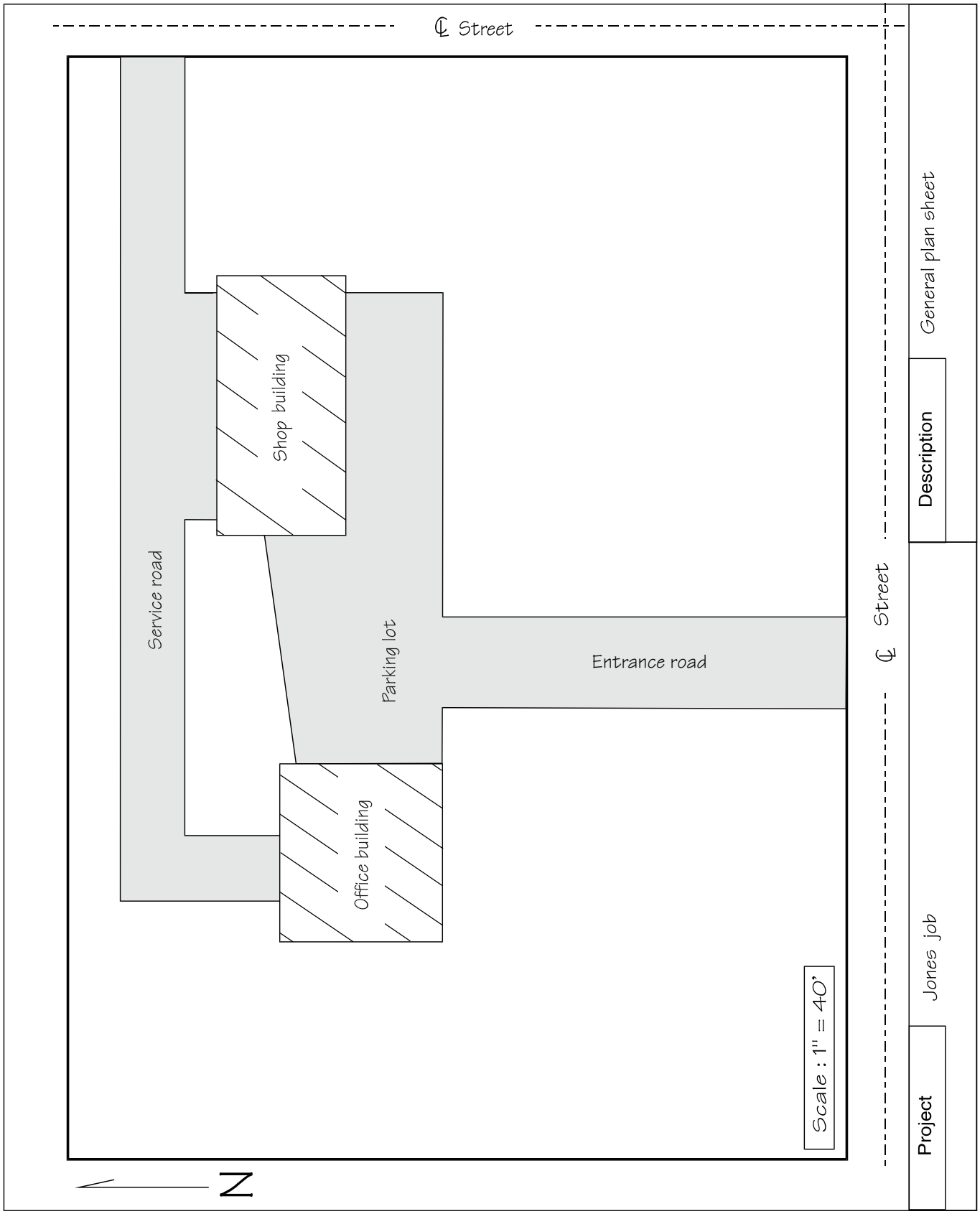


Figure 14-1
General plan sheet

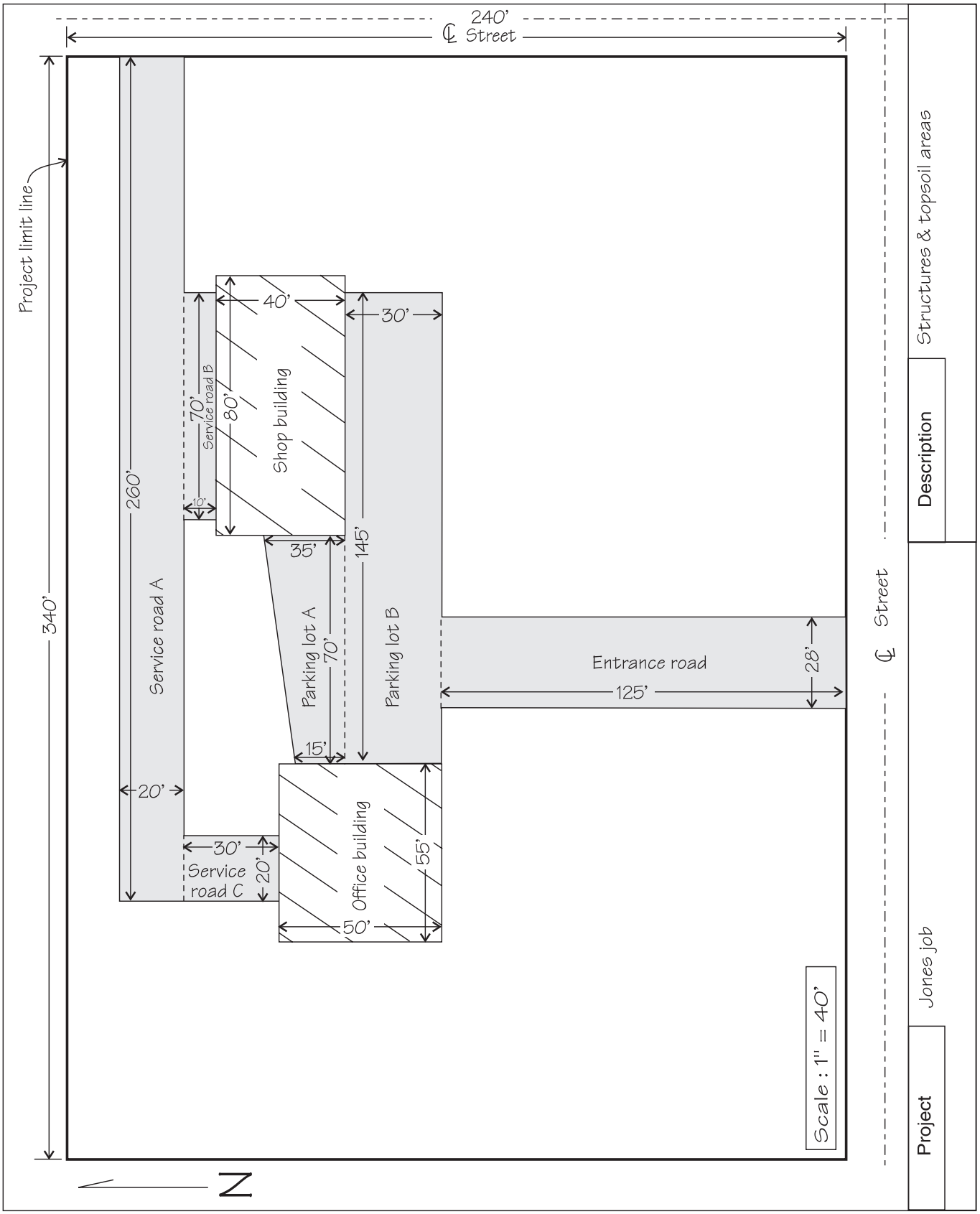


Figure 14-2
Site plan

Calculation Sheet

Project: Jones job **Date:** 4/20

Site dimensions: 340' x 240'

Strip 6", entire site

$$\text{volume (CY)} = \frac{340 \times 240 \times 0.5}{27}$$

$$= 1{,}511.11 \text{ CY}$$

Dispose of top 2" offsite

$$\text{volume (CY)} = \frac{340 \times 240 \times 0.1666}{27}$$

$$= 503.7 \text{ CY}$$

Stockpile remaining 4" for later replacement

$$\text{volume (CY)} = \frac{340 \times 240 \times 0.3333}{27}$$

$$= 1{,}007.41 \text{ CY}$$

Replace 6" on all areas without structures

$$\text{volume (CY)} = \frac{(\text{site area} - \text{structures area}) \times 0.5'}{27}$$

Site area = 340 x 240
= 81,600 SF

Structures area

Entrance road	28 x 125	=	3,500
Office building	50 x 55	=	2,750
Shop building	80 x 40	=	3,200
Parking lot A	$\frac{(15 + 35)}{2} \times 70$	=	1,750
Parking lot B	145 x 30	=	4,350
Service road A	260 x 20	=	5,200
Service road B	10 x 70	=	700
Service road C	20 x 30	=	600
Total structures area		=	22,050 SF

$$\text{Replace volume (CY)} = \frac{(81{,}600 - 22{,}050) \times 0.5}{27}$$

$$= \frac{59{,}550 \times 0.5}{27}$$

$$= \frac{29{,}775}{27}$$

$$= 1{,}102.77 \text{ CY}$$

Conclusion

Need 1,102.77 CY of replacement topsoil. Stockpile contains 1,007.41 CY, leaving shortfall of 95.36 CY to purchase offsite. (1,102.77 – 1,007.41 = 95.36)

Figure 14-3
Topsoil quantities calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/20

Quantities for: Topsoil **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:**

Item	Length (ft)	Width (ft)	Depth (ft)	Volume (CY)	Notes
Strip 6", entire site	340	240	0.5	1,511.11	Strip and distribute as follows:
Top 2", non-reuseable	340	240	0.1666	503.7	Remove for disposal off site
Lower 4", reuseable	340	240	0.3333	1,007.41	Stockpile on site for reuse
Replace 6" (area without strutures)				1,102.77	Shortfall, 96 CY, to be brought on site

Note:

Figure 14-4
Topsoil calculations summary

Calculation Sheet

Project: Jones job **Date:** 4/20

Total area service road (SF) = area A* + area B* + area C*
= 5,200 + 700 + 600
= 6,500 SF
* (see Figure 14-3)

6" rock

$$\text{volume (CY)} = \frac{6{,}500 \times 0.5}{27}$$

= 120.37 CY

Conclusion

120 CY of rock needed.

Figure 14-5
Rock on service roads calculations

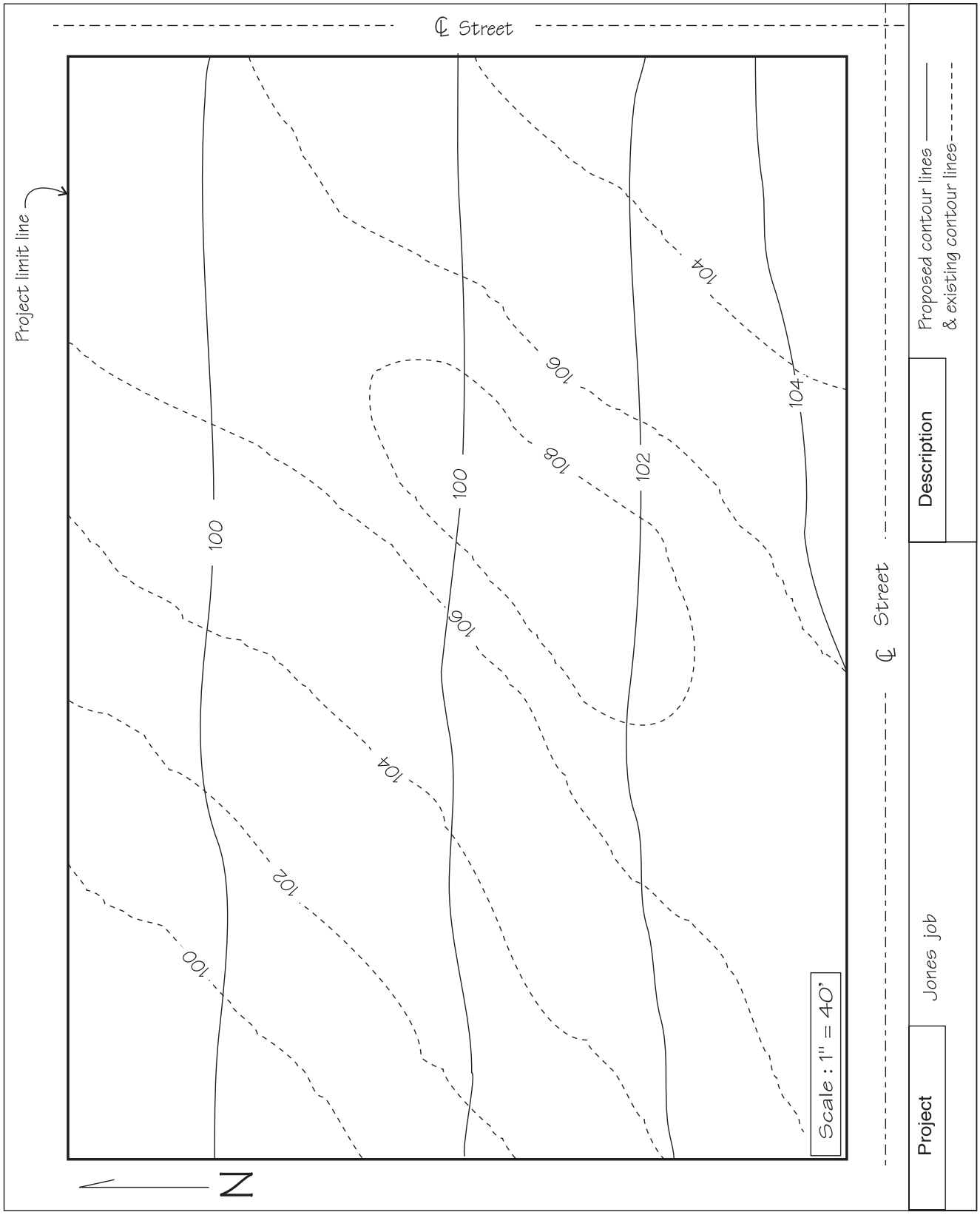


Figure 14-6
Plan showing proposed and existing contour lines

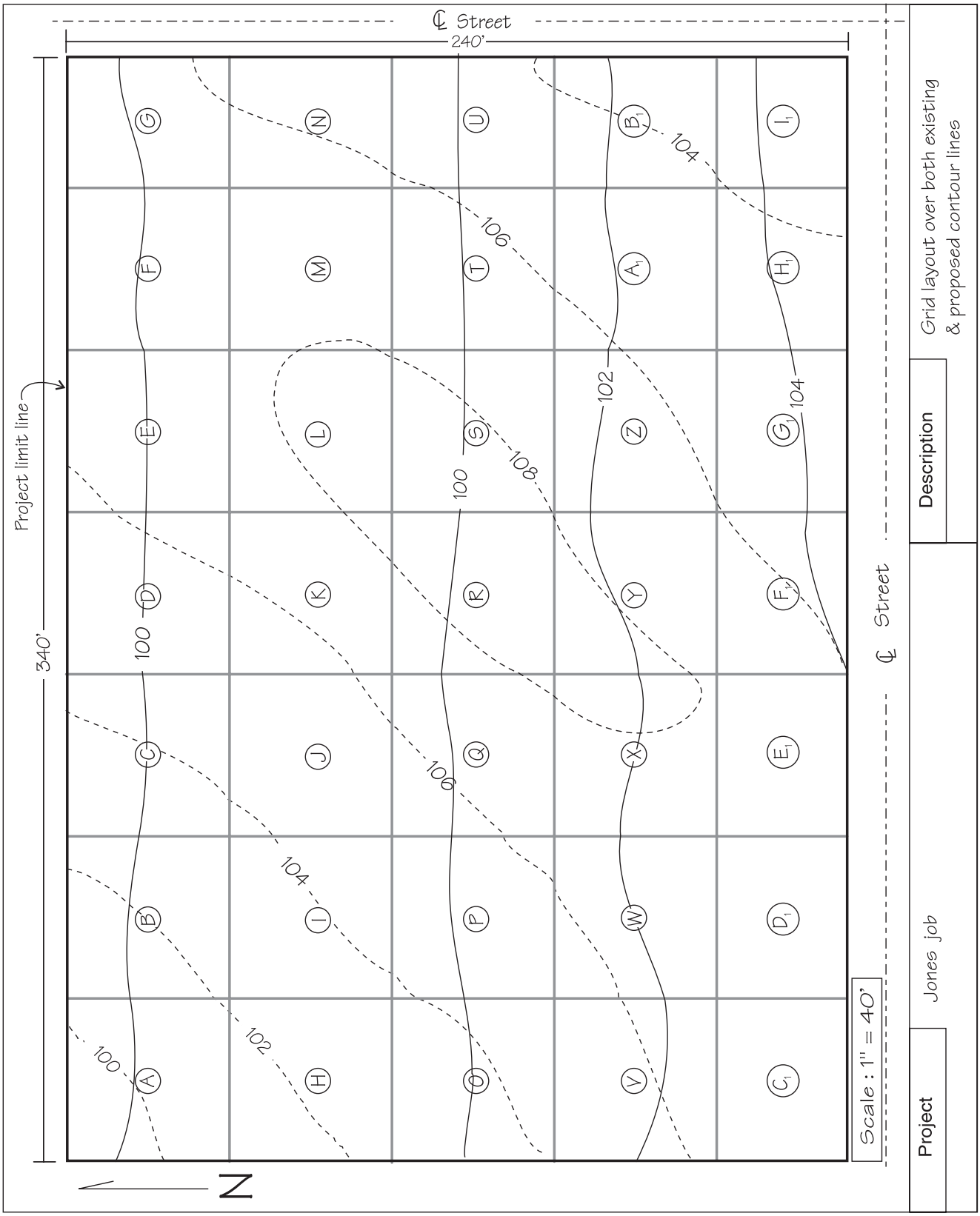


Figure 14-7
Grid layout over existing and proposed contour lines

Grid Take-off, Existing Contour Only

Prepared by (initials): DB **Date:** 4/20

Sheet: 1 **of** 6 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
A-1	100.0	102.0	7/40 (est.)	2.0	0.35	100.35
A-2	102.0	104.0	3/43	2.0	0.14	102.14
A-3	100.0	102.0	25/55 (est.)	2.0	0.91	100.91
A-4	100.0	100.0		2.0		100.0
B-1	102.0	104.0	11/48 (est.)	2.0	0.46	102.46
B-2	102.0	104.0	36/46	2.0	1.57	103.57
B-3	(A-2)			2.0		102.14
B-4	(A-1)			2.0		100.35
C-1	104.0	106.0	9/61 (est.)	2.0	0.15	104.3
C-2	104.0	106.0	32/59	2.0	1.10	105.08
C-3	(B-2)			2.0		103.57
C-4	(B-1)			2.0		102.46
D-1	104.0	106.0	45/55 (est.)	2.0	1.64	105.64
D-2	106.0	108.0	19/45	2.0	0.84	106.84
D-3	(C-2)			2.0		105.08
D-4	(C-1)			2.0		104.3
E-1	106.0	106.0		2.0		106.0
E-2	106.0	106.0		2.0		106.0
E-3	(D-2)			2.0		106.84
E-4	(D-1)			2.0		105.64
F-1	106.0	106.0		2.0		106.0
F-2	106.0	106.0		2.0		106.0
F-3	(E-2)			2.0		106.0
F-4	(E-1)			2.0		106.0

Figure 14-8
Grid square calculations for existing contours

Grid Take-off, Existing Contour Only

Prepared by (initials): DB **Date:** 4/20

Sheet: 2 **of** 6 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
G-1	106.0	106.0		2.0		106.0
G-2	106.0	104.0	11/50 (est.)	2.0	-0.44	105.56
G-3	(F-2)			2.0		106.0
G-4	(F-1)			2.0		106.0
H-1	(A-2)			2.0		102.14
H-2	102.0	104.0	42/48	2.0	1.75	103.75
H-3	102.0	104.0	12/55 (est.)	2.0	0.44	102.44
H-4	(A-3)			2.0		100.91
I-1	(B-2)			2.0		103.57
I-2	104.0	106.0	31/55	2.0	1.13	105.13
I-3	(H-2)			2.0		103.75
I-4	(H-3)			2.0		102.44
J-1	(C-2)			2.0		105.08
J-2	106.0	108.0	10/34	2.0	0.59	106.59
J-3	(I-2)			2.0		105.13
J-4	(I-1)			2.0		103.57
K-1	(D-2)			2.0		106.84
K-2	108.0	108.0		2.0		108.0
K-3	(J-2)			2.0		106.59
K-4	(J-1)			2.0		105.08

Note:

The values in the "Add Elevation" column for locations G-2 and U-2 are negative.

You may find it helpful to recall that: 106.0 + (-0.44) and 106.0 – 0.44 give the same result, 105.56.

Figure 14-8 (continued)
Grid square calculations for existing contours

Grid Take-off, Existing Contour Only

Prepared by (initials): DB **Date:** 4/20

Sheet: 3 **of** 6 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
L-1	(E-2)			2.0		106.0
L-2	106.0	108.0	2/50	2.0	0.08	106.08
L-3	(K-2)			2.0		108.0
L-4	(K-1)			2.0		106.84
M-1	(F-2)			2.0		106.0
M-2	106.0	106.0		2.0		106.0
M-3	(L-2)			2.0		106.08
M-4	(L-1)			2.0		106.0
N-1	(G-2)			2.0		105.56
N-2	104.0	106.0	35/50 (est.)	2.0	1.4	105.4
N-3	(M-2)			2.0		106.0
N-4	(M-1)			2.0		106.0
O-1	(H-2)			2.0		103.75
O-2	104.0	106.0	28/47	2.0	1.19	105.19
O-3	104.0	106.0	2/43	2.0	0.09	104.09
O-4	(H-3)			2.0		102.44
P-1	(I-2)			2.0		105.13
P-2	106.0	108.0	11/59	2.0	0.37	106.37
P-3	(O-2)			2.0		105.19
P-4	(O-1)			2.0		103.75
Q-1	(J-2)			2.0		106.59
Q-2	108.0	108.0		2.0		108.0
Q-3	(P-2)			2.0		106.37
Q-4	(P-1)			2.0		105.13

Figure 14-8 (continued)
Grid square calculations for existing contours

Grid Take-off, Existing Contour Only

Prepared by (initials): DB **Date:** 4/20

Sheet: 4 **of** 6 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
R-1	(K-2)			2.0		108.0
R-2	108.0	108.0		2.0		108.0
R-3	(Q-2)			2.0		108.0
R-4	(Q-1)			2.0		106.59
S-1	(L-2)			2.0		106.08
S-2	106.0	108.0	31/45	2.0	1.38	107.38
S-3	(R-2)			2.0		108.0
S-4	(R-1)			2.0		108.0
T-1	(M-2)			2.0		106.0
T-2	104.0	106.0	22/54	2.0	0.81	104.81
T-3	(S-2)			2.0		107.38
T-4	(S-1)			2.0		106.08
U-1	(N-2)			2.0		105.4
U-2	104.0	102.0	8/51 (est.)	2.0	-0.31	103.69
U-3	(T-2)			2.0		104.81
U-4	(T-1)			2.0		106.0
V-1	(O-2)			2.0		105.19
V-2	106.0	106.0		2.0		106.0
V-3	106.0	106.0		2.0		106.0
V-4	(O-3)			2.0		104.09
W-1	(P-2)			2.0		106.37
W-2	106.0	106.0		2.0		106.0
W-3	(V-2)			2.0		106.0
W-4	(V-1)			2.0		105.19

Figure 14-8 (continued)
Grid square calculations for existing contours

Grid Take-off, Existing Contour Only

Prepared by (initials): DB **Date:** 4/20

Sheet: 5 **of** 6 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
X-1	(Q-2)			2.0		108.0
X-2	106.0	108.0	7/42	2.0	0.33	106.33
X-3	(W-2)			2.0		106.0
X-4	(W-1)			2.0		106.37
Y-1	(R-2)			2.0		108.0
Y-2	106.0	108.0	42/45	2.0	1.87	107.87
Y-3	(X-2)			2.0		106.33
Y-4	(X-1)			2.0		108.0
Z-1	(S-2)			2.0		107.38
Z-2	104.0	106.0	23/71	2.0	0.65	104.65
Z-3	(Y-2)			2.0		107.87
Z-4	(Y-1)			2.0		108.0
A_1-1	(T-2)			2.0		104.81
A_1-2	104.0	106.0	56/59	2.0	1.9	105.9
A_1-3	(Z-2)			2.0		104.65
A_1-4	(Z-1)			2.0		107.38
B_1-1	(U-2)			2.0		103.69
B_1-2	102.0	104.0	30/71 (est.)	2.0	0.85	102.85
B_1-3	(A_1-2)			2.0		105.9
B_1-4	(A_1-1)			2.0		104.81
C_1-1	(V-2)			2.0		106.0
C_1-2	106.0	106.0		2.0		106.0
C_1-3	106.0	106.0		2.0		106.0
C_1-4	(V-3)			2.0		106.0

Figure 14-8 (continued)
Grid square calculations for existing contours

Grid Take-off, Existing Contour Only

Prepared by (initials): DB **Date:** 4/20

Sheet: 6 **of** 6 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
D_1-1	(W-2)			2.0		106.0
D_1-2	106.0	106.0		2.0		106.0
D_1-3	(C_1-2)			2.0		106.0
D_1-4	(C_1-1)			2.0		106.0
E_1-1	(X-2)			2.0		106.33
E_1-2	106.0	106.0		2.0		106.0
E_1-3	(D_1-2)			2.0		106.0
E_1-4	(D_1-1)			2.0		106.0
F_1-1	(Y-2)			2.0		107.87
F_1-2	104.0	106.0	29/87 (est.)	2.0	0.67	104.67
F_1-3	(E_1-2)			2.0		106.0
F_1-4	(E_1-1)			2.0		106.33
G_1-1	(Z-2)			2.0		104.65
G_1-2	104.0	106.0	63/79 (est.)	2.0	1.6	105.6
G_1-3	(F_1-2)			2.0		104.67
G_1-4	(F_1-1)			2.0		107.87
H_1-1	(A_1-2)			2.0		105.9
H_1-2	102.0	104.0	17/90 (est.)	2.0	0.38	102.38
H_1-3	(G_1-2)			2.0		105.6
H_1-4	(G_1-3)			2.0		104.65
I_1-1	(B_1-2)			2.0		102.85
I_1-2	102.0	104.0	55/85 (est.)	2.0	1.29	103.29
I_1-3	(H_1-2)			2.0		102.38
I_1-4	(H_1-1)			2.0		105.9

Figure 14-8 (continued)
Grid square calculations for existing contours

Grid Take-off, Proposed Contour Only

Prepared by (initials): DB **Date:** 4/21

Sheet: 1 **of** 4 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
O-1	100.0	100.0		2.0		100.0
O-2	100.0	102.0	37/70	2.0	1.06	101.06
O-3	100.0	102.0	35/83	2.0	0.84	100.84
O-4				2.0		100.0
P-1	100.0	100.0		2.0		100.0
P-2	100.0	102.0	44/78	2.0	1.13	101.13
P-3	(O-2)			2.0		101.06
P-4	(O-1)			2.0		100.0
Q-1	100.0	100.0		2.0		100.0
Q-2	100.0	102.0	44/72	2.0	1.22	101.22
Q-3	(P-2)			2.0		101.13
Q-4	(P-1)			2.0		100.0
R-1	100.0	100.0		2.0		100.0
R-2	100.0	102.0	47/64	2.0	1.47	101.47
R-3	(Q-2)			2.0		101.22
R-4	(Q-1)			2.0		100.0
S-1	100.0	100.0		2.0		100.0
S-2	100.0	102.0	40/67	2.0	1.19	101.19
S-3	(R-2)			2.0		101.47
S-4	(R-1)			2.0		100.0

Note:

Grid squares A to N are not included here because they are all in the limits of proposed elevation (100.0).

Therefore, all these elevations are 100.0.

Figure 14-9
Grid square calculations for proposed contours

Grid Take-off, Proposed Contour Only

Prepared by (initials): DB **Date:** 4/21

Sheet: 2 **of** 4 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
T-1	100.0	100.0		2.0		100.0
T-2	100.0	102.0	40/62	2.0	1.29	101.29
T-3	(S-2)			2.0		101.19
T-4	(S-1)			2.0		100.0
U-1	100.0	100.0		2.0		100.0
U-2	100.0	102.0	40/60	2.0	1.33	101.33
U-3	(T-2)			2.0		101.29
U-4	(T-1)			2.0		100.0
V-1	(O-2)			2.0		101.06
V-2	102.0	104.0	21/94 (est.)	2.0	0.45	102.45
V-3	102.0	104.0	22/99 (est.)	2.0	0.44	102.44
V-4	(O-3)			2.0		100.84
W-1	(P-2)			2.0		101.13
W-2	102.0	104.0	23/97 (est.)	2.0	0.47	102.47
W-3	(V-2)			2.0		102.45
W-4	(V-1)			2.0		101.06
X-1	(Q-2)			2.0		101.22
X-2	102.0	104.0	39/81	2.0	0.96	102.96
X-3	(W-2)			2.0		102.47
X-4	(W-1)			2.0		101.13
Y-1	(R-2)			2.0		101.47
Y-2	102.0	104.0	43/80	2.0	1.08	103.08
Y-3	(X-2)			2.0		102.96
Y-4	(X-1)			2.0		101.22

Figure 14-9 (continued)
Grid square calculations for proposed contours

Grid Take-off, Proposed Contour Only

Prepared by (initials): DB **Date:** 4/21

Sheet: 3 **of** 4 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
Z-1	(S-2)			2.0		101.19
Z-2	102.0	104.0	55/80	2.0	1.38	103.38
Z-3	(Y-2)			2.0		103.08
Z-4	(Y-1)			2.0		101.47
A_1-1	(T-2)			2.0		101.29
A_1-2	102.0	104.0	43/60	2.0	1.43	103.43
A_1-3	(Z-2)			2.0		103.38
A_1-4	(Z-1)			2.0		101.19
B_1-1	(U-2)			2.0		101.33
B_1-2	102.0	104.0	43/60	2.0	1.43	103.43
B_1-3	(A_1-2)			2.0		103.43
B_1-4	(A_1-1)			2.0		101.29
C_1-1	(V-2)			2.0		102.45
C_1-2	102.0	102.0		2.0		102.0
C_1-3	102.0	102.0		2.0		102.0
C_1-4	(V-3)			2.0		102.44
D_1-1	(W-2)			2.0		102.47
D_1-2	102.0	102.0		2.0		102.0
D_1-3	(C_1-2)			2.0		102.0
D_1-4	(C_1-1)			2.0		102.45
E_1-1	(X-2)			2.0		102.96
E_1-2	102.0	102.0		2.0		102.0
E_1-3	(D_1-2)			2.0		102.0
E_1-4	(D_1-1)			2.0		102.47

Figure 14-9 (continued)
Grid square calculations for proposed contours

Grid Take-off, Proposed Contour Only

Prepared by (initials): DB **Date:** 4/21

Sheet: 4 **of** 4 **Approved by (initials):** LL **Date:** 4/22

Location	Low elevation	High elevation	Scale distance	Contour interval	Add elevation	Point elevation
F_1-1	(Y-2)			2.0		103.08
F_1-2	104.0	106.0	19/49 (est.)	2.0	0.78	104.78
F_1-3	(E_1-2)			2.0		102.0
F_1-4	(E_1-1)			2.0		102.96
G_1-1	(Z-2)			2.0		103.38
G_1-2	104.0	106.0	24/44 (est.)	2.0	1.09	105.09
G_1-3	(F_1-2)			2.0		104.78
G_1-4	(F_1-1)			2.0		103.08
H_1-1	(A_1-2)			2.0		103.43
H_1-2	104.0	106.0	36/44 (est.)	2.0	1.64	105.64
H_1-3	(G_1-2)			2.0		105.09
H_1-4	(G_1-1)			2.0		103.38
I_1-1	(B_1-2)			2.0		103.43
I_1-2	104.0	106.0	40/51 (est.)	2.0	1.57	105.57
I_1-3	(H_1-2)			2.0		105.64
I_1-4	(H_1-1)			2.0		103.43

Figure 14-9 (continued)
Grid square calculations for proposed contours

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 1 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid A
Average depth: 0.85

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	100.35	102.14	100.91	100.0
Depth	0.35	2.14	0.91	0

Grid B
Average depth: 2.13

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	102.46	103.57	102.14	100.35
Depth	2.46	3.57	2.14	0.35

Grid C
Average depth: 3.85

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	104.3	105.08	103.57	102.46
Depth	4.3	5.08	3.57	2.46

Grid D
Average depth: 5.47

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	105.64	106.84	105.08	104.3
Depth	5.64	6.84	5.08	4.3

Grid E
Average depth: 6.12

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	106.0	106.0	106.84	105.64
Depth	6.0	6.0	6.84	5.64

Figure 14-10
Grid square calculations to find average depth of cut or fill

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 2 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid F
Average depth: 6.0

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	106.0	106.0	106.0	106.0
Depth	6.0	6.0	6.0	6.0

Grid G
Average depth: 5.89

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	106.0	105.56	106.0	106.0
Depth	6.0	5.56	6.0	6.0

Grid H
Average depth: 2.31

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	102.14	103.75	102.44	100.91
Depth	2.14	3.75	2.44	0.91

Grid I
Average depth: 3.72

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	103.57	105.13	103.75	102.44
Depth	3.57	5.13	3.75	2.44

Grid J
Average depth: 5.09

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	105.08	106.59	105.13	103.57
Depth	5.08	6.59	5.13	3.57

Figure 14-10 (continued)
Grid square calculations to find average depth of cut or fill

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 3 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid K
Average depth: 6.63

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	106.84	108.0	106.59	105.08
Depth	6.84	8.0	6.59	5.08

Grid L
Average depth: 6.73

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	106.0	106.08	108.0	106.84
Depth	6.0	6.08	8.0	6.84

Grid M
Average depth: 6.02

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	106.0	106.0	106.08	106.0
Depth	6.0	6.0	6.08	6.0

Grid N
Average depth: 5.74

Element	1	2	3	4
Proposed	100.0	100.0	100.0	100.0
Existing	105.56	105.4	106.0	106.0
Depth	5.56	5.4	6.0	6.0

Grid O
Average depth: 3.39

Element	1	2	3	4
Proposed	100.0	101.06	100.84	100.0
Existing	103.75	105.19	104.09	102.44
Depth	3.75	4.13	3.25	2.44

Figure 14-10 (continued)
Grid square calculations to find average depth of cut or fill

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 4 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid P
Average depth: 4.56

Element	1	2	3	4
Proposed	100.0	101.13	101.06	100.0
Existing	105.13	106.37	105.19	103.75
Depth	5.13	5.24	4.13	3.75

Grid Q
Average depth: 5.94

Element	1	2	3	4
Proposed	100.0	101.22	101.13	100.0
Existing	106.59	108.0	106.37	105.13
Depth	6.59	6.78	5.24	5.13

Grid R
Average depth: 6.98

Element	1	2	3	4
Proposed	100.0	101.47	101.22	100.0
Existing	108.0	108.0	108.0	106.59
Depth	8.0	6.53	6.78	6.59

Grid S
Average depth: 6.7

Element	1	2	3	4
Proposed	100.0	101.19	101.47	100.0
Existing	106.08	107.38	108.0	108.0
Depth	6.08	6.19	6.53	8.0

Grid T
Average depth: 5.45

Element	1	2	3	4
Proposed	100.0	101.29	101.19	100.0
Existing	106.0	104.81	107.38	106.08
Depth	6.0	3.52	6.19	6.08

Figure 14-10 (continued)
Grid square calculations to find average depth of cut or fill

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 5 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid U
Average depth: 4.32

Element	1	2	3	4
Proposed	100.0	101.33	101.29	100.0
Existing	105.4	103.69	104.81	106.0
Depth	5.4	2.36	3.52	6.0

Grid V
Average depth: 3.62

Element	1	2	3	4
Proposed	101.06	102.45	102.44	100.84
Existing	105.19	106.0	106.0	104.09
Depth	4.13	3.55	3.56	3.25

Grid W
Average depth: 4.11

Element	1	2	3	4
Proposed	101.13	102.47	102.45	101.06
Existing	106.37	106.0	106.0	105.19
Depth	5.24	3.53	3.55	4.13

Grid X
Average depth: 4.73

Element	1	2	3	4
Proposed	101.22	102.96	102.47	101.13
Existing	108.0	106.33	106.0	106.37
Depth	6.78	3.37	3.53	5.24

Grid Y
Average depth: 5.37

Element	1	2	3	4
Proposed	101.47	103.08	102.96	101.22
Existing	108.0	107.87	106.33	108.0
Depth	6.53	4.79	3.37	6.78

Figure 14-10 (continued)
Grid square calculations to find average depth of cut or fill

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 6 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid Z
Average depth: 4.7

Element	**1**	**2**	**3**	**4**
Proposed	101.19	103.38	103.08	101.47
Existing	107.38	104.65	107.87	108.0
Depth	6.19	1.27	4.79	6.53

Grid A_1
Average depth: 3.36

Element	**1**	**2**	**3**	**4**
Proposed	101.29	103.43	103.38	101.19
Existing	104.81	105.9	104.65	107.38
Depth	3.52	2.47	1.27	6.19

Grid B_1
Average depth: 1.94

Element	**1**	**2**	**3**	**4**
Proposed	101.33	103.43	103.43	101.29
Existing	103.69	102.85	105.9	104.81
Depth	2.36	-0.58	2.47	3.52

Grid C_1
Average depth: 3.78

Element	**1**	**2**	**3**	**4**
Proposed	102.45	102.0	102.0	102.44
Existing	106.0	106.0	106.0	106.0
Depth	3.55	4.0	4.0	3.56

Grid D_1
Average depth: 3.77

Element	**1**	**2**	**3**	**4**
Proposed	102.47	102.0	102.0	102.45
Existing	106.0	106.0	106.0	106.0
Depth	3.53	4.0	4.0	3.55

Figure 14-10 (continued)
Grid square calculations to find average depth of cut or fill

Individual Grid Square Calculation Sheet

Job number: 498 **Project:** Jones job **Prepared by (initials):** DB **Date:** 4/21

Sheet: 7 **of** 7 **Approved by (initials):** LL **Date:** 4/22

Grid E_1
Average depth: 3.73

Element	1	2	3	4
Proposed	102.96	102.0	102.0	102.47
Existing	106.33	106.0	106.0	106.0
Depth	3.37	4.0	4.0	3.53

Grid F_1
Average depth: 3.01

Element	1	2	3	4
Proposed	103.08	104.78	102.0	102.96
Existing	107.87	104.67	106.0	106.33
Depth	4.79	-0.11	4.0	3.37

Grid G_1
Average depth: 1.62

Element	1	2	3	4
Proposed	103.38	105.09	104.78	103.08
Existing	104.65	105.6	104.67	107.87
Depth	1.27	0.51	-0.11	4.79

Grid H_1
Average depth: 0.25

Element	1	2	3	4
Proposed	103.43	105.64	105.09	103.38
Existing	105.9	102.38	105.6	104.65
Depth	2.47	-3.26	0.51	1.27

Grid I_1
Average depth: -0.91

Element	1	2	3	4
Proposed	103.43	105.57	105.64	103.43
Existing	102.85	103.29	102.38	105.9
Depth	-0.58	-2.28	-3.26	2.47

Figure 14-10 (continued)
Grid square calculations to find average depth of cut or fill

Quantities Take-off Sheet

Project: Jones job **Date:** 4/22

Quantities for: Grid square take-off **Sheet** 1 **of** 2

By: DB **Checked:** LL **Misc:**

Location		Length (ft)	Width (ft)	Ave. depth (ft)	Vol. cut (CY)	Vol. fill (CY)
Grid A		50	50	0.85	78.70	
Grid B		50	50	2.13	197.22	
Grid C		50	50	3.85	356.48	
Grid D		50	50	5.47	506.48	
Grid E		50	50	6.12	566.67	
Grid F		50	50	6.0	555.56	
Grid G		50	40	5.89	436.30	
Grid H		50	50	2.31	213.89	
Grid I		50	50	3.72	344.44	
Grid J		50	50	5.09	471.30	
Grid K		50	50	6.63	613.89	
Grid L		50	50	6.73	623.15	
Grid M		50	50	6.02	557.41	
Grid N		50	40	5.74	425.19	
Grid O		50	50	3.39	313.89	
Grid P		50	50	4.56	422.22	
Grid Q		50	50	5.94	550.00	
Grid R		50	50	6.98	646.30	
Grid S		50	50	6.70	620.37	
Grid T		50	50	5.45	504.63	
Subtotal					9,004.09	

Note:

Figure 14-11
Grid square take-off, cut and fill calculations summary

Quantities Take-off Sheet

Project: Jones job **Date:** 4/22

Quantities for: Grid square take-off **Sheet** 2 **of** 2

By: DB **Checked:** LL **Misc:**

Location		Length (ft)	Width (ft)	Ave. depth (ft)	Vol. cut (CY)	Vol. fill (CY)
Grid U		50	40	4.32	320.00	
Grid V		50	50	3.62	335.19	
Grid W		50	50	4.11	380.56	
Grid X		50	50	4.73	437.96	
Grid Y		50	50	5.37	497.22	
Grid Z		50	50	4.70	435.19	
Grid A_1		50	50	3.36	311.11	
Grid B_1		50	40	1.94	143.70	
Grid C_1		40	50	3.78	280.00	
Grid D_1		40	50	3.77	279.26	
Grid E_1		40	50	3.73	276.30	
Grid F_1		40	50	3.01	222.96	
Grid G_1		40	50	1.62	120.00	
Grid H_1		40	50	0.25	18.52	
Grid I_1		40	40	-0.91		53.93
Subtotal (this page)					4,057.97	
Subtotal (page 1)					9,004.09	
Total cut					13,062.06	
Total fill						53.93

Note:

Total spoil = 17,040.65 LCY*

Total spoil = (total cut - total fill) x 1.31 [swell factor]

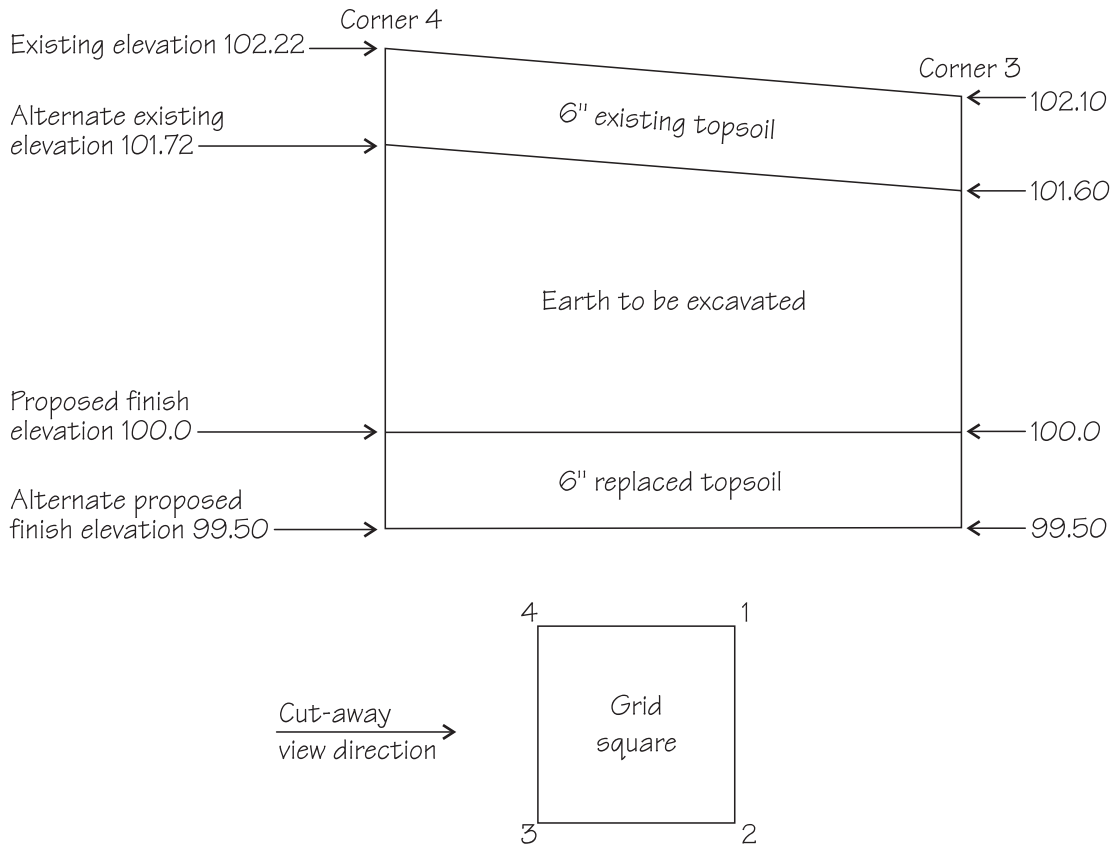
*LCY = loose cubic yards

Figure 14-11 (continued)
Grid square take-off, cut and fill calculations summary

Standard Drawings

Drawing # 3342

Item Topsoil excavation



Notes and comments

Figure 14-12
Cut-away view of grid square

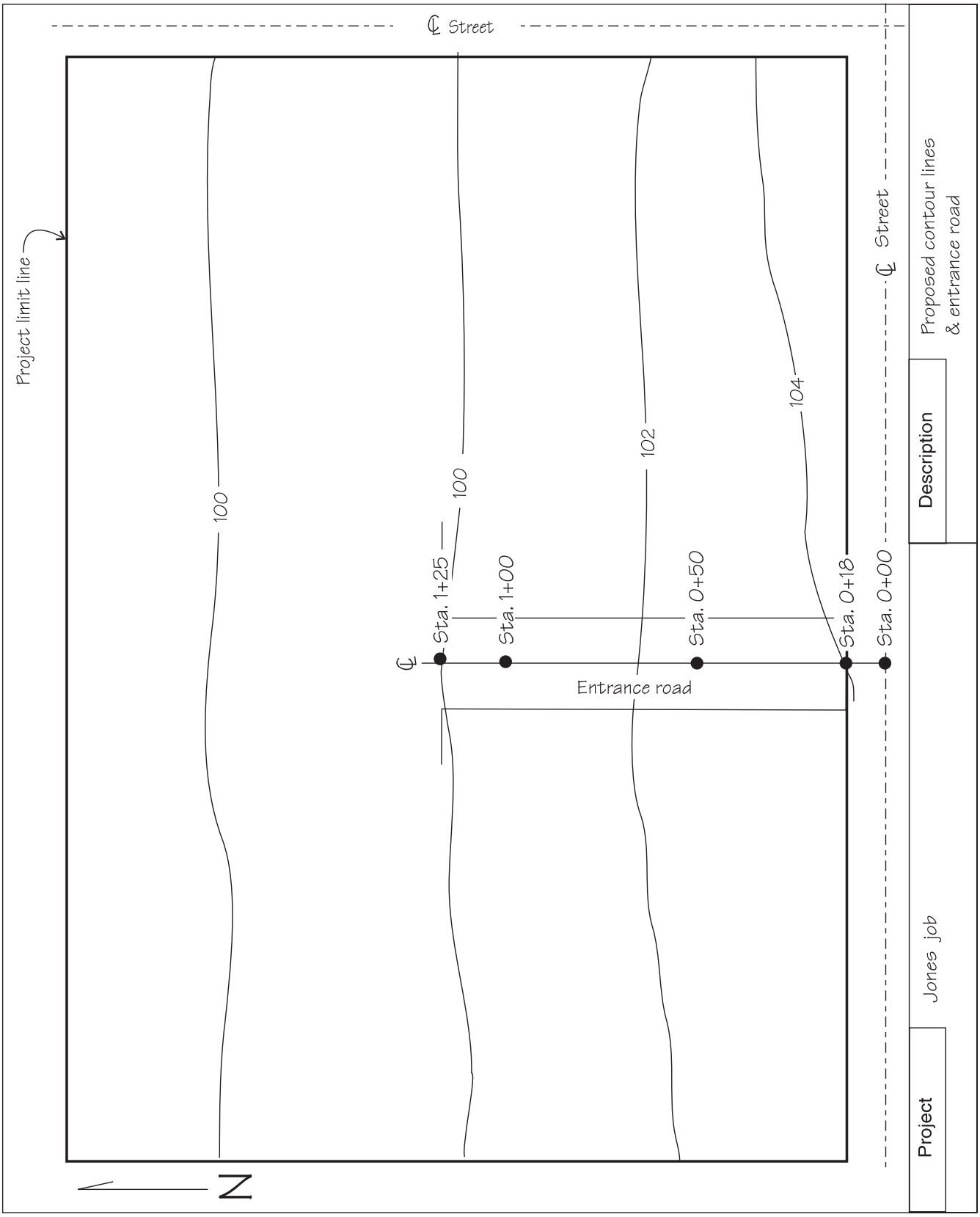


Figure 14-13
Proposed contour lines and entrance road

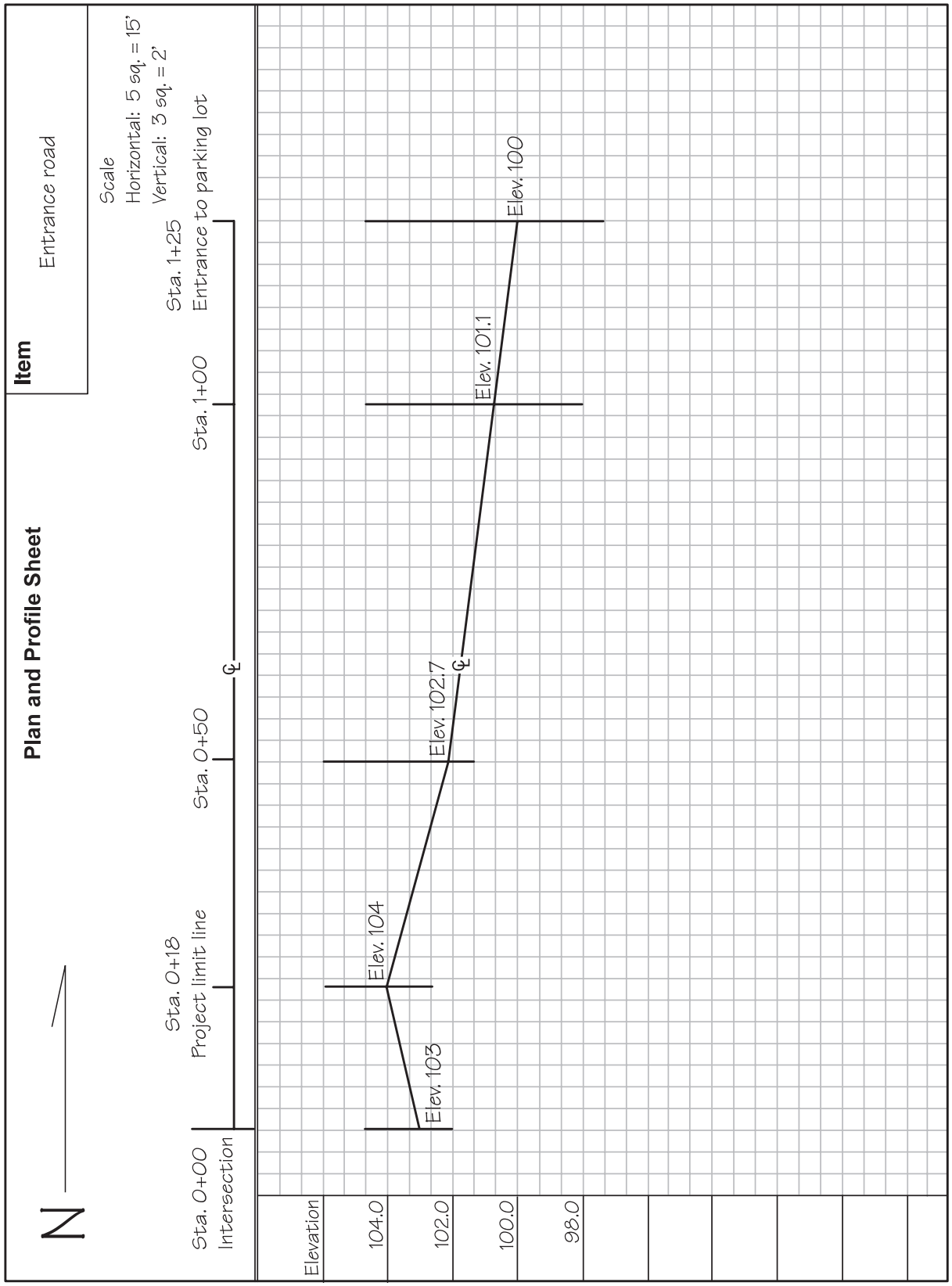
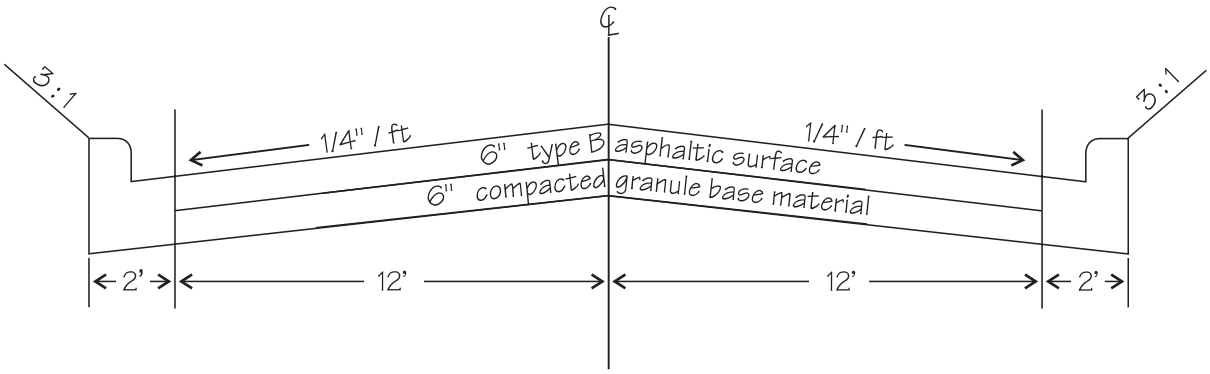


Figure 14-13 A
Entrance road plan and profile sheet

Standard Drawings

Drawing # 3343

Item Entrance road section



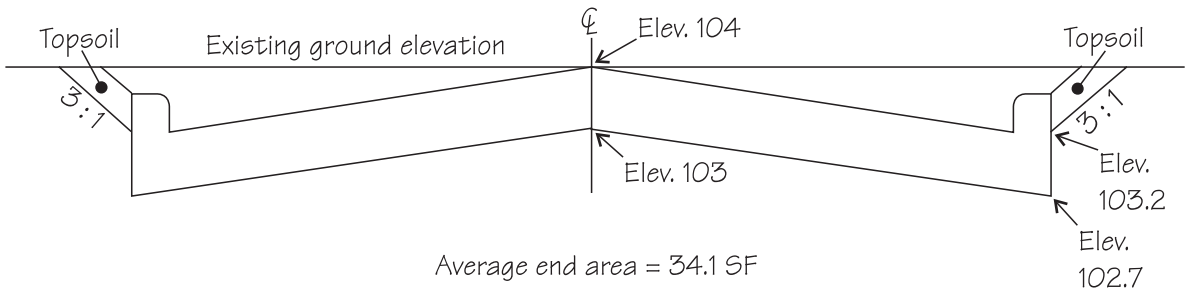
Notes and comments

Figure 14-14
Standard drawing, entrance road section

Standard Drawings

Drawing # 3344

Item Entrance rd. exc. limits



Average end area = 34.1 SF

Cross-section view Sta. 0+18

Notes and comments

Figure 14-15
Entrance road excavation limits shown in cross section

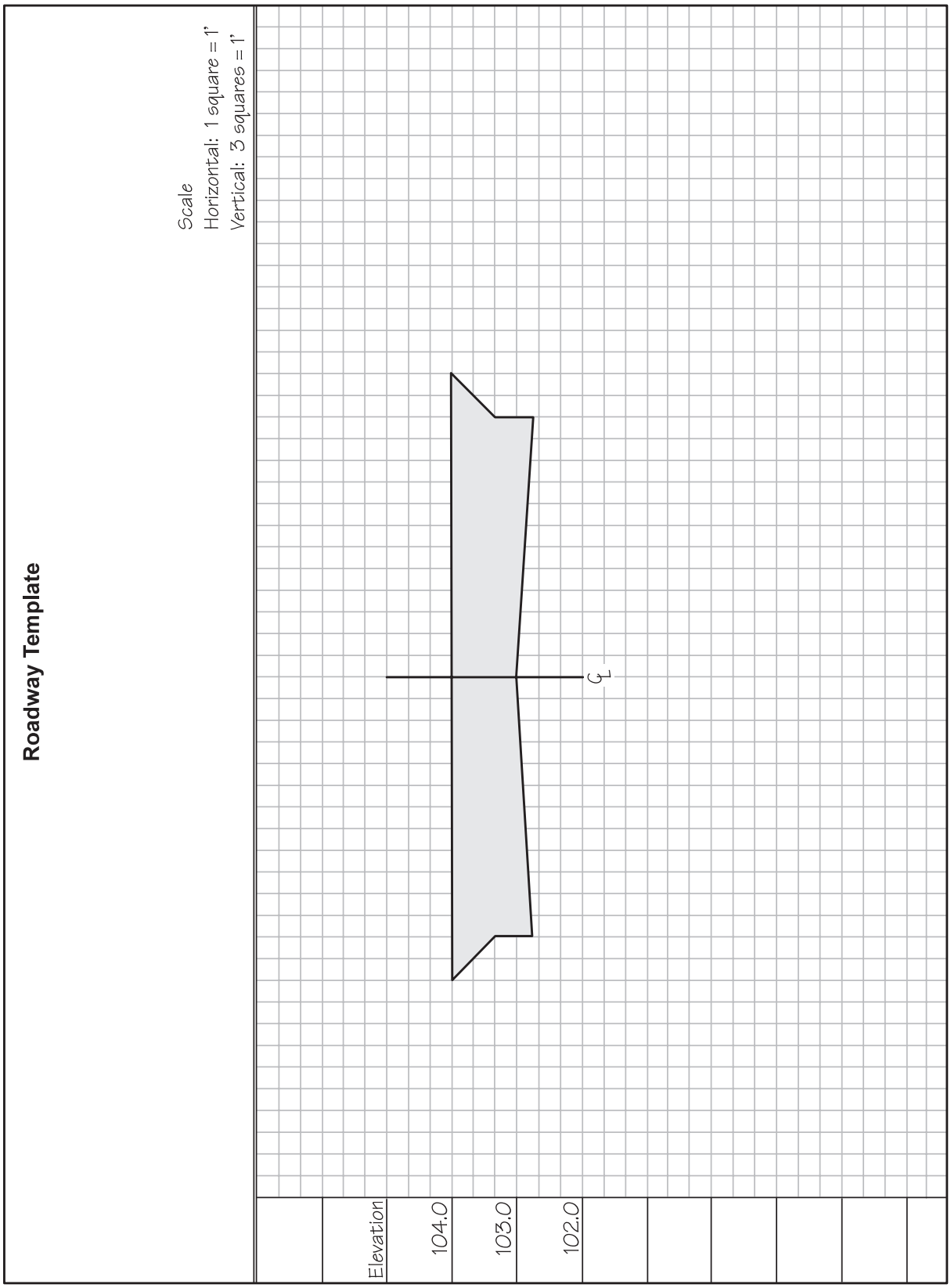


Figure 14-16
Roadway template

Quantities Take-off Sheet

Project: Jones job
Quantities for: Entrance drive
By: DB **Checked:** LL

Date: 4/22
Sheet 1 **of** 1
Misc:

Sta.			AEA*	Distance (sta. to sta.)	Vol. (CF)	Vol. (CY)
0 + 00			0	0	0	0
0 + 18			34.1	18	306.9	11.37
0 + 50			34.1	32	1,091.2	40.42
1 + 00			34.1	50	1,705.0	63.15
1 + 25			34.1	25	852.5	31.57
Total volume excavated						146.51
Actual vol. (total vol. x 1.31**)						191.93
Total (rounded to full CY)						192.00

Note:

*AEA = Average end area
**Swell factor

Figure 14-17
Entrance road calculations summary

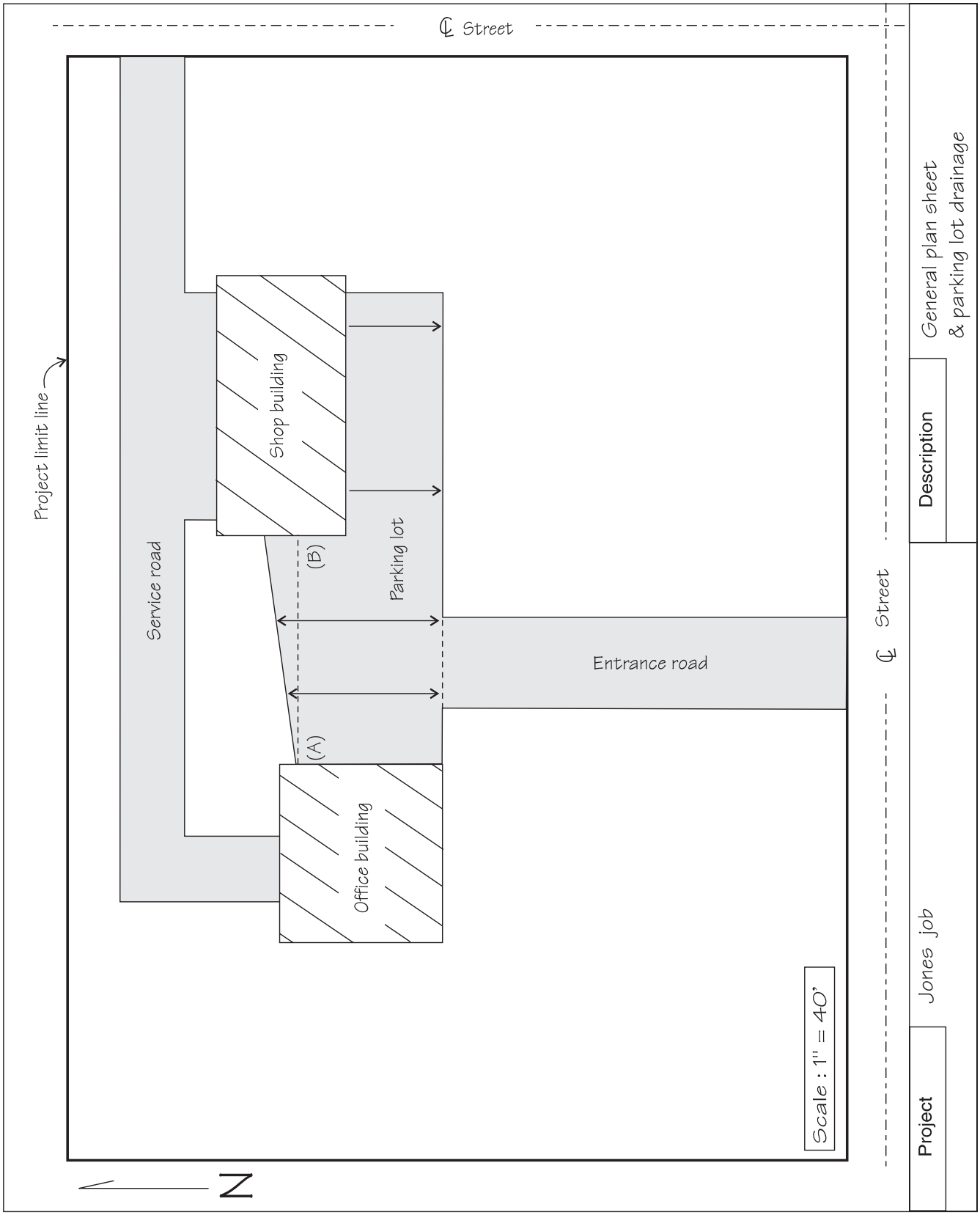


Figure 14-18
Parking lot drainage plan sheet

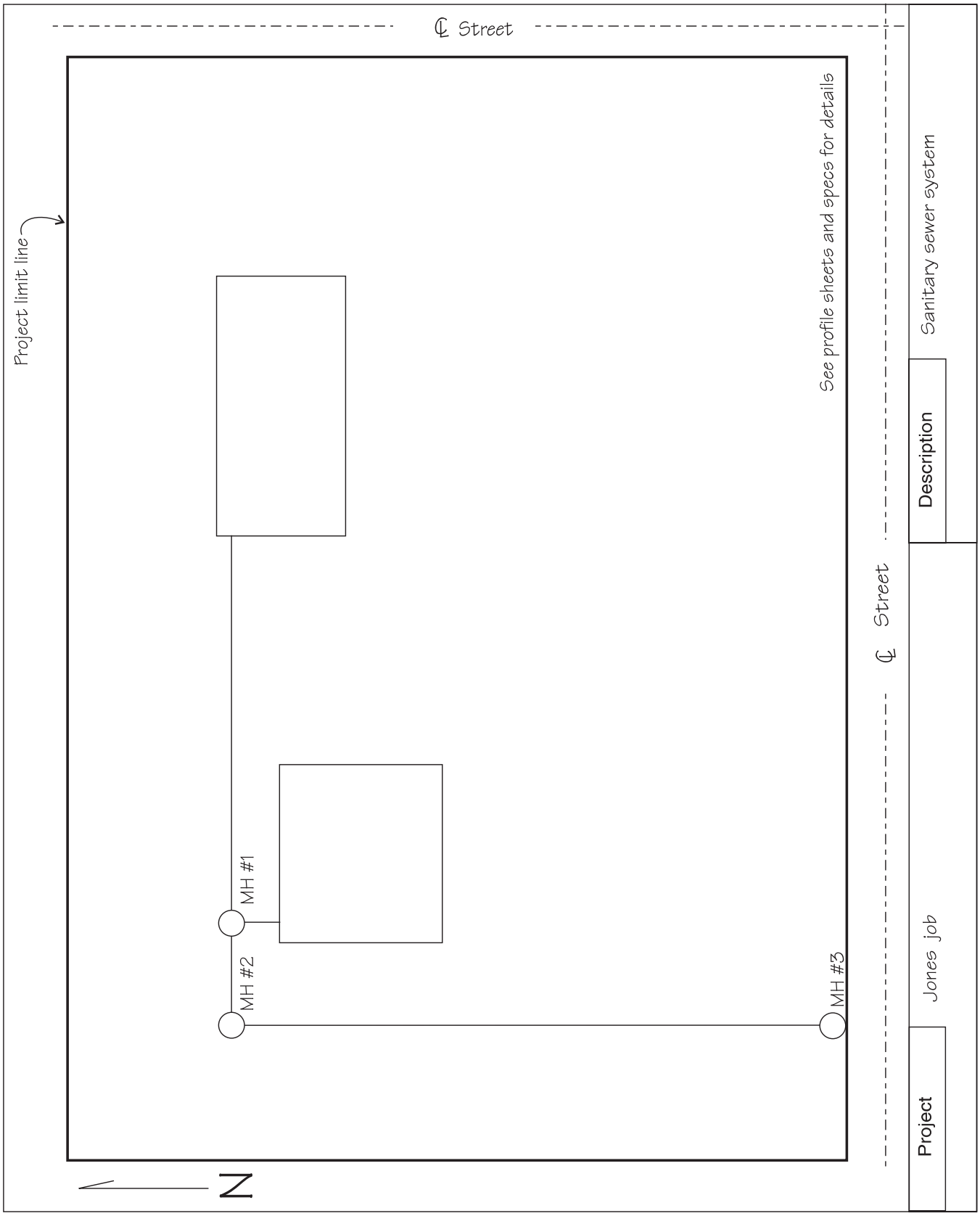


Figure 14-19
Sanitary sewer system plan sheet

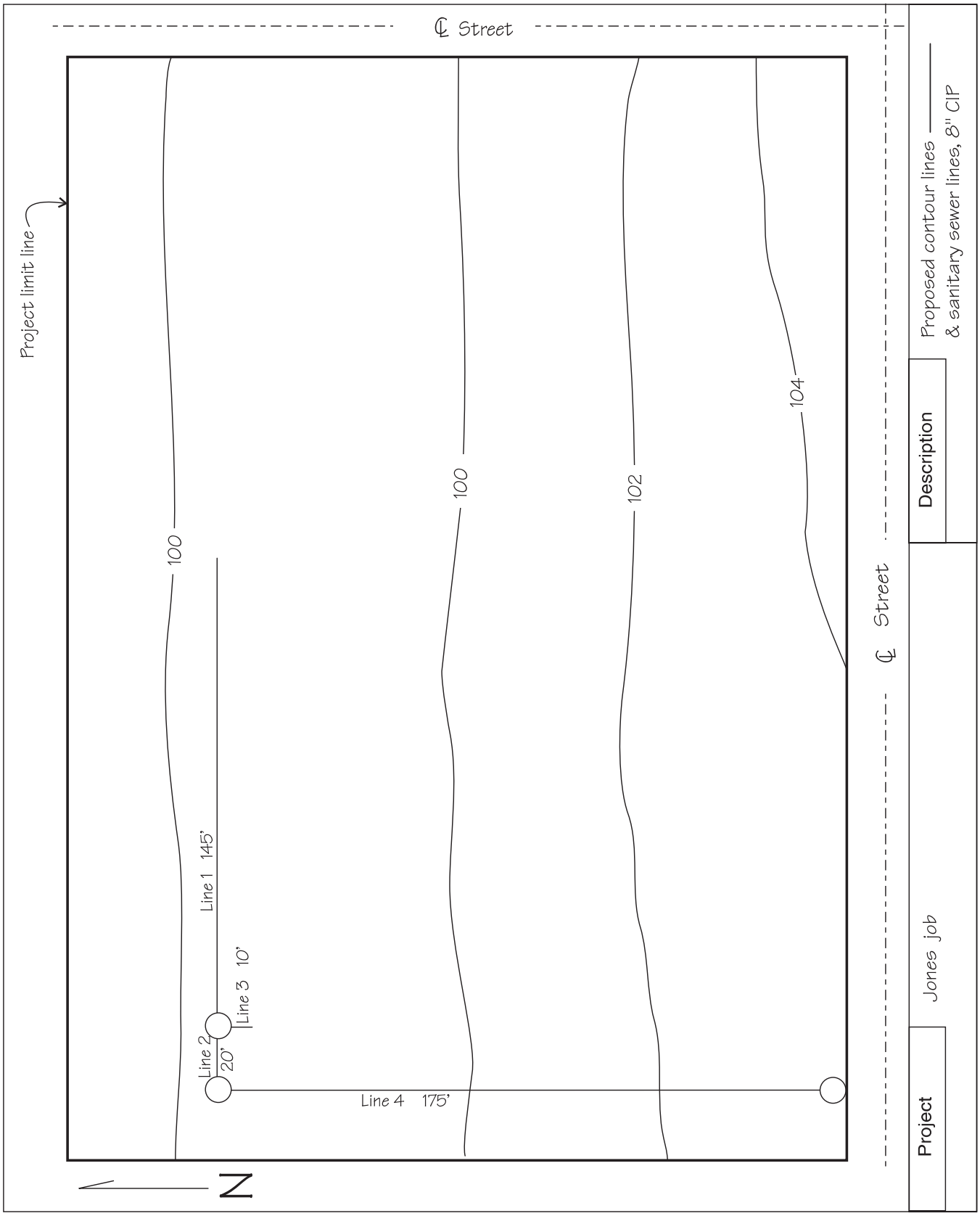


Figure 14-20
Sanitary sewer system plan sheet shown with proposed contours

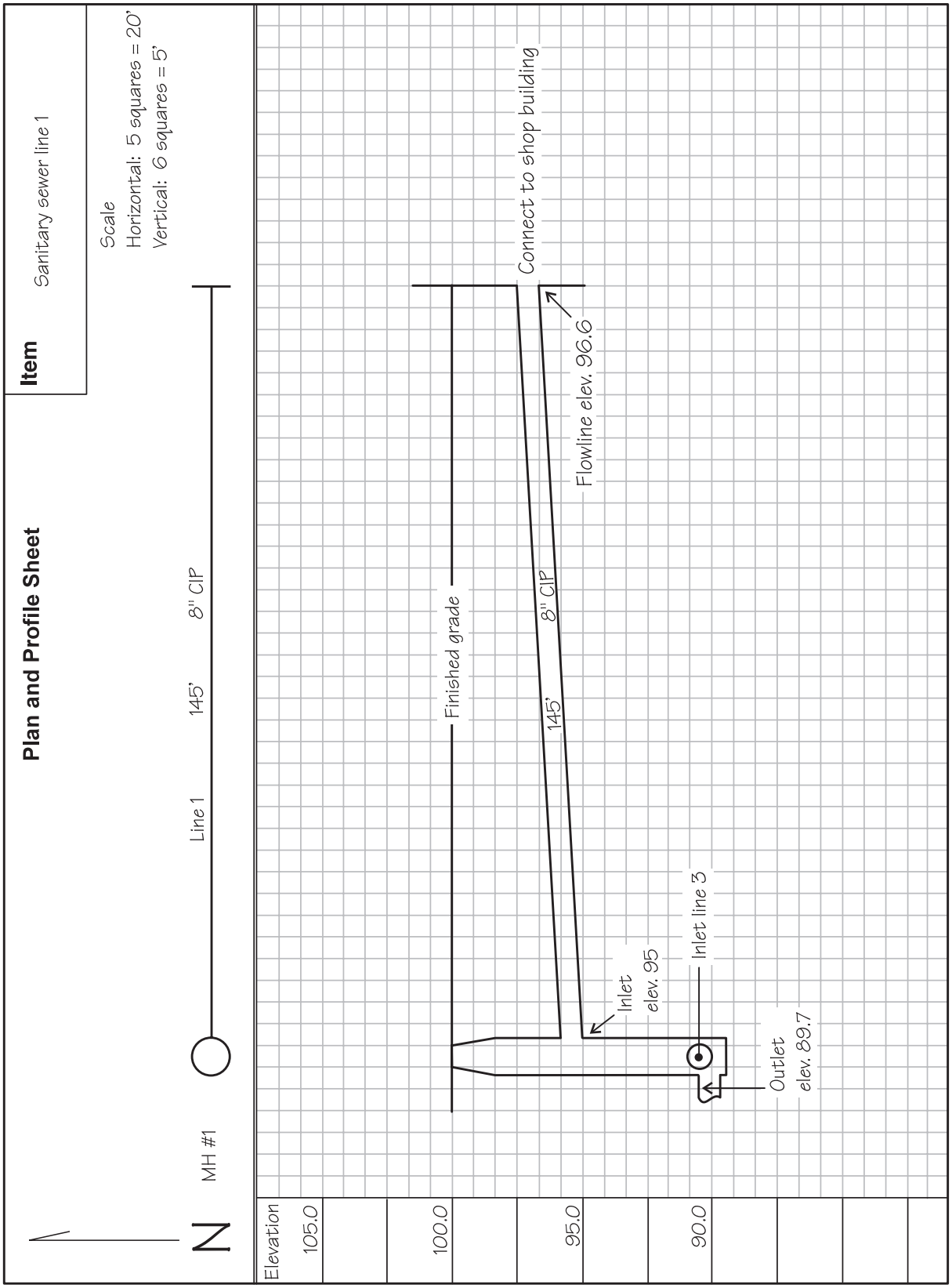


Figure 14-21
Sanitary sewer line 1, plan and profile sheet

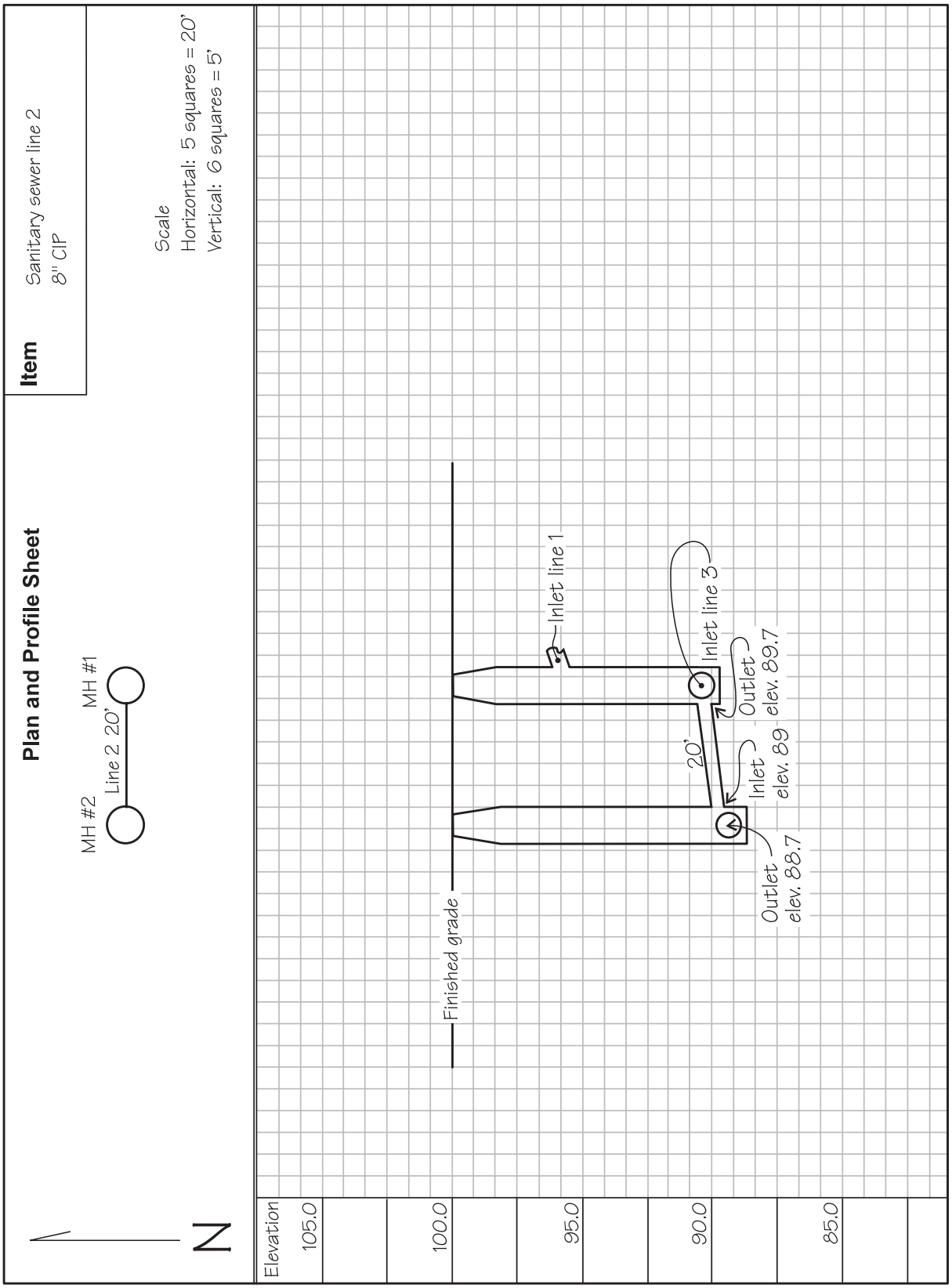


Figure 14-22
Sanitary sewer line 2, plan and profile sheet

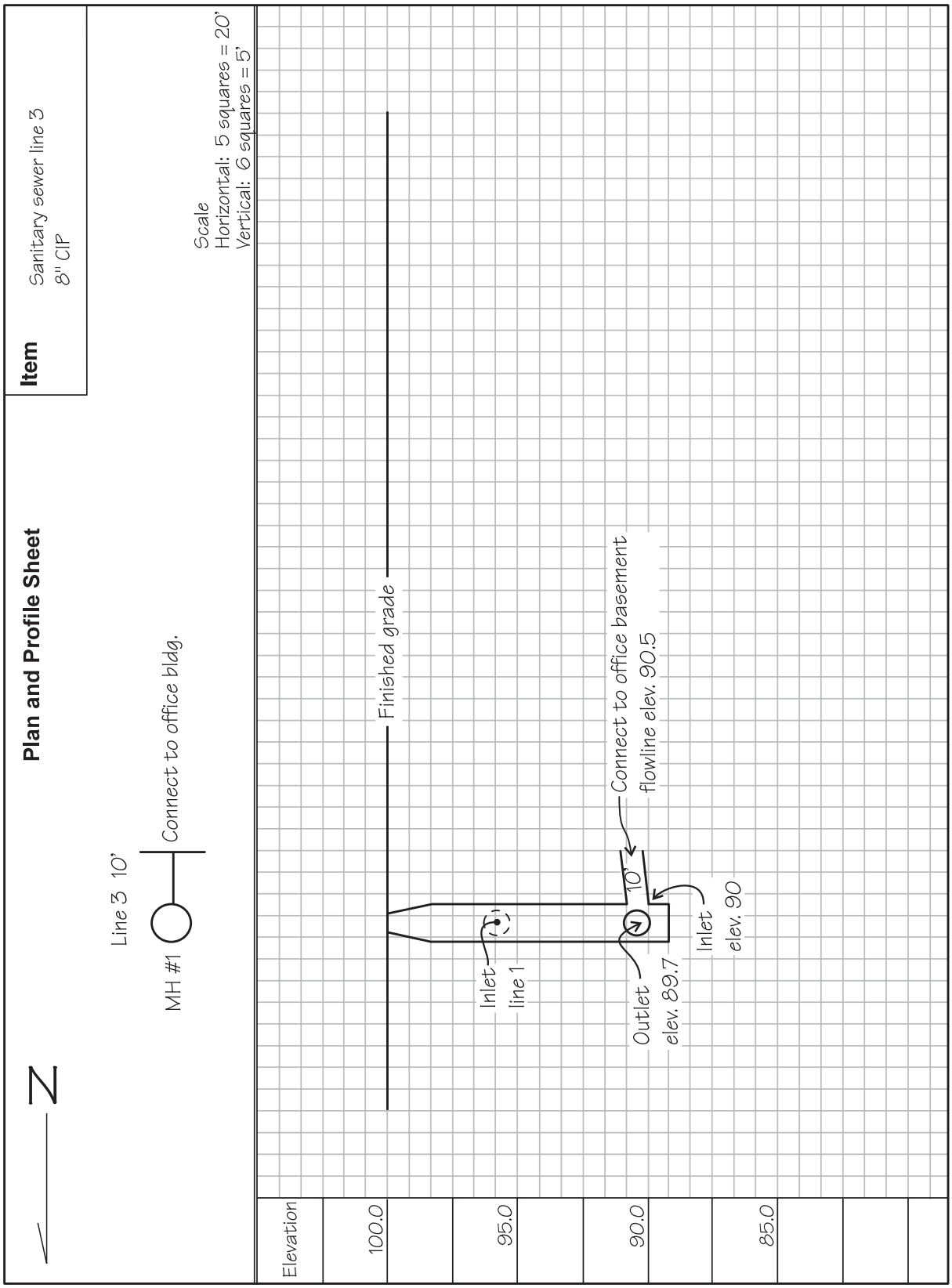


Figure 14-23
Sanitary sewer line 3, plan and profile sheet

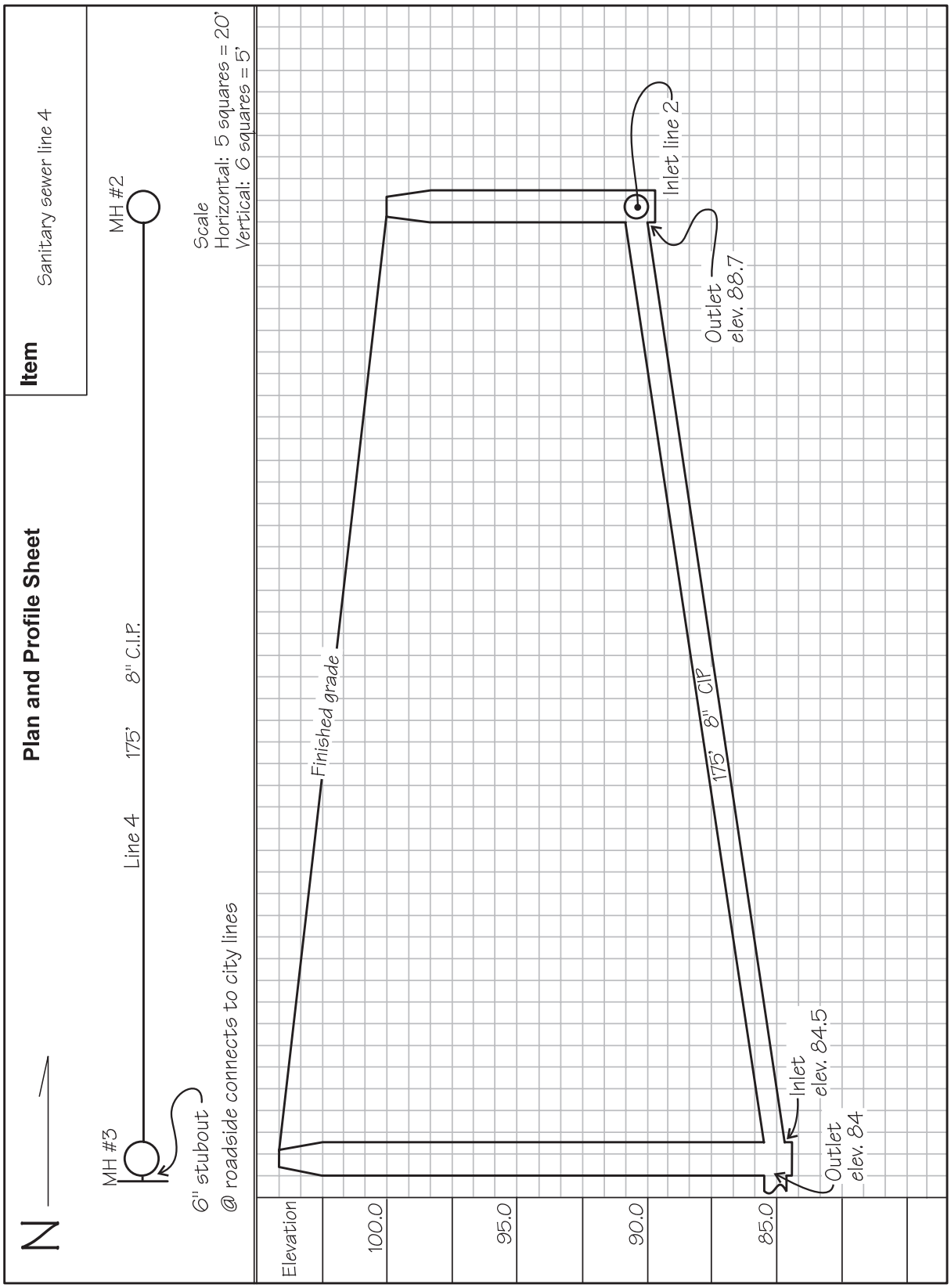


Figure 14-24
Sanitary sewer line 4, plan and profile sheet

Calculation Sheet

Project: Jones job **Date:** 4/22

Line 1

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade elev. - flowline elev.) + 0.5' (6" undercut, see standard drawing Figure 14-30)
= (100' - 96.6') + 0.5'
= 3.4' + 0.5'
(A) = 3.9'

(B) = (finish grade elev. - inlet MH1 elev.) + 0.5' (6" undercut)
= (100' - 95') + 0.5'
= 5' + 0.5'
(B) = 5.5'

$$\text{Average depth} = \frac{3.9' + 5.5'}{2} = \frac{9.4'}{2} = 4.7'$$

Conclusion
Average depth = 4.7'
Width = 2' (see standard drawing, Figure 14-30)
Length = 145' (see Figure 14-20)

Figure 14-25
Sanitary sewer line 1, average depth calculations

Calculation Sheet

Project: Jones job **Date:** 4/22

Line 2

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade elev. - outlet MH1 elev.) + 0.5' (6" undercut, see standard drawing Figure 14-30)
= (100' - 89.7') + 0.5'
= 10.3' + 0.5'
(A) = 10.8'

(B) = (finish grade elev. - outlet MH2 elev.) + 0.5' (6" undercut)
= (100' - 88.7') + 0.5'
= 11.3' + 0.5'
(B) = 11.8'

$$\text{Average depth} = \frac{10.8' + 11.8'}{2}$$
$$= \frac{22.6'}{2}$$
$$= 11.3'$$

Conclusion
Average depth = 11.3'
Width = 2' (see standard drawing, Figure 14-30)
Length = 20' (see Figure 14-20)

Figure 14-26
Sanitary sewer line 2, average depth calculations

Calculation Sheet

Project: Jones job **Date:** 4/22

Line 3

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade elev. - flowline elev.) + 0.5' (6" undercut, see standard drawing Figure 14-30)
= (100' - 90.5') + 0.5'
= 9.5' + 0.5'
(A) = 10'

(B) = (finish grade elev. - outlet MH1 elev.) + 0.5' (6" undercut, see standard drawing Figure 14-30)
= (100' - 89.7') + 0.5'
= 10.3' + 0.5'
(B) = 10.8'

$$\text{Average depth} = \frac{10' + 10.8'}{2} = \frac{20.8'}{2} = 10.4'$$

Conclusion
Average depth = 10.4'
Width = 2' (see standard drawing, Figure 14-30)
Length = 10' (see Figure 14-20)

Figure 14-27
Sanitary sewer line 3, average depth calculations

Calculation Sheet

Project: Jones job **Date:** 4/22

Line 4

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade MH2 elev. - outlet MH2 elev.) + 0.5' (6" undercut, see Figure 14-30)
= (100' - 88.7') + 0.5'
= 11.3' + 0.5'
(A) = 11.8'

(B) = (finish grade MH3 elev. - outlet MH3 elev.) + 0.5' (6" undercut, see Figure 14-30)
= (103.7' - 84') + 0.5'
= 19.7' + 0.5'
(B) = 20.2'

$$\text{Average depth} = \frac{11.8' + 20.2'}{2}$$
$$= \frac{32'}{2}$$
$$= 16'$$

Conclusion
Average depth = 16'
Width = 2' (see standard drawing, Figure 14-30)
Length = 175' (see Figure 14-20)

Figure 14-28
Sanitary sewer line 4, average depth calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/22

Quantities for: Sanitary sewer lines **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Excavation only dry clay - 100% Proctor

Location	Length (ft)	Width (ft)	Ave. depth (ft)	Volume (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)
Line 1	145	2	4.7	50.48	+1.31	66.13
Line 2	20	2	11.3	16.74	+1.31	21.93
Line 3	10	2	10.4	7.70	+1.31	10.09
Line 4	175	2	16.0	207.41	+1.31	271.71
Total volume excavated				282.33	+1.31	369.86
Total (rounded to full CY)						370.00

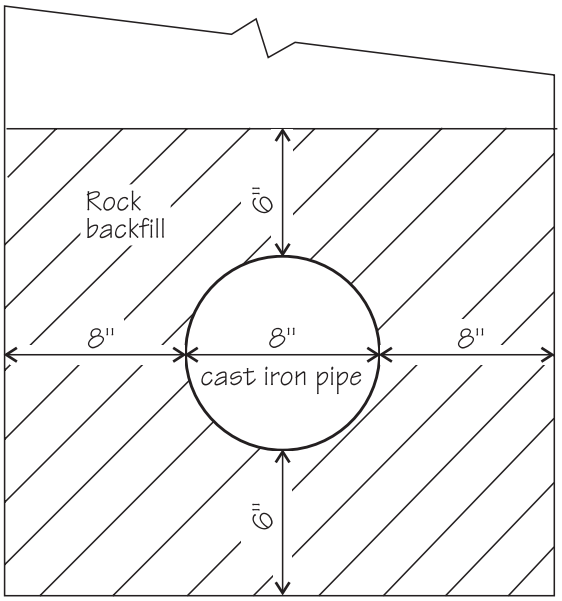
Note:

Figure 14-29
Sanitary sewer lines excavation calculations summary

Standard Drawings

Drawing # 3345

Item Rock backfill, sanitary sewer lines



Notes and comments

Figure 14-30
Standard drawing, sanitary sewer lines with rock backfill

Quantities Take-off Sheet

Project: Jones job **Date:** 4/23

Quantities for: Sanitary sewer lines **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Dirt backfill only dry clay - 90% Proctor

Location	Length (ft)	Width (ft)	Ave. depth (ft)	Rock depth (ft)	Shrink (-) or swell (+) factor	Actual vol. (CY)
Line 1	145	2	4.7	1.67	-1.25	40.68
Line 2	20	2	11.3	1.67	-1.25	17.84
Line 3	10	2	10.4	1.67	-1.25	8.08
Line 4	175	2	16.0	1.67	-1.25	232.20
Total vol. dirt backfill						298.79
Total (rounded to full CY)						299.00

Note:
370 exc -299 backfill = 71 CY spoil

Figure 14-31
Sanitary sewer lines, dirt backfill calculations summary

Quantities Take-off Sheet

Project: Jones job **Date:** 4/23

Quantities for: Sanitary sewer lines **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Rock backfill only

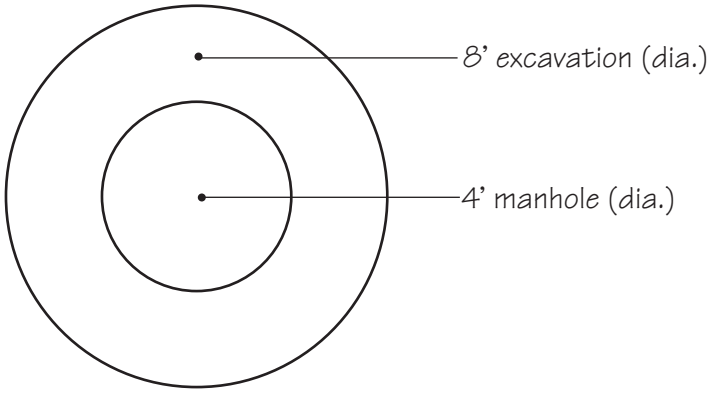
Location	Length (ft)	Width (ft)	Depth (ft)	Area of pipe (SF)	Rock fill vol. (CY)	
Line 1	145	2	1.67	0.35	16.06	
Line 2	20	2	1.67	0.35	2.21	
Line 3	10	2	1.67	0.35	1.11	
Line 4	175	2	1.67	0.35	19.38	
Total vol. rock backfill					38.76	
Total (rounded to full CY)					39.00	

Note:

Figure 14-32
Sanitary sewer lines, rock backfill calculations summary

Calculation Sheet

Project: Jones job **Date:** 4/23



Area of circle = πr^2

π = 3.14

$r = \frac{\text{dia.}}{2}$

Manhole area = 3.14×2^2

= 12.6 SF

Excavation area = 3.14×4^2

= 50.24 SF

Areas are for each foot of manhole depth

Total manhole depth = finished elev. - outlet elev. + 1'

Conclusion

Figure 14-33
Manhole area calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/23

Quantities for: Manhole volumes **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Excavation only

Location	Elevation difference* (ft)	Depth** (ft)	Excavation area (SF)	Exc. vol. (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)
No. 1	100-89.7 = 10.3	11.3	50.24	21.03	+1.31	27.55
No. 2	100-88.7 = 11.3	12.3	50.24	22.89	+1.31	29.99
No. 3	103.7-84 = 19.7	20.7	50.24	38.52	+1.31	50.46
Total volume excavated						108.00
Total (rounded to full CY)						108.00

Note:
*Elevation difference = finished elevation - outlet elevation
**Depth = elevation difference + 1'

Figure 14-34
Manhole excavation volume calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/23

Quantities for: Manhole volumes **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Backfill only 90% Proctor

Location	Depth (ft)	Excavation (SF)	Manhole (MH) area (SF)	Exc. area - MH area (SF)	Backfill vol (CF)	Shrink (-) or swell (+) factor	Actual vol. (CY)
No. 1	11.3	50.24	12.6	37.64	425.33	-1.25	19.69
No. 2	12.3	50.24	12.6	37.64	462.97	-1.25	21.43
No. 3	20.7	50.24	12.6	37.64	779.15	-1.25	36.07
Total vol. dirt backfill							77.19
Total (rounded to full CY)							77.00

Note:
108 exc - 77 backfill = 31 CY spoil

Figure 14-35
Manhole backfill calculations summary

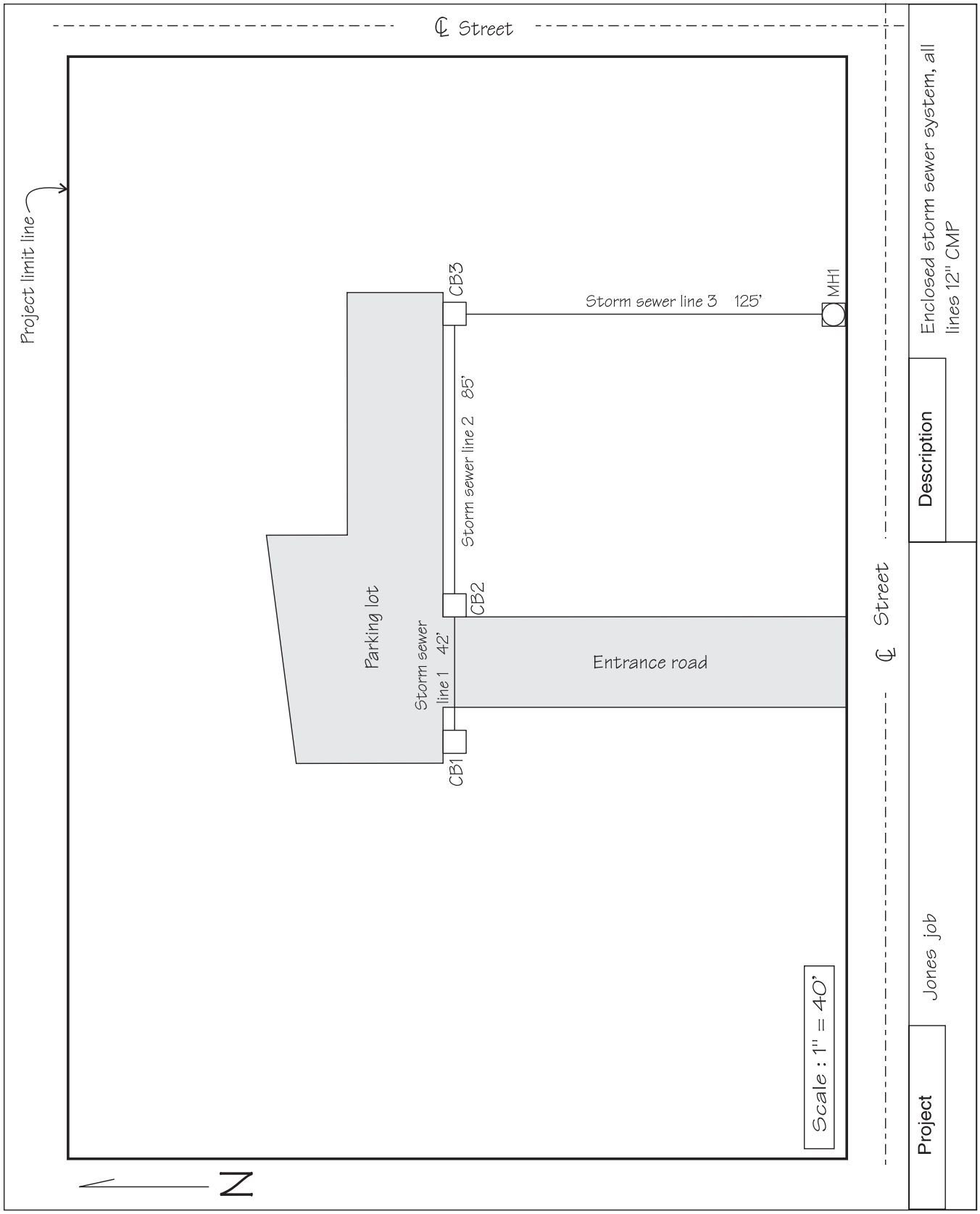
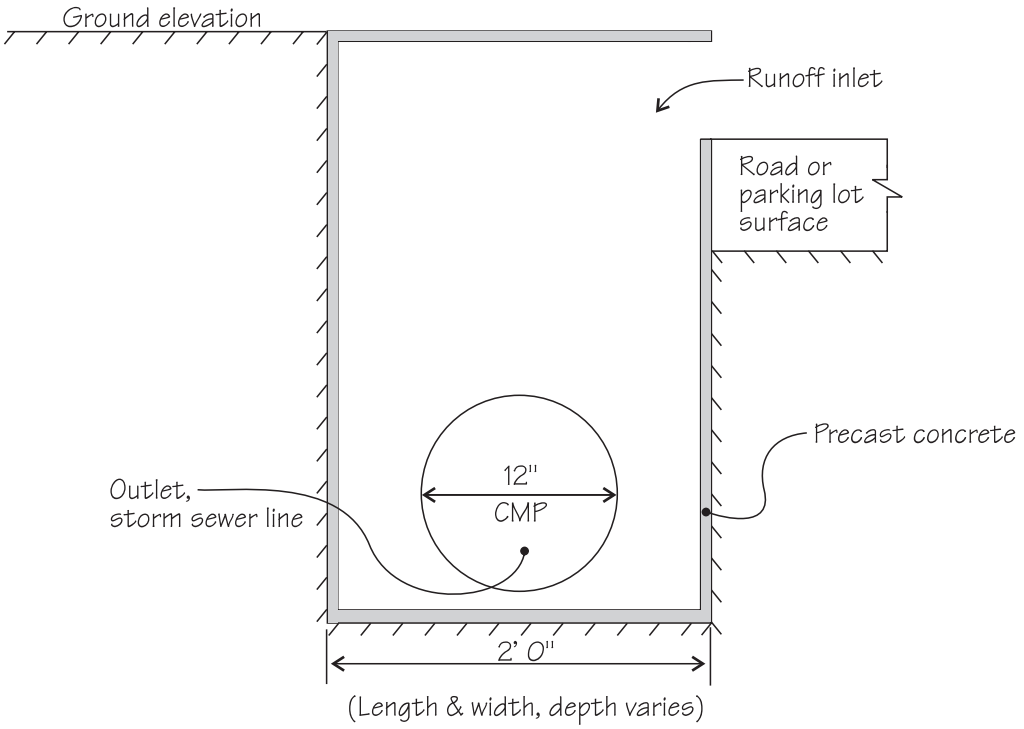


Figure 14-36
Enclosed storm sewer system, general plan sheet

Standard Drawings

Drawing # 3346

Item Drop / curb inlet, storm sewer system catch basin



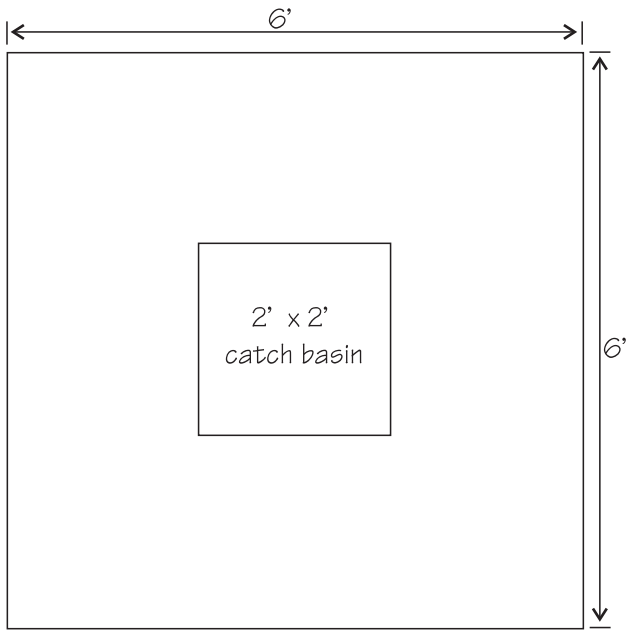
Notes and comments

Figure 14-37
Standard drawing, section view, catch basin drop / curb inlet

Standard Drawings

Drawing # 3347

Item Catch basin excavation limits



Notes and comments

Structure area = 2' x 2'
= 4 SF for each foot in depth

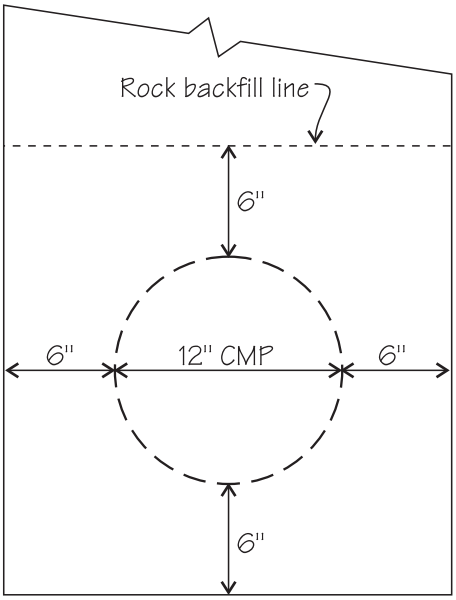
Excavation limits = 6' x 6'
= 36 SF for each foot in depth

Figure 14-38
Catch basin excavation limits

Standard Drawings

Drawing # 3348

Item Rock backfill, storm sewer lines



Notes and comments

Figure 14-39
Standard drawing, storm sewer lines with rock backfill

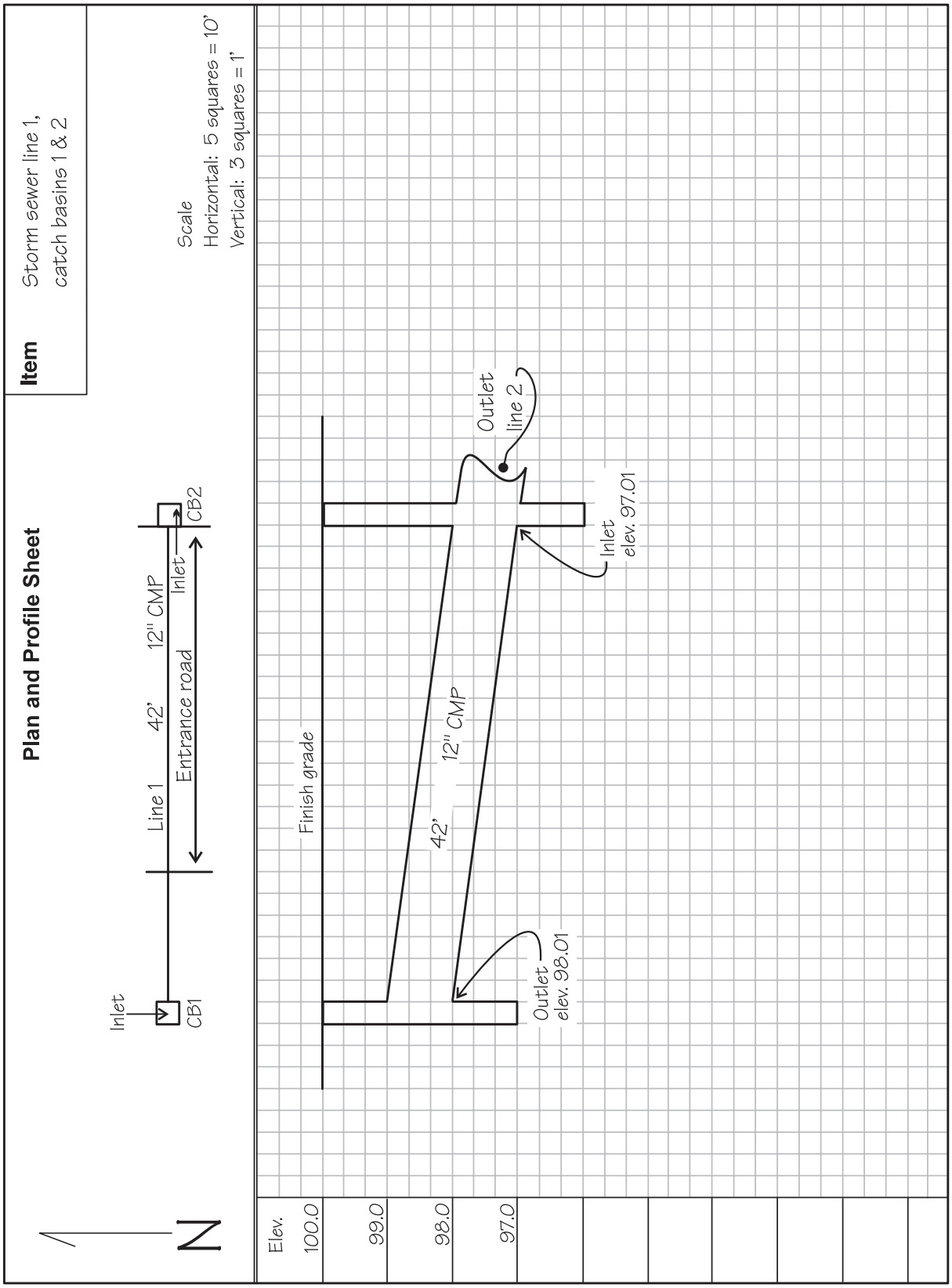


Figure 14-40
Storm sewer line 1, plan and profile sheet

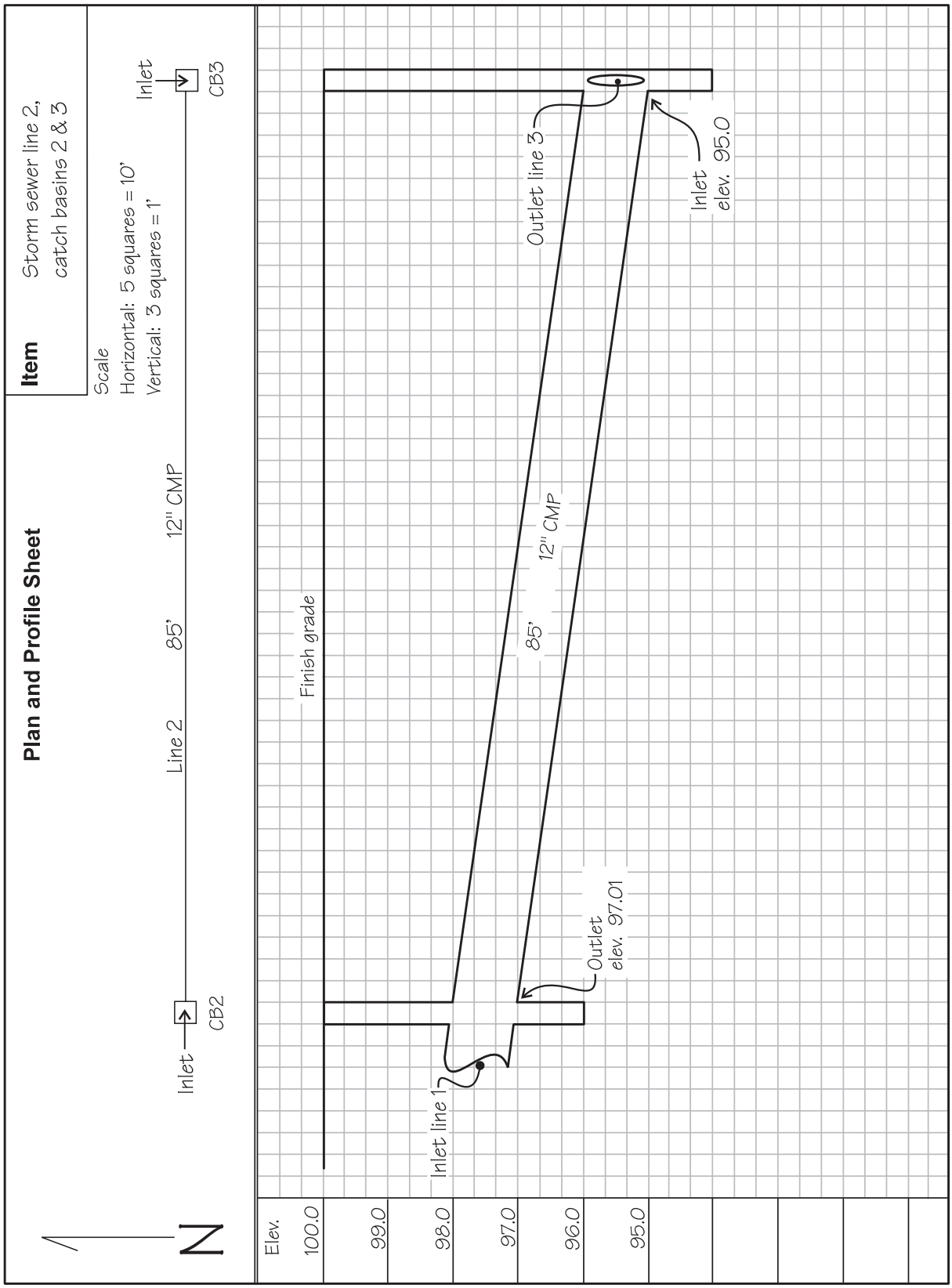


Figure 14-41
Storm sewer line 2, plan and profile sheet

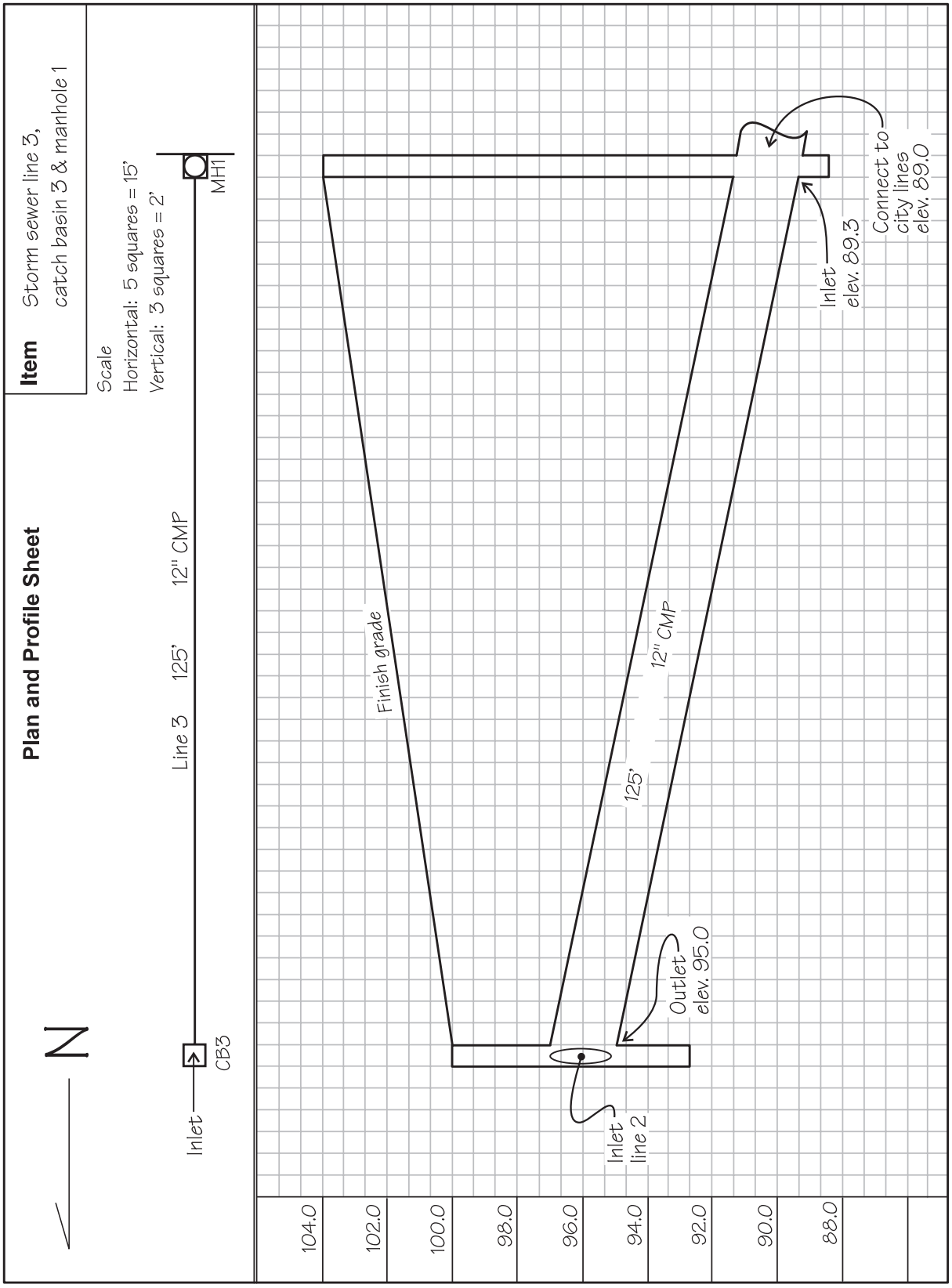


Figure 14-42
Storm sewer line 3, plan and profile sheet

Quantities Take-off Sheet

Project: Jones job **Date:** 4/23

Quantities for: Structure volumes **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Excavation only

Location	Elev. dif.* (ft)	Depth** (ft)	Struct. exc. area (SF)	Volume (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)
Catch basin no. 1 (CB1)	100-98 = 2	3	36	4	+1.31	5.24
Catch basin no. 2 (CB2)	100-97 = 3	4	36	5.33	+1.31	6.98
Catch basin no. 3 (CB3)	100-95 = 5	6	36	8	+1.31	10.48
Manhole no. 1 (MH1)	104-89 = 15	16	50.24	29.77	+1.31	39.00
Total volume excavated						61.70
Total (rounded to full CY)						62.00

Note:
*Elev. dif. = finished elev. - outlet elev.
**Depth = elev. dif. + 1'

Figure 14-43
Storm sewer system catch basins, excavation calculations summary

Quantities Take-off Sheet

Project: Jones job **Date:** 4/23

Quantities for: Structure volume **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Backfill only 90% Proctor

Location	Depth (ft)	Struct. area (SF)	Exc. area (SF)	Backfill area* (SF)	Vol. (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)
Catch basin no. 1 (CB1)	3	4	36	32	3.56	-1.25	4.45
Catch basin no. 2 (CB2)	4	4	36	32	4.74	-1.25	5.93
Catch basin no. 3 (CB3)	6	4	36	32	7.11	-1.25	8.89
Manhole no. 1 (MH1)	16	12.6	50.24	37.64	22.31	-1.25	27.89
Total vol. dirt backfill							47.16
Total (rounded to full CY)							47.00

Note:
*Backfill area = exc. area - struct. area
62 exc - 47 backfill = 15 CY spoil

Figure 14-44
Storm sewer system catch basins, backfill calculations summary

Calculation Sheet

Project: Jones job **Date:** 4/23

Storm sewer line 1
run = CB1 to CB2

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade elev. - outlet CB1 elev.) + 0.5' (6" rock fill see standard drawing, Figure 14-39)
= (100' - 98.01') + 0.5'
= 1.99' + 0.5'
(A) = 2.49'

(B) = (finish grade elev. - outlet CB2 elev.) + 0.5' (6" rock fill see standard drawing, Figure 14-39)
= (100' - 97.01') + 0.5'
= 2.99' + 0.5'
(B) = 3.49'

$$\text{Average depth} = \frac{2.49' + 3.49'}{2} = \frac{5.98'}{2} = 2.99'$$

Conclusion
Average depth = 2.99'
Width = 2' (see standard drawing, Figure 14-39)
Length = 42' (see Figure 14-36)

Figure 14-45
Storm sewer line 1, average depth calculations

Calculation Sheet

Project: Jones job **Date:** 4/24

Storm sewer line 2
run = CB2 to CB3

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade elev. - outlet CB2 elev.) + 0.5' (6" rock fill see standard drawing, Figure 14-39)
= (100' - 97.01') + 0.5'
= 2.99' + 0.5'
(A) = 3.49'

(B) = (finish grade elev. - outlet CB3 elev.) + 0.5' (6" rock fill see standard drawing, Figure 14-39)
= (100' - 95.01') + 0.5'
= 4.99' + 0.5'
(B) = 5.49'

$$\text{Average depth} = \frac{3.49' + 5.49'}{2}$$
$$= \frac{8.98'}{2}$$
$$= 4.49'$$

Conclusion
Average depth = 4.49'
Width = 2' (see standard drawing, Figure 14-39)
Length = 85' (see Figure 14-36)

Figure 14-46
Storm sewer line 2, average depth calculations

Calculation Sheet

Project: Jones job **Date:** 4/24

Storm sewer line 3
run = CB3 to MH1

$$\text{Average depth} = \frac{(A) + (B)}{2}$$

(A) = (finished grade elev. - outlet CB3 elev.) + 0.5' (6" rock fill see standard drawing, Figure 14-39)
= (100' - 95.01') + 0.5'
= 4.99' + 0.5'
(A) = 5.49'

(B) = (finish grade elev. - outlet MH1 elev.) + 0.5' (6" rock fill see standard drawing, Figure 14-39)
= (104' - 89') + 0.5'
= 15' + 0.5'
(B) = 15.5'

$$\text{Average depth} = \frac{5.49' + 15.5'}{2} = \frac{20.99'}{2} = 10.5'$$

Conclusion
Average depth = 10.5'
Width = 2' (see standard drawing, Figure 14-39)
Length = 125' (see Figure 14-36)

Figure 14-47
Storm sewer line 3, average depth calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/24

Quantities for: Storm sewer lines **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Excavation only dry clay

Location	Length (ft)	Width (ft)	Average depth (ft)	Volume (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)
Line 1	42	2	2.99	9.3	+1.31	12.19
Line 2	85	2	4.49	28.27	+1.31	37.03
Line 3	125	2	10.5	97.22	+1.31	127.36
Total volume excavated						176.58
Total (rounded to full CY)						177.00

Note:

Figure 14-48
Storm sewer lines, excavation calculations summary

Quantities Take-off Sheet

Project: Jones job **Date:** 4/24

Quantities for: Storm sewer lines **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Dirt backfill only dry clay 90% Proctor

Location	Length (ft)	Width (ft)	Ave. depth (ft)	Rock depth (ft)	Shrink (-) or swell (+) factor	Actual vol. (CY)
Line 1	42	2	2.99	2	-1.25	3.85
Line 2	85	2	4.49	2	-1.25	19.6
Line 3	125	2	10.50	2	-1.25	98.38
Total vol. dirt backfill						121.83
Total (rounded to full CY)						122.00

Note:
177 exc - 122 backfill = 55 CY spoil

Figure 14-49
Storm sewer lines, dirt backfill calculations summary

Quantities Take-off Sheet

Project: Jones job **Date:** 4/24

Quantities for: Storm sewer lines **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** Rock backfill

Location	Length (ft)	Width (ft)	Depth (ft)	Area of pipe (SF)	Rock fill vol. (CY)	
Line 1	42	2	2	0.78	5.01	
Line 2	85	2	2	0.78	10.14	
Line 3	125	2	2	0.78	14.91	
Total vol. rock backfill					30.06	
Total (rounded to full CY)					30.00	

Note:

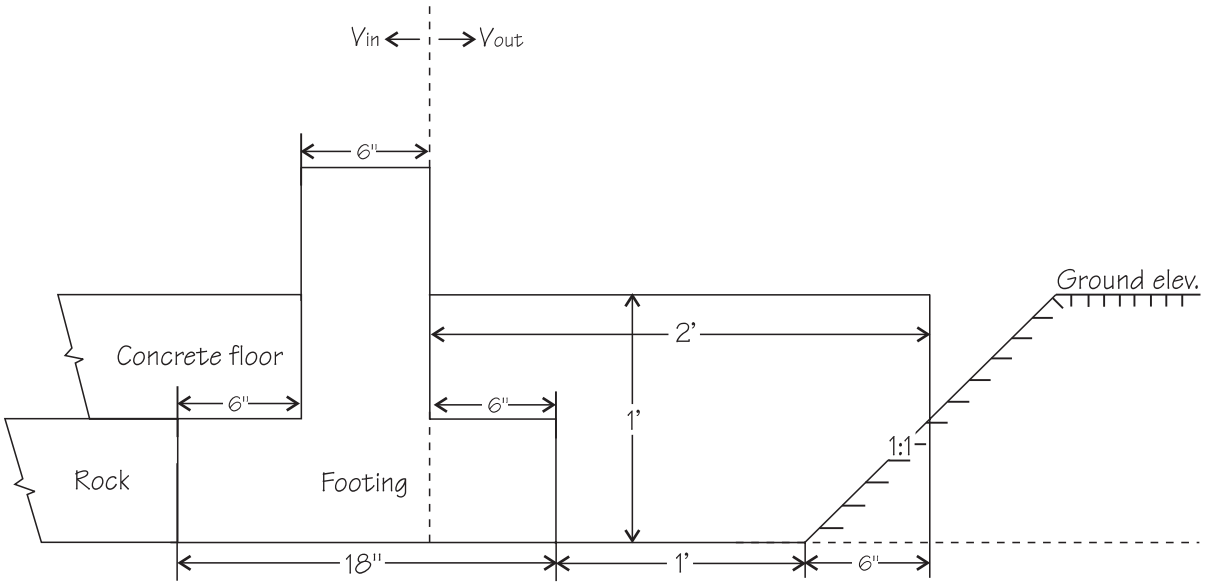
Rock backfill volume (CF) = (width x depth – area of pipe) x length.
CY = CF divided by 27

Figure 14-50
Storm sewer lines, rock backfill calculations summary

Standard Drawings

Drawing # 3349

Item Footing exc., shop bldg.



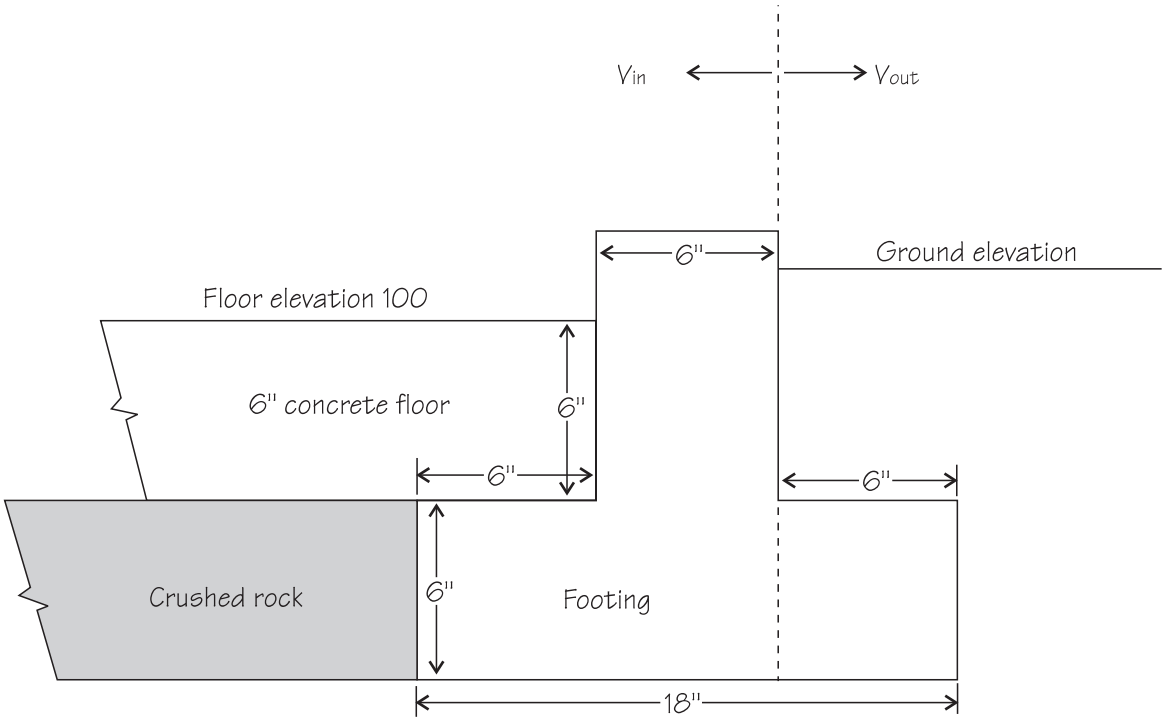
Notes and comments

Figure 14-51
Shop building, footing excavation detail

Standard Drawings

Drawing # 3350

Item Footing backfill, shop bldg.



Notes and comments

Figure 14-52
Shop building, footing backfill detail

Calculation Sheet

Project: Jones job **Date:** 4/24

Shop building dimensions: 80' x 40' (see Figure 14-2)

$$V_{out}\ (CY) = \frac{\text{excavation vol. (CF)}}{27} + \frac{\text{total exc. corner volume (CF)}}{27}$$

excavation vol. (CF) = length x width x depth

total exc. corner volume (CF) = ($^1/_3\ \pi r^2$) x depth x # of corners

$$V_{out}\ (CY) = \frac{(80 + 80 + 40 + 40) \times 2 \times 1}{27} + \frac{0.3333 \times 3.1416 \times 1^2 \times 1 \times 4}{27}$$

$$= 17.8 + 0.16$$

$$= 17.96\ CY$$

$$V_{in}\ (CY) = \frac{\text{excavation vol. (length x width x depth)}}{27}$$

$$= \frac{80 \times 40 \times 1}{27}$$

$$= 118.52\ CY$$

$$\text{Rock backfill (CY)} = \frac{V_{in}\ \text{vol. (CF)}}{27} - \frac{\text{interior concrete footing vol. (CF)}}{27}$$

V_{in} vol. = exc. length x exc. width x (exc. depth – depth concrete floor) (6", see Figure 14-52)

interior concrete footing vol. (see Figure 14-52) = length x width x depth

$$\text{Rock backfill (CY)} = \frac{80 \times 40 \times (1 - 0.5)}{27} - \frac{240 \times 1 \times 0.5}{27}$$

$$= \frac{1{,}600}{27} - \frac{120}{27}$$

$$= 59.26 - 4.44$$

$$= 54.82\ CY$$

$$\text{Dirt backfill (CY)} = V_{out}\ (CY) - \frac{\text{exterior concrete footing vol. (CF)}}{27}$$

V_{out} = 17.96 CY (see above)

exterior concrete footing vol. (see Figure 14-52) = length x width x depth

$$\text{Dirt backfill (CY)} = 17.96 - \frac{240 \times 0.5 \times 0.5}{27}$$

$$= 17.96 - 2.22$$

$$= 15.74\ CY$$

Conclusion

V_{out} = 17.96 CY
V_{in} = 118.52 CY
Rock backfill = 54.82 CY
Dirt backfill = 15.74 CY

Figure 14-53
Shop building footing, excavation and backfill calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/24

Quantities for: Shop footing **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:**

Item		Exc volume (CY)	Backfill, dirt (d) or rock (r) vol. (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)	Spoil vol. (CY)
V_{out}		17.96		+1.31	23.53	
V_{out}			15.74 (d)	-1.25	19.68	3.85
V_{in}		118.52		+1.31	155.26*	155.26*
V_{in}			54.82 (r)		54.82	
Total volume excavated		136.48		+1.31	178.79	
(rounded to full CY)					179.00	
Total volume dirt backfill			15.74 (d)	-1.25	19.68	
(rounded to full CY)					20.00	
Total volume rock backfill			54.82 (r)		54.82	
(rounded to full CY)					55.00	
Total volume spoil						159.11
(rounded to full CY)						159.00

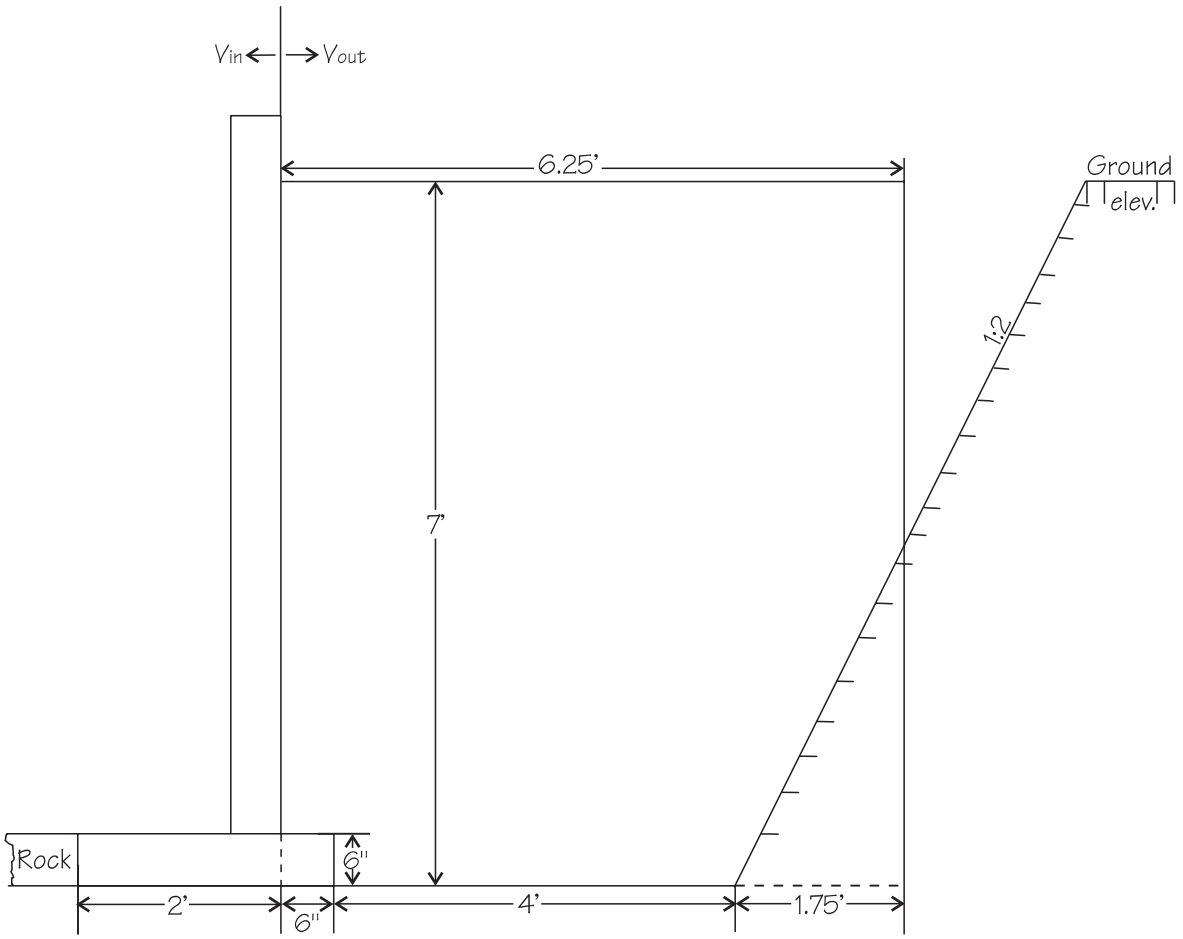
Note:
*All V_{in} excavated material is spoil because only rock backfill is used for the V_{in}.

Figure 14-54
Shop building, footing calculations summary

Standard Drawings

Drawing # 3351

Item Office bldg. basement



Notes and comments

Figure 14-55
Office building basement, excavation and backfill details

Calculation Sheet

Project: Jones job **Date:** 4/24

Office building dimensions: 55' x 50' (see Figure 14-2)

$$V_{out} = \frac{\text{perimeter x average slope line area (SF)}}{27} + \frac{\text{total exc. corner volume (CF)}}{27}$$

average slope line area (SF) = (total width) x depth

total exc. corner volume (CF) = ($^1/_3\,\pi r^2$) x depth x # of corners

$$V_{out}\ (CY) = \frac{(50 + 50 + 55 + 55) \times (0.5 + 4 + 1.75) \times 7}{27} + \frac{0.3333 \times 3.1416 \times 3.5^2 \times 7 \times 4}{27}$$

$$= \frac{9{,}187.5 + 359.1536}{27}$$

$$= 340.28 + 13.3$$

$$= 353.58\ CY$$

$$V_{in}\ (CY) = \frac{\text{excavation vol. (length x width x depth)}}{27}$$

$$= \frac{55 \times 50 \times 7}{27}$$

$$= \frac{19{,}250}{27}$$

$$= 712.96\ CY$$

$$\text{Rock backfill (CY)} = \frac{V_{in}\ \text{backfill vol. (CF)}}{27}$$

V_{in} backfill vol. = (length - footing width) x (width – footing width) x depth

$$\text{Rock backfill (CY)} = \frac{(55 - 2) \times (50 - 2) \times 0.5}{27}$$

$$= \frac{1{,}272}{27}$$

$$= 47.11\ CY$$

$$\text{Dirt backfill (CY)} = V_{out}\ (CY) - \frac{\text{concrete footing vol. (CF)}}{27}$$

V_{out} = 353.58 CY (see above)

concrete footing vol. = length x width x depth

$$\text{Dirt backfill (CY)} = 353.58 - \frac{210 \times 0.5 \times 0.5}{27}$$

$$= 353.58 - 1.94$$

$$= 351.64\ CY$$

Conclusion

V_{out} = 353.58 CY
V_{in} = 712.96 CY
Rock backfill = 47.11 CY
Dirt backfill = 351.64 CY

Figure 14-56
Office building, basement excavation and backfill calculations

Quantities Take-off Sheet

Project: Jones job **Date:** 4/24

Quantities for: Office bldg. basement **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:**

Item		Exc. volume (CY)	Backfill, dirt (d) or rock (r) vol. (CY)	Shrink (-) or swell (+) factor	Actual vol. (CY)	Spoil vol. (CY)
V_{out}		353.58		+1.31	463.19	
V_{out}			351.64 (d)	-1.25	439.55	23.64
V_{in}		712.96		+1.31	933.97*	933.97*
V_{in}			47.11 (r)		47.11	
Total volume excavated		1,066.54		+1.31	1,397.17	
(rounded to full CY)					1,397.00	
Total volume dirt backfill			351.64 (d)	-1.25	439.55	
(rounded to full CY)					440.00	
Total volume rock backfill			47.11 (r)		47.11	
(rounded to full CY)					47.00	
Total volume spoil						957.61
(rounded to full CY)						958.00

Note:
*All V_{in} excavated material is spoil because only rock backfill is used for the V_{in}.

Figure 14-57
Office building, basement excavation and backfill calculations summary

Quantities Take-off Sheet

Project: Jones job **Date:** 4/24

Quantities for: Summary sheet **Sheet** 1 **of** 1

By: DB **Checked:** LL **Misc:** All quantities rounded to full CY

Item	Fill vol. (CCY†)	Exc. vol. (LCY‡)	Dirt bkfill (CCY)	Spoil vol. (LCY)	Rock fill vol. (CY)	Topsoil vol.* (CY)	Notes
Topsoil (top 2")						504	Non-usable material
Topsoil (usable)						1,007	Stockpile & replace
Topsoil (total to replace)						1,103	Need additional 96 CY
Grid square site take-off	67	17,111		17,041			
Service road					120		
Entrance road		192		192			
Parking lot		99		99			
Sanitary sewer all lines		370	299	71	39		
Sanitary sewer all mnhls.		108	77	31			
Storm sewer all struct.		62	47	15			
Storm sewer all lines		177	122	55	30		
Shop footing/floor area		179	20	159	55		
Office bldg. basement		1,397	440	958	47		
Totals	67	19,695	1,005	18,621	291	2,614	

Note:
†CCY = compact cubic yards, shrink factor (x 1.25) applied
‡LCY = loose cubic yards, swell factor (x 1.31) applied
*No shrink or swell factor applied to topsoil quantities

Figure 14-58
Project summary sheet

15

Costs & Final Bid for the Sample Estimate

In the last chapter we did a quantity take-off for a sample project. Now we'll take it one step further. In this chapter, we'll price the work. I'll show how to use the estimated quantities and costs to create an accurate bid and win a profitable contract.

As an excavation subcontractor, most of your bids will be submitted to general contractors. On every bid, the general contractor has to decide what work will be subcontracted and what work will be done with the contractor's own crews and equipment. That's an important decision — the choice of subcontractors can make or break the contractor. When the general decides not to do the excavation with his company's crews, he'll request bids from subcontractors who specialize in that work.

The general contractor signs the contract with the owner to complete the project according to the plans and specifications. In doing so, he's accepting responsibility for the entire project, even though subcontractors are doing much of the work. The owner pays the general contractor as work is completed, and the general contractor disburses payments to subcontractors and suppliers.

Some general contractors are no more than "paper contractors." They own no construction equipment and have no work crews. Instead, they subcontract everything, just administering and coordinating the job with subcontractors who actually do the work. Some states now restrict that type of contracting. They require that the general contractor's crews handle most of the work on a project.

The trend in the construction industry for at least the last 20 years has been toward specialization. More and more contractors and subcontractors are specializing in certain types of work. Fewer and fewer general contractors routinely handle the entire job, from excavation, concrete work and masonry to carpentry. When I began my career in construction, most of the larger general contracting companies owned at least some

earthmoving equipment. Today, because of the high cost of equipment (and the high wages paid to experienced operators), even the larger construction companies leave excavation work to specialists.

That's good news for excavation contractors. You'll have a chance to bid on most projects that require excavation equipment. But with the good news comes extra responsibility. You're bidding because the general contractor expects you'll do the work faster, better and at a lower cost. If you can do that, keeping your equipment busy should be no problem.

The Bid Preparation Process

The best way to explain how to price an estimate is to work through an example. Most of this chapter is that example, based on the take-off in Chapter 14. Study the details in this sample estimate, use the information I've presented earlier in the book, and you'll have no trouble mastering the skills required for excavation estimating.

We're preparing this sample estimate for J. Q. Corporation, a land development company. J. Q. Corp. bought some property last year. Now they're developing the northwest corner as a manufacturing plant and office complex. A major regional manufacturer has agreed to buy the building under a turnkey contract once construction is completed.

J. Q. Corp. has asked our company, Quality Construction, to submit a bid for the sitework. J. Q. Corp. has told all bidders that they can dispose of excess material in an adjoining area. (You can look ahead to area "A" on Figure 15-C-1, if you're interested.) Temporary storage space for topsoil is available on the same property. The only condition is that topsoil in the storage area has to be stripped off before stockpiling and then replaced when the job is finished. Any additional topsoil needed can be taken from this area. This is a condition of the bid, not part of it.

Quality Construction is a small excavation and site-improvement contracting company that handles work in this size range. We do most of our own excavation and have late model equipment. Though the equipment fleet is small, it's all in good condition.

In this sample estimate, we're going to work backwards. First, you can see the bid we prepared, and then we'll study the supporting documents to understand how to arrive at the figures.

The Scope of Work

We've reviewed the specifications and plans and have visited the jobsite. Figure 15-A-1 is the bid summary we've prepared for submission to J. Q. Corp.

The Bid Sheet

Figure 15-B-1 is our worksheet for compiling the bid. It shows bid prices for the individual line items and who'll do the work — either Quality or a subcontractor. The column headed "By" shows either the name of our sub or Self, meaning Quality will do the work. The Unit cost column shows Quality's cost for each line item. Notice the Profit column. In this case, Quality decided to add a 7 percent profit to each line item. How much you add depends on competitive conditions and the market for excavation work.

Let's review each of the bid items in Figure 15-B-1 so you can see how these costs were developed.

Mobilization

This is the lump sum cost of moving an office trailer, equipment and materials to the jobsite and getting ready to work. It may also include getting utilities hooked up. On small projects, this cost may be insignificant. On larger jobs in remote areas, it may be substantial. This amount will be included in the first payment from the general contractor. A unit cost of $500 is appropriate for this job; including profit, the bid total is $535.

Clearing and Grubbing

Very little clearing or grubbing is required on this job. Normally clearing and grubbing includes removing trees and brush or existing structures, usually calculated on a square yard basis. On this project, we only need to clear a few small trees and some light brush. We've allowed a lump sum of $535.

Topsoil

This includes all the required topsoil work. Topsoil requires special consideration because Quality has to separate the material and move it twice. Quality will save the good topsoil and dispose of the waste portion offsite. On this job there are 504 CY of unusable material to haul off, and 1,007 CY of usable material to store and then return. We'll need an additional 96 CY from offsite to total the 1,103 CY we need for total replacement material. That totals 2,614 CY of material to move for the topsoil item. On some jobs there's no available onsite space for topsoil storage. In that case, you'd have to haul the topsoil to temporary offsite storage. Then, after construction's finished, you'd haul the topsoil back to the site. As we saw earlier, this jobsite has a storage area for topsoil. As a result, we can summarize all the topsoil costs on just one line.

You can follow along with my calculations for this job on Figures 15-C-1 through C-5. Figure C-1 shows the jobsite, the offsite stockpile site (A) and the topsoil center of mass (CM). Since the average depth of removal and replacement is the same throughout the project, the center of mass is the center of the project. Figures C-2 and C-3 show the production output for the machines we'll use and establish the haul

time of 0.11 minute when loaded. Figure C-4 is the production output for the empty segment. The result is an hourly production rate of 472.5 CY. But look at Figure C-5. Even though the theoretical rate would be about one day, I'm using two days because of the difficulty of maneuvering in the small area.

My actual cost comes to $.86 per CY. When I adjust that for my 7 percent profit, I'll bid it at $.92 per CY.

Earthwork, Cut, General

This is the largest cost on this project. Notice that cut and fill are separated into two categories because the cost and volume of each is different. The general cut volume is 17,111 CY. This includes the 99 CY of additional excavation for the parking lot, which isn't a separate bid item. We'll use 67 CY of the total for onsite fill. That leaves 17,044 to haul off and dispose of. Figures 15-D-1 through D-7 show how we arrive at a unit cost of $.80 per CY, or $.86 with profit.

Earthwork, Fill, General

The procedure for calculating this volume is the same as the procedure for calculating cut. This is 67 CY fill at the $.86 unit cost.

Earthwork, Cut, Roads

Calculations are the same as for cut and fill. We have 192 CY of cut for roads at the same unit cost.

Utility Trenches

The usual way of bidding trench work is with a separate line for each range of depths. On our bid sheet the depths are in ranges of 5 feet. The range you'll select depends on the terrain, type of project, soil conditions and design data. The range might be 1 to 2 feet for a small job where accuracy is important. On a larger job with high capacity trenching equipment, the range might be 10 or 20 feet. Generally, ranges of 5 feet will be accurate enough. Precision usually isn't necessary. It's not uncommon for grades to be raised or lowered during excavation to avoid obstacles.

To find the specified sections, simply review each section of pipe to locate where the trench depth goes from one depth limit to another. When you know the length of each section, take it off from the plans. We'll only account for excavation time in this part of the estimate. Figures 15-E-1 through E-5 show the calculations for the cost of each segment of trench.

In this section, trenching is kept separate from the other production costs. The excavator time includes trenching only. An equal amount of crew time is shown for the excavator for placing bedding and pipe, moving the trench box, and other miscellaneous

work. Estimated cycle times and production amounts are from the charts in the back of this chapter and the general production figures we discussed earlier in this book.

Throughout this section, I've increased times slightly to allow for unanticipated delays and inefficiency. These estimates are based on my experiences, but even with no experience you can anticipate some of the potential problems.

All material prices are shown in the worksheets. Crew times on the trench compactor and small crawler tractor are split half-and-half. Use the procedures from Chapter 13 to calculate the time and costs, including the storm sewer lines.

All of the costs to this point will be handled with Quality crews and equipment.

AB-3 Rock Bedding

The base rock is the material used as bedding under pipes and structures and as a base for the service road. There'll also be base rock in parking areas, but this cost is included in the asphalt placement bid.

Asphalt Surface

Because Quality doesn't do this type of work, we'll get a bid from a subcontractor. The bid assumes that the base is prepared to within 0.1 foot, plus or minus, before asphalt is placed.

Cast Iron Pipe

Quality will install this pipe. Figure 15-B-1 lists the name of the pipe supplier. Our bid price must cover pipe, rock bedding and backfill, including labor and equipment cost. Prices in the "By" column are the material-only price. Multiple-page Figures 15-F through 15-G show the calculations for the utility line structures, and storm and sanitary sewer line work. You'll also find the price workup for cast iron pipe, corrugated metal pipe, and the precast manholes and catch basins.

Precast Manholes and Catch Basins

Like the utility trenches, these structures are grouped into ranges based on depth. These bid prices include all the installation costs, equipment, materials and labor. I like to list the material-only price for each precast structure in the "By" column.

Type G Curb and Gutter

Because Quality doesn't do concrete work, we'll get a bid from a concrete subcontractor for these items. The bid includes concrete materials and labor only. Quality will do the necessary excavation.

Shop Building Footing

Quality will dig the footing and haul it off as spoil, using the track excavator and one wheeled scraper. Although the job is small, the cycle time is fairly long because of the loading and maneuver times. From the cycle time and bucket capacity, we can calculate the volume as shown in Figure 15-H-1. Since the bid forms request a bid per linear foot, we'll figure the cost of excavation and translate it into linear feet.

Sands Construction, operating as our subcontractor, will place the concrete footing at $11.90 per linear foot.

Office Building Footing and Walls

In this situation, the amount of material to be excavated for the basement and work area, and backfill material, aren't separate bid items. We'll figure the excavation cost and convert it into a unit cost per linear foot. Quality will do the excavation with the track loader and use a one-wheel scraper to haul off spoil. Cycle time is relatively long because the loader must move into the pit, load, and come back out to fill the scraper. The calculations for cycle time and bucket capacity in Figure 15-I-1 show the time required. I'm figuring a time of 9.5 hours to do this. The excess material can be done at the same time as the general excavation, so we'll use the compactor and grader with no additional time charged to this line item. Figure 15-I-2 shows the results.

Sands Construction will do concrete work in the basement at $31.00 per linear foot.

Overhead

Figure 15-J-1 shows Quality's annual overhead cost calculations. Again, pay attention to the method, not the actual costs. These may be entirely different from your costs.

Machine Selection

We've gone through the estimate step-by-step, calculating quantities and costs, then preparing the bid prices. But it took a lot of work to get to the point where we could do that. Before it's possible to figure actual costs, we have to have accurate machine owning and operating costs. Then we can begin planning for equipment. We need to know what machines are needed. Do we have the equipment needed for this job or will we have to rent other equipment for better efficiency?

I used the forms and procedures from Chapter 13 and the data from the bid list. But I have one disclaimer to make: The costs here may not be accurate for the work you do. I've tried to make this example realistic. But the prices are my prices, not yours. Concentrate on the process, not the bid costs. Labor, fuel and other costs vary widely throughout the country. Your cycle times and production figures may not be even close to the figures I'm using. In your bids, always rely on your current costs and accurate production figures for your machines.

Most construction equipment manufacturers provide manuals, guidelines and other publications that contain the exact specifications for their machines. Cycle time, hauling and maneuvering time, bucket capacity, gear ranges and power available are all available from these books. Don't be afraid to ask for all the information they have.

Ownership and Operating Cost

Using the individual machine cost and the total ownership and operating cost of all machines in inventory, we can calculate each machine's hourly cost. That leads to the line item cost, based on production and time used.

My calculations are in Figures 15-K and 15-L. Each machine has been assigned a company number. In Figures 15-K-1 through 15-K-40 you'll find specific operating and ownership information for each machine used on this project. Be sure you've mastered the information in Chapter 13 before following along on this portion of the bid. It's unlikely that any contractor will have all the needed equipment on hand — or use all the equipment that's available. The total machine cost includes rental on leased machines and the expense for owned machines that aren't used. Figure 15-L-1 shows a summary of the O&O costs for each machine.

Bid Sheet

Project: C-17 **No:**

Owner: J.Q. Corp.

Item	Quantity	Unit	Cost per unit	Total cost
Mobilization	1	LS	535.00	535.00
Clearing / grubbing	1	LS	535.00	535.00
Topsoil	2,614	CY	.92	2,404.88
Earthwork, cut, general	17,111	CY	0.86	14,715.46
Earthwork, fill, general	67	CY	0.86	57.62
Earthwork, cut, roads	192	CY	0.86	165.12
Utility trenches, 24" W, 1 - 5' D	272	LF	0.50	136.00
Utility trenches, 24" W, 6' - 10' D	135	LF	1.62	218.70
Utility trenches, 24" W, 11' - 15' D	20	LF	2.71	54.20
Utility trenches, 24" W, over 15' D	175	LF	2.55	446.25
AB-3 rock bedding, roads & parking lots	600	Ton	Included in individual line item costs	
Asphaltic surface in place	276	Ton	34.78	9,599.28
8" C.I.P. in place	350	LF	12.06	4,221.00
12" C.M.P. in place	252	LF	16.93	4,266.36
Precast manhole set 10' to 13' D	2	Ea	4,790.25	9,580.50
Precast manhole set 13' to 21' D	2	Ea	7,095.21	14,190.42
Precast catch basin set 2' to 4' D	2	Ea	1,346.81	2,693.62
Precast catch basin set 4' to 6' D	1	Ea	2,425.84	2,425.84
Type "G" curb & gutter	405	LF	5.53	2,239.65
Shop building footing 1' - 1-1/2'	240	LF	20.43	4,903.20
Office building walls/footings	210	LF	46.04	9,668.40
			JOB TOTAL	83,056.50

Figure 15-A-1
Bid summary

Bid Preparation Form

Item	By	Unit	Quantity	Unit cost	Profit	Bid price
Mobilization	Self	LS	1	500.00	35.00	535.00
Clearing / grubbing	Self	LS	1	500.00	35.00	535.00
Topsoil	Self	CY	2,614	0.86	0.06	0.92
Earthwork, cut, general	Self	CY	17,111	0.80	0.06	.86
Earthwork, fill, general	Self	CY	67	0.80	0.06	.86
Earthwork, cut, roads		CY	192	0.80	0.06	.86
Utility trenches, 24" W, 1 - 5' D	Self	LF	272	0.47	0.03	.50
Utility trenches, 24" W, 6' - 10' D	Self	LF	135	1.51	0.11	1.62
Utility trenches, 24" W, 11' - 15' D	Self	LF	20	2.53	0.18	2.71
Utility trenches, 24" W, over 15' D	Self	LF	175	2.38	0.17	2.55
AB-3 rock bedding, roads & parking lots	Murray Quarry bid received	Ton	600	Included in other line items		
Asphaltic surface in place	Citywide	Ton	276	32.50	2.28	34.78
8" C.I.P. in place	Self/Manns Sup.	LF	350	11.27	0.79	12.06
12" C.M.P. in place	Self/Manns Sup.	LF	252	15.82	1.11	16.93
Precast manhole set 10' to 13' D	Material only $4000 ea on site	Ea	2	4,476.87	313.38	4,790.25
Precast manhole set 13' to 21' D	Material only $6000 ea on site	Ea	2	6,631.04	464.17	7,095.21
Precast catch basin set 2' to 4' D	Material only $1100 ea on site	Ea	2	1,258.70	88.11	1,346.81
Precast catch basin set 4' to 6' D	Material only $1800 on site	Ea	1	2,267.14	158.70	2,425.84
Type "G" curb & gutter	Sands Const.	LF	405	5.17	0.36	5.53
Shop building footing 1' - 1-1/2'	Sands Const.	LF	240	19.09	1.34	20.43
Office building walls/footings	Sands Const.	LF	210	43.03	3.01	46.04

Figure 15-B-1
Bid preparation form

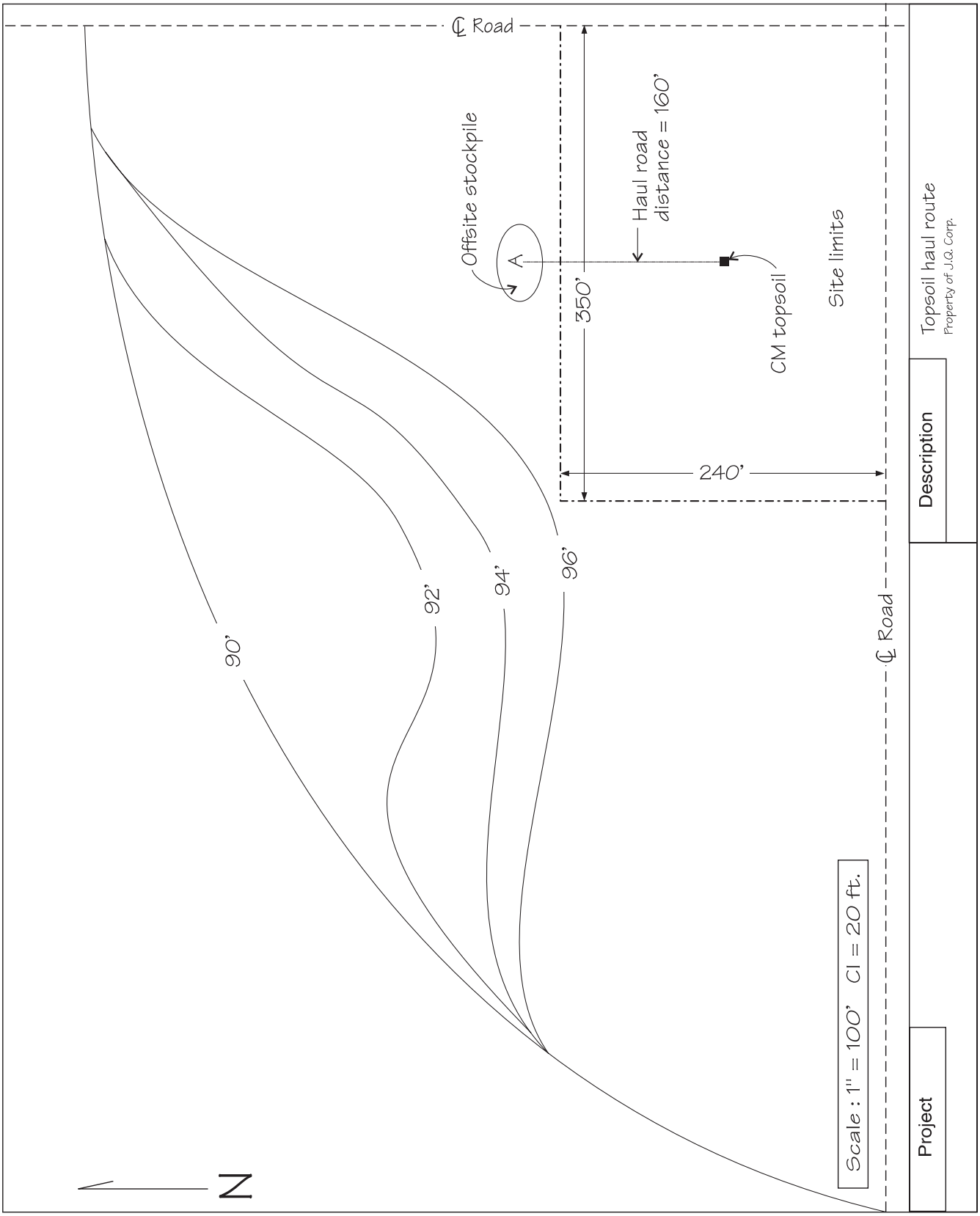


Figure 15-C-1
Topsoil haul route

Haul Road Criteria

Job No.: C-17 **Date:** _____ **Checked:** _____

Loaded

Road length 160'

High elevation 108' **Difference** 8'

Low elevation 100'

% grade = elevation difference / road length

% grade = + / - 5% (Favorable)

Surface type Dirt **RR factor** 100

Notes:

This % will remain the same

Same

Empty

Road length _____

High elevation _____ **Difference** _____

Low elevation _____

% grade = elevation difference / road length

% grade = + / - 5% Uphill

Surface type _____ **RR factor** _____

Notes:

Figure 15-C-2
Haul road criteria

Production Work Form

Job No. C-17 **Area** Topsoil **Segment** Loaded

Empty wt / lbs 65,000 **Ton** 32.5 **Mach. no.** 501

Capacity / CY 21 **Ton** 24 **Type** Wheel scraper

No. wheels 4 **No. drivers** 2 **Add** ---

Resistance

Rolling = weight on wheels x RR factor

= 56.5 ton **x** 100 (RRF)

= 5650 lb

Grade = total weight x 20 lb / ton x unit of % grade

= 56.5 **x 20 lb / ton x** 5

= 5650

Total R = RR +/- GR

= 5650 **+ /⊖** 5650

= 0 *This is odd, but it does show use of retarder curve is needed

$$\textbf{Effective grade} = \frac{\textbf{RR lb / ton}}{\textbf{20 lb / ton / \% grade}} + \textbf{\% grade}$$

$$= \frac{100}{\textbf{20 lb / ton / \% grade}} + 5$$

= 10%

Power / Gear selection From retarder curve

Power required = Rct 6th gear **In** 17 MPH

Power available = _____ **In gear** 6 **at** 17 MPH

Note: this data from machine inventory form

Usable power = Weight on drivers x coefficient of traction

= 103,000 lb **x** .55

= 56,650 lb

Note: coefficient of traction from charts **Page 1**

Figure 15-C-3
Production work form

Production Work Form

Cycle time

Haul time = $\frac{\text{Distance}}{\text{MPH x 88}}$ = $\frac{160}{17 \text{ x } 88}$ = $\frac{160}{1496}$ = .11

Load time _____ **+ Maneuver time** _____ **+ Dump time** _____

+ Haul time .11 **+ Return time** _____ **= Total cycle time** _____

N/A

Actual production

Trips / hour = $\frac{\text{60 minutes}}{\text{Cycle time}}$ = 60 = _____

Hr / production = CY / trip x No of trips / hr

= _____ x _____

= _____

Actual hourly production = Hr / production x Eff. factor

= _____ x _____

= _____

Compaction

Compacted CY / Hr = $\frac{\text{W x S x L x 16.3}}{\text{P}}$

= _____ x _____ x _____ x 16.3

= _____

Where:

P = No. of passes
W = Compactor width
S = Average speed
L = Lift thickness
16.3 = Constant

Final production results, notes, units and miscellaneous calculations

Page 2

Figure 15-C-3 (continued)
Production work form

Production Work Form

Job No. C-17 **Area** Topsoil **Segment** Empty

Empty wt / lbs 65,000 **Ton** 32.5 **Mach. no.** 501

Capacity / CY --- **Ton** --- **Type** Wheel scraper

No. wheels 4 **No. drivers** 2 **Add** ---

Resistance

Rolling = weight on wheels x RR factor

= 32.5 ton x 100

= 3250 lb

Grade = total weight x 20 lb / ton x unit of % grade

= 32.5 x 20 lb / ton x 5

= 3250

Total R = RR +/- GR

= 3250 ⊕/ - 3250

= 6500 lbs

Effective grade = $\frac{\text{RR lb / ton}}{\text{20 lb / ton / \% grade}}$ **+ % grade**

= $\frac{\quad}{\text{20 lb / ton / \% grade}}$ + _____

= 10% uphill

Power / Gear selection

Power required = 6500 **In** lbs rim pull

Power available = _____ **In gear** 8th **at** 30 MPH

Note: this data from machine inventory form

Usable power = Weight on drivers x coefficient of traction

= 65,000 lb x .55

= 35,750 lbs

Note: coefficient of traction from charts **Page 1**

Figure 15-C-4
Production work form

Production Work Form

Cycle time

Haul time = $\frac{\text{Distance}}{\text{MPH x 88}}$ = $\frac{160}{30 \text{ x } 88}$ = $\frac{160}{2640}$ = .06

Load time .95 **+ Maneuver time** .60 **+ Dump time** .25

+ Haul time .06 **+ Return time** .06 **= Total cycle time** 1.92 or 2 min.

Actual production

Trips / hour = $\frac{\text{60 minutes}}{\text{Cycle time}}$ = $\frac{60}{2.00}$ = 30

Hr / production = CY / trip x No of trips / hr

= 21 x 30

= 630

Actual hourly production = Hr / production x Eff. factor

= 630 x .75

= 472.5 CY/hr

Compaction

Compacted CY / Hr = $\frac{\text{W x S x L x 16.3}}{\text{P}}$

= _____ x _____ x _____ x 16.3

= _____

Where:

P = No. of passes
W = Compactor width
S = Average speed
L = Lift thickness
16.3 = Constant

Final production results, notes, units and miscellaneous calculations

Page 2

Figure 15-C-4 (continued)
Production work form

Calculation Form

Job No. _____ **Date** _____

Unit capacity 21 CY **Job Amount** 2614

Units per day 3780 per 8 hour **No. days** 2

Calculations

Machine & crew
1 - scraper
1 - grader
1 - pickup

Note: Because of small area, moving material at a different times, will use 2 days even though theoretical value would be about 1 day or less.

Figure 15-C-5
Topsoil calculations

Calculation Form

Line item Topsoil **Segment** All movement

No. units 2614 **Type** CY **Special** _____

Total cost 2252.96 **Unit cost** .86

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	101	8	23.17	185.36				
	401	8	48.27	386.16				
	501	8	69.37	554.96				
Subtotals				1126.48				

Calculations and notes

$$\frac{1126.48 \times 2 \text{ days}}{2614 \text{ units}} = \frac{2252.96}{2614} = .86 / CY$$

Figure 15-C-5 (continued)
Topsoil calculations

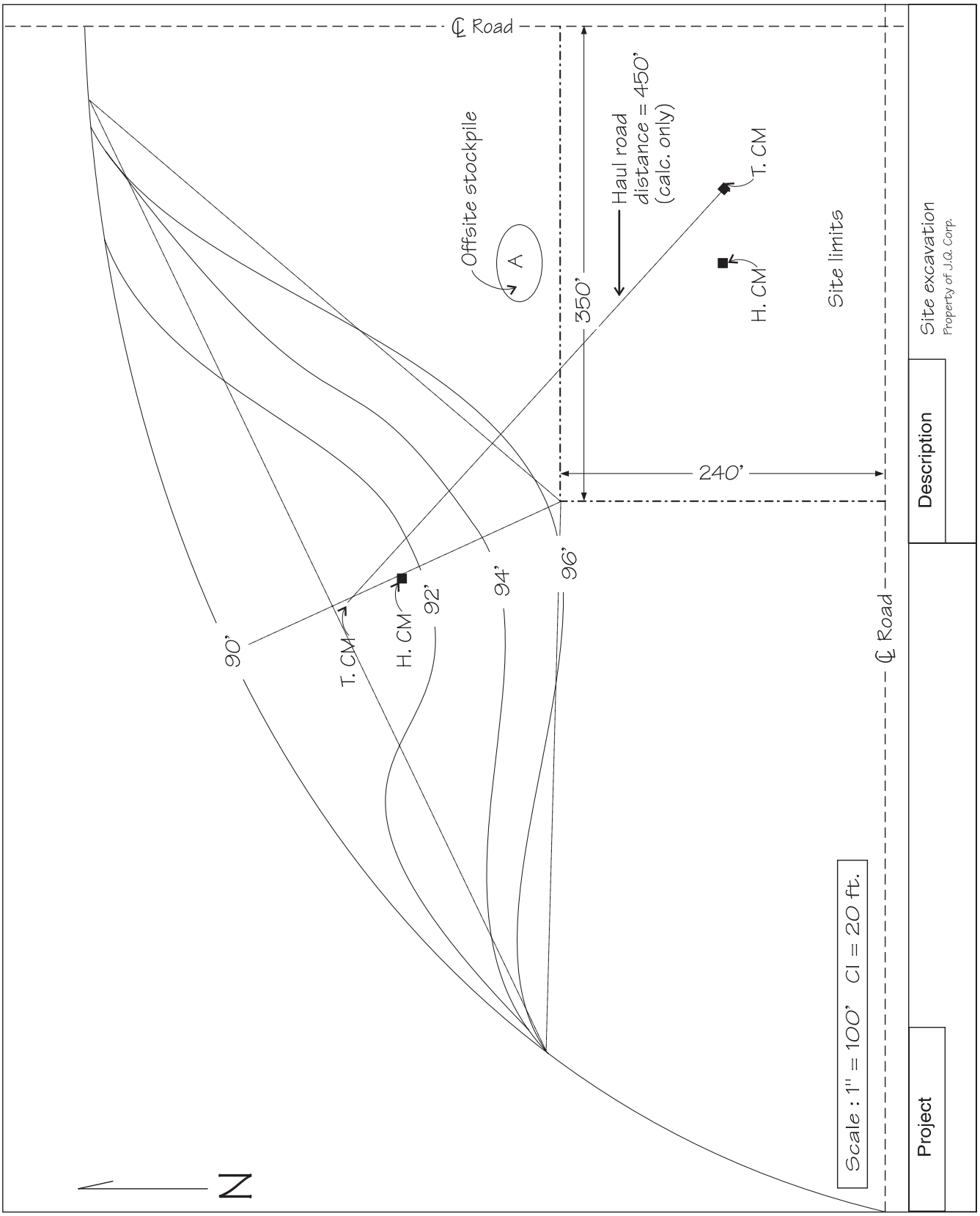


Figure 15-D-1
Main site excavation haul route

Haul Road Criteria

Job No.: C-17 **Date:** _____ **Checked:** _____

Loaded

Road length 450'

High elevation 108' **Difference** 17'

Low elevation 91'

% grade = elevation difference / road length

% grade = + / - 4% (2%) (Favorable)

Surface type Clay-rutted **RR factor** 150

Notes:

Will use 2% grade because averages

Same

Empty

Road length _____

High elevation _____ **Difference** _____

Low elevation _____

% grade = elevation difference / road length

% grade = + / - 2% Uphill

Surface type _____ **RR factor** _____

Notes:

Figure 15-D-2
Haul road criteria

Production Work Form

Job No. C-17 **Area** E & E **Segment** Loaded

Empty wt / lbs 65,000 **Ton** 32.5 **Mach. no.** 501 / 502

Capacity / CY 21 **Ton** 24 **Type** Wheel scraper

No. wheels 4 **No. drivers** 2 **Add** ---

Resistance

Rolling = weight on wheels x RR factor

= 56.5 ton **x** 150

= 8475

Grade = total weight x 20 lb / ton x unit of % grade

= 56.5 **x 20 lb / ton x** 2

= 2260

Total R = RR +/- GR

= 8475 **+ /⊖** 2260

= 6215

Effective grade = $\frac{\textbf{RR lb / ton}}{\textbf{20 lb / ton / \% grade}}$ **+ % grade**

= $\frac{150}{\textbf{20 lb / ton / \% grade}}$ **+** 2

= 9% uphill

Power / Gear selection

Power required = 6215 **In** Rimpull

Power available = 7211 **In gear** 7 **at** 24

Note: this data from machine inventory form

Usable power = Weight on drivers x coefficient of traction

= 103,000 **x** .40

= 41,200 lbs

Note: coefficient of traction from charts **Page 1**

Figure 15-D-3
Production work form

Production Work Form

Cycle time

Haul time = $\frac{\text{Distance}}{\text{MPH x 88}}$ = $\frac{450}{24 \text{ x } 88}$ = $\frac{450}{2112}$ = .21

Load time _____ **+ Maneuver time** _____ **+ Dump time** _____

+ Haul time .21 **+ Return time** _____ **= Total cycle time** _____

Actual production

Trips / hour = $\frac{\text{60 minutes}}{\text{Cycle time}}$ = 60 = _____

Hr / production = CY / trip x No of trips / hr

= _____ x _____

= _____

Actual hourly production = Hr / production x Eff. factor

= _____ x _____

= _____

Compaction

Compacted CY / Hr = $\frac{\text{W x S x L x 16.3}}{\text{P}}$

= _____ x _____ x _____ x 16.3

= _____

Where:

P = No. of passes
W = Compactor width
S = Average speed
L = Lift thickness
16.3 = Constant

Final production results, notes, units and miscellaneous calculations

Haul time = .21

Page 2

Figure 15-D-3 (continued)
Production work form

Production Work Form

Job No. C-17 **Area** E & E **Segment** Empty

Empty wt / lbs 65,000 **Ton** 32.5 **Mach. no.** 501/502

Capacity / CY --- **Ton** --- **Type** ---

No. wheels 4 **No. drivers** 2 **Add** ---

Resistance

Rolling = weight on wheels x RR factor

= 32.5 ton **x** 150

= 4875

Grade = total weight x 20 lb / ton x unit of % grade

= 32.5 **x 20 lb / ton x** 2

= 1300

Total R = RR +/- GR

= 4875 **⊕ / -** 1300

= 6175

Effective grade = $\frac{\textbf{RR lb / ton}}{\textbf{20 lb / ton / \% grade}}$ **+ % grade**

= $\frac{150}{\textbf{20 lb / ton / \% grade}}$ **+** 2

= 9%

Power / Gear selection

Power required = 6175 **In** Rimpull

Power available = 7211 **In gear** 7th **at** 24

Note: this data from machine inventory form

Usable power = Weight on drivers x coefficient of traction

= 65,000 lb **x** .40

= 26,000 lbs

Note: coefficient of traction from charts **Page 1**

Figure 15-D-4
Production work form

Production Work Form

Cycle time

Haul time = $\frac{\text{Distance}}{\text{MPH x 88}}$ = $\frac{460}{24 \text{ x } 88}$ = $\frac{460}{2112}$ = .22

Load time .75 **+ Maneuver time** .80 **+ Dump time** .40

+ Haul time .22 **+ Return time** .21 **= Total cycle time** 2.38

Actual production

Trips / hour = $\frac{\text{60 minutes}}{\text{Cycle time}}$ = $\frac{60}{2.38}$ = 25

Hr / production = CY / trip x No of trips / hr

= 21 **x** 25

= 525 CY

Actual hourly production = Hr / production x Eff. factor

= 525 **x** .75

= 394

Compaction

Compacted CY / Hr = $\frac{\text{W x S x L x 16.3}}{\text{P}}$

= _____ **x** _____ **x** _____ **x 16.3**

= _____

Where:

P = No. of passes
W = Compactor width
S = Average speed
L = Lift thickness
16.3 = Constant

Final production results, notes, units and miscellaneous calculations

2 machines each @ 394 / hr = 3152 / 8 hr

Page 2

Figure 15-D-4 (continued)
Production work form

Total weight = 90,000 lbs

Production Work Form

Job No. C-17 **Area** E & E **Segment** Compaction

Empty wt / lbs 62,000 **Ton** 31 **Mach. no.** 302

Capacity / CY --- **Ton** --- **Type** Crawler tr.

No. wheels _____ **No. drivers** 2 **Add** No 901 sheepsfoot

Resistance

Rolling = weight on wheels x RR factor

= _____ x _____

= _____

Grade = total weight x 20 lb / ton x unit of % grade

= _____ x 20 lb / ton x _____

= _____

Total R = RR +/- GR

= _____ + / - _____

= _____

Effective grade = $\frac{\text{RR lb / ton}}{\text{20 lb / ton / \% grade}}$ **+ % grade**

= $\frac{\text{_____}}{\text{20 lb / ton / \% grade}}$ + _____

= _____

Power / Gear selection

Power required = _____ **In** _____

Power available = _____ **In gear** 3rd **at** 3.2

Note: this data from machine inventory form

Usable power = Weight on drivers x coefficient of traction

= _____ x _____

= _____

Note: coefficient of traction from charts

Page 1

Figure 15-D-5
Production work form

Production Work Form

Cycle time

Haul time = $\frac{\text{Distance}}{\text{MPH x 88}}$ = _____ = _____ = _____

_____ x 88

Load time _____ **+ Maneuver time** _____ **+ Dump time** _____

+ Haul time _____ **+ Return time** _____ **= Total cycle time** _____

Actual production

Trips / hour = $\frac{\text{60 minutes}}{\text{Cycle time}}$ = _____60_____ = _____

Hr / production = CY / trip x No of trips / hr

= _____ x _____

= _____

Actual hourly production = Hr / production x Eff. factor

= _____ x _____

= _____

Compaction

Compacted CY / Hr = $\frac{\text{W x S x L x 16.3}}{\text{P}}$

= $\frac{\text{6 x 3.2 x 6 x 16.3}}{\text{5}}$

= 376/hr = 3008 / 8 hr

Where:

P = No. of passes
W = Compactor width
S = Average speed
L = Lift thickness
16.3 = Constant

Final production results, notes, units and miscellaneous calculations

Will keep ahead of hauler, but will need to be on job same time.

Page 2

Figure 15-D-5 (continued)
Production work form

Calculation Form

Job No. _____ **Date** _____

Unit capacity 21 CY **Job Amount** 17402

Units per day 3152 **No. days** 5.4 use 6

Calculations

Using one scraper - 501
1 - grader - 401
1 - trac & compactor - 301+
1- trac – push load - 302
1- pickup / foreman - 101

Figure 15-D-6
Calculations

Calculation Form

Line item *Excavation **Segment** All

No. units 17402 **Type** CY **Special**

Total cost 13,989.12 **Unit cost** .80

Section	Mach. no.	Mach. hrs	Mach $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	101	48	23.17	1112.16				
	301	48	59.77	2868.96				
	302	48	84.23	4043.04				
	401	48	48.26	2316.48				
	501	48	69.37	3329.76				
	1101	48	6.64	318.72				
Subtotals				13989.12				

Calculations and notes

* Calc. will be for all earthwork including cut, fill, roadway & parking lot

Figure 15-D-7
Final calculations

Calculation Form Trench work only

Job No. _____ **Date** _____

Unit capacity _____ **Job Amount** _____

Units per day _____ **No. days** _____

Calculations

Depth	Storm	Sanitary	Total	Exc. Hr.
0'-6'	127'	145'	272'	1.25
6'-11'	125'	10'	135'	2.0
11'-16'		20'	20'	0.5
16'-20'		175'	175'	4.0

0'-6'	45 min.	30 min.	1.25 hr.
6'-11'	45 min.	30 min.	1.25 hr.
11'-16'	1.5 hr.	60 min.	2.5 hr.
16'-20'		30 min.	0.5 hr.

Figure 15-E-1
Trench work calculations

Calculation Form

Line item Trenching **Segment** 0'-6'

No. units 272 **Type** LF **Special** _____

Total cost 126.61 **Unit cost** $0.47

Section	Mach. no.	Mach. hrs.	Mach. $/hr.	Mach. total/$	Materials used	Material cost	Other	Notes
	701	1.25	101.29	126.61				
Subtotals								

Calculations and notes

Figure 15-E-2
Trenching 0'-6'

Calculation Form

Line item Trenching **Segment** 6'-11'

No. units 135 **Type** LF **Special** _____

Total cost 202.58 **Unit cost** 1.51

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	2.0	101.29	202.58				
Subtotals								

Calculations and notes

Figure 15-E-3
Trenching 6'-11'

Calculation Form

Line item Trenching **Segment** 11'-16'

No. units 20 **Type** LF **Special** _____

Total cost 50.61 **Unit cost** 2.53

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	0.5	101.29	50.65				
Subtotal								

Calculations and notes

Figure 15-E-4
Trenching 11'-16'

Calculation Form

Line item Trenching **Segment** 16'-20'

No. units 175 **Type** LF **Special** _____

Total cost 405.16 **Unit cost** 2.38

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach total/$	Materials used	Material cost	Other	Notes
	701	4.0	101.29	405.16				
Subtotals								

Calculations and notes

Figure 15-E-5
Trenching 16'-20'

Calculation Form

Line item Catch basin **Segment** 2'-4'

No. units 2 **Type** Precast **Special** #1 & 2

Total cost 2517.40 **Unit cost** 1258.70

Section	Mach. no.	Mach. hrs.	Mach. $/hr.	Mach. total/$	Materials used	Material cost	Other	Notes
	701	.5	101.29	50.64	Precast	1104.51	Labor	3 @ 7.00 = 21.00/crew
	601	.5	79.52	39.76				
	801	.5	29.36	14.68				
	101	.5	23.17	11.58				
	1001	.5	2.84	1.42				
	901	.25	42.69	10.67				
	301	.25	59.77	14.94				
Subtotal				143.69				

Calculations and notes

Eq. = 143.69
Mat. = 1104.51
Lab. = 10.50
1258.70

Figure 15-F-1
Catch basin calculations

Structure Construction Production Cost

Structure type Catch basin **No.** 1 & 2 **Location** Storm line 1

Width 2' x 2' **Depth** 2-4 (3) **Length** _____

Material Precast concrete **CY volume for structure** 4.5 CY

Vol. / _____

Work description:

Excavate, place bedding, install & backfill

Equipment needed:

1- track excavator #701
1- track loader #601
1- boom truck #801
1- pu / foreman #101
1- compactor @ 1/2 time
1- small dozer @ 1/2 time

Crew:

3 additional laborers

Struct. material Precast concrete **From** Royal **Cost / ~~LF~~** 1100.00 lump sum

Bedding material AB-3 **From** Murray **Cost / ~~LF~~** 4.51 lump sum

Other _____ **From** _____ **Cost / LF** _____

Calculations:

$$\frac{2.5 \times 2.5}{27} = .23 \text{ CY} = .46 \text{ ton @ } 9.75 = 4.51$$

Total material cost _____ **/ LF**

Production cycle time _____ **Bucket volume** _____ **Job eff.** _____

Hr. production dig time 15 min.

Other time _____

Total time = 30 min. **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-2
Catch basin calculations

Calculation Form

Line item Catch basin **Segment** 4'-6'

No. units 1 **Type** Precast **Special** #3

Total cost **Unit cost** 2267.14

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	1.5	101.29	151.94	Precast	1804.51	Labor	3@7.00 = 21.00/crew hr.
	601	1.5	79.52	119.28				
	801	1.5	29.36	44.04				
	101	1.5	23.17	34.76				
	901	.75	42.69	32.02				
	1001	1.5	2.84	4.26				
	301	.75	59.77	44.83				
Subtotal				431.13				

Calculations and notes

Eq. = 431.13
Mat. =1804.51
Lab. = 31.50
2267.14

Figure 15-F-3
Catch basin calculations

Structure Construction Production Cost

Structure type Catch basin **No.** 3 **Location** Storm line 1-2

Width 2' x 2' **Depth** 4'-6' 5' **Length** _____

Material Precast concrete **CY volume for structure** 6.00

Vol. / _____

Work description:

Same

Equipment needed:

Crew:

Struct. material _____ **From** _____ **Cost / ~~LF~~** $1800.00 lump sum

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $1804.51 **/ LF**

Production cycle time _____ **Bucket volume** _____ **Job eff.** _____

Hr. production dig time _____

Other time _____

Total time = 1.5 hr all **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-4
Catch basin calculations

Calculation Form

Line item Manhole **Segment** 16'-18'

No. units 2 **Type** _____ **Special** Storm tie-in

Total cost _____ **Unit cost** 6631.04

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	2.0	101.29	202.58	Precast	6014.24	Labor	3@7.00 = 21.00 crew hr
	601	2.0	79.52	159.04				
	801	2.0	29.36	58.72				
	101	2.0	23.17	46.34				
	1001	2.0	2.84	5.68				
	901	1.0	42.67	42.67				
	301	1.0	59.77	59.77				
Subtotal				574.80				

Calculations and notes

Eq. = 574.80
Mat. = 6014.24
Lab. = 42.00
6631.04

Figure 15-F-5
Manhole calculations

Structure Construction Production Cost

Structure type Manhole **No.** 1 **Location** Storm

Width 4' dia. **Depth** 16' **Length** _____

Material Precast concrete **CY volume for structure** 30

Vol. / _____

Work description:

Same

Equipment needed:

Same

Crew:

Same

Struct. material Precast concrete **From** Royal **Cost / LF** 6000.00 lump sum

Bedding material AB-3 **From** Murray **Cost / LF** 14.20 lump sum

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost 6014.24 **/ LF**

Production cycle time --- **Bucket volume** _____ **Job eff.** _____

Hr. production dig time ---

Other time ---

Total time = 2 hr all **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-6
Manhole calculations

Utility Line Construction Production Cost

Utility line type Storm sewer **No.** 1 **Length** 42'

Width 3' **Depth** 1-5 2-5 **(Average for both) Size** _____

Line type 12" C.M.P. **CY volume for line** 11.7

Vol. /LF 0.28

Work description:

Same as sanitary sewer

Equipment needed:

Same

Crew:

Same

Line material C.M.P **From** Murray Supply **Cost / LF** 4.70

Bedding material Same as sanitary **From** Murray Supply **Cost / LF** 2.32

Other _____ **From** _____ **Cost / LF** _____

Calculations:

$$\frac{R = (2'\text{x } 2') - 6'' = 5^2 \text{ x } 3.1416}{27} = .12 \text{ CY} = .24 \text{ ton @ } 9.75/\text{ton} = 2.32$$

Total material cost $6.02 **/ LF**

Production cycle time 17 sec. **Bucket volume** 1.31 **Job eff.** _____

Hr. production dig time 15 min.

Other time 30 min. for all except 901/301 = 1 hr., 701 = 15 min.

Total time = 30 min. **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-7
Storm sewer calculations

Utility Line Construction Production Cost

Utility line type Storm sewer **No.** 2 **Length** 85'

Width 3.0' **Depth** 1-5 2-5 **(Average for both) Size** _____

Line type 12" C.M.P. **CY volume for line** 23.62

Vol. /LF 0.28

Work description:

Same

Equipment needed:

Same

Crew:

Same

Line material _____ **From** _____ **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $6.02 **/ LF**

Production cycle time Same **Bucket volume** --- **Job eff.** _____

Hr. production dig time use 1/2 hr

Other time Use 1 hr all except 901/301 = 2 hr, 701 = 30 min

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-8
Storm sewer calculations

Utility Line Construction Production Cost

Utility line type Storm sewer **No.** 3 **Length** 60'

Width 3.0' **Depth** 6-10 8' **(Average for both) Size** _____

Line type 12" C.M.P. **CY volume for line** 53

Vol. /LF 0.89

Work description:

Same

Equipment needed:

Same

Crew:

Same

Line material _____ **From** _____ **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $6.02 **/ LF**

Production cycle time 30 sec. **Bucket volume** 1.31 **Job eff.** _____

Hr. production dig time use 3/4 hr

Other time 1.5 all, 3 compactor

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-9
Storm sewer calculations

Utility Line Construction Production Cost

Utility line type Storm sewer **No.** 3 **Length** 65'

Width 3.0' **Depth** 11-15 13' **(Average for both) Size** _____

Line type 12" C.M.P. **CY volume for line** 93.9

Vol. /LF 1.44

Work description:

Same

Equipment needed:

Same

Crew:

Same

Line material _____ **From** _____ **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $6.02 **/ LF**

Production cycle time 42 sec. **Bucket volume** 1.31 **Job eff.** _____

Hr. production dig time use 1-1/2 hr

Other time 3 all, 6 hr compactor

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-F-10
Storm sewer calculations

Calculation Form

Job No. _____ **Date** _____

Unit capacity _____ **Job amount** 252

Units per day _____ **No. days** _____

Calculations

In minutes

Line	701	601	801	101	1001	901	301	Extra labor
1	15	30	30	30	30	60	60	30
2	30	60	60	60	60	120	120	60
3A	45	90	90	90	90	180	180	90
3B	90	180	180	180	180	360	360	180
	180M / 3 hr	360M / 6 hr	6 hr.	6 hr.	6 hr.	720M / 12 hr	720M / 12 hr	6 hr.

252 feet total

Figure 15-F-11
Equipment calculations

Calculation Form

Line item 12" C.M.P. **Segment** _____

No. units 252 **Type** LF **Special** _____

Total cost 3985.53 **Unit cost** 15.82

Section	Mach. no.	Mach. hrs	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	3	101.29	303.87			Labor	3@7.00 = 21 x 6 hr = 126
	601	6	79.52	477.12				
	801	6	29.36	176.16				
	101	6	23.17	139.02				
	1001	6	2.84	17.04				
	901	12	42.67	512.04				
	301	12	59.77	717.24				
Subtotal				2342.49		1517.04	126	

Calculations and notes

Eq. = 2342.49
Mat. = 1517.04
Lab. = 126.00
3985.53

Figure 15-F-12
Pipe calculation summary

Utility Line Construction Production Cost

Utility line type Sanitary sewer **No.** 1 **Length** 145'

Width 3' **Depth** 2.5' **(Average for both) Size** _____

Line type 8" C.I.P **CY volume for line** 40

Vol. /LF 0.28 CY

Work description:

Evacuate trench, place bedding, install pipe, cover with bedding material, backfill and compact to 90% Proctor. Trench box will be used. Hoe will dig trench, move box, place bottom bedding and pipe. Hoe will have 36" bucket to allow for work room and trench box. Extra bedding material will not be charged to job. Pipe is in 20' sections. Small dozer and ditch compactor will be run by one man with a 50-50 time and cost split. Track loader will place top bedding and help backfill. Boom truck will place pipe along trench.

Equipment needed:

1 - Track excavator no. 701
1 - Track loader no. 601
1 - Boom truck no. 801
1 - Pickup / foreman no. 101
1 - Laser Gun no. 1001
1 - Trench compactor no. 901
1 - Small dozer no. 301
1 - operator / both

Crew:

3 laborers in addition to above operator and foreman

Line material 8" C.I.P. **From** Manns Supply **Cost / LF** 3.77

Bedding material AB-3 **From** Murray Quarries **Cost / LF** 2.38

Other _____ **From** _____ **Cost / LF** _____

Calculations:

$$\frac{\text{Rock/LF} = (3 \times 1) - 8\text{" pipe converted. to dec.} = (3.14)\,(.33)^2}{27} = .12\text{ CY} = .24\text{ ton @ } 9.75\text{/ton} = 2.38\text{ LF}$$

Total material cost $6.15 **/ LF**

Production cycle time 17 sec. **Bucket volume** 1.31 CY **Job eff.** _____

Hr. production dig time 1 hr = 110 CY /// use 30 min.

Other time lay pipe. 2 min. to place, 2 min. to align, 2 min. to seal, 1 min. to move and 3 min. to hand shade pipe = 10 min. / 20 ft. joint

Total time = _____ **Ft / Hr.** Same as others 120

701 - 30 min
main crew - 60 min.
901 / 301 - 120 min.

Job hours n/a **Job days** n/a

Figure 15-G-1
Utility line production cost

Utility Line Construction Production Cost

Utility line type Sanitary sewer **No.** 2 **Length** 20'

Width 3' **Depth** 5-10 7.5 **(Average for both) Size** _____

Line type 8" C.I.P. **CY volume for line** 17

Vol. /Line foot 0.83

Work description:

Same

Equipment needed:

Same

Crew:

Same

Line material _____ **From** _____ **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $6.15 **/ LF**

Production cycle time 17 **Bucket volume** 131 **Job eff.** _____

Hr. production dig time 1/4 (15 min.) = 55 CY

Other time Crew 30

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

701 = 15 min.
main crew = 30 min.
901/301 = 60 min.

Figure 15-G-2
Utility line production cost

Utility Line Construction Production Cost

Utility line type Sanitary sewer **No.** 4 **Length** 45'

Width 3' **Depth** 16-20 18' **(Average for both) Size** _____

Line type 8" C.I.P. **CY volume for line** 90

Vol. /Line foot 2

Work description:

Same

Equipment needed:

Same

Crew:

Same

Line material _____ **From** _____ **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $6.15 **/ LF**

Production cycle time 17 sec. **Bucket volume** 1.31 **Job eff.** _____

Hr. production dig time 1/2 hr = 110 CY

Other time 1/2 hr for 2+ joints

Total time = _____ **Ft / Hr.** 120

Job hours _____ **Job days** _____

701 = 30 min
main crew = 60 min
901/301 = 120 min

Figure 15-G-3
Utility line production cost

Utility Line Construction Production Cost

Utility line type Sanitary sewer **No.** 4 **Length** 130'

Width 3' **Depth** 11-15 13 **(Average for both) Size** _____

Line type 8" C.I.P. **CY volume for line** 188

Vol. /Line foot 1.44

Work description:

Same

Equipment needed:

Same

Crew:

Same

Line material _____ **From** _____ **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost $6.15 **/ LF**

Production cycle time 17 sec. **Bucket volume** 1.31 **Job eff.** _____

Hr. production dig time 1 hr = 220 CY

Other time 6+ joints @ 10 min.

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

701 = 60 min.
main crew = 120 min.
901/301 = 240 min.

Figure 15-G-4
Utility line production cost

Calculation Form

Job No. _____ **Date** _____

Unit capacity _____ **Job amount** _____

Units per day _____ **No. days** _____

Calculations

In minutes

Line	701	601	801	101	1001	901	301	Extra labor
1	30	60	60	60	60	120	120	60
2	15	30	30	30	30	60	60	30
4	30	60	60	60	60	120	120	60
11	60	120	120	120	120	240	240	120
	2.25	4.5	4.5	4.5	4.5	9 hr.	9 hr.	4.5 hr.

Figure 15-G-5
Utility line summary

Calculation Form

Line item 8" C.I.P. **Segment** _____

No. units 350 **Type** LF **Special** _____

Total cost 3945.75 **Unit cost** 11.27

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	2.25	101.29	227.90	8" C.I.P.		Labor	3@7.00 = 21.00 x 4.5 = 94.50
	601	4.5	79.52	357.84				
	801	4.5	29.36	132.12				
	101	4.5	23.17	104.27				
	1001	4.5	2.84	12.78				
	901	9.0	42.67	384.02				
	301	9.0	59.77	537.92				
Subtotals				1756.85		2094.40	94.50	

Calculations and notes

Eq. = 1756.85
Mat. = 2094.40
Lab. = 94.50
3945.75

Figure 15-G-6
Cast iron pipe

Calculation Form

Line item Manhole **Segment** 16'-18'

No. units 1 **Type** LF **Special** _____

Total cost _____ **Unit cost** $6,616.80

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Machine total/$	Materials used	Material cost	Other	Notes
3	701	2.0	101.29	202.58	Precast concrete	6000.00	Labor	3@7.00/hr = 21.00 crew
	601	2.0	79.52	159.04				
	801	2.0	29.36	58.72				
	101	2.0	23.17	46.34				
	1001	2.0	2.84	5.68				
	901	1.0	42.67	42.67				
	301	1.0	59.77	59.77				
Subtotal				574.80		6000.00	42.00	

Calculations and notes

Eq. =6000.00
Mat. = 574.80
Lab. = 42.00
6616.80

Figure 15-G-7
Manhole

Calculation Form

Line item Manhole **Segment** 10'-12'

No. units 2 **Type** --- **Special** _____

Total cost --- **Unit cost** 4476.87

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
1 & 2	701	1.5	101.29	151.94	Precast conc. 10'-12	4014.24	Labor	3@7.00/hr. = 21.00 crew hr
	601	1.5	79.52	119.28				
	801	1.5	29.36	44.04				
	101	1.5	23.17	34.76				
	1001	1.5	2.84	4.26				
	901	.75	42.69	32.02				
	301	.75	59.77	44.83				
Subtotal				431.13		4014.24	31.50	Subtotals are for each MH

Calculations and notes

```
  4014.24
   431.13
  -------
  4445.37
    31.50
  -------
  4476.87
```

Figure 15-G-8
Manholes

Structure Construction Production Cost

Structure type Manhole **No.** 1 **Location** Sanitary Line 1-2

Width MH = 4' Dia. Exc = 8' Dia. **Depth** 11.30 **Length** _____

Material Precast concrete **CY volume for structure** 28

Vol. / _____

Work description:

Excavate, install 6" AB-3 under structure with 6" overhang. Backfill & compact 20% Proctor. Manholes will remain above grade 1 - 2.5 ft. All else is same as sanitary lines.

Equipment needed:

Same

Crew:

Same

Struct. material Precast concrete **From** Royal Conc. (1-10'-12') **Cost / ~~LF~~** 4000.00 lump sum

Bedding material AB-3 **From** Murray **Cost / ~~LF~~** 14.24 lump sum

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Bedding 4' MH dia + 6" overhang = 5 ft R = 2.5 $A = \frac{(2.5)^2(3.1416)}{27} = .73$ CY

1.5 ton @ 9.75/ton = 1.5 ton

Total material cost 4014.24 **/ ~~LF~~** LS

Production cycle time .17 **Bucket volume** 1.31 **Job eff.** _____

Hr. production dig time ---

Other time Use 1.5 hr for all to allow for all work as this is tight working

Total time = 1.5 hr all **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-G-9
Structure construction cost

Structure Construction Production Cost

Structure type Manhole **No.** 1 **Location** Sanitary Line 2-3

Width MH = 4' dia. Exc. = 8' dia. **Depth** 12.3 **Length** _____

Material Precast concrete **CY volume for structure** 30

Vol. / _____

Work description:

Same

Equipment needed:

Same

Crew:

Same

Struct. material _____ **From** 1-10'-12' **Cost / LF** _____

Bedding material _____ **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost 4014.24 ~~LLF~~ LS

Production cycle time _____ **Bucket volume** _____ **Job eff.** _____

Hr. production dig time _____

Other time Same

Total time = 1.5 hr all **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-G-10
Structure construction cost

Structure Construction Production Cost

Structure type Manhole **No.** 3 **Location** Sanitary line - 3 end

Width MH = 4' dia. Exc. = 8' dia. **Depth** 20.70 **Length** _____

Material Precast concrete **CY volume for structure** 51

Vol. / _____

Work description:

Same

Equipment needed:

Same

Crew:

Same

Struct. material Precast concrete **From** Royal Conc. 1 -MH 16-19' **Cost / ~~LF~~** 6000.00 lump sum

Bedding material Same **From** _____ **Cost / LF** _____

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Total material cost 6014.24 **/ ~~LF~~** LS

Production cycle time --- **Bucket volume** _____ **Job eff.** _____

Hr. production dig time ---

Other time Use 2 hr.

Total time = 2.0 / all **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-G-11
Structure construction cost

Structure Construction Production Cost

Structure type Concrete **No.** --- **Location** Shop footing

Width _____ **Depth** _____ **Length** _____

Material _____ **CY volume for structure** 155.23

Vol. / _____

Work description:

701 to load
501 to haul
Because of short work areas - cycle time will be about 30 sec. considering maneuver time.

Equipment needed:

Crew:

Struct. material Concrete **From** Sands **Cost / LF** 11.90

Bedding material AB-3 **From** Murray **Cost / LF** 4.35

Other _____ **From** _____ **Cost / LF** _____

Calculations:

AB-3 - 35 CY = 110 ton @ 9.50
240

Total material cost _____ **/ LF**

Production cycle time 30" **Bucket volume** 2 **Job eff.** _____

Hr. production dig time 4 hr. Exc CY = 136± Backfill = 16

Other time _____

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-H-1
Structure production cost

Calculation Form

Line item Shop building footing **Segment** _____

No. units 240 **Type** LF **Special** _____

Total cost 4582.64 **Unit cost** 19.09

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	701	4	101.29	405.16	Concrete	11.90		
	501	4	69.37	277.48	AB-3 bedding	4.35		
								Conc. in place by Sands Const. Co. @ 11.90/LF
Subtotal				682.64		16.25		

Calculations and notes

Eq. = .72
Conc. = 11.90
12.62

Material = 16.25 / LF
Exc. = 682.64 / 240 = 2.84 / LF
= 19.09 / LF

Figure 15-H-2
Shop building footing

Structure Construction Production Cost

Structure type Office basement **No.** --- **Location** ---

Width _____ **Depth** _____ **Length** _____

Material _____ **CY volume for structure** 934

Vol. / _____

Work description:

Excavate for basement. Concrete to be placed by Sands Construction for 31.00 / LF of wall

Equipment needed:

601 to load
502 to haul
101 supervise

Crew:

Struct. material Concrete **From** Sands **Cost / LF** 31.00

Bedding material AB-3 **From** Murray **Cost / LF** 4.25

Other _____ **From** _____ **Cost / LF** _____

Calculations:

Prior experience says it will take about 1 min. cycle time to go into & out of the hole.

Bedding = 47 CY = 94 ton

Total material cost _____ **/ LF**

Production cycle time 1 min. **Bucket volume** 2 **Job eff.** .83

Hr. production dig time 9.5 hr. 120 CY/hr 100

Other time _____

Total time = _____ **Ft / Hr.** _____

Job hours _____ **Job days** _____

Figure 15-I-1
Office basement

Calculation Form

Line item Office basement **Segment** _____

No. units 210 **Type** LF **Special** _____

Total cost 9036.30 **Unit cost** 43.03

Section	Mach. no.	Mach. hrs.	Mach. $/hr	Mach. total/$	Materials used	Material cost	Other	Notes
	601	9.5	79.52	755.44	Concrete	31.00		Concrete in place by Sands Const. @ 31.00
	502	9.5	69.37	659.02	AB-3	4.25		
	101	9.5	23.17	220.12				
Subtotal				1634.58		35.25		

Calculations and notes

1634.58/210 = 7.78 / LF Exc.
= 35.25 / Material
43.03

Figure 15-I-2
Office basement

Overhead Inventory List

Item	Quantity	Cost Each	Yearly cost
Office and shop grounds	1	n/a	25,000.00
Shop Inventory	1	n/a	7,000.00
Service truck	1	n/a	3,000.00
Low boy / trailer	1	n/a	2,800.00
Pickups	2	2,500.00	5,000.00
Office help and supplies	n/a	n/a	19,000.00
Insurance, taxes, etc. other than mach's	n/a	n/a	4,000.00
Dues, subscriptions	n/a	n/a	750.00
Advertising	n/a	n/a	1,500.00
Computer rental	n/a	n/a	2,000.00
Utilities/all	n/a	n/a	2,900.00
Field supervision	1	n/a	25,000.00
Miscellaneous	n/a	n/a	5,000.00
		Page totals	
		Item totals	102,950.00

Figure 15-J-1
Overhead inventory

Operating Costs No. 101

Fuel			
Unit price	**Used / hr**		
.72	1.9 gal/hr		1.75
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.06 gal / hr	0.27
Trans	6.00 / gal	.02 gal / hr	0.12
Finals			
Hyd			
Grease	1.25 / lb	104 lb / hr	0.05
Filters	4 sets @ 20.00		.04
Other _____			
Total lubricants			2.23
Tires			
$\frac{\text{Replacement cost}}{\text{Estimated hours}} = \frac{500}{10{,}000}$			0.50
Repairs			
$\frac{\text{Factor x del price - tires}}{1000} = \frac{.09 \times 13.500}{1000}$			.01
Other			
Total operation cost			2.74
Operator wages Supervisor			15.00
Ownership cost			3.09
Total operation and ownership cost			20.83

Figure 15-K-1
Machine no. 101

Hourly Ownership Cost Estimate

Machine type Pickup No. 101

Purchase date _____ **Purchase price** $14,000

Depreciation value				
Delivered price (total cost)				14,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front			250	
Rear			250	
Drive				
Total tires				500
Delivered price minus tire cost				13,500
Minus resale or trade-in value				1,500
Net depreciation value				12,000
Ownership cost				
Depreciation value				
$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$				
$= \frac{12{,}000}{5{,}000}$				2.40
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 2,200				
$\frac{\text{Factor x delivered price}}{1000} = \frac{.049 \times 14{,}000}{1000}$				
Owning cost				.69
Total ownership cost = Depreciation cost + owning cost				3.09

Figure 15-K-2
Machine no. 101

Machine inventory

Mach. no. 101 **Type** Pickup **Brand** Ace

Purchase date _____ **Purchase price** $14,000

Average hours per year use 2,200

HP _____ **Operating weight** _____ **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-3
Machine no. 101

Operating Costs No. 301

Fuel			
Unit price	**Used / hr**		
.72	20 gal/hr		14.40
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.06 gal / hr	0.27
Trans	6.00 / gal	.05 gal / hr	0.30
Finals			
Hyd	6.00 / gal	.05 gal / hr	0.30
Grease	1.25 / lb	.03 lb / hr	0.04
Filters	6 sets @ 60.00 / 1700		0.21
Other No. 101			
Total lubricants			15.52
Tires			
$\frac{\text{Replacement cost}}{\text{Estimated hours}} = \frac{-0-}{-0-}$			-0-
Repairs			
$\frac{\text{Factor x del price - tires}}{1000} = \frac{.09 \times 110{,}000}{1000}$			9.99
Other			
Total operation cost			25.51
Operator wages No. II			12.00
Ownership cost			16.20
Total operation and ownership cost			53.71

Figure 15-K-4
Machine no. 301

Hourly Ownership Cost Estimate

Machine type Crawler tractor No. 301

Purchase date _____ **Purchase price** $110,000

Depreciation value

Delivered price (total cost)				110,000.00
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				110,000.00
Minus resale or trade in value				10,000.00
Net depreciation value				100,000.00

Ownership cost

Depreciation value

$$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$$

$$= \frac{100{,}000}{10{,}000}$$ 10.00

Interest, insurance, taxes

Rate **Int.** 9% **Insc** 4% **Taxes** 5%

Estimated yearly use in hours 1,700

$$\frac{\text{Factor x delivered price}}{1000} = \frac{.062 \times 100{,}000}{1000}$$

Owning cost 6.20

Total ownership cost = depreciation cost + owning cost 16.20

Figure 15-K-5
Machine no. 301

Machine inventory

Mach. no. 301 **Type** Crawler tractor **Brand** Ace - A10

Purchase date _____ **Purchase price** $110,000

Average hours per year use 1,700

HP 140 **Operating weight** 39,000 **/ ton** 19.5

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1	1.6			36,000	47,000	
2	2.4			25,000	32,000	
3	3.5			17,000	21,000	
4	4.7			11,000	14,000	
5	7.1			8,000	10,000	
6						
7						
8						

Comments

Figure 15-K-6
Machine no. 301

Operating Costs No. 302

Fuel			
Unit price	**Used / hr**		
.72	28 Gal/hr		20.16
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.07 gal / hr	0.32
Trans	6.00 / gal	.07 gal / hr	0.42
Finals			
Hyd	6.00 / gal	.06 gal / hr	0.36
Grease	1.25 / lb	.03 lb / hr	0.04
Filters	6 sets @ 55.00 / 1400		0.24
Other No. 101			
Total lubricants			21.54
Tires			
$\frac{\textbf{Replacement cost}}{\textbf{Estimated hours}} = \frac{-0-}{-0-}$			-0-
Repairs			
$\frac{\textbf{Factor x del price - tires}}{\textbf{1000}} = \frac{.09 \times 165{,}000}{1000}$			14.85
Other			
Total operation cost			36.39
Operator wages No II			12.00
Ownership cost			27.38
Total operation and ownership cost			75.77

Figure 15-K-7
Machine no. 302

Hourly Ownership Cost Estimate

Machine type Crawler tractor No. 302

Purchase date _____ **Purchase price** $165,000

Depreciation value				
Delivered price (total cost)				165,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				165,000
Minus resale or trade in value				15,000
Net depreciation value				150,000
Ownership cost				
Depreciation value				
$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$				
$= \frac{150{,}000}{10{,}000}$				15.00
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 1,400				
$\frac{\text{Factor x delivered price}}{1000} = \frac{.075 \times 165{,}000}{1000}$				
Owning cost				12.38
Total ownership cost = depreciation cost + owning cost				27.38

Figure 15-K-8
Machine no. 302

Machine inventory

Mach. no. 302 **Type** Crawler tractor **Brand** Ace - A15

Purchase date _____ **Purchase price** $165,000

Average hours per year use 1,400

HP 300 **Operating weight** 62,000 **/ ton** 31

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPm
		Rated	Maximum	Rated	Maximum	
1	1.8			58,000	68,000	
2	2.5			49,000	59,000	
3	3.2			38,000	49,000	
4	4.4			27,000	37,000	
5	5.7			19,000	26,500	
6	7.1			12,000	18,000	
7						
8						

Comments

Figure 15-K-9
Machine no. 302

Operating Costs No. 401

Fuel			
Unit price	**Used / hr**		
.72	18 gal/hr		12.96
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.06 gal / hr	0.27
Trans	6.00 / gal	.04 gal / hr	0.24
Finals			
Hyd	6.00 / gal	.06 gal / hr	0.36
Grease	1.25 / lb	.04 lb / hr	0.05
Filters	5 sets @ 75.00 / 1800		0.21
Other Bits	7 sets @ 125.00 / 1800		0.49
Total lubricants			14.58
Tires			
$\frac{\text{Replacement cost}}{\text{Estimated hours}} = \frac{3{,}000}{5{,}000}$			0.60
Repairs			
$\frac{\text{Factor x del price - tires}}{1000} = \frac{.05 \times 76.000}{1000}$			3.80
Other			
Total operation cost			18.98
Operator wages No II			12.00
Ownership cost			12.14
Total operation and ownership cost			43.12

Figure 15-K-10
Machine no. 401

Hourly Ownership Cost Estimate

Machine type Motor grader No. 401

Purchase date _____ **Purchase price** $79,000

Depreciation value				
Delivered price (total cost)				79,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front			1000	
Rear			1000	
Drive			1000	
Total tires				3,000
Delivered price minus tire cost				76,000
Minus resale or trade in value				10,000
Net depreciation value				66,000
Ownership cost				
Depreciation value				
$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$				
$= \frac{66{,}000}{8000}$				8.25
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 1,800				
$\frac{\text{Factor x delivered price}}{1000} = \frac{.049 \times 79{,}000}{1000}$				
Owning cost				3.89
Total ownership cost = depreciation cost + owning cost				12.14

Figure 15-K-11
Machine no. 401

Machine inventory

Mach. no. 401 **Type** Motor grader **Brand** Ace - A21

Purchase date _____ **Purchase price** $79,000

Average hours per year use 1,800

HP 150 **Operating weight** 30,000 **/ ton** 15.0

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-12
Machine no. 401

Operating Costs No. 501

Fuel			
Unit price	**Used / hr**		
.72	28.6 gal/hr		20.60
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.07 gal / hr	0.32
Trans	6.00 / gal	.06 gal / hr	0.36
Finals			
Hyd	6.00 / gal	.09 gal / hr	0.54
Grease	1.25 / lb	.08 lb / hr	0.10
Filters	5 sets @ 300.00 / 1450		1.03
Other Cutting bits	3 sets @ 400.00 / 1450		0.83
Total lubricants			
Tires			
$\frac{\text{Replacement cost}}{\text{Estimated hours}} = \frac{10{,}000}{10{,}000}$			1.00 24.78
Repairs			
$\frac{\text{Factor x del price - tires}}{1000} = \frac{.09 \times 95{,}000}{1000}$			8.55
Other			
Total operation cost			33.33
Operator wages No. 1			15.00
Ownership cost			13.94
Total operation and ownership cost			62.27/hr

Figure 15-K-13
Machine no. 501

Hourly Ownership Cost Estimate

Machine type Wheel scraper No. 501

Purchase date _____ **Purchase price** $95,000

Depreciation value

Delivered price (total cost)	95,000
Minus tire replacement cost	

Loc	Size	Qt	Amount
Front			
Rear			5000
Drive			5000

Total tires	10,000
Delivered price minus tire cost	85,000
Minus resale or trade in value	15,000
Net depreciation value	70,000

Ownership cost

Depreciation value

$$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$$

$$= \frac{70{,}000}{10{,}000} \qquad 7.00$$

Interest, insurance, taxes

Rate **Int.** 9% **Insc** 4% **Taxes** 5%

Estimated yearly use in hours 1,450

$$\frac{\text{Factor x delivered price}}{1000} = \frac{.073 \times 95{,}000}{1000}$$

Owning cost 6.94

Total ownership cost = depreciation cost + owning cost 13.94

Figure 15-K-14
Machine no. 501

Machine inventory

Mach. no. 501 **Type** Wheel scraper **Brand** Ace - 250

Purchase date _____ **Purchase price** $95,000.00

Average hours per year use 1,450

HP 1,900 **Operating weight** 65,000 **/ ton** 32.5

Capacity full 21 **CY** **Scraped** 15 **CY**

Rated load 42,000 lb **Rated RPM** 1,900

Weight distribution

Empty drive 65% **No. of drivers** 2 **Loaded drive** 57%

Rear 35% **Rear** 43%

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1	2.5	52,105	67,910			
2	5.0	48,000	61,235			
3	7.5	40,005	51,063			
4	10.0	32,000	46,729			
5	14.0	21,979	37,031			
6	19.5	12,163	26,019			
7	24.0	7,211	19,306			
8	30.0	4,107	15,601			

Comments

Figure 15-K-15
Machine no. 501

Operating Costs No. 502

Fuel			
Unit price	**Used / hr**		
.72	30.5 gal/hr		21.93
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.06 gal / hr	0.27
Trans	6.00 / gal	.08 gal / hr	0.48
Finals			
Hyd	6.00 / gal	.10 gal / hr	0.60
Grease	1.25 / lb	.09 lb / hr	0.11
Filters	5 sets @ 300.00 / 1450		1.03
Other Cutting bits	3 sets @ 400.00 / 1450		0.83
Total lubricants			25.25
Tires			
$\frac{\textbf{Replacement cost}}{\textbf{Estimated hours}} = \frac{10{,}000}{10{,}000}$			1.00
Repairs			
$\frac{\textbf{Factor x del price - tires}}{\textbf{1000}} = \frac{.09 \times 85{,}000}{1000}$			7.65
Other			
Total operation cost			33.90
Operator wages No. 1			15.00
Ownership cost			13.94
Total operation and ownership cost			62.84

Figure 15-K-16
Machine no. 502

Hourly Ownership Cost Estimate

Machine type Wheel scraper No. 502

Purchase date _____ **Purchase price** $95,000

Depreciation value				
Delivered price (total cost)				95,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear			5000	
Drive			5000	
Total tires				10,000
Delivered price minus tire cost				85,000
Minus resale or trade in value				15,000
Net depreciation value				70,000
Ownership cost				
Depreciation value				
$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$				
$= \frac{70{,}000}{10{,}000}$				7.00
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 1,450				
$\frac{\text{Factor x delivered price}}{1000} = \frac{.073 \times 95{,}000}{1000}$				
Owning cost				6.94
Total ownership cost = depreciation cost + owning cost				13.94

Figure 15-K-17
Machine no. 502

Machine inventory

Mach. no. 502 **Type** Wheel scraper **Brand** Ace - 250

Purchase date _____ **Purchase price** $95,000.00

Average hours per year use 1,450

HP 330 **Operating weight** 65,000 **/ ton** 32.5

Capacity full 21 **CY** **Scraped** 15 **CY**

Rated load 42,000 Lb **Rated RPM** 1,900

Weight distribution

Empty drive 65% **No. of drivers** 2 **Loaded drive** 57%

Rear 35% **Rear** 43%

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1	2.5	52,105	67,910			
2	5.0	48,000	61,235			
3	7.5	40,005	51,063			
4	10.0	32,000	46,729			
5	14.0	21,979	37,031			
6	19.5	12,163	26,019			
7	24.0	7,211	19,306			
8	30.0	4,107	15,601			

Comments

Figure 15-K-18
Machine no. 502

Operating Costs No. 601

Fuel			
Unit price	**Used / hr**		
.72	18 gal/hr		12.96
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.08 gal / hr	0.36
Trans	6.00 / gal	.05 gal / hr	0.30
Finals			
Hyd	6.00 / gal	.08 gal / hr	0.48
Grease	1.25 / lb	.07 lb / hr	0.09
Filters	6 sets @ 150.00 / 2000		0.45
Other Teeth bucket	5 sets @ 375.00 / 2000		0.94
Total Lubricants			
Tires			
Replacement cost / **Estimated hours** = -0- / -0-			-0- 15.58
Repairs			
Factor x del price - tires / **1000** = .09 x 175,000 / 1000			15.75
Other			
Total operation cost			31.33
Operator wages No. 1			15.00
Ownership cost			24.95
Total operation and ownership cost			71.28

Figure 15-K-19
Machine no. 601

Hourly Ownership Cost Estimate

Machine type Tractor loader No. 601

Purchase date _____ **Purchase price** $175,000

Depreciation value

Delivered price (total cost)				175,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				175,000
Minus resale or trade in value				20,000
Net depreciation value				155,000

Ownership cost

Depreciation value

$$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$$

$$= \frac{155{,}000}{10{,}000} \qquad 15.50$$

Interest, insurance, taxes

Rate **Int.** 9% **Insc** 4% **Taxes** 5%

Estimated yearly use in hours 2,000

$$\frac{\text{Factor x delivered price}}{1000} = \frac{.054 \times 175{,}000}{1000}$$

Owning cost 9.45

Total ownership cost = depreciation cost + owning cost 24.95

Figure 15-K-20
Machine no. 601

Machine inventory

Mach. no. 601 **Type** Track loader **Brand** Ace - H5

Purchase date _____ **Purchase price** $175,000.00

Average hours per year use 2,000

HP 110 **Operating weight** 40,000 **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1	1.5					
2	3.1					
3	7.0					
4						
5						
6						
7						
8						

Comments

Figure 15-K-21
Machine no. 601

Operating Costs No. 701

Fuel			
Unit price	**Used/Hr**		
.72	19 gal/hr		13.68
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.07 gal / hr	0.32
Trans	6.00 / gal	.03 gal / hr	0.18
Finals			
Hyd	6.00 / gal	.09 gal / hr	0.54
Grease	1.25 / lb	.08 lb / hr	0.10
Filters	9 sets @ 95.00 / 1800		.48
Other Bucket teeth	12 sets @ 180 per set / 1800		1.20
Total lubricants			16.50
Tires			
$\frac{\textbf{Replacement cost}}{\textbf{Estimated hours}} = \frac{-0-}{-0-}$			-0-
Repairs			
$\frac{\textbf{Factor x del price - tires}}{\textbf{1000}} = \frac{.09 \times 250{,}000}{1000}$			22.50
Other			
Total operation cost			39.00
Operator wages No. 1			15.00
Ownership cost			37.00
Total operation and ownership cost			91.00

Figure 15-K-22
Machine no. 701

Hourly Ownership Cost Estimate

Machine type Track excavator No. 701

Purchase date _____ **Purchase price** $250,000

Depreciation value				
Delivered price (total cost)				250,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				250,000
Minus resale or trade in value				25,000
Net depreciation value				225,000
Ownership cost				
Depreciation value				
= **Net depreciation value (from above)** / **Depreciation period in hours**				
= 225,000 / 10,000				22.50
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 1,800				
Factor x delivered price / **1000** = .058 x 250,000 / 1000				
Owning cost				14.50
Total ownership cost = depreciation cost + owning cost				37.00

Figure 15-K-23
Machine no. 701

Machine inventory

Mach. no. 701 **Type** Track excavator **Brand** Ace - R200

Purchase date _____ **Purchase price** $250,000

Average hours per year use 1,800

HP 102 **Operating weight** 38,000 **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height 9'9" **Maximum reach** 29' **Maximum depth** 20'

Dig unit width 36"

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-24
Machine no. 701

Operating Costs No. 801

Fuel			
Unit price	**Used / hr**		
.70	3.1 gal/hr		2.17
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.05 gal / hr	0.23
Trans	6.00 / gal	.01 gal / hr	0.06
Finals			
Hyd	6.00 / gal	.07 gal / hr	0.42
Grease	1.25 / lb	.03 lb / hr	0.04
Filters	5 sets @ 22.50 / 1900		0.06
Other No. 101			
Total lubricants			2.98
Tires			
$\frac{\textbf{Replacement cost}}{\textbf{Estimated hours}} = \frac{1{,}000}{12{,}000}$			0.08
Repairs			
$\frac{\textbf{Factor x del price - tires}}{\textbf{1000}} = \frac{.06 \times 69{,}000}{1000}$			4.14
Other			
Total operation cost			7.20
Operator wages No. IV			10.00
Ownership cost			9.18
Total operation and ownership cost			26.38

Figure 15-K-25
Machine no. 801

Hourly Ownership Cost Estimate

Machine type Boom truck No. 801

Purchase date _____ **Purchase price** $70,000

Depreciation value

Delivered price (total cost)				70,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear			500.00	
Drive			500.00	
Total tires				1000
Delivered price minus tire cost				69,000
Minus resale or trade in value				5,000
Net depreciation value				64,000

Ownership cost

Depreciation value

$$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$$

$$= \frac{64{,}000}{12{,}000} \qquad 5.33$$

Interest, insurance, taxes

Rate **Int.** 9% **Insc** 4% **Taxes** 5%

Estimated yearly use in hours 1,900

$$\frac{\text{Factor x delivered price}}{1000} = \frac{.055 \times 70{,}000}{1000}$$

Owning cost 3.85

Total ownership cost = depreciation cost + owning cost 9.18

Figure 15-K-26
Machine no. 801

Machine inventory

Mach. no. 801 **Type** Boom truck **Brand** Right - 2000

Purchase date _____ **Purchase price** $70,000

Average hours per year use 1,900

HP 65 **Operating weight** 9,000 **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-27
Machine no. 801

Operating Costs No. 901

Fuel			
Unit price	**Used/Hr**		
.72	3.4 gal/hr		2.45
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine	4.50 / gal	.05 gal / hr	0.23
Trans	6.00 / gal	.07 gal / hr	0.42
Finals			
Hyd	6.00 / gal	.06 gal / hr	0.36
Grease	1.25 / lb	.02 lb / hr	0.03
Filters	5 sets @ 25.00 / 8.00		0.16
Other Teeth	40 sets @ 3.50 / 8.00		0.18
Total lubricants			3.83
Tires			
$\frac{\text{Replacement cost}}{\text{Estimated hours}} = \frac{-0-}{-0-}$			-0-
Repairs			
$\frac{\text{Factor x del price - tires}}{1000} = \frac{.03 \times 95{,}000}{1000}$			2.85
Other			
Total operation cost			6.68
Operator wages No. II			12.00
Ownership cost			20.13
Total operation and ownership cost			38.81

Figure 15-K-28
Machine no. 901

Hourly Ownership Cost Estimate

Machine type Trench compactor No. 901

Purchase date _____ **Purchase price** $95,000

Depreciation value				
Delivered price (total cost)				95,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				95,000
Minus resale or trade in value				10,000
Net depreciation value				85,000
Ownership cost				
Depreciation value				
$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$				
$= \frac{85{,}000}{8{,}000}$				10.63
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 800				
$\frac{\text{Factor x Delivered price}}{1000} = \frac{.10 \times 95{,}000}{1000}$				
Owning cost				9.50
Total ownership cost = depreciation cost + owning cost				20.13

Figure 15-K-29
Machine no. 901

Machine inventory

Mach. no. 901 **Type** Trench compactor **Brand** Ace - 102

Purchase date _____ **Purchase price** $95,000

Average hours per year use 800

HP 45 **Operating weight** 7000 **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width 30”

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-30
Machine no. 901

Operating Costs No. 1001

Fuel		None		
Unit price	**Used / hr**			
Lubricants / filters				
Item	**Unit price**		**Used / hr**	
Engine				
Trans				
Finals				
Hyd				
Grease				
Filters				
Other _____				
Total lubricants				
Tires				
Replacement cost / **Estimated hours** = _____				
Repairs				
Factor x del price - tires / **1000** = _____				
Other				
Total operation cost				-0-
Operator wages (supervisor)				-0-
Ownership cost				2.53
Total operation and ownership cost				2.53

Figure 15-K-31
Machine no. 1001

Hourly Ownership Cost Estimate

Machine type Laser gun No. 1001

Purchase date _____ **Purchase price** $7,500.00

Depreciation value				
Delivered price (total cost)				7,500
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				7,500
Minus resale or trade in value				-0-
Net depreciation value				7,500
Ownership cost				
Depreciation value				
= **Net depreciation value (from above)** / **Depreciation period in hours**				
= 7,500 / 4,000				1.88
Interest, insurance, taxes				
Rate Int. 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 1000				
Factor x delivered price / **1000** = .10 x 7,500 / 1000				
Owning cost				.75
Total ownership cost = depreciation cost + owning cost				2.63

Figure 15-K-32
Machine no. 1001

Machine inventory

Mach. no. 1001 **Type** Laser gun **Brand** Tong - 175

Purchase date _____ **Purchase price** 7,500

Average hours per year use 1000

HP _____ **Operating weight** _____ **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

Dig unit width _____

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-33
Machine no. 1001

Operating Costs No. 1101

Fuel			
Unit price	**Used / hr**		
			-0-
Lubricants / filters			
Item	**Unit price**	**Used / hr**	
Engine			-0-
Trans			-0-
Finals			
Hyd			
Grease	1.25 / lb	0.05 lb/hr	0.06
Filters			-0-
Other _____			
Total lubricants			0.06
Tires			
$\frac{\text{Replacement cost}}{\text{Estimated hours}} = \frac{-0-}{-0-}$			-0-
Repairs			
$\frac{\text{Factor x del price - tires}}{1000} = \frac{.01 \times 25{,}000}{1000}$			0.25
Other			
Total operation cost			0.31
Operator wages (supervisor)			-0-
Ownership cost			5.75
Total operation and ownership cost			6.06

Figure 15-K-34
Machine no. 1101

Hourly Ownership Cost Estimate

Machine type Pull type sheepsfoot No. 1101

Purchase date _____ **Purchase price** $25,000

Depreciation value				
Delivered price (total cost)				25,000
Minus tire replacement cost				
Loc	**Size**	**Qt**	**Amount**	
Front				
Rear				
Drive				
Total tires				-0-
Delivered price minus tire cost				25,000
Minus resale or trade in value				-0-
Net depreciation value				25,000
Ownership cost				
Depreciation value				
$= \frac{\text{Net depreciation value (from above)}}{\text{Depreciation period in hours}}$				
$= \frac{25{,}000}{10{,}000}$				2.50
Interest, insurance, taxes				
Rate **Int.** 9% **Insc** 4% **Taxes** 5%				
Estimated yearly use in hours 700				
$\frac{\text{Factor x delivered price}}{1000} = \frac{.13 \times 25{,}000}{1000}$				
Owning cost				3.25
Total ownership cost = depreciation cost + owning cost				5.75

Figure 15-K-35
Machine no. 1101

Machine inventory

Mach. no. 1101 **Type** Pull sheepsfoot **Brand** Ace HR-5

Purchase date _____ **Purchase price** $25,000

Average hours per year use 700

HP _____ **Operating weight** 22,000 **/ ton** _____

Capacity full _____ **CY** **Scraped** _____ **CY**

Rated load _____ **Rated RPM** _____

Weight distribution

Empty drive _____ **No. of drivers** _____ **Loaded drive** _____

Rear _____ **Rear** _____

Maximum height _____ **Maximum reach** _____ **Maximum depth** _____

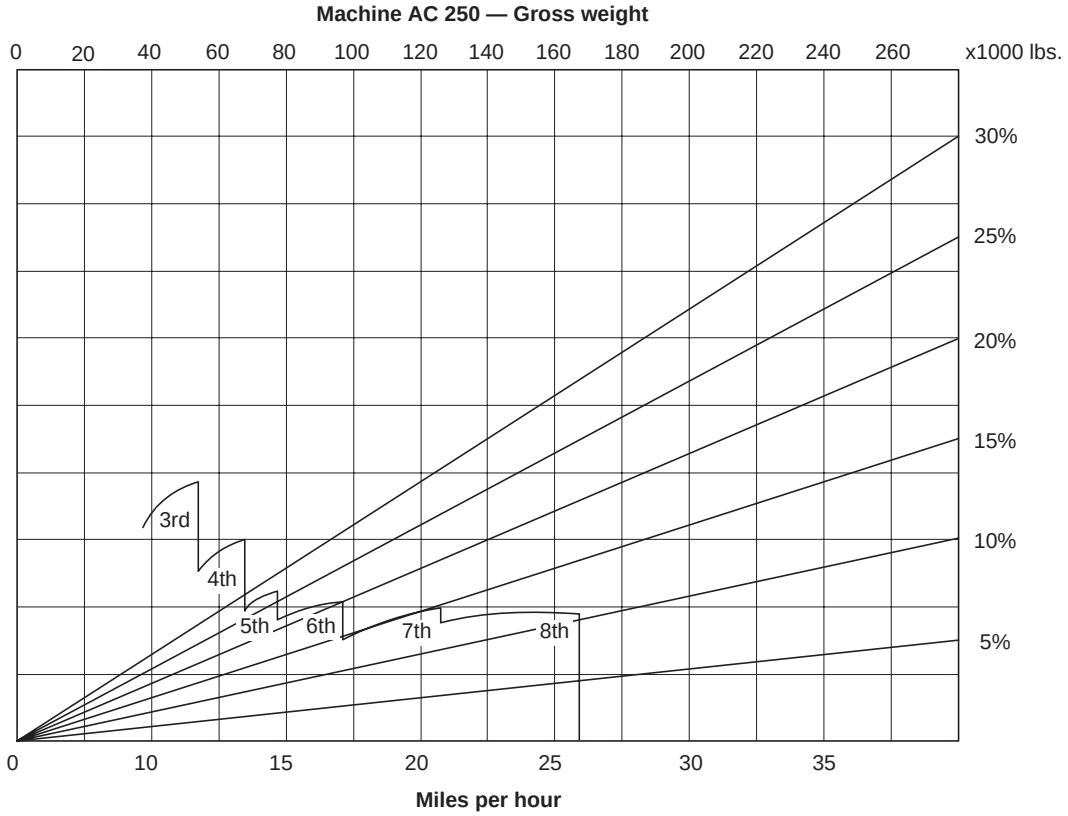
Dig unit width 12'

Gear / power / weight chart

Gear	Speed	Pounds of rim pull		Drawbar pull		RPM
		Rated	Maximum	Rated	Maximum	
1						
2						
3						
4						
5						
6						
7						
8						

Comments

Figure 15-K-36
Machine no. 1101



To use: Locate gross weight on top scale. Move down to intercept the effective grade line. Move to the left to intercept the retarder curve in gear range. Read down to intercept point on speed scale in mph.

Figure 15-K-37
Retarder chart

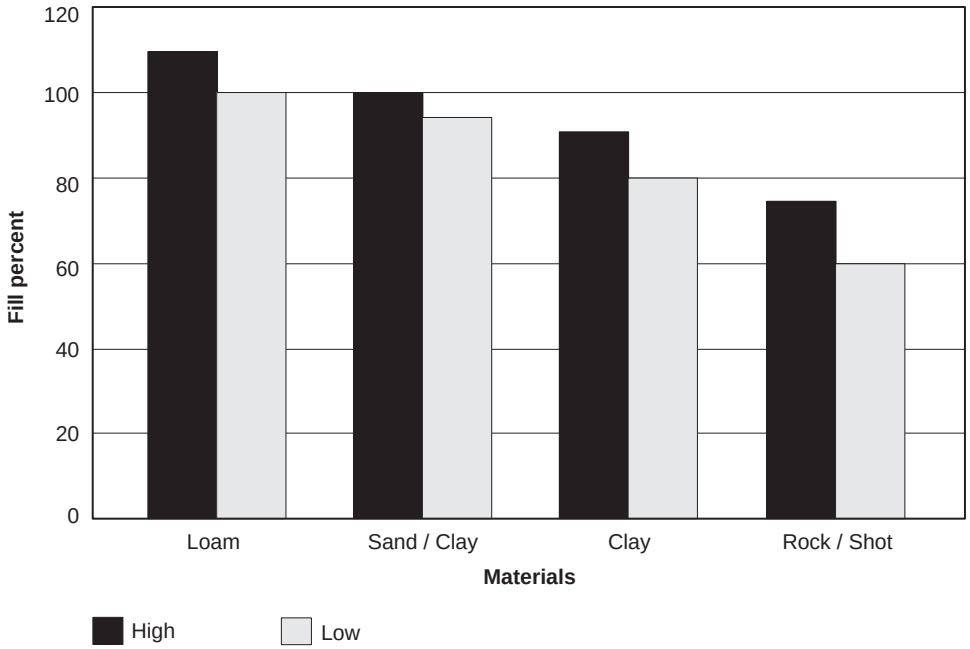


Figure 15-K-38
Bucket payload factor

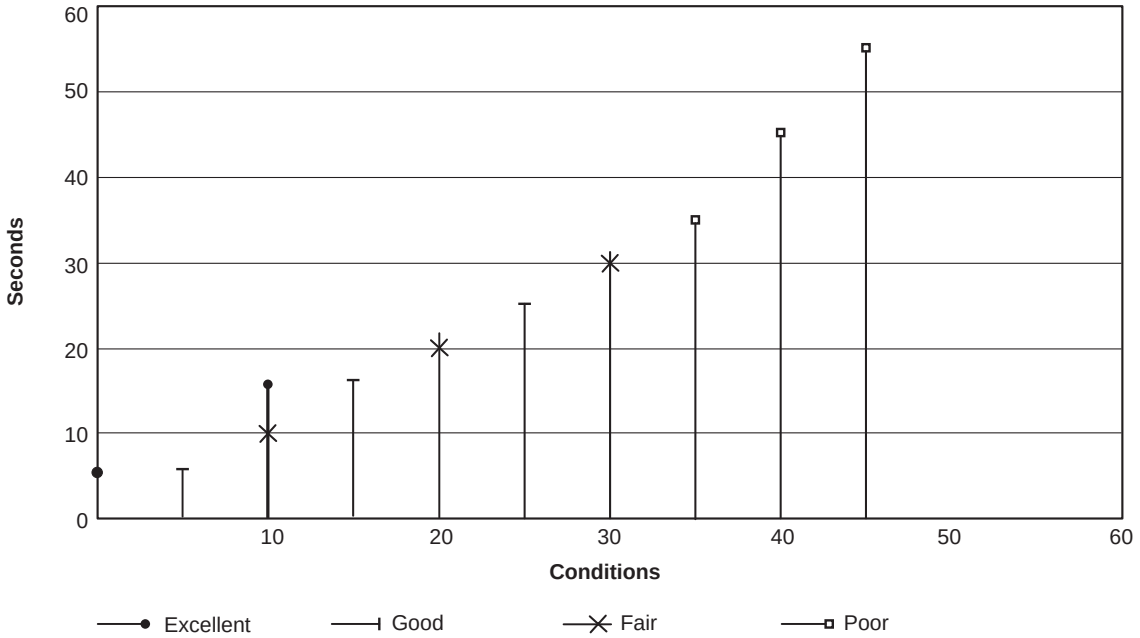


Figure 15-K-39
Backhoe cycle time

Estimated cycle times (seconds)	Estimated bucket payload									Cycles per hour
	1.0	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	
10										
11										
12	300									
13	270	404	540	675	810	945	1012	1215	1350	270
15	240	360	480	600	720	840	960	1080	1200	240
17	210	315	420	525	630	735	840	945	1050	210
20	180	270	350	450	540	630	720	810	900	180
24	150	225	300	375	450	525	600	675	750	150
30	120	180	240	300	360	420	480	510	600	120
35	102	154	205	256	308	360	410	462	513	102
40		135	180	225	270	315	360	405	450	90
45				200	240	280	320	360	400	78

Figure 15-K-40
Backhoe production per 60 minutes

Calculation Form

Line item Equipment costs **Segment**

Mach. No.	O&O Cost / hr	Average Hours / Yr	O&O Cost / Year	% Overhead	Term Overhead	Overhead Cost / Hr	Total Hr / Cost
101	20.83	2200	45,826.00	5.0	5,147.50	2.34	23.17
301	53.71	1700	91,307.00	10.0	10,295.00	6.06	59.77
302	75.77	1400	106,078.00	11.8	12,148.10	8.46	84.23
401	43.12	1800	77,616.00	9.0	9,265.50	5.15	48.27
501	62.27	1450	90,291.00	10.0	10,295.00	7.10	69.37
502	62.84	1450	91,118.00	10.0	10,295.00	6.53	69.37
601	71.28	2000	142,560.00	16.0	16,472.00	8.24	79.52
701	91.00	1800	172,900.00	19.0	19,560.50	10.29	101.29
801	26.38	1900	50,122.00	5.5	5,662.25	2.98	29.36
901	38.81	800	31,048.00	3.0	3,088.50	3.86	42.67
1001	2.63	1000	2,530.00	0.3	308.85	0.21	2.84
1101	6.06	700	4,242.00	0.4	411.80	0.58	6.64
			905,638.00	100.00%	102,950.00		

page 1 **of** 1

Figure 15-L-1
Machine costs per hour

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16

Computers & Computer Estimating Programs

Contractors today communicate with their clients and with other contractors via email, and transmit photographs, copies of documents, and links to pertinent websites. You can download PDF and CAD files, browse the Internet for technical information and videos about new products, follow local material and rental prices, or just go online to check the weather forecast or read the newspaper. Our computers, smart phones and tablet apps keep us constantly connected and updated with industry happenings.

There are also programs and applications that can help you run your business, track your expenses and keep you organized, like Excel and the many bookkeeping programs. But in my opinion, the most valuable commodities for the construction or excavation estimators are estimating programs.

Computers and Earthwork Programs

Some of you may not have invested in earthwork take-off programs and are curious about how they work and what they can do for you, while others may own older software and would like to get a glimpse of current technology. Many are discovering that their projects can only be taken-off from PDF and CAD files downloaded from the Internet. Technology is changing every day, and it's not always easy to keep up.

In this chapter I'll cover earthwork software, including the roadwork and trenching software available at the time of this writing. Progress in this area moves so fast that by the time you're reading this, I'm sure there will be even more sophisticated programs on the market. It's impossible to keep up — just use the program you have and get updates only as you need them.

Before we move on, let me warn you: A computerized earthwork program can be like your backhoe — the most valuable tool you own — or the most dangerous. If you don't know how to use it properly; if you're not trained and have previous earthwork estimating experience, a simple input error can take all the profit out of a job, and even put you out of business. "Garbage in; garbage out." So be aware.

An earthwork take-off done with a correctly applied program is much more accurate than one taken-off by hand using the grid or cross-section methods. Projects done by hand produce results usually within 10 to 20 percent of the actual volumes, but earthwork software will yield results within 3 to 5 percent of actual volumes in far less time. No matter how much time you have for setting up grids or cross sections by hand, you'll never be able to compete with a program that automatically calculates thousands of elevation points internally. On average, you'll be able to do take-offs for at least three times as many projects using earthwork software as you could by hand.

There are several construction-related estimating programs available, including those used for earthwork, underground utilities, roadwork and general building estimating.

At the present time, there are two basic methods used for doing earthwork take-offs:

1. One that requires printed plans, a digitizer board and electronic stylus pen. We'll refer to this as a stylus-take-off (ST) program. When you start this type of program, you'll see a white screen on your computer monitor. At the present time, road cross sections and trench profiles must be taken off using an ST program.

2. The other method allows you to work with PDF files and a mouse. PDF (Portable Document Format) is a file format used for distributing files that contain images and text in a single file. PDF files are popular because they allow the designer to distribute plans over the Internet, eliminating printing costs, as well as distribution expenses. PDF files let you to download an earthwork plan file that you can then digitize with a mouse, eliminating the need for a digitizer board or stylus pen. When you open a PDF file, you'll see the entire project to be taken-off on your monitor. We'll refer to this as a mouse-take-off (MT) program. See Figure 16-1.

To use these programs you'll need a fast computer and high-speed Internet access. A good estimator is usually under tremendous pressure to meet deadlines and can't afford to wait for calculations to be processed. Also, good estimators are well-paid and idle time spent waiting for PDF downloads and calculations is money out the window.

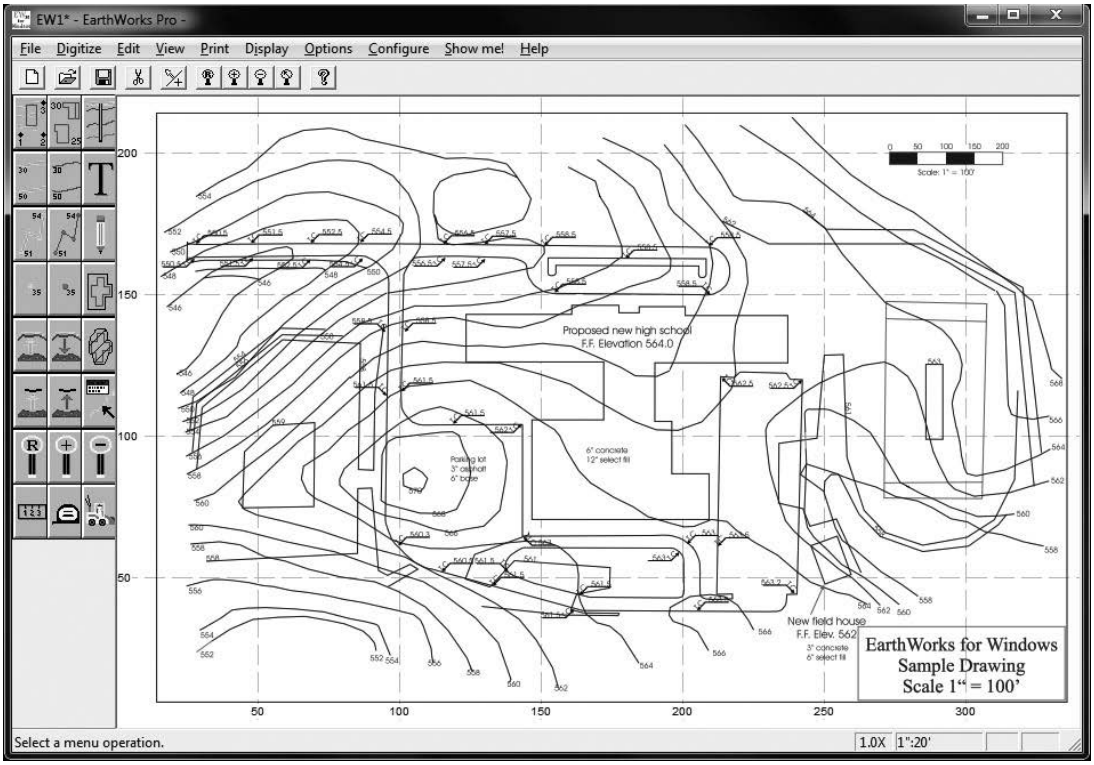

Figure 16-1
Project display on an MT program

Taking off an Earthwork Project

Whether you prefer an ST or MT program, you'll still use the following sequence to do your take-off.

Open a Project

ST program — You'll secure the drawing to a digitizer board with drafting tape.

MT program — You'll import a file from an engineering firm's website.

With either program, you start by opening a window where you give the project a name, as well as other optional information, such as the estimator's name, project location, date of the take-off, and specific comments regarding the project.

Set the Scale

ST program — You set the scale by entering the scale shown on the scale bar on the plan. You can also use a "unique scale" option when the plans aren't drawn or printed at the correct scale.

A word to the wise: Always check a given dimension on the plan with an engineer's scale. I've seen projects that weren't in scale because the plan was either slightly enlarged or reduced due to paper expansion or contraction. I've also seen a plan with an incorrect scale bar due to an engineer's error.

MT program — You should always generate a scale, since PDFs aren't always "printed" to the correct paper size. To generate a scale, simply digitize the length of the scale bar or some other known distance shown in the file.

With either program, you can set the scale in U.S. or metric units.

Set the Safety Options

ST or MT programs — With either program type you can set up a safety option where you enter a range of elevations from the lowest to the highest acceptable in the take-off. This feature keeps you from accidentally entering an extremely high or low elevation. For example, if you accidentally enter a 1000-foot elevation when you'd intended to enter 100 feet, you'll get a warning telling you that you've exceeded the range of allowable elevations initially set up. These programs are very forgiving and flexible. For example, you might think the maximum elevation on a project is 60 feet and later discover a higher elevation during the take-off process. You can always go back and change the maximum or minimum elevation acceptable for the project.

Locate and Color-Code the Drawing

ST program — You locate the drawing on the digitizer board by digitizing three points (lower left, lower right and upper right) beyond the work area. Before you do this, very carefully examine where all the work will be. You don't want to later discover that your drawing field is too small to account for work that will have to be done beyond the drawing field.

It's a good idea to take the time to color-code many items on the blueprint. For example, I use colored pencils or pens to prepare the drawing, using green for existing contours and purple for proposed contours. I also use a yellow highlighter to mark point elevations in parking lots, top-of-slab elevations and important notes. I use another color to outline the site perimeter, or boundary of the work. On many projects, color-coding can become fairly complex if you're working with different thicknesses, such

as heavy-duty paving versus light-duty paving. However, the time you spend color-coding will be well worth the effort because it allows you to have a "dry run" of the take-off and discover unforeseen problems. Color-coding gives you a well-organized project to work with by the time you're ready to digitize the drawing.

> ***In this chapter***, there are two meanings for the term *digitize*. One applies to ST programs and the other to MT programs:
>
> - *ST program* — Digitize means to press the point of a specialized electronic pen (stylus) down on a digitizer (electronic tablet) board.
> - *MT program* — Digitize means that you move the crosshairs of your mouse to a point on the computer monitor and left-click with the mouse

If your digitizer board is a rollup board, *do not* mark the drawing with a lead pencil. This will cause interference with the data you enter. However, pencil lead doesn't have any effect on a solid digitizer board. Digitizer boards (tablets) are available as rollup or solid boards, with work areas ranging from 20 x 24 inches to 60 x 138 inches. The most popular sizes are the 36 x 48 inches and 48 x 60 inches. If you can afford it, purchase a large digitizer board. I prefer a 48- x 60-inch solid board because it's usually big enough to handle most large drawings. With any digitizer board, set it up with a convenient switch so you can turn it off at the end of the day. Otherwise, you'll have to physically unplug the board from the receptacle and plug it back in before it'll work properly the next morning.

Enter Existing Contour Lines

ST or MT program — Using either program, enter existing contour lines, going from the lowest to the highest elevation.

With an MT program, you have a very convenient and time-saving option called the turbo trace function. After you start tracing a contour line, the program "sees" and automatically traces the remainder of the line. See Figure 16-2.

Enter Existing Point Elevations

ST or MT program — In areas with low relief, existing elevations are usually given as single points. Both programs have a "point contour" feature that allows you to connect one elevation to another and then automatically slopes the elevations of a line from one point to the next. This is more accurate than entering single points whose elevations stand alone. The philosophy is this: If you're blindfolded and asked to describe what's on top of a desk, you'll be more accurate if you sweep your hand across the desk (point contour) instead of touching random items (single points) on it.

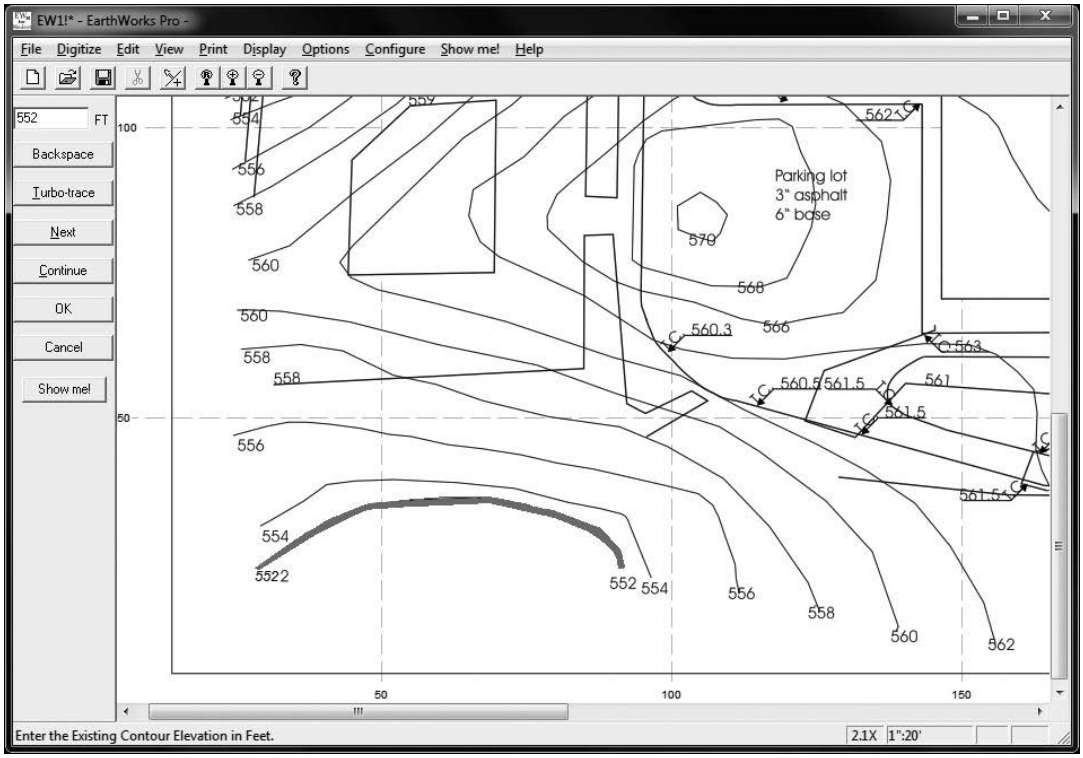

Figure 16-2
MT program turbo trace feature

When using an ST program for a project like this, before you digitize the points, color-code a series of points as close to a straight line as possible from left to right across the plan sheet. Then use another color for the next line of elevations. I usually start at the bottom of the plan and move to the top, alternating the colors I use to mark each "string" of points. This helps me keep track of each string of elevations as I'm digitizing them on the plan sheet.

Once the drawing is "placed" on the digitizer and the scale is entered, the differences between an ST and an MT program are negligible, so you can apply the instructions that follow to either program type. The screen displays shown in the figures should also be similar, regardless of the program type.

Enter Existing Areas

Enter the elevations of existing structures (slabs, pavement) that have to be demolished before earthmoving is started. Digitize the elevations of each demolition area, and then lower each area to subgrade elevation. Be sure to lower each one sufficiently to account for additional material that'll be removed as the structure is demolished. For

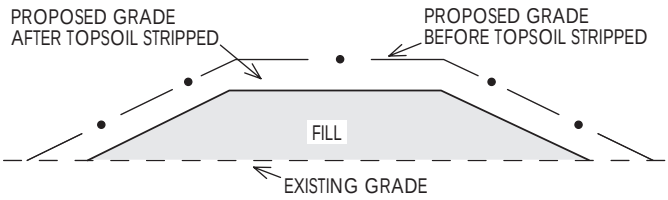

Figure 16-3
Flawed diagram for bid

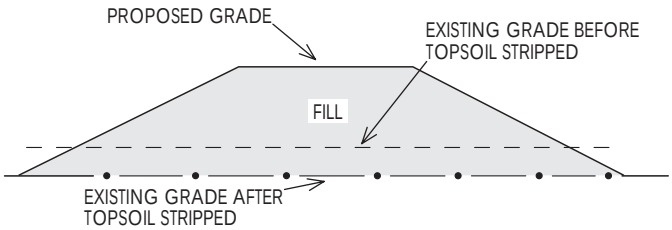

Figure 16-4
Corrected diagram for bid

example, while demolishing a slab, you'll probably also remove at least 6 inches of earth beneath the slab as the demolition proceeds. This is important since you'll usually be required to fill the remaining void with fill material. As you digitize the elevations, you'll be given the option to name the area as well as enter a description of each component of the existing area (concrete, rubble, etc.). When you perform the final calculations, the quantities of materials in the area will show up as separate line items with quantities in the summary (totals) window. Keep in mind that if you forget to enter some existing data, you can always go back and enter it later.

Be sure to keep demolition areas separate from topsoil areas, and lower each area individually — and be sure to lower them from the existing surface. Lowering them from the proposed surface will create a serious error. Figure 16-3 shows an example of such an error. Topsoil was stripped from the proposed grade rather than the existing grade, resulting in calculations that provided less fill than required for the project. Figure 16-4 shows topsoil correctly stripped from the existing layer, resulting in an accurate take-off.

Enter Proposed Contours

Enter the proposed elevations. If you have contour lines, you can start with the lowest and proceed to the highest, or vise versa. If you miss digitizing a contour line, you can go back and enter it.

Enter Proposed Point Elevations

On most projects, parking lot elevations are given as point elevations. My suggestion is that you enter elevations on a straight run using a *point contour* option that automatically slopes the line from one point to the next. See Figure 16-5. This option is available with both types of programs. When elevations occur along a curved portion

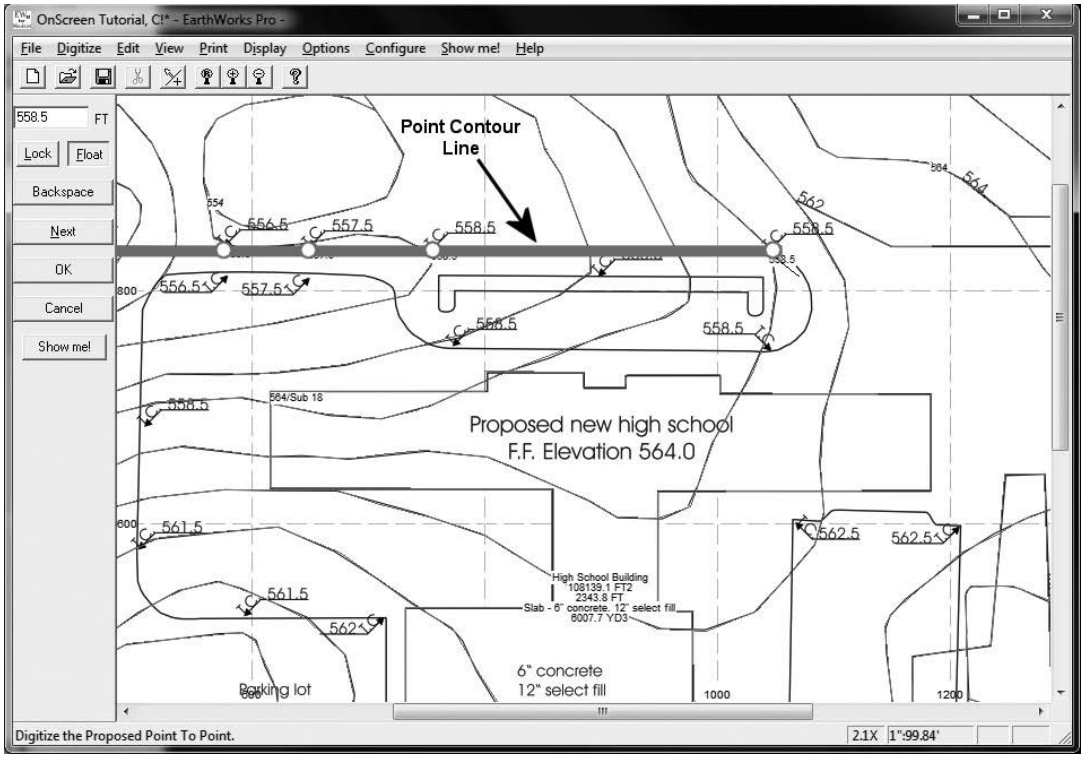

Figure 16-5
Using the point contour option

of the lot, use a *trace contour* option, which allows you to enter the starting and ending elevations along a contour line. The elevations throughout the line will automatically be interpolated between the starting and end points.

You can also use these options to enter point elevations on sidewalks. When you have a structure, such as a retaining wall where there's a sudden drop-off, enter a point contour on the high and low sides of the wall as close to the wall as possible without creating a conflict from elevation lines intersecting.

Elevations along the edges of a parking lot are usually given at the flowline of the curb. To account for elevations at the top-of-curb, you can create a second set of elevations by moving previously entered bottom-of-curb elevations beyond the parking lot. In Figure 16-6, I've moved all of the parking lot elevations to the left 6 inches and raised the elevations by 6 inches.

Enter Proposed Areas

Digitize proposed areas that have to be lowered to subgrade, since proposed elevations in structural areas are given at top-of-slab or top-of-paving. Each area must be

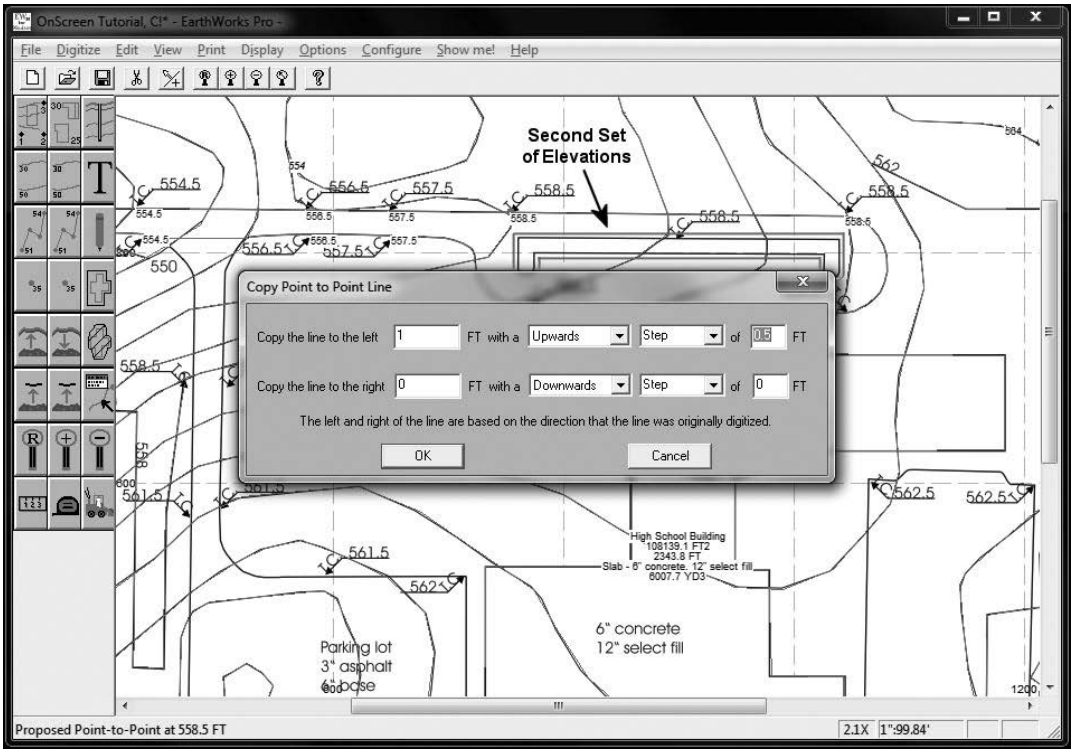

Figure 16-6
Moving flow-line elevations to top-of-curb

digitized separately, depending on the amount of lowering required. Each time you digitize an area in the proposed area window, you'll also be given the option to name the area, as well as add a description of each component of the area (concrete, granular fill, etc.). See Figure 16-7. When you perform the final calculations, the quantities of materials within the area will show up as separate line items, with quantities in the summary window.

With some programs you'll need to be careful not to overlap proposed areas. If you do, the overlapping portion will be lowered by the sum of both area thicknesses. For example, if a slab to be lowered 4 inches overlaps a paved area to be lowered by 12 inches, the overlapped portion will be lowered by 16 inches! There will be some areas you'll want to want to trace and name, but not lower the elevations. For example, you could trace the area of a proposed pond in order to see if the total cut generated for the pond could be used for fill on the site.

Strip Topsoil

Strip the topsoil, but before you do, determine the boundary of your work area (site perimeter). Trace the area, then lower existing elevations by the depth of topsoil you

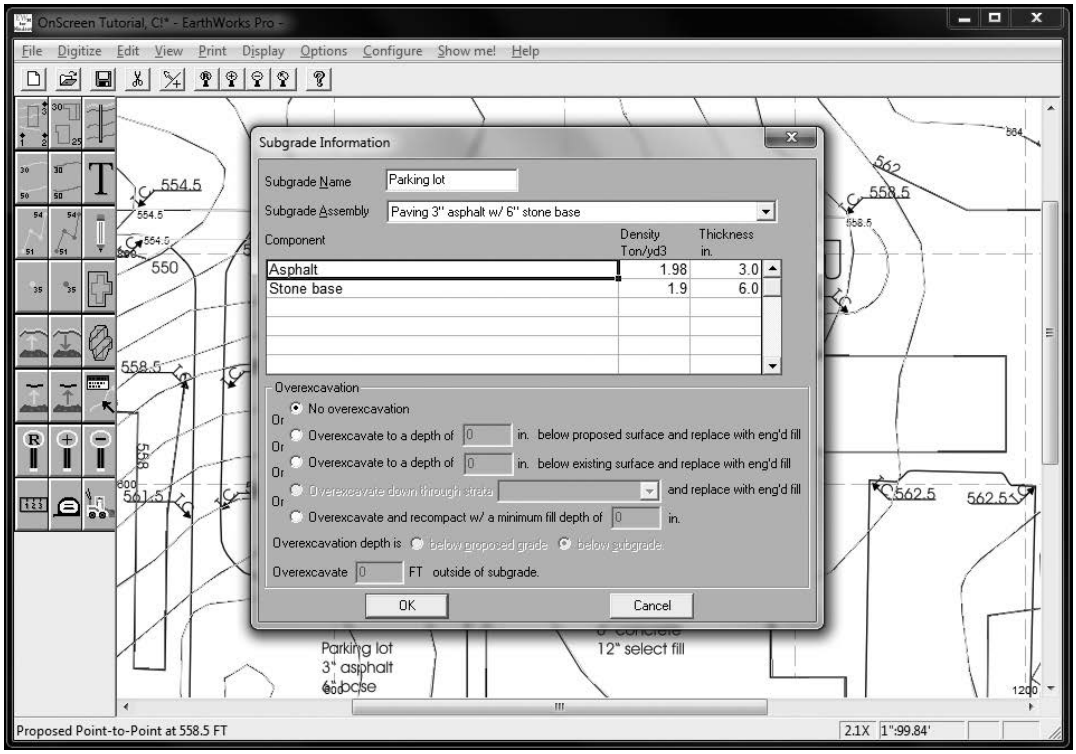

Figure 16-7
Add a name and description to proposed areas

plan to strip. See Figure 16-8. This will physically lower existing elevations throughout the entire work area to subgrade elevation in the program. Keep in mind that this means that on your summary page, the cut required for the project won't include the volume of the topsoil stripped. Be sure to keep demolition areas separate from the topsoil stripped area to avoid having overlapping areas on the same surface.

Replace Topsoil

You can replace topsoil by tracing all of the "green" areas on the site, then lowering the proposed elevations in those areas. In some programs, after the site perimeter has been entered, you can kill two birds with one stone by using a function that strips the entire work area and replaces topsoil only in the "green" areas. See Figure 16-9. The program knows where all of the proposed structure areas (slabs, paving, etc.) will be. But since this lowers all proposed elevations in all of the green areas, keep in mind that on the totals page, the fill required for the project won't include the volume of the topsoil replaced. When bidding a project with alternates, you'll need to strip and replace topsoil in each area, so that the summary page will show the volume of topsoil stripped and replaced in these areas.

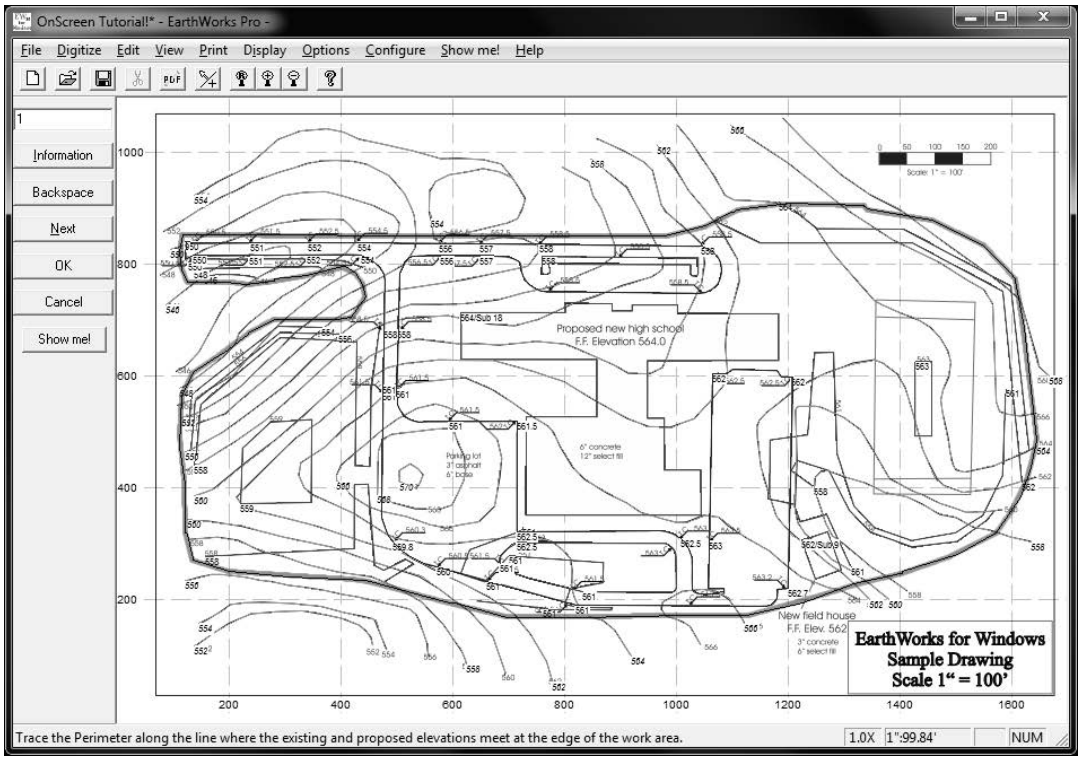

Figure 16-8
Trace the site perimeter

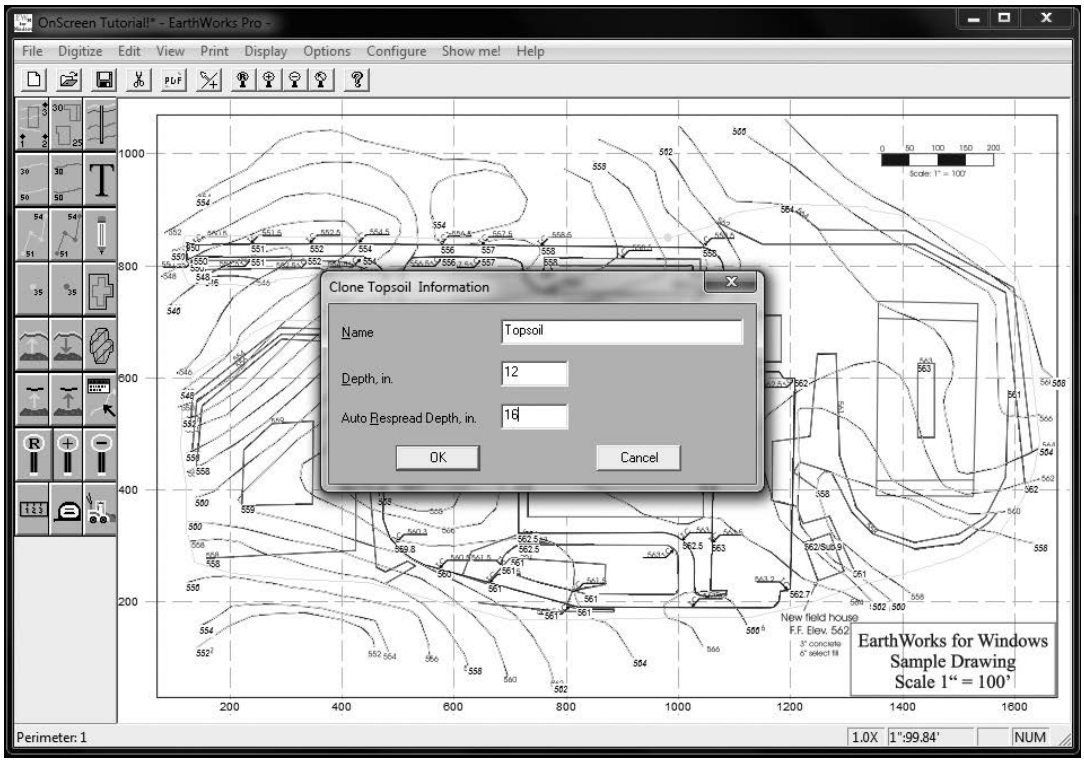

Figure 16-9
Stripping and replacing topsoil

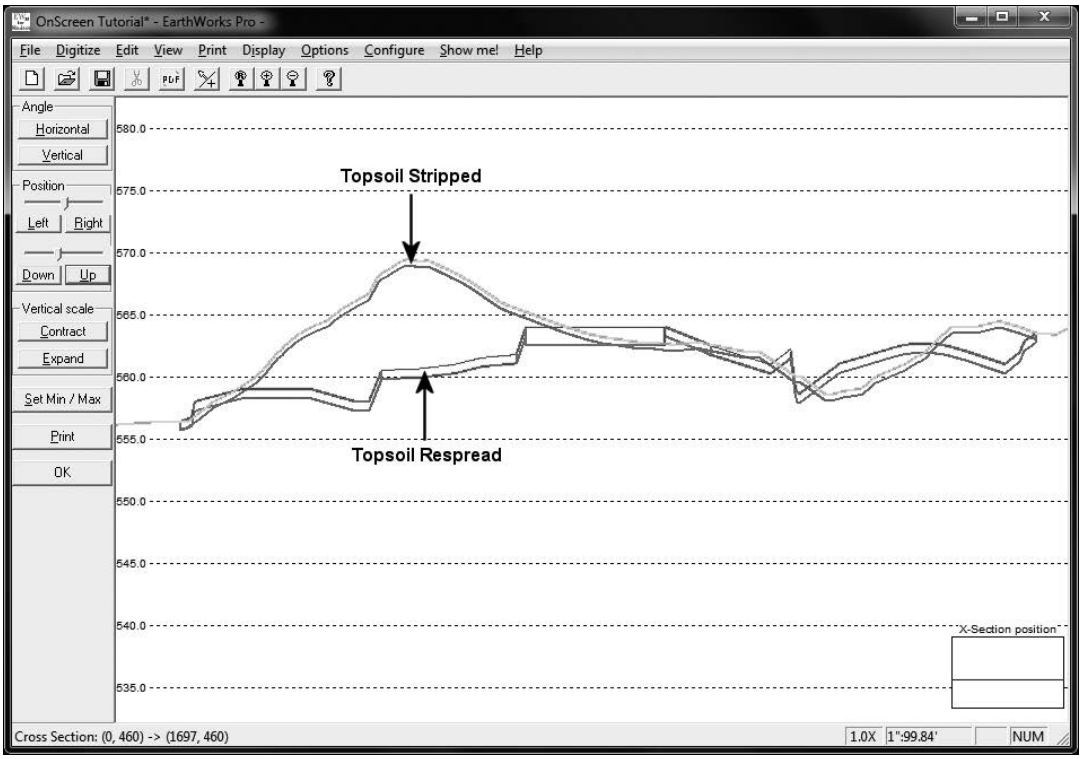

Figure 16-10
Cross-section view

Verify Your Take-off

There are several tools you can use to verify the accuracy of your take-off, including a cross-section view, existing color map, proposed color map, cut/fill color map, or the 3-D views for the existing and proposed surfaces.

Figure 16-10 shows a cross-section view taken in the parking lot of our proposed project. You can see the existing surface before and after the topsoil is stripped, the proposed surface including the top of asphalt, as well as the level of fill and topsoil to be respread. Figure 16-11 shows a color map indicating areas requiring cut and fill. On any color map screen, clicking the mouse in the colored area of the screen will display the data about that point on the sidebar. In this program, a red shade indicates areas requiring cut and blue shade indicates areas requiring fill. (Unfortunately, our picture in Figure 16-11 doesn't show color, so you can't get the full effect of what is being shown.) Figure 16-12 shows a 3-D view of the proposed surface. You can also display a 3-D view of the existing surface.

These views allow you to watch for unusual spikes on the surface that indicate an elevation was mistakenly entered too high or too low, or that "like" contours of differing elevations intersect. A saw-toothed-shaped line will indicated that two "like" contours with differing elevations were traced along identical paths. An unexplained feature such as a ridge line of a valley that shouldn't be there will be caused by a contour that was entered with an incorrect elevation.

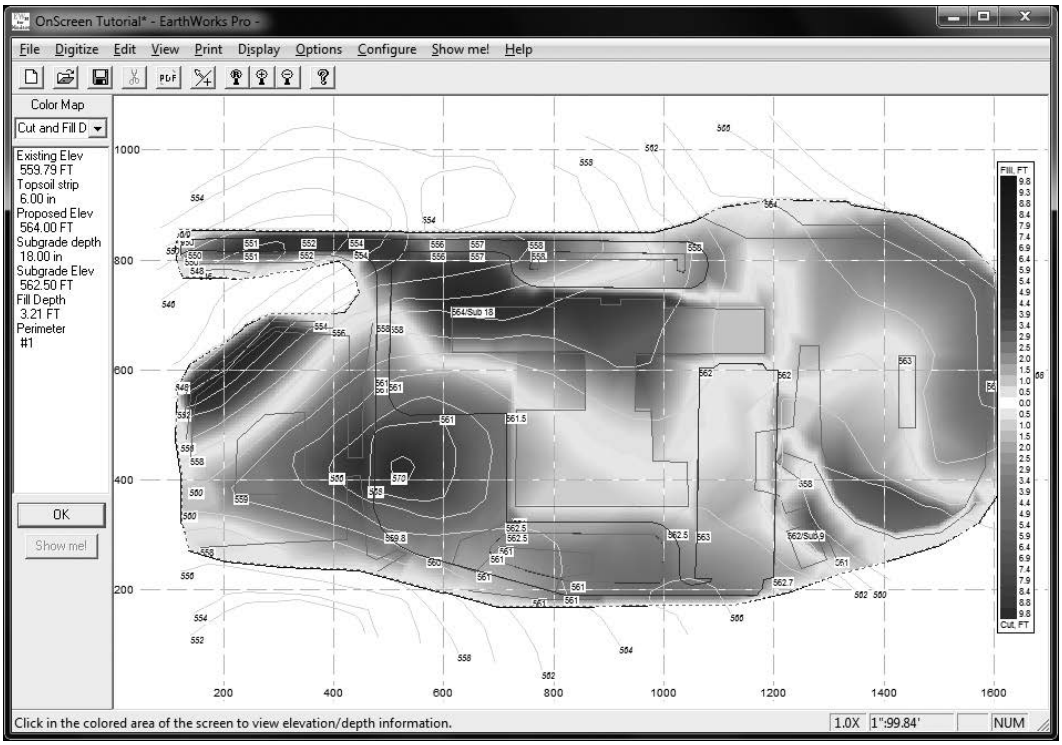

Figure 16-11
Cut and fill color map

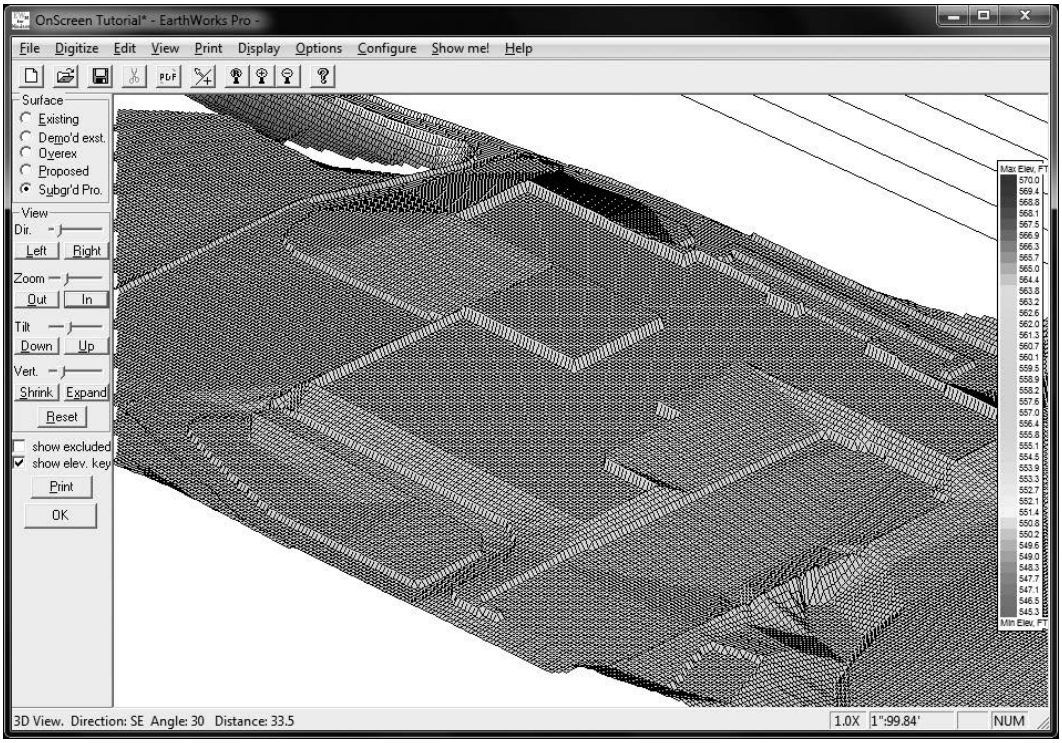

Figure 16-12
Proposed 3-D view

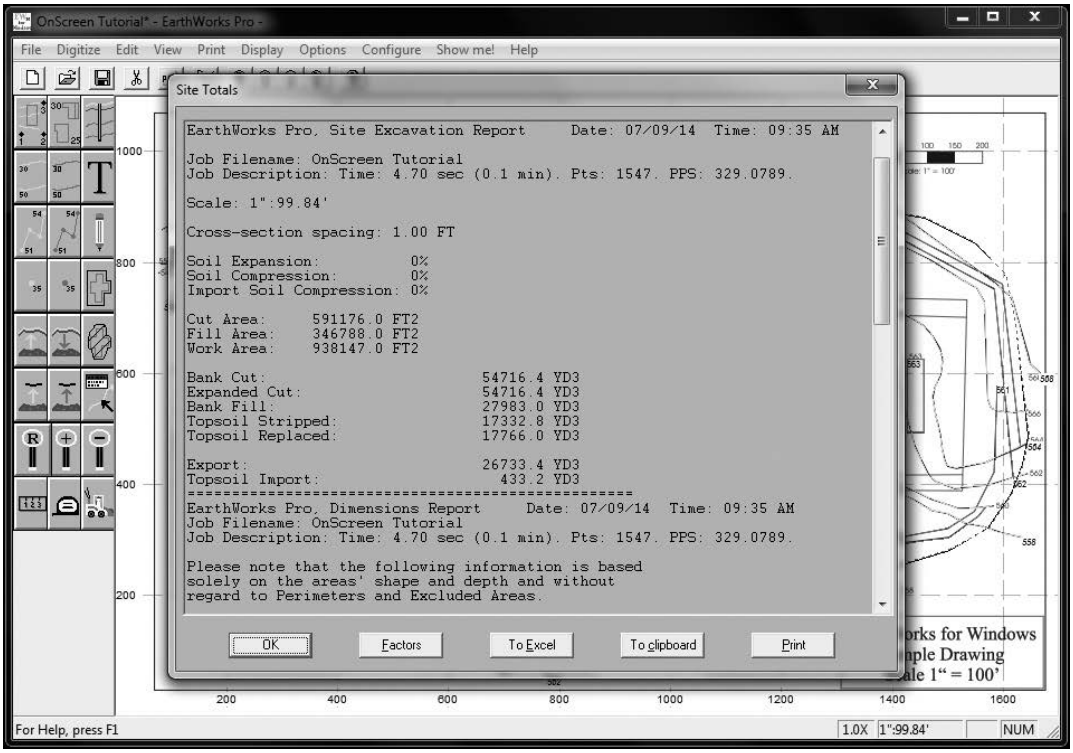

Figure 16-13
Summary page

Check the Totals

View the totals generated. After you enter all of the elevation and area information, you can go to a summary page showing the total work required. See Figure 16-13. Here you'll see that area information, as well as the cut, fill and topsoil volume information. At this point, you can add the soil expansion and compression factors (Figure 16-14). You can see in Figure 16-15 that this changes the results on your totals page. The totals page also gives you information regarding materials required, such as concrete, asphalt, stone base and select fill in terms of cubic yards and tons, as shown in Figure 16-16.

Balance the Site

There are occasions when you might want to balance the site in order to reduce the import or export required. There's a function that allows you to do this. See Figure 16-17. This feature allows you to balance the site manually, or automatically. You can also unbalance the site in order to return the site to its original condition. There's even an option to balance only the "green" areas, when it's impossible or unwise to raise or lower structure areas while balancing the site. Offering this suggested option in the bidding process could land you a job with a lucrative change order.

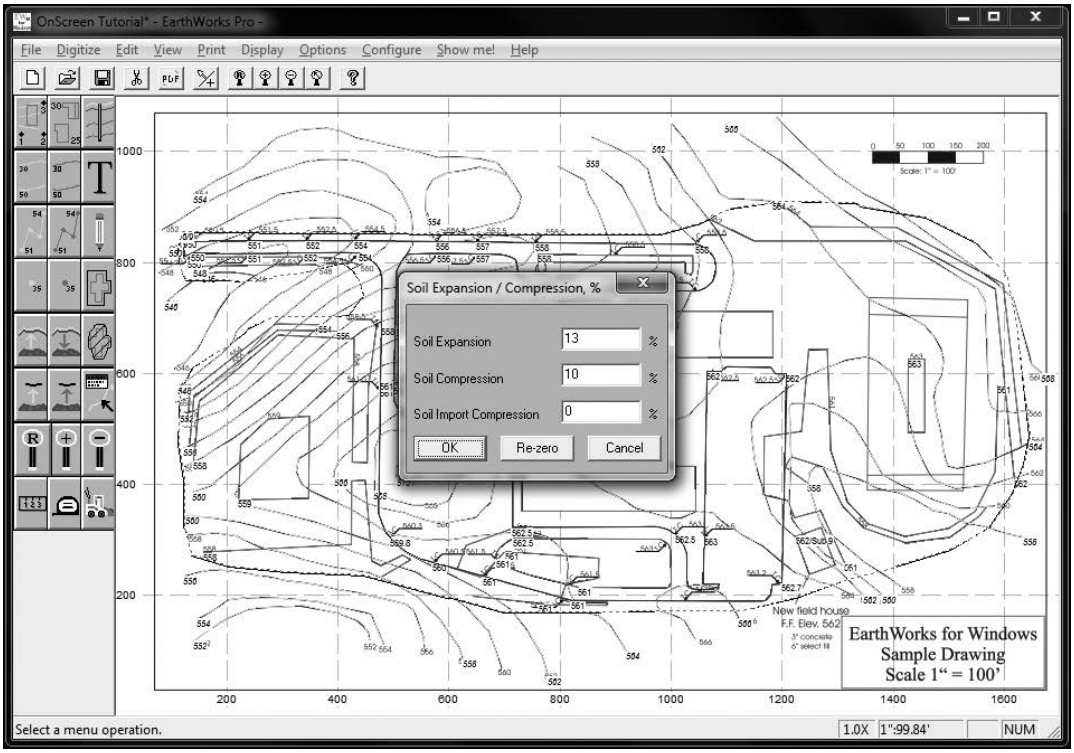

Figure 16-14
Add soil expansion and compression factors

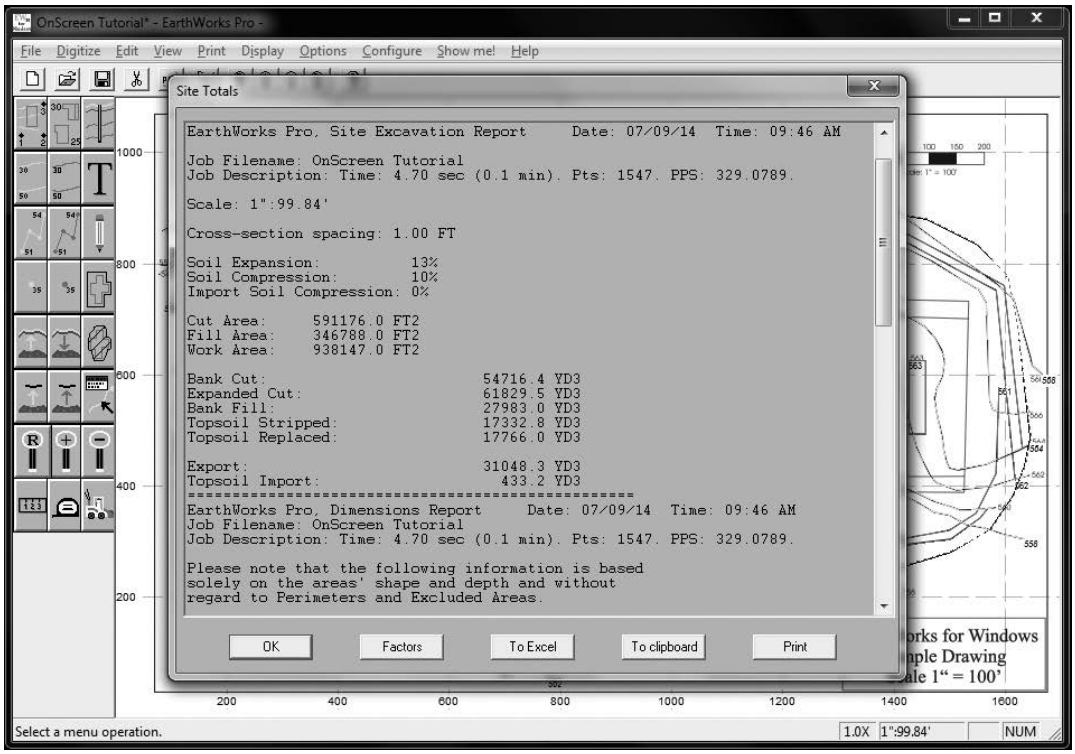

Figure 16-15
Summary page with soil expansion and compression factors added

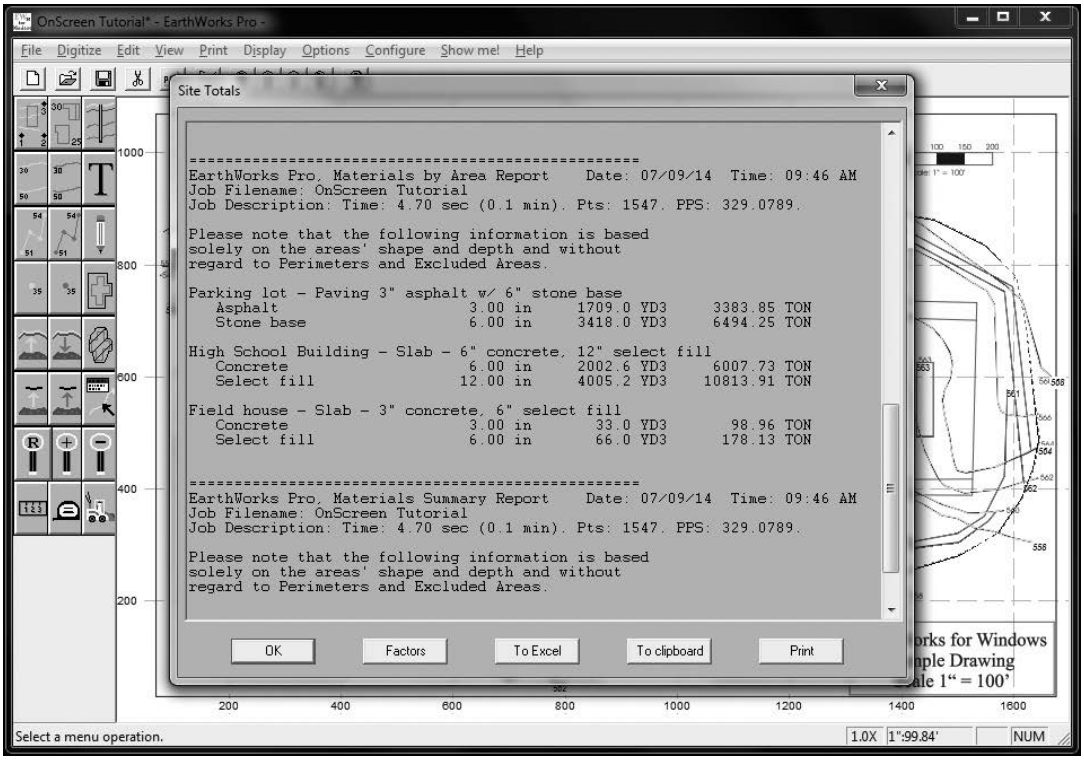

Figure 16-16
Summary page with required materials shown in cubic yards

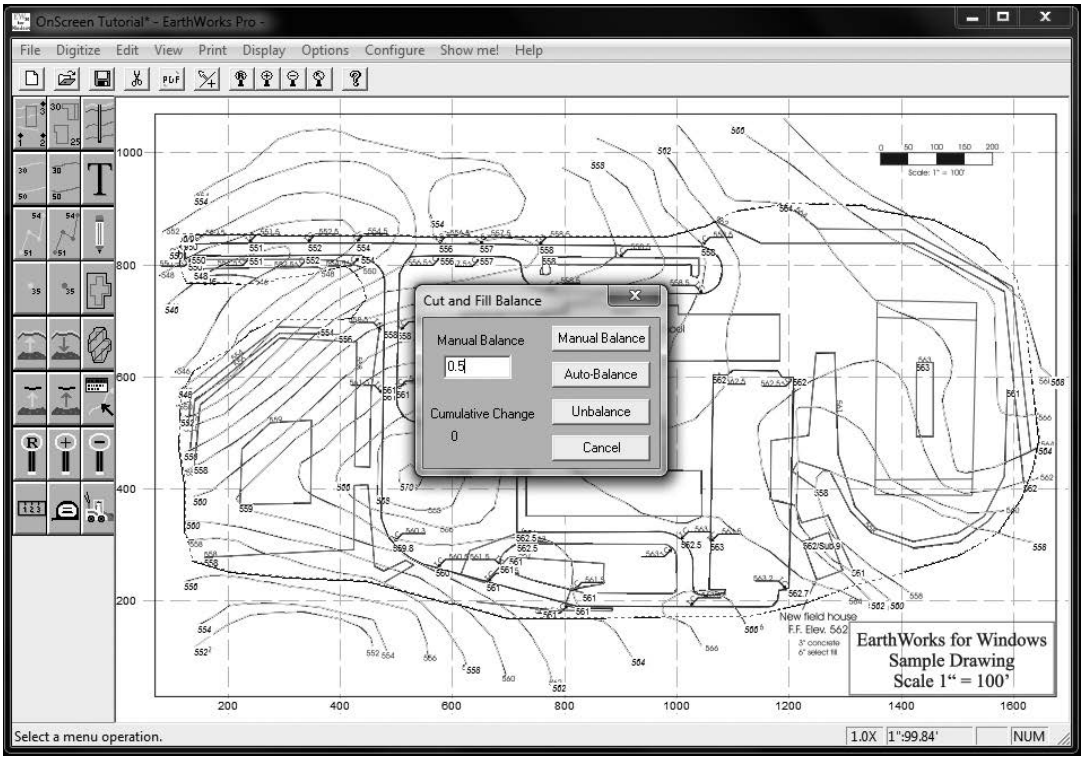

Figure 16-17
Balancing the site

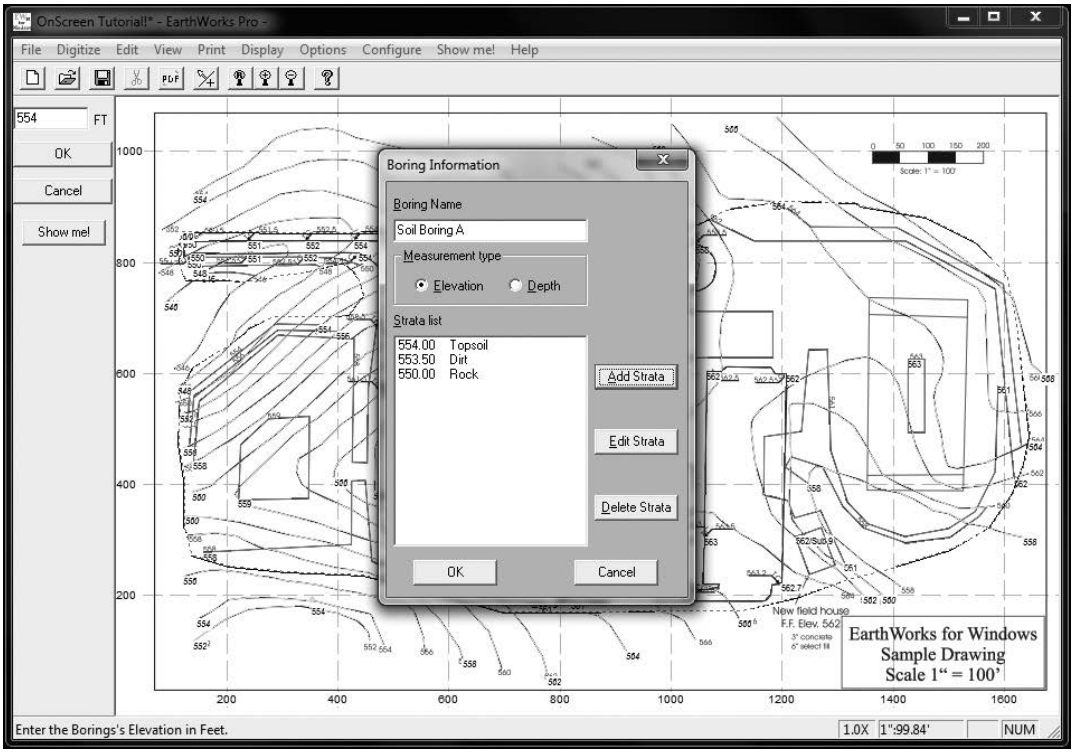

Figure 16-18
Enter soil borings

Enter Soil Borings

If you have a project with soil borings, you'll need to enter them, especially if there's an undesirable layer of material under the existing surface, such as peat, clay or rock. You need only one soil boring if that's all that's given on the project. To enter soil borings, digitize the location of each hole and enter the thickness or top elevation of each material in the hole, as well as whether the material can be used for fill, or if it's unusable and to be exported. The result will be that the cut volume shown on the totals page will be broken down into different materials, and the import quantities changed accordingly. Figure 16-18 shows a soil boring entered using the elevations at the top of each layer of strata. When you've entered all of the soil borings, the volumes of the different layers to be excavated will appear on the totals page (Figure 16-19). And, the cross section views will also indicate where the subsurface layers exist. See Figure 16-20.

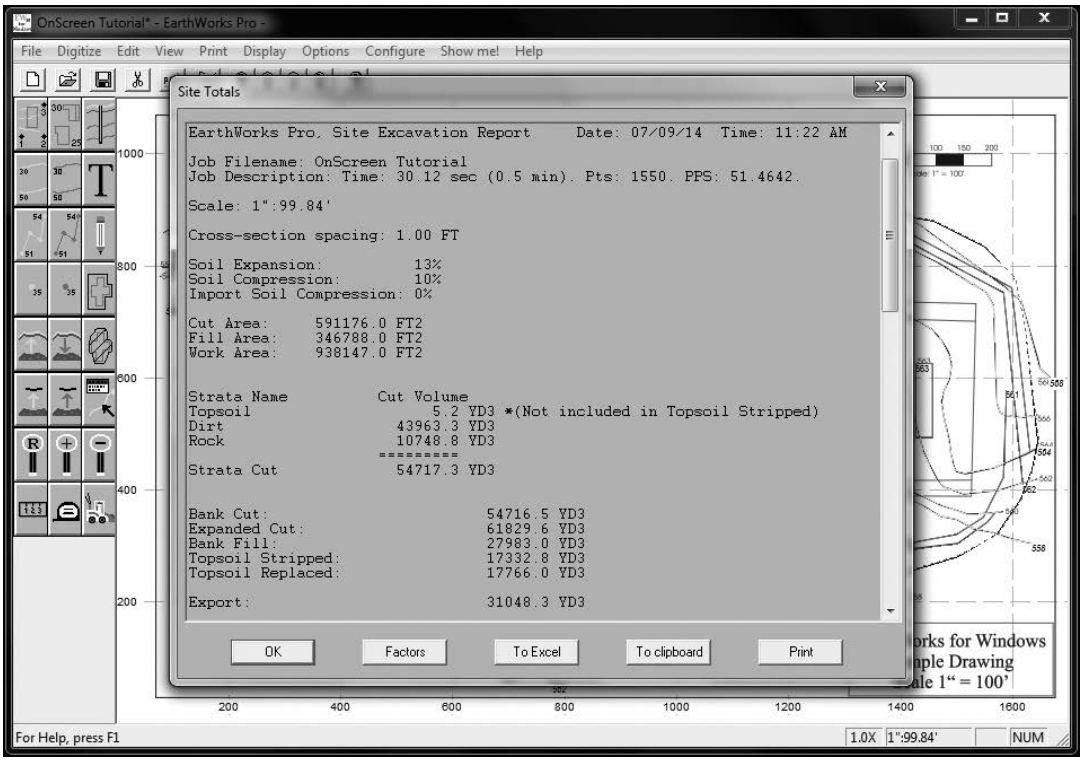

Figure 16-19
Summary page with soil boring information

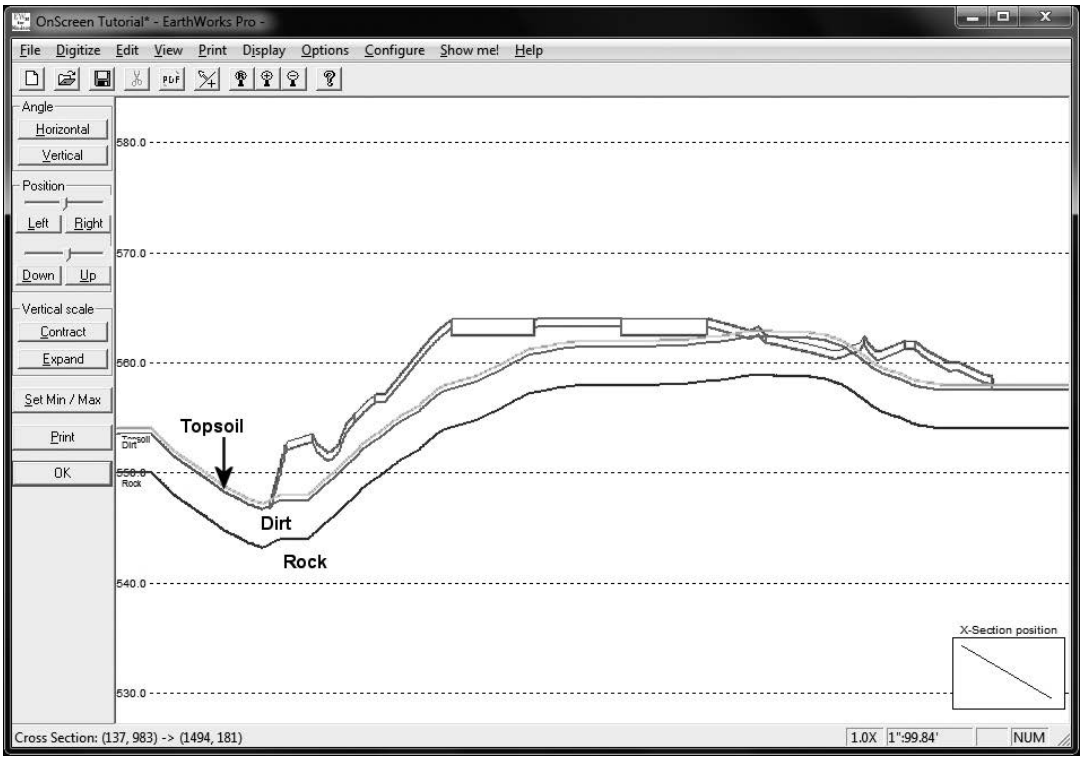

Figure 16-20
Cross-section view with soil strata

Working with Plans on Separate Sheets

Whether you're working with an ST or MT program, some projects can be a real challenge. For example, I've seen projects where existing elevations are drawn on one sheet at one scale, and the proposed elevations on another sheet drawn at a different scale. When this happens, it's well worth your time and expense to go to a print shop and have one of the drawings resized so both drawings are at the same scale. You can then place the existing elevation plan on the board and place the proposed elevation plan on top of it. If you tape the left edges of the drawings together, you can enter the existing data given on the top drawing, turn the page and enter proposed data on the other. You can then return to the existing elevation drawing again without having to relocate it. Before you tape the drawings together, align both drawings by placing them up against a large glass, such as a sliding glass door, and overlay the features common to both drawings.

Some projects are so large that they're drawn on many different plan sheets. I've often taped drawing sheets together if they'll fit on the board. The "merge drawing" feature will allow you to add sheets to the take-off. This can be faster and more convenient than going to a print shop or taping drawings together. Many times, you'll have to work with phased projects, or projects with several alternates, and those areas must be entered as separate entities.

To merge two drawings, do separate take-offs and save each file. On each drawing, locate and digitize two landmarks common to both drawings, such as two corners of a slab. When the merge drawing feature is accessed, you instruct the program which drawings to merge in order to bring the drawings together within a single file. Be careful to enter every item on each sheet before you merge them, because you have to reverse the process in order to go back to the original drawing and add the missed information.

After you're satisfied with your totals, you can export the results to an Excel program to be priced out. See Figure 16-21.

Importing CAD Drawings

The most modern earthwork software allows you to import computer-aided drawings (CAD files). It's an amazing feature that can save you a tremendous amount of time in most situations, but they're no "free lunch." CAD files are crafted by the CAD operator to be optimally "read" by the human eye and NOT by another program. These programs are built in layers of lines and text, so you have to determine which layers contain existing and proposed elevations from the list of layers making up the drawings. You often have to make this determination through trial and error. Typically, the existing elevation information is good, since it's normally generated from surveying programs. The problem starts when the CAD operator starts entering the proposed

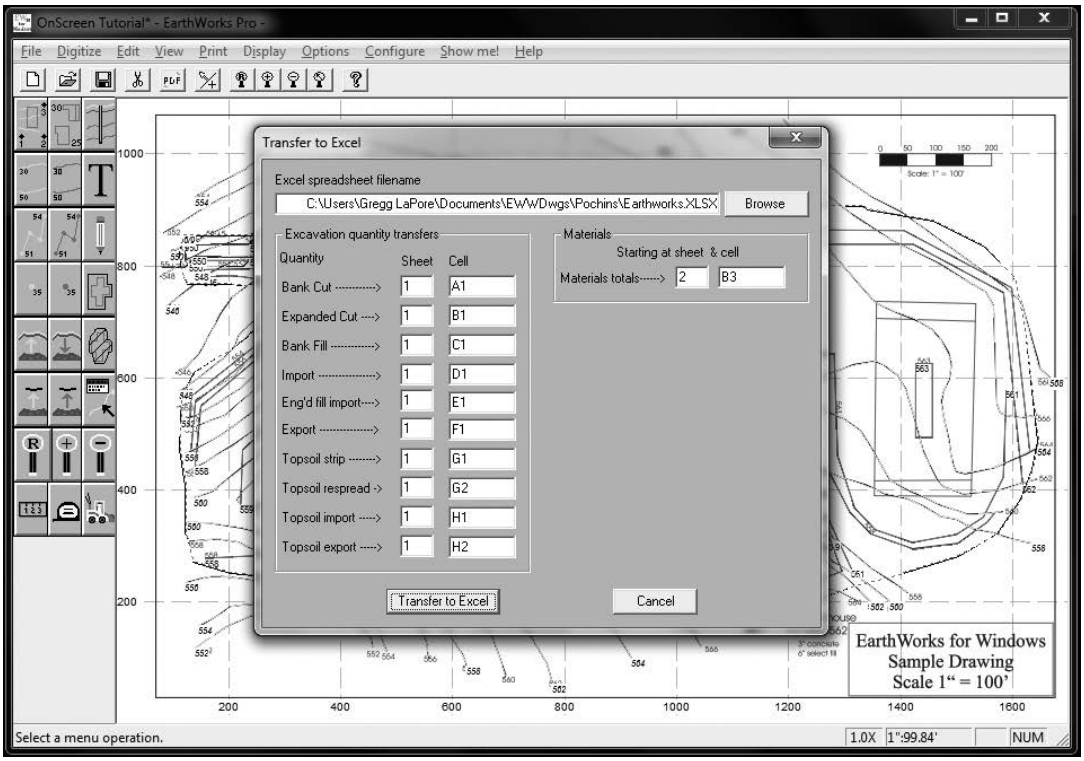

Figure 16-21
Export totals to Excel

information. The goal is to make the drawing as readable as humanly possible, so the operator will typically put in the proposed contours as lines with 0.0 elevations, along with text labels for the elevations. That way, he can control how the proposed elevation text is displayed. Spot elevations are typically entered with an "X" or a cross with a text label nearby rather than a point elevation. Each proposed contour, along with the text showing the elevation, must be selected and assigned a correct elevation. However, once this is done, the lines or points won't have to be traced. This usually makes the take-off more accurate, and saves time.

CAD programs don't have any concept of areas, but only lines; buildings are just outlines with the finished floor elevation as text in the center. Buildings are often drawn in a layer separate from contours, so when this layer is brought into the drawing, it often also contains other architectural features, such as door swings, stairs, toilets, etc. You'll want to delete these items from the site plan.

AutoCAD has no concept of subgrades, topsoil areas or borings. You'll have to enter all these into the program separately.

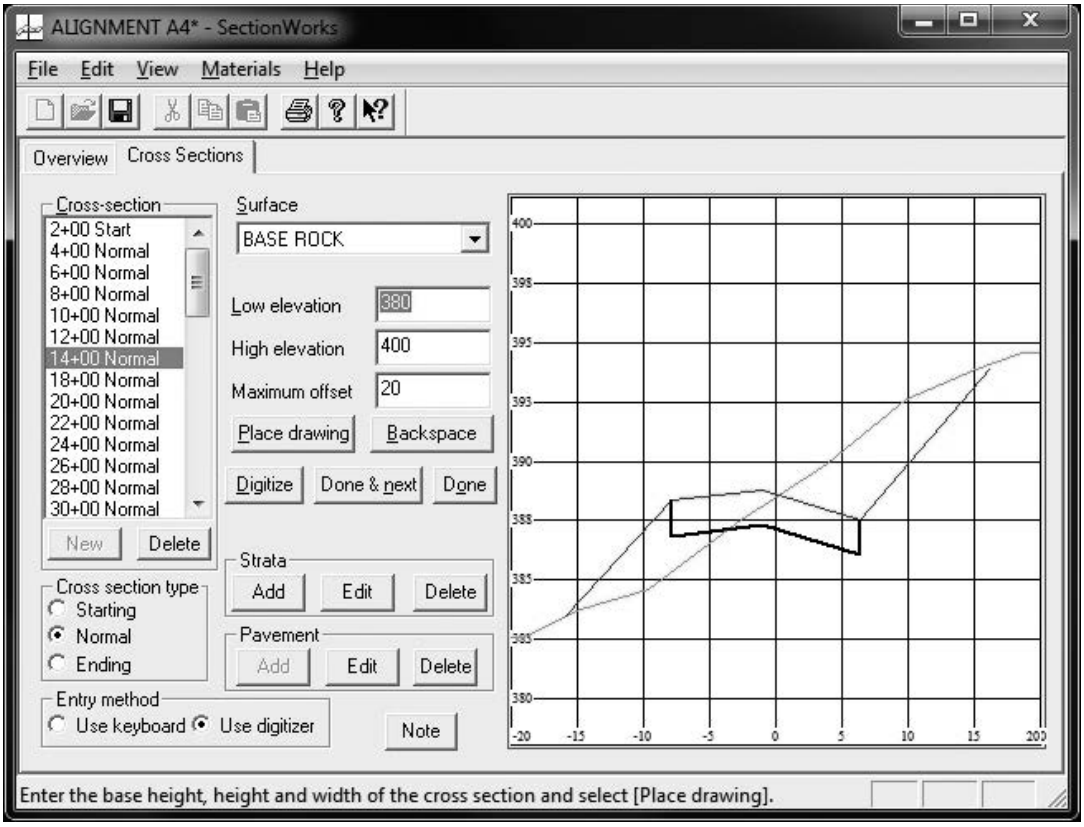

Figure 16-22
Cross-section template

Additional Programs

There are two more programs I want to discuss briefly. They are the cross-section and trenching programs.

In the cross-section software, you open a job, give it a name, enter the scales (horizontal as well as vertical), and locate the drawing field. You enter the starting and ending station numbers, as well as the station interval (distance between cross sections). You'll then create a cross-section template indicating the road materials to be used. See Figure 16-22. After you digitize each cross section, you can view the total material quantities, road profile (Figure 16-23) and a mass diagram of the project (Figure 16-24).

Using the trenching software, you open a job, give it a name, enter the scales (horizontal as well as vertical), and locate the drawing field. You create a trench template indicating the type and size of pipe, trench width, side slope and types and thicknesses of bedding material, as shown in Figure 16-25. You then create a manhole template in

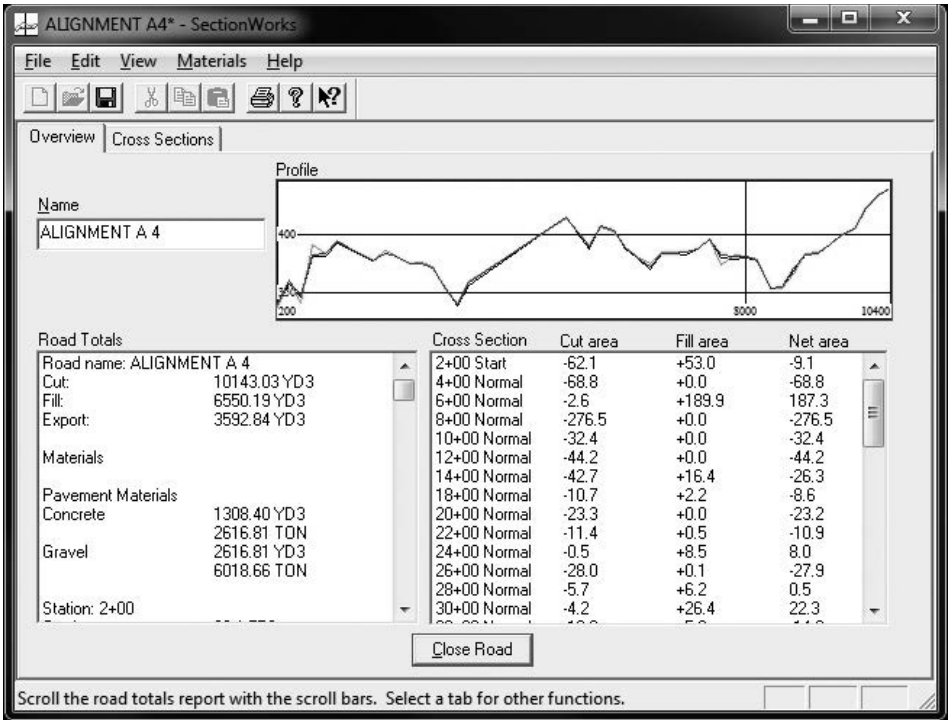

Figure 16-23
Road profile and material quantities

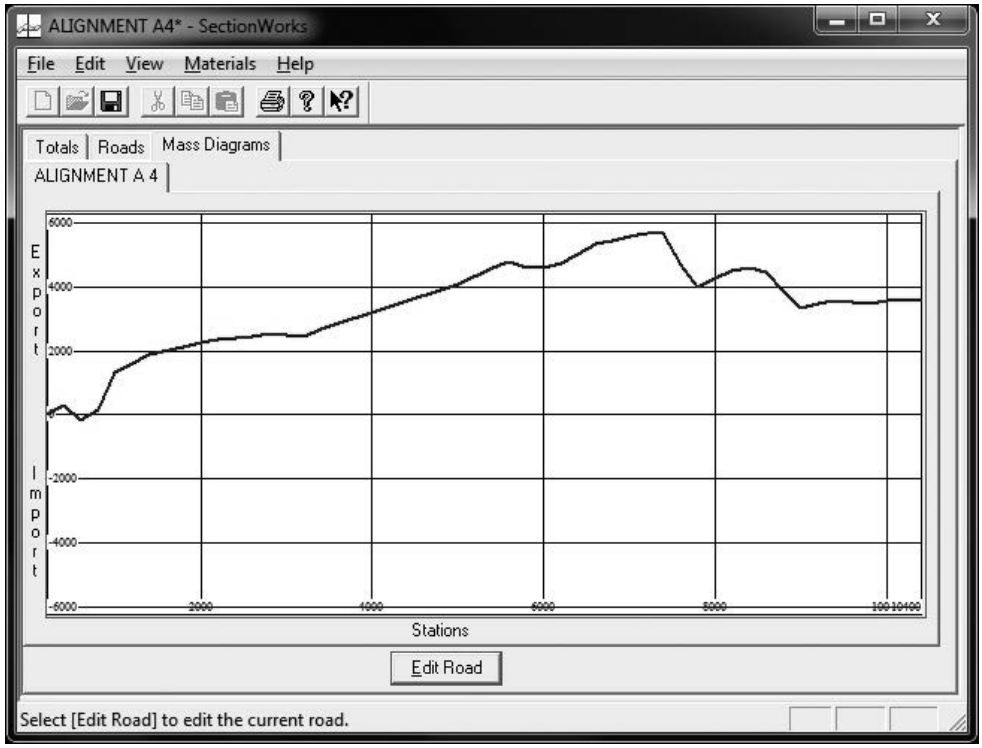

Figure 16-24
Mass diagram

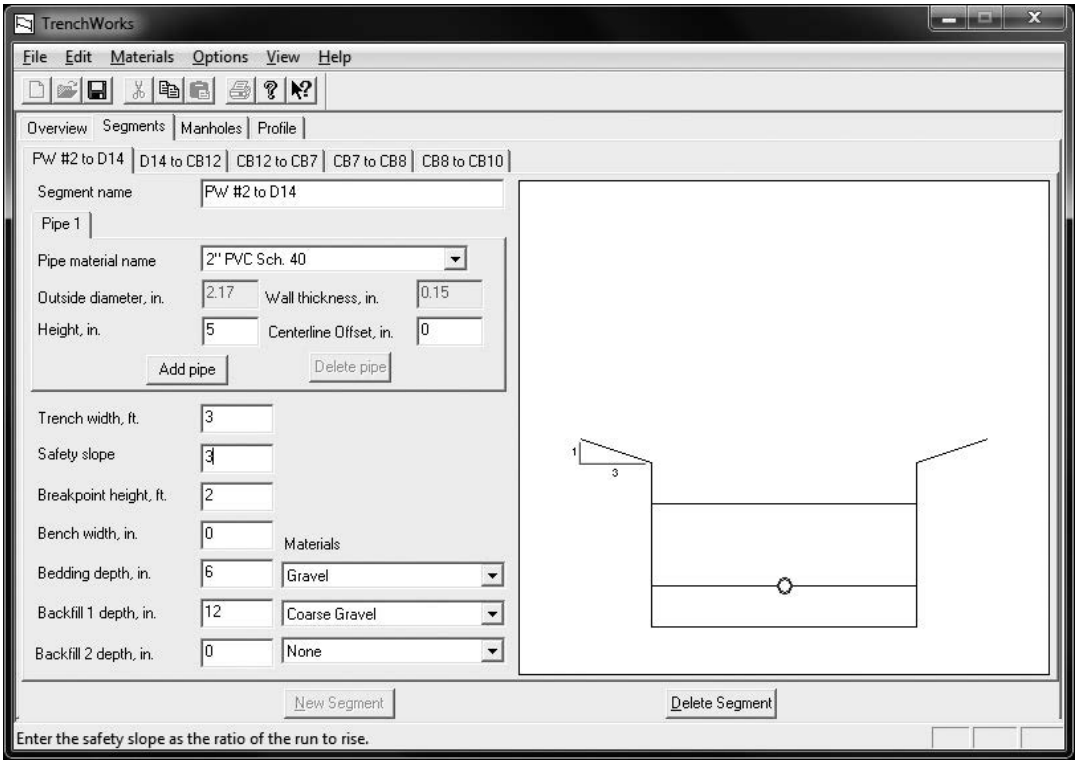

Figure 16-25
Trenchwork template

a similar way (see Figure 16-26). After you digitize the pipe from manhole to manhole, and your totals are calculated, you'll have a profile view of the project, as well as the total quantities of cut, fill and road material required for the project. Figure 16-27 shows the summary page.

Solving Complex Earthwork Problems with Software

Earthwork software will enable you to solve many real-world problems that would be extremely difficult to solve by hand. Here are some examples.

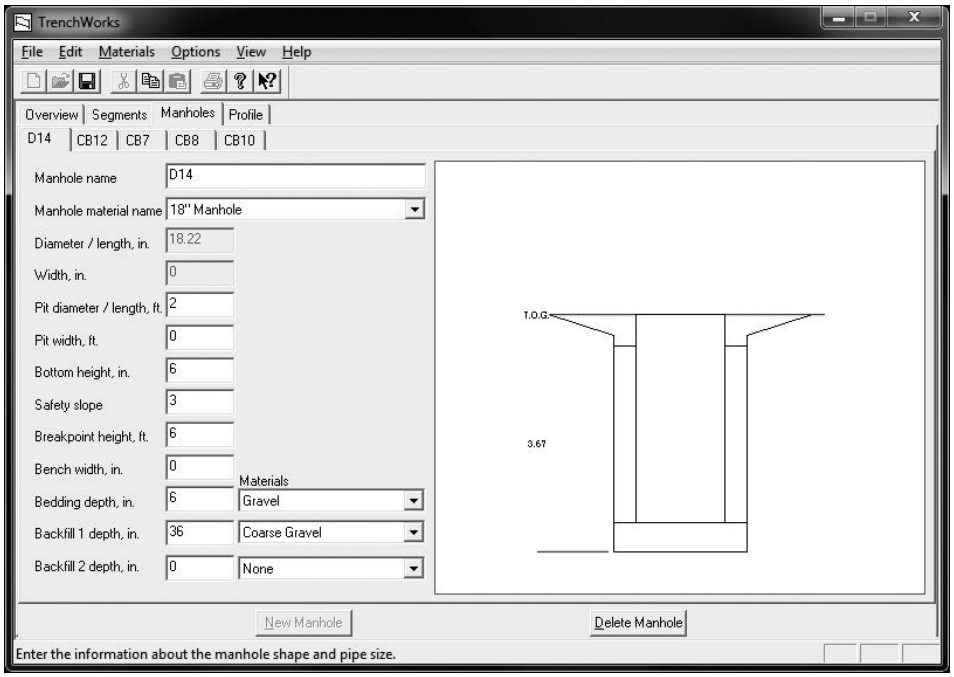

Figure 16-26
Manhole template

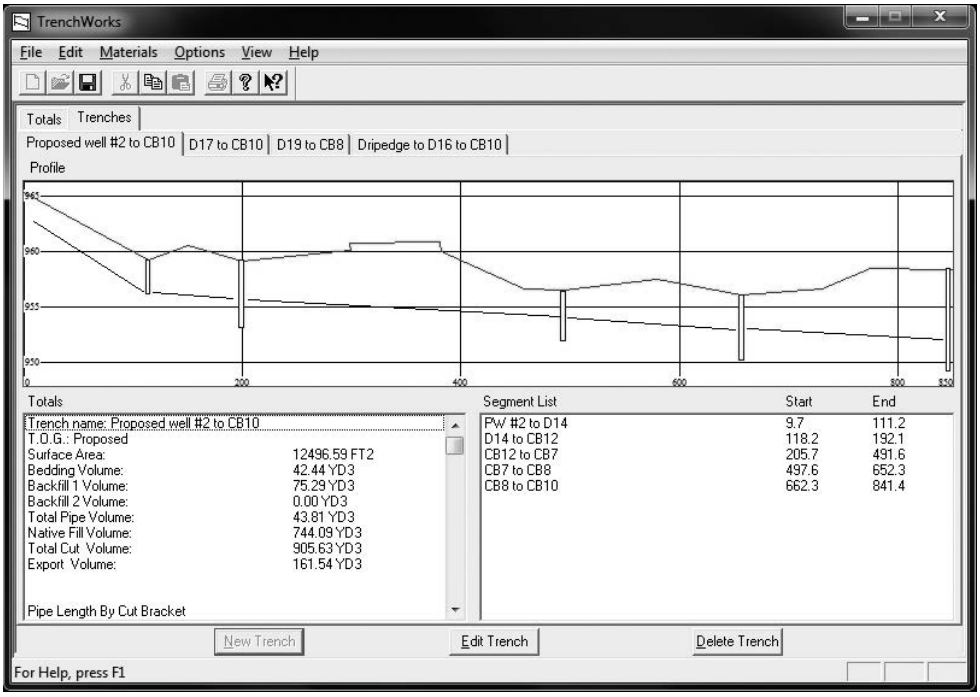

Figure 16-27
Trenchwork summary page

Where Ground Water Will Be Encountered On a Site

If you have soil borings or test pits that indicate the depth at which ground water will be encountered on a jobsite, perform the following steps to determine the volumes of various layers encountered, as well as the location(s) where the ground water will be encountered:

1. Do a normal take-off of the project.
2. Enter the soil boring information in only two layers: dirt and water.
3. Enter the thickness of the "dirt" from the ground surface to the top of the water, and enter the thickness of "water" at 3 inches (0.25 feet) thick.
4. Open the proposed color window, using "water" as the active layer. Any red shading will indicate locations where the ground water will be encountered.

Determining a Rock Surface Blasting Area

When you have to blast rock, you must excavate down to the rock and set up a grid pattern of blast holes to be drilled and loaded with explosives. Since the number of blast holes required depends on the surface area of the rock, you'll need to know the rock surface area to be blasted. You'll also want to know the volume of rock to be blasted.

To accomplish both goals, enter all substrata information in the soil boring window. The cubic yards of blasted rock will then show up in the summary window.

You can obtain the surface area of the rock using the following procedure:

1. Select the rock layer as the active layer.
2. Open the proposed color window.
3. Estimate the area with red shading. This will give you the surface area of rock to be blasted.
4. Open the totals report and read the Rock Cut volume from there to verify your estimate.

In Conclusion

Most dirt estimators use digitizer boards and earthwork software to calculate cut and fill volumes. I use a digitizer myself when doing consulting work, and recommend this approach. Today, nearly all excavation estimates are prepared with a computer. But

no computer program is a substitute for good judgment and sound estimating practice. Finding the centerline of a sloping surface in a basement requires hands-on knowledge based on experience. For several years I was an instructor of computerized earthwork estimating. And, as an instructor, I recognized that those who came to class with experience doing earthwork take-offs by hand consistently made better use of their software.

This chapter will help prepare you for the present and future solutions of earthwork take-offs. But always keep in mind that the best of the earthwork estimators also understand how to solve these problems without software, because the hands-on solutions are the ones that give you the knowledge.

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