$35.00

Pipe & Excavation Contracting Revised

by
Dave Roberts

Revised by
Dan Atcheson

Craftsman Book Company
6058 Corte del Cedro / P.O. Box 6500 / Carlsbad, CA 92018

Acknowledgements

The author wishes to express his appreciation to the following companies and organizations for furnishing materials used in the preparation of various portions of this book:

John Azar, Azar & Co., LLC, Sarasota, FL

Terry Newman, Glen Rose, TX

Don Bundock, Lubbock, TX

Caterpillar, Inc., Peoria, IL

Richard Johnson, R.E. Johnson Enterprises, Sarasota, FL

Dymax Construction Equipment, Wamego, KS

Wacker Corporation, Menomonee Falls, WI

Rome Plow Company, Cedartown, GA

Ardaman & Associates, Inc., Sarasota, FL

Woodruff & Sons, Bradenton, FL

Joe Sorace, Sarasota, FL

Trench Shoring Services – Orlando, Orlando, FL

Strayer Surveying and Mapping, Inc., Venice, FL

TT Technologies, Inc., Aurora, IL

Terry Jacobson, S.O.S. Septic, Englewood, FL

EBAA Iron, Inc., Eastland, TX

The Ford Meter Box Company, Inc., Wabash, IN

CST/berger, Watseka, IL

Allied Construction Products, LLC, Cleveland, OH

Ferguson Waterworks Sarasota, Sarasota, FL

Ken Gallup, Florida Excavations, Inc., Venice, FL

McLeod Land Services, Sarasota, FL

Richard Langedyk, Construction Estimating Institute of America, Sarasota, FL

James Edward Atcheson, AIA, 1906-1986

Glenn Hadley Thomson, Estimator, 1922-2005

This book is dedicated to all who help with, or offer homes to, orphaned pets.

Edited by Ben Moselle and Michelle Striler; Template Devona Quindoy, dqartdesigns.com and Joan Hamilton; Layout by Christine Bruneau; Cover design by Bill Grote

CONTENTS

1 Estimating, Bidding, Bonding 5

Starting at the Beginning 6
Nature of the Business 8
The Design Engineer 9
Knowing Your Costs 13
Watching Your Profit 27
The Estimate 30
Preparing and Submitting Your Bid 36
Controlling Costs 42
Getting Bonds 44
Contract Pitfalls to Avoid 47
Prequalifying for Bonds 52

2 Crew & Equipment Productivity 59

Trench Excavation Quantities (Volume) 60
Equipment Performance 64
An In-Depth Review 69
Comparing Crew and Equipment Costs 95

3 Reading Plans & Surveying 105

Reading Plans 106
Surveying 110
Lasers 121

4 Site Preparation 129

Clearing Grass and Brush 129
Clearing Trees 130
Site Preparation and Material Layout 137

5 Operating a Backhoe 141

How Wheeled Backhoes and Trackhoes (Excavators) Work 142
Calculating Backhoe Production Rates 146
The Wheeled Backhoe 149
Working Around Crosslines 151
Hard Digging 154
Sewer System Work 155
Water System Work 156
Using the Front Bucket 160
The Track Excavator (Trackhoe or Track Backhoe) 163
Trenchless Construction 176

6 Soil Compaction 181

Soil Structure 182
Determining Soil Density 182
Compaction Methods 186

7 **Installing Water Systems** .. 195

Water Pressure and Thrust 196

Pipe Materials................................ 198

Selecting Equipment 198

Forming a Crew 200

Installing Service Lines.................. 203

Joining New and Existing Service Lines................................ 206

8 **Installing Sewer & Stormwater Systems**..... 211

Septic Tank Systems and Drainfields............................. 211

Municipal Sewer Systems 218

Backfill, Compaction and Surface Restoration...................... 251

9 **Estimating Surface Excavation**.............................. 253

Calculating Area............................ 254

Calculating Volumes of Solids........ 255

Reading Contour Lines 257

Estimating Cut and Fill Quantities with the Cross Section Method.... 259

The Average End Area Method 262

The Zero (Daylight) Line 264

Topsoil.. 266

Cut and Fill Volumes Under Slabs and Paving.................................... 269

Earthwork Estimating Accuracy ... 270

Minimize the Risks......................... 271

10 **Dealing with Rock & Groundwater**.................... 275

Rock.. 275

Ripping and Rock Work 279

Working in Groundwater 290

11 **Pipe Materials** 297

DWV and Pressure Pipe................. 297

Size or Material Change and Directional Fittings............... 308

Gaskets... 311

Water Control Fittings................... 313

Joints.. 314

Repair Clamps 318

Index... 321

1

ESTIMATING, BIDDING, BONDING

Pipeline contracting can be a very rewarding business — if you know what you're doing and do it right. It's less plagued by the economic cycle that pushes many excavation and construction contractors to the brink of bankruptcy when the market for residential and commercial building dries up. And the profit margins are usually better because it's harder to get started in this business. You need money, manpower, skill and knowledge to get into sewer, water and drainage line contracting. That limits your competition and can fatten your margins.

Just owning a backhoe doesn't make you a pipeline contractor. There's far more to it than simply digging a hole and filling it up. If you've considered pipeline work but have never done any, keep reading. This book is for you. If you've bid some pipeline work but aren't satisfied with the results, the tips and suggestions in this manual may be just what you need to succeed where others are striking out.

True, every pipeline contractor (or utility contractor, as we're sometimes called) needs special skills, know-how and expensive equipment. But if you can estimate accurately, pay close attention to your costs, keep your overhead low, do nothing but quality work and eliminate wasted time and materials, you've got a good chance of making it in this demanding business.

Understand from the beginning that Rome wasn't built in a day. No one jumps into this field and makes big money handling multi-million-dollar jobs right from the start. You're going to have to crawl before you walk and walk before you run. But if you've got the determination to work hard, and if you're willing to take the time to study and understand what I've written here, you're well on your way to a good professional career.

Nearly all utility line work is awarded by competitive bid. If your bid is too high, you won't get the job. If your bid is too low, you'll get the job but lose your shirt. A few jobs like that and your company will go belly up.

Every year, hundreds of men and women set out to become underground utility line contractors. Many were making good wages as tradesmen, equipment operators or supervisors in the business, and decided to try their hand at bidding and contracting for the work they did formerly as wage earners. Unfortunately, most don't survive more than a few years in the business.

But don't let the failure of others discourage you. The fact that you're reading this book shows that you plan on going into the business as an *informed* entrepreneur. And if you're already in the business, it shows you plan on finding out what to avoid by studying *my* mistakes instead of making your own. Work with care, both at your estimating table, and on the jobsite. With the information in this book, and, I can't deny, with a little bit of luck, you can have a successful and profitable underground utility contracting business.

There's plenty of work available if you're willing to move, be flexible, work long hours and accept challenges. The private developers of residential and commercial projects need utility contractors. Governing bodies — the U.S. Forest Service, the Bureau of Land Management, the Soil Conservation Service, military bases — all are regular customers. And many government contracts require that a percentage of the contract be let to small businesses or minority-owned businesses.

While this book is primarily aimed at the underground utility contractor, be aware that you can get a wider scope of work if you're willing to compile bids and manage contracts that contain other kinds of work, such as mechanical, electrical, and building work. As a small contractor, you'll get a lot more business if you're willing to take on contracts that are more complex than a simple pipe job. Move into unfamiliar areas very cautiously, however. Use reliable subcontractors and beware of getting into fields that are too far beyond your experience and knowledge.

Starting at the Beginning

In this book, I'll describe all the common pitfalls and how to avoid them. We'll take a detailed look at the practical know-how you'll use on the job every day — estimating and bidding, equipment and crew performance, practical work methods and techniques, equipment operation, surveying, site clearance, compaction, water systems, and sewer systems. In short, I'll cover everything a utility line contractor needs to know to thrive in this business.

You'll need a working knowledge of the skills of the four important professionals on every utility line team: the pipe layer, the equipment operator, the foreman and the contractor. The success of your company depends on how well each of these four works together toward a common goal.

The Pipe Layer

Laying pipe can be simple work, but that's more the exception than the rule. Crosslines, groundwater, rocky soil or a combination of these will usually complicate the work. Installing miles of pipe exactly right and at a fast pace is no easy task. Your pipe layers especially can make or break you. I'll explain this important task in detail later.

The Equipment Operator

Modern earthmoving equipment can be maneuvered as easily as your family car. But that isn't the whole story. The trick is to get *maximum productivity* from each man and machine hour. Many heavy equipment operators are careless or have only average skills. As an underground utility contractor, your survival depends on finding and keeping highly skilled, experienced, and motivated operators.

The Foreman or Superintendent

Another name for the foreman, superintendent or crew leader is *pusher*. A good pusher knows utility line construction backwards and forwards. He (or she) probably worked as a pipe layer and equipment operator before becoming a supervisor. It's much easier to supervise work if you've done that kind of work yourself. There's no substitute for practical experience.

Most of a superintendent's time is spent dealing with minor catastrophes so the job stays on schedule. Bad weather, machinery breakdowns, wrong materials deliveries — anything that can go wrong — is his problem. And at the same time, he has to stay on good terms with his crew, the engineers, the inspectors, the owner, and the public, while trying to get each to do what they should at the time and place they should be doing it.

In the final analysis, a superintendent's chief job responsibility is making sure the project finishes on time and under budget. If it does, nothing he did along the way makes much difference. If it doesn't, all the excuses he can think of are irrelevant. A good superintendent is worth his weight in progress payments. If you have a good superintendent and can't keep him up to his eyeballs in work, send me his name and phone number. I'll take it from there.

The Contractor

You need to know everything a good superintendent knows, plus lots more: taxes, insurance, handling personnel problems, borrowing and investing, estimating and bidding, hiring and working with reputable professionals, and then some. Your job is the biggest and most difficult of all.

By now you should see that underground utility contracting is demanding and risky work. All construction contracting is. But underground work is especially risky. And the highly competitive nature of utility line work doubles the risk for all players.

The potential rewards are in proportion to the risk, however. Some utility line contractors have retired at a relatively early age with enough earnings and savings to support them comfortably for a lifetime. Many started from scratch, probably with less knowledge and no more cash than you have. Not everyone can do it, of course, but you'll never know how good you can be until you try. So my advice is: Give it a try. Let this book be your first step toward a successful career in underground utility contracting. Or allow it to boost your existing career by showing techniques and methods that will increase your profitability.

This chapter will explain the best way to prepare an estimate and submit the bid. Once I've covered the procedure, I'll test your knowledge with a sample bid on an actual underground utility project. Later in this chapter, there's a sample estimate for a small drainage and slide abatement project.

Bonding is another important component to the utility line contracting business — far more important than in home building or remodeling, for example. If you can't get bonded, you're closed out of most of the larger, more profitable jobs. That's why there's an extensive section in this chapter on getting bonding and increasing your bonding capacity.

Nature of the Business

As an underground utility contractor, most work will come from either private developers or publicly-funded municipal projects.

Land developers usually let subcontracts for street construction and utility installation. Some branches of city government will require that your work meet their standards. They'll inspect what you've done. That makes sense because, when you're finished, the city will accept responsibility for maintaining what you installed.

Public projects include work like installing new utilities and replacing old utilities in existing cities or developments. This type of work is funded by selling bonds to the public, or by federal loans and grants. A small city, for example, may borrow federal money to pay for a replacement water or sewer system. This money will be repaid by water users over a period of years.

It's in the owner's best interest to get bids from several contractors. And on publicly-funded jobs, no qualified contractor can be excluded. You'll see upcoming projects advertised in newspapers, on the Internet, and listed in local and regional bid call magazines. Some magazines, websites and newsletters list projects being put out for bid and report the prices submitted by successful bidders.

Some large projects are divided into several small projects because smaller jobs attract more bidders. Most contractors can't handle a $10 million project. So don't be surprised to see a job that large divided into several smaller contracts. The more bidders there are, the stiffer your competition will be.

The Design Engineer

Whether the job you're bidding is public or private work, the project usually begins with a utility line design and an engineering company. On some large jobs, the contractor's engineering team prepares the design drawings, oversees the work, authorizes progress payments, and issues a certificate upon completion. The design and build contracts are usually undertaken by large multinational companies.

On most jobs, a separate engineering company is hired by the owner. The engineering company usually works for a percentage of the projected cost, or a fixed fee. On some jobs, the design work will be done by an engineering firm hired by the city, county or developer, or by engineers employed by the contracting authority.

Following current engineering standards, the designer draws up plans and specs that show the required materials and workmanship. Once he's designed the project, he'll make the *engineer's estimate*. This is the first real cost estimate on the work to be done. But it probably won't be based on a careful analysis of labor, material and equipment costs. Instead, the engineer will use bid *abstracts* (or bid *tabulations*) to help him prepare this estimate.

Bid abstracts show contract prices from other jobs that have been awarded by government agencies. The designing engineer will try to find the cost of completing a project similar to the one he's planning. When he does, he'll adjust the cost per linear foot up or down as seems appropriate and then multiply by the total length of the current project. This isn't the best way to estimate, but it does establish a projected cost. *You'll* have to do much better.

Bid abstracts are available to engineers, contractors and the public for nearly all work that's publicly funded. Figure 1-1 shows a bid abstract.

Bid abstracts show unit prices — usually the cost per linear foot of utility line installed. In theory, if you were to average all the bids submitted for each item of work, you'd have a good average price for that item. But it doesn't work that way. Many bids are unbalanced, being padded (too high) for some items and showing unrealistically low prices for others. This distorts the picture. You'll find more discussion of unbalanced bids later in this chapter.

"It's common for city, county and state procurement offices to provide archived bid tabs on their websites for viewing or download."

There's a reason for unbalanced bids, of course. No contractor is anxious to have his competitors know his real costs. Also, padding the price of work that will be done early in the project can fatten progress payments that are to be received early in construction. You're not supposed to do that, of course, but it happens because contractors like the comfort of having extra cash to work with. I can't blame them.

But bid tabulations can still be a useful tool. Use them to crosscheck prices on items that are unfamiliar to you. If the bid tabs you use aren't for jobs awarded within the last few months, allow for changes in labor and material prices that may have occurred since the estimate was prepared.

It's common for city, county and state procurement offices to provide archived bid tabs on their websites for viewing or download. They're also available in several trade magazines. The comparative unit prices give you an idea of the range of prices.

Several estimating guides are available to help you estimate prices. These guides show material, labor, and equipment costs, and typical manhours for most work. But be careful when using estimating guides. The cost of utility line work can vary drastically. Installing utilities in a busy city street requires different tools, equipment, labor and materials than you'll use in a rural area. That makes the cost very different.

Tabulation of Bids Submitted for City Sewer Project 275

Date: July 1, 2011 **Time:** 3:45PM **Place:** City Hall

Item	Approx. Qty.	Unit	Firm Engineer Unit Price	Firm Engineer Ext.	Firm Jones Construction Unit Price	Firm Jones Construction Ext.	Firm Smith Construction Unit Price	Firm Smith Construction Ext.	Firm Green Construction Unit Price	Firm Green Construction Ext.	Firm Nolan Construction Unit Price	Firm Nolan Construction Ext.
Trench Excavation Type I & Type II Backfill (Type I)	1,090	LF	23.00	25,070.00	11.00	11,990.00	19.50	21,255.00	12.00	13,080.00	25.00	27,250.00
Type I Bedding Material (1-1/2" Drain rock)	1,090	LF	2.00	2,180.00	2.00	2,180.00	5.00	5,450.00	4.00	4,360.00	3.00	3,270.00
Type "P" Surface Restoration	1,120	LF	15.50	17,360.00	15.00	16,800.00	8.00	8,960.00	22.00	24,640.00	23.00	25,760.00
Sanitary Sewer Pipe Size 8"	1,090	LF	7.50	8,175.00	8.00	8,720.00	2.50	2,725.00	10.00	10,900.00	9.00	9,810.00
Sanitary Sewer MH's	4	ea	1,000.00	4,000.00	1,100.00	4,400.00	1,400.00	5,600.00	1,500.00	6,000.00	1,100.00	4,400.00
Service Lines Size 4"	675	LF	12.00	8,100.00	12.00	8,100.00	15.00	10,125.00	15.00	10,125.00	7.00	4,725.00
Service Lines Size 6"	50	LF	15.00	750.00	14.00	700.00	9.00	450.00	50.00	2,500.00	9.00	450.00
Service Line Connections (8" x 4")	27	ea	100.00	2,700.00	100.00	2,700.00	75.00	2,025.00	125.00	3,375.00	50.00	1,350.00
Service Line Connections (8" x 6")	2	ea	120.00	240.00	100.00	200.00	95.00	190.00	175.00	350.00	60.00	120.00
Standard 8" Temporary Cleanout	1	ea	250.00	250.00	300.00	300.00	250.00	250.00	1,000.00	1,000.00	350.00	350.00
TOTALS				**68,825.00**		**56,090.00**		**57,030.00**		**76,330.00**		**77,485.00**

Bid abstract
Figure 1-1

Estimating guides are better suited to other trades in the construction industry, such as structural work. If there's a pump station on your project, an estimating guide may be useful. But costs for the underground portion of the job depend too much on variables unique to every job. Here are some questions to consider:

- How accessible is the site? Will tight workspaces or steep slopes hamper production? Can existing roads and bridges bear the weight of heavy equipment?
- How far will you need to haul imported or exported material?
- Are utilities, housing, food, and first aid facilities readily available for employees?
- How much compaction will the fill material require? The more density that's required, the more compaction it'll need. Soil density testing and re-testing can be expensive.
- Is the equipment you need available locally? Will you need specialized equipment?
- Can you anticipate shortages of labor, equipment or qualified subcontractors? Costs will be higher when resources are scarce.

- What type of earth is to be excavated? Hard, wet soil costs more to excavate than soft, dry material.
- What equipment is most appropriate for the surface conditions? Poor drainage, sharp rocks and steep slopes call for crawler-mounted equipment. Crawlers are less mobile than rubber-tired vehicles and must be transported to the site by truck.
- What are the subsurface conditions? When excavating below the local water table, you'll need continuous de-watering. Excavating wet material takes more time, even when a firm, dry surface is available above the pit.
- Will existing site conditions such as trees, power lines, traffic and adjacent structures hamper production?
- What type of fill material is required? If on-site material isn't suitable, fill has to be imported and excess material hauled away.
- What weather can you expect? A heavy rain can stop production for days after the skies have cleared. High temperatures affect evaporation. Cold weather can stop all work. Keep in mind that you'll be paying equipment rental costs even during work stoppages.
- What limits are imposed by government: fees, hours of operation, noise limits, environmental regulations, advance notice requirements, permits?
- What's the retainage — the percentage withheld from progress payments? Excavation will be finished long before the entire project is finished. Will you have to wait until substantial completion before collecting in full?

The best guide to costs on your next job will always be costs on the last several projects you've completed — plus your judgment, of course. Use labor, material and equipment costs and labor production rates from your own cost records whenever possible.

Working with the Engineer

The contracting authority selects the engineer. It's the engineer's job to make sure you do the work right. He'll be responsible for the work you do long after your warranty period ends. This means he'll want to monitor your work very carefully. This is no problem, provided he knows his business. He should be tough but fair. An engineer who isn't a competent professional may try to make you the scapegoat for his mistakes. Avoid working with engineers or engineering firms that have a reputation for ruining contractors and construction projects. If you end up in court, the only winners will be the attorneys.

Before you decide to bid a project, check into the reputation of the engineering firm. Ask other contractors what they know about the firm. Do they have a history of lawsuits, contractor failures and incomplete projects? How much experience do they have? If you have any doubt about the competency or professionalism of the designing engineer, either don't bid the work or cover yourself with a high margin.

When you've signed the contract, work must be completed at any cost. Walking off a job usually means you're out of business. Remember, every bid is, in essence, a firm commitment to enter a contract. If you withdraw your bid or fail to enter into the contract, the owner will demand that you pay a stiff penalty or request that your bid bond be forfeited. That's why you should select your jobs carefully.

Knowing Your Costs

As an independent contractor, you have the freedom to charge any price you want. The catch is that if your price isn't competitive, you'll never have any work. To win the contract and make a profit, you have to bid accurately. That's possible only if you know your costs. Guessing will get you into trouble.

Your major cost categories include equipment, labor, materials, subcontracts, and taxes, of course. These are sometimes called *direct costs* because they're the direct result of taking some specific job. If you hadn't taken that job, you wouldn't have these costs. But just as important and just as real are the *indirect costs*. These are also known as *overhead*: office staff, rent, heat, light, advertising, insurance, auto and truck expense, and all the other costs that every business has — no matter what their product. You incur indirect costs even if you didn't have the specific job in question, and they need to be included in every job you have. I'll talk more about overhead later.

Last, and most important, is your markup. That includes your profit — the reason for doing the job. Don't forget it!

Let's take a detailed look at the major cost categories and how they come together in your estimates. Then we'll look at the direct cost sheets you'll use to write up your estimate.

Tool and Equipment Costs

Utility line contracting is capital intensive. If you can afford to buy all the tools and equipment you need for installing utility lines, you probably don't need to work. Owning several million dollars worth of heavy equipment would make you independently wealthy. Sell the stuff, invest the proceeds and retire on the interest.

Home builders and remodelers can load all the tools and equipment they need into the back of a truck at the end of the day. In the utility line business, most jobs will require equipment that costs hundreds of thousands of dollars. No one is going to start out owning that much equipment. In fact, even many of the big boys — contractors with multi-million-dollar projects and dozens of employees — don't buy their equipment. They can't afford to. They rent or lease most of what they need, and buy only the less-expensive equipment that's sure to be in use nearly all the time. This trend seems likely to continue. Most equipment dealers offer lease-purchase plans. In any case, you can nearly always rent what you need for the time you need it. Buying equipment should be the last thing you consider until you're handling a heavy volume of work nearly all the time. Any equipment you buy reduces your working capital.

"In the utility line business, most jobs will require equipment that costs hundreds of thousands of dollars."

The daily costs of short-term rentals will be relatively high because the dealer has higher overhead and maintenance costs for short-term customers. Also, there's a better chance that the equipment won't be rented out every day if it's offered for short-term rental.

My advice for the beginner is to ignore the higher daily costs for day-by-day rentals. Whenever you can, rent equipment for the exact number of days that you need it. When construction slows down, you won't be stuck making payments on expensive equipment that you're not using. Remember, you have to pay rent on equipment even during weather delays.

Whether you rent, lease or buy your tools and equipment, you must figure out the *daily operating costs*. That's just part of knowing your true costs. Entire books have been written on how to calculate equipment operating costs. But you don't need to know that much to be successful in this business. If you rent or lease your equipment, here's a simple way to calculate your daily operating cost. Add together your rental fee (daily, weekly or monthly), and your fuel and service costs. Divide this total by the number of working days. The answer is your *daily* operating cost. To get an *hourly* operating cost, just divide the daily cost by the number of working hours in a day.

Equipment Owning and Operating Costs

If you own the equipment, calculating your operating costs is a little harder. Your costs include depreciation, taxes, insurance, storage, major repairs, fuel, lubricants, servicing, tire repair and tire replacement costs.

As a rule, owning and operating costs for this equipment will be slightly less. But remember, ownership costs will vary dramatically depending on how you use the equipment. For example, your hourly owning and operating costs will be lowest when you can use the equipment for a full construction year of 1,600 hours. The less you actually use the equipment, the higher your hourly costs will be.

But this is still an optimistic owning and operating cost estimate. It doesn't include any interest you may be paying on the initial purchase price of the equipment. And it assumes you won't have any major accidents or unusual breakdowns during the machine's lifetime.

Damage and Hard Usage

Repairing major damage on large equipment can cost you a lot of money. Machines roll over. Materials fall on top of them. A careless operator can puncture your brand new tire. Vandals can sabotage your equipment. I recommend you get insurance to cover this type of damage.

Working conditions will also affect the amount you spend on major repairs. If you're working in soft soil and there isn't much dust, your backhoe will have a longer and less costly working life. If you're working in hard soil and in dry, dusty conditions, your operating costs will be 8 to 10 percent higher. If your basic operating cost is $50 per hour, your hard usage operating cost may be 10 percent higher — $55 per hour.

Today's equipment is designed and built for hard usage. If you maintain your equipment properly, it can probably be run at maximum capacity under hard usage conditions without doing serious damage. I'll run my equipment hard to complete a job on schedule or to cut my labor cost. Other contractors baby their equipment, even if it slows down production. To my way of thinking, that isn't usually necessary. But if it's your equipment, you get to be the judge.

OK, so you've calculated your hourly equipment cost. But how do you figure the amount of work a machine can do in an hour? That's the most important consideration when pricing any job. Unfortunately, estimating equipment productivity isn't easy. That's why I'll devote all of Chapter 2 to that topic. I'll show you the most accurate way I know to estimate equipment performance.

Estimating Labor Costs

Your next major cost is labor. Labor is your most controllable job cost. Your hourly labor cost will usually be set by a combination of labor agreement and government regulation. Be sure to check your contract for wage and benefit requirements. And remember that the hourly labor rate is only part of the picture. Payroll taxes and insurance, which I'll cover shortly, will add another 20 to 30 cents for every dollar of payroll.

If the wage rate is set by contract, your hourly labor cost is a fixed cost. But a contractor who hires the right tradesmen and provides good supervision will end up spending less on labor than a contractor who hires slow or inexperienced tradesmen. Minimize your labor cost *per unit* by using motivated, skilled tradesmen. Remember, it's your most controllable cost.

Chapter 2 explains how to estimate labor and equipment productivity per manhour. It's always hard to predict labor costs accurately — weather, illness, working conditions and routine construction delays will affect your labor costs on most jobs. But the more you know about your crews and the more accurate your records of their past performance, the more accurate your labor estimates are likely to be. I'll cover cost record keeping later in this chapter.

"States generally require employers to maintain worker's compensation insurance to cover their employees in the event of a job-related injury."

There are good production rate estimates and there are bad production rate estimates. That's unavoidable. But you *can* avoid making completely unrealistic estimates. It should be easy to see what's simply *not possible*. For example, if a machine can move 110 cubic yards of dirt in an hour, don't assume you're going to move 880 cubic yards in an 8-hour day. You'll never put 8 hours of 100 percent pure production back-to-back. That just doesn't happen. Even under the most ideal conditions, figure that any machine will be productive for only 50 minutes out of each hour.

It's always good practice to visit the jobsite before drawing up your labor estimate. All your calculations may suggest an installation rate of

300 feet per day. But when you visit the site, you may discover problems that will make even 150 feet per day an optimistic estimate. Overhead lines, large trees, restricted workroom and unavoidable damage to property will all lower your production rate well below projections. I'll cover these and other similar variables in detail in the next chapter.

Your Labor Burden

Your hourly labor cost is far more than what you pay employees. The contractor's "labor burden" will add between 20 and 30 percent to all of your labor costs. For every dollar of payroll, you must pay an additional 20 to 30 cents in taxes and insurance to government agencies and insurance carriers. That 20 to 30 percent will usually be more than your profit in the job. Here's a breakdown of where all that money goes.

Unemployment Insurance — Most states levy an unemployment insurance tax on employers, based on the total payroll for each calendar quarter. The actual tax percentage is usually based on the employer's history of unemployment claims, and it may vary from less than 1 percent of payroll to 4 percent or more.

FICA — The Federal government collects Social Security (FICA) taxes. This comes to about 7½ percent of payroll, depending on the earnings of each employee, and is collected through regular payroll deductions.

FUTA — The Federal government also levies an unemployment insurance tax based on payroll. The tax has traditionally been about 0.8 percent of payroll.

Worker's Comp — States generally require employers to maintain worker's compensation insurance to cover their employees in the event of a job-related injury. Heavy penalties are imposed on employers who fail to provide the required coverage. The cost of this insurance is a percentage of payroll and varies with the type of work each employee does. Clerical and office workers have a very low rate. Your cost may be less than 1 percent of payroll. Hazardous occupations — such as roofing and sewer installation — can carry rates as high as 25 percent or more. Equipment operators and truck drivers will fall somewhere between the two.

The actual cost of worker's compensation insurance varies from state to state and from one year to the next, depending on the history of injuries for the previous period. Your insurance carrier can quote the cost of coverage for the type of work your employees are doing.

Liability Insurance — Every contractor should maintain liability insurance to protect his business in the event of an accident. There are two types of liability coverage: personal injury and property damage.

Both are based on your total payroll. A comprehensive liability package with coverage up to $1 million per accident will be about 5 percent of payroll. Higher liability limits cost more.

Remember, these contractor's burden percentages are approximate. Your accountant or bookkeeper will have numbers that are more exact.

Can you skip paying some of these taxes? Not hardly. There's no legal way to avoid paying 100 percent of the taxes just outlined. If you have payroll, you have to add this labor burden into every estimate and make the insurance and tax deposits when due. No contractor can ignore these requirements and operate for long.

How do you add these costs? Easy. If your labor burden is 25 percent of payroll, add 25 percent to the total hourly cost (including fringe benefits). For example, if your tractor operator makes $40 per hour including base pay and benefits, your hourly cost will be $50 (1.25 times $40). Taxes and insurance will cost you, the contractor, $10 per hour. You won't have to pay taxes and insurance on certain fringe benefits. Your accountant can supply figures that are more exact.

Some contractors add their labor burden to the estimate after all other costs are tabulated. That's the way I do it — with labor burden set as a line item in my cost estimate sheets, entered directly beneath the total labor cost. Other contractors prefer to include the labor burden in each hourly or daily labor cost. That way, they don't have to worry about remembering to include this important item, because it's built right into the estimate. When you see any labor cost in this book, you can assume that it includes the base rate, fringe benefits, and all taxes and insurance. But beware. Wage rates and employment costs vary widely from area to area.

Estimating Material Costs

Publicly advertised projects will attract the attention of your local material suppliers. Major suppliers have employees who will do the material takeoff for you at no charge. The supplier makes up a materials list for the job and quotes a price for all materials he can provide. His hope, of course, is to sell you the materials if you're awarded the job.

Many of these takeoff people are very professional and can be expected to produce accurate material lists. But don't put blind faith in their work. It's too easy to leave out one section of the project accidentally, or to make a math error. Even experienced professionals make mistakes. And the more complex the job, the more room there is for error. This is why it's important for you, or your estimator, to do your own detailed material takeoff.

More than one company will probably quote on the materials needed for each contract. Crosscheck the takeoff sheets from different suppliers. Compare their quotes. Make sure nothing has been left out. But it isn't ethical to tell one supplier what his competitor's prices are. If you call a supplier, reveal his competitor's quote and ask if the price can be trimmed, it probably will be. But the small advantage you'll gain on this one bid isn't worth tarnishing your reputation. Bid shopping makes it harder to find suppliers willing to quote prices until the "11th hour" on the day of the bid opening. And others might flat out refuse to bid your work again in the future. When I was competitively bidding jobs, I was the successful low bidder about a third of the time and left an average of 2 percent on the table. One of the reasons for my success is that our company had a good reputation with all the subcontractors regarding bid shopping, bid peddling and timely payments. Because of this, we received the majority of our subcontractors' bids well before bid day, allowing me to fine-tune my takeoff by thinking of ways to save time in building the project.

BE WARY of incomplete quotations or bargain prices on one or two items. It's tempting to split your order among several suppliers to take advantage of isolated bargain prices. But splitting the order increases your overhead and doesn't give you as much leverage with any one supplier. In the long run, that probably means higher costs for you.

Some suppliers will want a commitment from you in return for their takeoff and price quotation. They want as complete an order as possible — even before you get the contract — for everything they can supply for the job. But my advice is to avoid making any commitments before you have the job. Most suppliers are more willing to negotiate when you're ready to place a major order.

If the project you're bidding isn't a large job, don't be surprised if no material supplier is willing to do the takeoff. You'll have to prepare your own takeoff and gather quotes on materials.

Collecting Subcontract Bids

Every prudent utility line contractor is cautious when dealing with material suppliers. And it's equally important to be cautious with subcontractors. An unreliable subcontractor can get you into deep trouble in a hurry. A sub that goes bankrupt, or can't do what's promised at the price quoted, will jeopardize your whole contract. Part of the foundation of the bid will have washed away, leaving you with a serious problem. And if he does a poor job, it's *your* reputation that suffers. The general contractor is always responsible for the work of his subs. Solicit subcontract bids from trustworthy and competent subcontractors. Also, keep in mind that some contracts may require your subcontractors to be bonded.

Even with the best subs, you should doublecheck each bid for accuracy before using it in your bid. Look out for sub prices significantly below the competitors'. When this sort of thing happened to me, I'd call the sub and warn him that he needed to re-check his estimate, or he might get hurt. Taking a few minutes to warn a low bidder may earn you a grateful and trusting business acquaintance. However, that doesn't necessarily mean I'd tell him what the other higher bids were, or by what percentage he's low. Of course, it's also your choice to just go ahead and use that low bid to get the job, regardless of the possible consequences.

So far, we've looked at the equipment, labor, material, and subcontract costs that make up your direct operating cost. Now let's look at the last items you'll add to most bids: overhead, contingency, escalation and profit. Together, these items are usually called *markup*.

Overhead

Just as important as direct operating costs, but perhaps less obvious, is overhead. Since every cost is important when preparing an estimate, you should be just as anxious to identify and price overhead costs as you are to price labor and material costs. Remember, good estimators identify every cost and put a price down beside every cost they identify. Your estimate for anything missed is always zero. That's a 100 percent miss every time it happens.

I'll divide overhead into two categories, direct overhead and indirect overhead.

Direct (Job) 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 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.

The following list 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 had 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 (pipe, soil density)
- Traffic control (barricades, flaggers, lane delineators)
- 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 (Office) Overhead

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
- Employee medical benefits
- Licenses and fees
- Maintenance and repair
- Office insurance (fire, liability, worker's comp, and hospitalization)
- Office rent
- Office staff (clerical, management)
- Office utilities (telephone, internet, water, power, gas, sewer)
- 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.

In the utility line contracting business, it's important to keep your overhead low — no more than 10 percent of gross receipts. If your overhead is too high, you won't be competitive.

Here's where being a small contractor can give you an edge over the larger contracting companies. They have fancy offices staffed with fulltime 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.

On the other hand, big contractors usually get the bigger jobs, which increase gross receipts. If that 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 the per-page costs. Also, it doesn't take much longer to take off a big project as it does a small project. The same items are usually required for either project, but the larger project has more of each item. Big contractors also have the advantage of getting reduced bonding costs.

Including Overhead in Your Bid

It's easy to include direct overhead in your bid. Just calculate the cost of supervision, insurance, mobilization, etc. and add those costs into your estimate. Indirect overhead is harder. In fact, there's no single correct way to estimate your indirect overhead cost on any job. Having admitted that, I'll suggest the system I use.

I start by estimating my overhead for the entire year. I've been involved in the business for many years and I know about how much I'll spend on office rent, heat, telephone, etc. Then I divide the estimated indirect overhead by my estimated gross volume for the year. Again, I can usually make a good guess as to what my billings will be for the year. The answer is my indirect overhead percentage for all jobs I estimate for that year.

Here's an example: If my gross is expected to be $2 million and my indirect overhead will be about $200,000 (including my salary for running the business), my indirect overhead should be 10 percent of every bid.

Other contractors divide annual indirect overhead by 40 or 50, depending on the number of productive weeks each year, and add a week's overhead to every job for each week it's expected to last. In my example, $200,000 divided by 50 is $4,000. If you have one job and it's expected to last one week, add $4,000 for indirect overhead. If you're doing two jobs of about the same size during a given week, each would bear one half of the indirect overhead cost for that week. Multiply by the duration of the project and you have the indirect overhead cost for that project.

"Forgetting overhead in your bid will more than wipe out the profit on just about every job you take."

Some contractors calculate the indirect overhead cost as a cost per productive manhour. Other contractors have reduced the indirect overhead to a cost per linear foot of line laid. Any of these systems is fine if it works. Do what makes the most sense to you. But the important thing is to keep a record of your indirect overhead and develop some method of dividing this amount among your jobs.

Don't forget to recover your job overhead and office overhead *on every job and in every estimate*. The total cost of direct and indirect overhead will usually be about 10 to 15 percent of the total cost on most jobs. Forgetting overhead in your bid will more than wipe out the profit on just about every job you take.

Before I leave the subject of overhead, let me make one more important point. If your overhead is 10 percent of gross receipts, you can't simply add 10 percent to each bid to cover overhead. That's because there's a difference between markup and margin — and we're really dealing with margin here. *Margin* is what's left after hard costs are recovered. To achieve any given percentage of margin, you'll need a slightly higher percentage markup. Here's an example.

Suppose I'm in the apple business, selling apples from a sidewalk stand. My overhead runs 10 percent of gross sales. How much do I have to mark up the apples to cover overhead? If you guessed 10 percent, you'd be wrong. Here's why:

Say my hard cost less overhead is $90. If I add 10 percent markup to cover overhead, I'll sell those apples for $99. But that's not enough. I have to sell them for $100 to recover all of my 10 percent overhead. By adding 10 percent markup, I'm recovering $1 less than my actual overhead cost.

So how do you calculate the correct selling price for the apples based on a 10 percent margin? Easy. Instead of marking up by 10 percent, divide the hard cost total by 90 percent — which is 1.0 minus the desired margin. Dividing $90 by 0.90, you get $100 exactly. That leaves a 10 percent ($10 ÷ $100) margin for overhead, and my selling price recovers the full $10.

Use the same system with your estimates. If overhead is 11 percent, divide by 0.89 to find the cost plus 11 percent overhead. Strangely enough, it doesn't make any difference whether you do this before or after factoring in other markup. The result will be that overhead is 11 percent of the bid price.

Vary the Markup with the Job

Now that I've made calculating markup so easy, I'm going to complicate it a little. Imagine we have a $100,000 job lined up — that is, one whose total direct job costs amount to $100,000. For simplicity's sake, let's say we've decided to mark that up 10 percent to cover direct and indirect overhead and 10 percent for profit. We bid the job at $120,000.

It isn't quite that simple in real life, however. The concept of a flat 10 percent doesn't allow for covering risks or for rating the varying proportions of the bid contents. There are other methods of adding markup.

For a moment, let's imagine that you're a large general contractor engaged in contracts worth millions of dollars a year. You bid a $2 million building contract, and intend to use subcontractors for almost all the work. If the total subcontract and overhead amount to $1.8 million, you would have a target profit of $200,000.

But look at that bid again. Since your own costs are fairly stable, you may be willing to cut the profit margin a little to get the contract. In theory at least, not a whole lot can go wrong. You may decide to add just 8 percent. In fact, many large general contractors operate on a margin smaller than 8 percent. When costs are stable and the general contractor runs an efficient operation, a small percentage of profit off a large volume of business amounts to a hefty chunk of change.

Now go back to our $120,000 bid for a minute. We'll look at two scenarios for that job. In the first, the materials for the job will cost $60,000. An asphalt contractor wants $10,000 to repair the street. That totals $70,000. The job will take about two weeks. Our portion of the work is about a $30,000 job, and we've marked it up $20,000. In the second scenario, imagine it's a 10-week job, and our labor portion amounts to $70,000. We'd have a $20,000 markup on $70,000 worth of what may be high-risk (i.e. labor intensive) work.

Estimators created the 20-10-10-10 or the 15-15-10-10 method of adding markup to compensate for such differences in job makeup and risk. Use a higher markup on the first two cost categories (labor and equipment) and a lower markup on the other two cost categories (material and subcontracts). The part that has the higher risk — your labor and equipment — should carry more markup. It's a lot chancier than the fairly stable fixed cost of materials and subcontract items.

Let's see how this system would affect the bid in the two jobs I've described.

Job 1

Labor and equipment: $30,000 plus 20% = $36,000

Materials and subcontracts: $70,000 plus 10% = $77,000

Total bid: $113,000

Job 2

Labor and equipment: $70,000 plus 20% = $84,000

Material and subcontracts: $30,000 plus 10% = $33,000

Total bid: $117,000

Your bid for Job 2 comes out higher, as it should, to cover the additional risk associated with all that labor and equipment. No two jobs have the exact same proportion of labor, equipment, material and subcontract costs. It's worth the time and effort to look at your overhead costs and try to place them where the costs are incurred. If you bid the $100,000 job at $120,000 and a competitor bid at $117,000 because he understood his operating costs better than you understand yours, he'd win the job by less than 3 percent. Remember, in competitive bidding there's no second-place winner.

Generally, if you bid at the total of labor, equipment, material, and subcontracts plus 10 percent, you're barely covering your direct job cost overheads. Unless your overheads are minimal, your profitability is at risk.

I can't begin to suggest a rule of thumb, but here's some general advice. If anything about a job bothers you — you don't like the engineer or the owner, you have some doubts about the general contractor, you consider the risks very high, you don't feel comfortable with your projections, your unit prices look low in comparison to bid tabulations on similar jobs, you already have a good workload — *mark it up*. Mark it up 12, 15, 20, or 35 percent. When in doubt, select a higher number. Feel comfortable with your bid going in. You may still get that job. Once the contract is signed, you're on the roller coaster and nobody will let you off until the ride is over.

Contingency and Escalation

Most contractors add a small amount to their bids to allow for the unexpected. That's good practice on utility line work and all excavation. Most surprises on utility line jobs, or any construction job, for that matter, will increase costs, not decrease them. Your allowance for *contingency* leaves a cushion to fall back on.

The right amount to add for contingency depends on the contractor and the job. Many excavation contractors routinely add 2 to 5 percent to their bids. Pipe jacking and tunneling might require larger allowances to meet difficulties, which can't be forecast accurately before work begins.

A word of caution here: Contingency isn't intended to cover for sloppy estimating. True, it's common to have a large contingency allowance in preliminary estimates that are made before the final bid is prepared. But you won't be bidding jobs like that. If you can't figure out what the job requires, either get more information, or don't bid. Don't use a contingency allowance to cover for what you don't understand.

Escalation is the increase in costs of labor, materials and equipment between the time the bid is submitted and the time work is actually done and paid for. Even though you're sure of the cost of labor when you submit your bid, you may not know what you'll be paying equipment operators when they do the work. This is very important during high inflation periods. It's a good idea to include in your bid that the price is good for only 30 days.

If the job is expected to continue for several months, and if there's a good chance that labor, material or equipment costs will increase before the job is completed, consider including a small allowance for escalation. If you can't get firm quotes for materials to be delivered in the future, either allow for price increases or specifically exclude price increases from your bid. Such qualified bids are usually not allowed in public utility work, but you can often qualify a subcontract bid to a general contractor.

Watching Your Profit

The profit is the return on the money you have invested in your business. It's not your pay for doing the work you do. You should get a wage for the work you do and, in addition, receive a return on the money invested in your business.

If a contractor has $100,000 invested in his business, he should receive a return on investment of $8,000 to $12,000 per year (8 to 12 percent of investment) in addition to a reasonable wage. This profit can be thought of as interest on the money invested in equipment, office, inventory, work in progress and everything else needed to run a utility line contracting business.

How much, then, should you include in your estimate for profit? You'll hear many conflicting figures. Some estimators say a 20 percent profit is a good target and they try to end up with a "profit" of 20 percent of the total contract price after all bills are paid. Some utility line contractors may operate efficiently enough to earn a 20 percent profit. But they certainly are the exception. The contractor who talks about a 20 percent profit may mean that he has 20 percent left after paying for labor, materials and equipment. Most of this 20 percent is probably needed to cover overhead and the contractor's wage. That's not profit in the true sense. A profit is what remains after *all* costs are considered. The cost of your own work should be included in your estimates either under direct or indirect overhead (or maybe under both).

What, then, is a realistic profit in the true sense? Dun and Bradstreet, the national credit reporting organization, has compiled figures on construction contractors for many years. They report the average net profit after taxes for all contractors sampled to be consistently between 1.2 and 1.5 percent of gross receipts. This includes many contractors who reported losses or became insolvent.

"If you include too much profit in your bids, you'll find yourself underbid for the jobs you'd like to have."

A 1½ percent profit, even after taxes, is slim. Not many contractors include so small a profit in their bid. On extremely large projects such as highways, power plants or dams, a contractor may include only 1 percent or less for profit — especially on a "cost plus" contract where there's little or no risk of losing money on the job. Residential construction, especially remodeling and repair work, traditionally carries a higher profit margin because the size of jobs is much smaller and the risk of loss is larger.

Of course, there's more to profit than just how much profit you would like to make. Sharp competition will reduce the amount of profit you can figure into your estimate. If you include too much profit in your bids, you'll find yourself underbid for the jobs you'd like to have. If you've developed a specialty, doing a particular type of work better than other contractors do, and have enough work to stay busy, then it's appropriate to increase your profit by a few percent.

In practice, there's no single profit figure to fit all situations. For most utility line work, an 8 to 10 percent profit is a very nice expectation. But even a 5 percent profit may be enough if your bid covers all costs, including direct and indirect overhead. And when work is plentiful and the job suits your experience and capabilities nicely, a 15 percent profit may not be excessive.

High-risk jobs should carry higher profit margins. If you have the know-how and equipment to handle the difficult jobs, you can normally demand and get a premium. But be aware that the difficult jobs usually come with complicated, unexpected and expensive problems. Even an estimated profit margin of 20 or 30 percent can evaporate quickly when problems begin to delay the work. Keep this in mind when you're deciding whether you want to bid high-risk jobs or not.

Every contract has risks, but some projects have risks that are guaranteed to cost you money. Make sure you cover these risks in your estimates. If you're working in a hilly, boggy area, there's a good chance your equipment will get stuck or overturned. If the project requires deep excavation in an area with groundwater, expect that shoring and dewatering problems will slow production and require special equipment. If the job requires blasting, sections of unfractured rock may have to be reshot. Keep that in mind when you're figuring contingency and profit.

Here's the acid test of your profit percentage. Are you earning a reasonable return on the money you have invested in the business (after taking a wage for yourself and paying all overhead expenses)? If you are, then your profit estimates are probably about right. If not, some adjustment is necessary. Each year you should earn a profit equal to 8 to 12 percent of the "tangible net worth" of your business. Tangible net worth is the value of all the assets of your business less the liabilities (anything your business owes) and less any intangible items such as goodwill.

Where the Markup Goes

Overhead, profit, escalation and contingency aren't usually itemized in your bid. They don't appear as separate items in the bid you submit to the contracting authority. Instead, these costs are distributed among all bid items by marking each up by some percentage. Here's how to do the calculation:

Add together your direct costs and markup (including overhead, profit, escalation and contingency). Divide the total by the amount of your direct costs. This will give you a factor. Multiply each bid item by that factor to find the bid price.

Item no.	Quantity		Price			Total
1	1000	@	$5.00			$5,000.00
2	2000	@	7.00			14,000.00
3	750	@	2.50			1,875.00
4	5000	@	1.50			7,500.00
			Total of direct costs			**$28,375.00**
Overhead and profit:			Office and shop			$2,837.50
			Supervision			1,600.00
			Mobilization			800.00
			Profit (10% of direct costs)			2,837.50
			Total of overhead and profit			**$8,075.00**
			Direct costs			$28,375.00
			Overhead and profit			8,075.00
			Total bid			**$36,450.00**

$\boxed{\dfrac{\$36{,}450.00}{\$28{,}375.00} = \text{Factor } \mathbf{\mathit{1.2846}}}$

Item no. 1	1000	@	5.00 x 1.2846	=	$6.4223 =	$6,423.00
Item no. 2	2000	@	7.00 x 1.2846	=	$8.9922 =	$17,984.40
Item no. 3	750	@	2.50 x 1.2846	=	$3.2115 =	$2,408.63
Item no. 4	5000	@	1.50 x 1.2846	=	$1.9269 =	$9,634.50
						$36,450.53

Increasing bid items to cover overhead and profit
Figure 1-2

Here's an example. Figure 1-2 shows estimated direct costs, overhead and profit for a sample job. Direct costs (materials, labor and equipment) plus markup (overhead and profit) equals $36,450. Divide this amount by the direct costs ($28,375) to get a factor of 1.2846. Now multiply each direct cost item by this factor to find the bid price for each item. Every cost line now includes your markup.

The Estimate

Every estimate begins with a labor, material and equipment quantity estimate. Cost items are listed one after another on an electronic or paper spreadsheet like in Figure 1-3. Notice that these are direct job costs. No overhead or markup is included here.

This particular estimate shows the direct cost sheets for a slide correction project along a roadway. Note the column headings on each sheet:

- Bid item number
- Crew, equipment and materials
- Quantity (hours or materials)
- Labor rate
- Labor amount
- Equipment operation rate
- Equipment operation amount
- Materials rate
- Materials amount
- Subcontractors rate
- Subcontractors amount
- Totals

We enter the bid item number in the first column, followed by a brief description of the work in the second. The third column, quantity, is vital to making an accurate estimate. Enter here the estimated number of days, or feet of pipe, or cubic yards of rock — whatever unit of measure you're using for the particular item. Multiply this quantity by the *rate* for that bid component. In item 1, for example, we multiply 4 days labor by the labor rate of $240. Enter the total, $960, in the labor amount column and carry it over to the total column on the far right.

After calculating each item on the page, determine the total for the page at the bottom. To check your total, add up each "amount" column (labor, equipment, materials and subcontracts) at the bottom of the page. Total these amounts. You should arrive at the same answer by adding all of the amounts in the total column and all of the amounts at the bottom of the labor, equipment, materials and subcontract columns. If not, you've made a mistake. Go back and recheck all of your numbers.

At the end of this sample estimate, we've totaled all the direct costs and added supervision and bonding costs. The total estimated direct field costs for this job will be $99,922.80.

You can do this worksheet with a simple spreadsheet program, like *Excel*. The program does the math for you, eliminating errors that creep in when you do it manually. Regardless of which method you use, crosscheck your answers as I described. You can't afford math errors.

Direct Field Costs

Schedule No. ______ **Project** Road Slide **Est. By** D. Roberts

Bid Item No(s). 1 thru 7 **Description** Remove slide, install 12" drain and 6" filter drain **Quantity** 4,500 yds. Ex. 500' of pipe **Date** 09/07/11 B.O. 09/12/11

Bid Item #	Crew Equipment and Materials For Each Work Item	Quantity Also Hours or Material	Labor		Equip. Operation		Construction Matls. & Supplies		Subcontractors		Total	
			Rate	Amount	Rate	Amount	Rate	Amount	Rate	Amount	Rate	Amount
1	Clear & Grub:											
	2 days for 2 men w/saws											
		4 man days	240	960								960
	2 days for chainsaws	2 days			50	100						100
												1060
2	Dozer:											
	Rental Rate	60 hrs.			500	30000						30000
	Dozer Operator	7 days	320	2240								2240
												32240
3	Mobilization:											
	Max. Allowable 6% of bid	100 miles			6	600						600
4	Compacted Road Base:	800 sq. yds.							3.50	2800		2800
5	Asphalt Surface:	800 sq. yds.							5.00	4000		4000
												6800
6	Concrete Catch Basin:											
	Subcontractor quote	$3500 ea.								3500		3500
7	12" CSP w/Pipe Bedding:											
	Pipe	250 ft.					40.00	10000				10000
	Connecting band	12 ea.					30.00	360				360
	Pipe outlet	1 ea.					50.00	50				50
	Pipe bedding											
	250' x 2 x 2											
	27 = 37 cu. yds.											
	wastage = 8 cu. yds.	45 cu. yds.					5.00	225				225
	Equipment											
	Backhoe	3 days			235	705						705
	Backhoe operator	3 days	320	960								960
	Backhoe laborer	3 days	200	600								600
	12,900											12900
	250 ft. = 51.60 per ft. direct cost											
Total Page 1				4760		31405		10635		10300		57100

Page 1 of 2

Direct cost sheets
Figure 1-3

Direct Field Costs, cont.

Schedule No. ____ Project Road Slide Est. By ____

Bid Item No(s). 8 & 9 Description ____ Quantity ____ Date ____

Bid Item #	Crew Equipment and Materials For Each Work Item	Quantity Also Hours or Material	Labor Rate	Labor Amount	Equip. Operation Rate	Equip. Operation Amount	Construction Matls. & Supplies Rate	Construction Matls. & Supplies Amount	Subcontractors Rate	Subcontractors Amount	Total Rate	Total Amount
8	Filter Drain:											
	6# ADS perforated pipe	250 ft.					20	5000				5000
	Filter fabric											
	250 ft. x 15											
	9 = 416	416 sq. yds.					9	3744				3744
	1/4" drain chips											
	250 x 3 x 4											
	27 = 111	111 cu. yds.					20	2220				2220
	Equipment											
	Backhoe	3 days			235	705						705
	Backhoe operator	3 days	320	960								960
	Backhoe laborer	3 days	200	600								600
	13229											13229
	250 ft. = 52.92 per ft. direct cost											
9	Hydroseeding:											
	Subcontractor's quote	1.5 acres								9800		9800
	Total Direct Costs:											
	Total Page 1											57100
	Total This Page											23029
	Total Direct											80129
	Other Costs:											
	Supervision	2 weeks	750	1500								1500
	Bond 2% of bid											
	82,000 x .02 =											1640
												83269
											x	1.2
												99922.80

Page 2 of 2

Direct cost sheets
Figure 1-3 (Cont.)

No matter how big or small the job may be, there are five important steps you'll take when making the estimate:

Step 1: Examine the plans and specifications.

Step 2: Visit the jobsite.

Step 3: Prepare a tentative work schedule.

Step 4: Secure bids from subcontractors.

Step 5: Prepare direct cost sheets.

These direct cost sheets are the foundation for your bid. The quantities and prices listed must be accurate. If you don't have accurate numbers, don't guess. Do the work. Many bad estimators are just lazy estimators. They cut corners to save time or effort. Don't be guilty of that crime. Call the suppliers. Talk to the subs. Get the opinion of your supervisors or equipment operators. Identify each work item in the job and list your expected cost. Check and recheck the plans for anything you might have omitted. Nail down each cost as accurately as humanly possible. The estimate isn't finished until there's nothing more you can do to make it a more accurate forecast of actual costs.

Avoiding and Finding Errors

The easiest way to prevent errors is to avoid them in the first place. The best insurance against errors is a consistent system, a procedure that starts with a careful review of the plans and specs and proceeds in some logical order from the beginning of the project to the end. When I do a takeoff, I highlight every note on the plans that I'll be responsible for. After I've taken off each item, I place a checkmark next to the note, showing that it's been done. Then I place a checkmark beside every note that I'm not responsible for. When every note has been checked on a sheet, I place a checkmark in the upper right corner of that sheet, telling me that everything on the sheet is done. Once every sheet has a checkmark in the upper right corner, I know the takeoff is complete.

When working with cost estimate sheets, here's the system I recommend. Visualize the first step in the project. Write down the name of that step on your direct cost estimate sheet. List all the direct cost components for that step: labor, material, equipment, or subcontract. Then go on to the next step in the project, identifying all direct costs for that step. Continue through all the steps, writing down every cost item in the order the work will be done.

Leave plenty of space on your estimate sheet to do calculations and make changes. Show all your work. Don't write on the back of the sheet.

You may forget to turn the sheet over when bringing page totals forward to an estimate summary. You should also number your sheets. That makes it easier to recognize when you've misplaced a sheet.

When all work in the project is listed, begin extending quantities, estimating labor hours and pricing each work item. If you've followed a logical order, used a checklist and worked carefully, there won't be many errors.

> *"The easiest way to prevent errors is to avoid them in the first place."*

But even one error is too many. What do you do to work through every error? First, recognize that everyone makes mistakes. Estimators are no exception. Plan on it. You're going to forget key items, misplace decimal points, transpose numbers, and worse. It's going to happen. But the mistakes you make won't cost you a dime *if they're caught before the bid is submitted*. That's why checking estimates is so important.

Check every estimate first by reviewing every line item and calculation. Never trust your results until you've checked all measurements and calculations. Addition *should* be done twice, but multiplications can often be checked by inspection.

Some errors are caused by transpositions. For example, you entered 129 instead of 192. If the difference between two totals (the sum of the bottom row versus the sum in the totals column of a cost estimate sheet) is divisible by nine, you probably have a transposition on that sheet. For example, 192 minus 129 equals 63, which is divisible by nine. The mathematical reason this works is complex, but trust me — it works.

It's easy to accidentally omit a material, labor, subcontract or direct overhead cost from time to time. To help make sure you haven't omitted anything, highlight the cells containing missing numbers on the cost estimate sheets and don't turn in a bid until there's a number in each highlighted cell. In my direct cost sheets, under each subcontract bid item, I leave several open lines. This allows me to enter the name of each sub, as well as his bid. Doing this allows me to quickly analyze and determine the lowest bid for that item of work.

Your own checking should identify 90 percent of the errors. What about the last 10 percent? Sometimes you can go over calculations again and again and still not find the error. You've become "blind" to the defect. That's why a second estimator is needed to verify your accuracy. Ideally, the second estimator would make a second estimate without referring to your estimate, making completely new measurements and calculations. But there usually isn't time for that. Checking your work will be almost as good and lots faster.

Remember that anything that seems wrong probably is. Step back and ask yourself, “Is that number about right?” If it seems too high or too low, keep checking. This is where bid tabulations are useful. If a certain bid item usually bids for about $20 a linear foot, your estimated cost should be in that range. Your financial future and reputation in the construction community are on the line with every estimate, so give your estimates the care and attention they deserve. If possible, have the superintendent you intend to use on the job look over your estimate before you turn in a bid.

When your estimate has been checked and verified, it’s time to prepare the bid and submit it for acceptance. Transfer the estimate totals to a bid sheet and check that all numbers were transferred correctly. Many bids are submitted electronically — especially with Department of Transportation and county work. Other times, you’ll need to deliver bids to the bid opening in person. It’s not uncommon for estimators to wait until the last minute to allow for a sudden change of heart or late subcontract prices.

You’ve prepared the most accurate bid possible. If your numbers are good, you may win the contract and make a profit on the job. If you don’t get the contract, don’t worry. There will be other projects. Get ready for the next job. You’ll never beat the guy who makes a mistake — but you don’t want to.

Preparing and Submitting Your Bid

The Associated General Contractors of America (AGC) has several publications that lay out the ground rules for competitive bidding. For more information, or to order from the AGC bookstore, visit their website at www.agc.org.

Public agencies are required to award the contract to the “lowest responsible” bidder. They can ignore bids from irresponsible bidders such as a company that doesn’t have the financial resources to carry the project.

I wouldn’t advise that you try to guess what the competition is going to bid. That’s a waste of time. But you can usually guess who’s going to bid against you. If a small job will attract too many bidders, stay away from it. The job will go cheap. Bidding costs you time and money. There’s no advantage to winning contracts that won’t earn a reasonable profit.

Some contractors front end load (or unbalance) their bids by charging a higher rate for the work they’re doing early in the project. This fattens progress payments received early in the project. The engineer will usually tolerate some front end loading. But if you overdo it, he’ll exercise his right to reject the bid.

There's another danger to front end loading, or distributing markup unevenly, among all the bid items. What happens if you pad or load one particular item, and the owner decides to cut back on that item? You lose money and it cuts into your profits. Let's say you're bidding a small job and your bid has only two items, and you put your full markup on one item and bid the other item at cost. Your bid contains 50 units of Item 1, which has a direct cost of $1, at a 40 percent markup, which comes to $70. Your bid also contains 50 units of Item 2, which has a direct cost of $1, but with no markup, so it totals $50. Your direct costs come to $100 and your total bid is $120.

You'll earn your full profit on the job, if the job actually requires the quantities shown on your bid sheet. If the owner cuts back on this item, he's taking a chunk out of your profit. In this example, the average markup on the two items is a fair 20 percent. But if the owner decided to decrease item 1 by 50 percent (to 25 units at $1.40) and increase item 2 by 50 percent (to 75 units at $1), your direct cost would still be $100, but your markup would decrease to only $10, or 10 percent.

But the opposite can also be true. If there's an overrun on the item you've marked up, your profits increase in proportion. If you believe one quantity will be increased, loading that item can greatly increase job profit.

If you decide to go the unbalancing route, keep this in mind: Unbalancing bids should be done with care. It's a dangerous game that can backfire by getting the bid rejected. By the same token, beware of an engineer who's playing a game with the bidders by grossly misstating quantities.

Another thing to watch out for is missing or unnecessary items on the plans. For example: If you find an unnecessary item, leaving it out of your bid will work to your advantage, so keep quiet about your finding. On the other hand, if you discover that a necessary item isn't shown on the plans, inform the engineer so that he can issue an *addendum* — a change made in the contract documents prior to the bid letting, so that each bidder is playing on the same ball field. Or keep silent, if you prefer, knowing that this will require a profitable change order in the future.

Sample Bid

Let's work through an estimate to be sure you understand the estimating process. Assume the work involves placing 250 feet of 12-inch pipe in a draw below the road. You'll install a catch basin at the upper end of the 12-inch pipeline and a 250-foot run of 6-inch perforated pipe, surrounded by ¾-inch of gravel and wrapped in filter fabric. You'll remove the slide material by dozing it across the road and over the drain line. This work is intended to provide an escape for the water on the uphill side of the road.

The job is a little unusual because the slide removal has to be bid at an hourly unit price for a 120 to 140 horsepower dozer. The county will supervise the dozing work. Bidding the job at an hourly unit price allows the county to extend or reduce work without any complicated surveying.

Each bidder must bid on nine items:

1. Clear and grub 1.5 acres of light sagebrush.
2. Excavation and embankment. Rent a 120 to 140 hp dozer.
3. Mobilization. The specifications show that up to 6 percent of the total bid price can be spent on mobilization.
4. Resurface road with 800 square yards of compacted gravel base.
5. Finish road surface with 800 square yards of asphalt.
6. Install concrete catch basin at the intersection of the two pipelines.
7. Install 250 feet of 12-inch pipe with pipe bedding.
8. Install 250 feet of 6-inch perforated pipe with gravel filter and filter fabric.
9. Hydroseed 1.5 acres in the area of cut and fill.

Preparing Your Direct Cost Sheets

Assuming you've examined the plans and specifications for this job and visited the jobsite (the first two steps when preparing a bid), it's time to prepare a tentative work schedule. The work schedule must show both the equipment and the labor required to do each phase of the project. Your schedule for the road slide project will look something like this:

Days 1 and 2:	Clear and grub — two men with chain saws.
Days 3 to 6:	Drive in wheeled backhoe; excavate for catch basin; install 12-inch pipe — backhoe, operator, and laborer.
Days 7 to 12:	Move in dozer, doze slide material; move out dozer — dozer and operator.
Days 13 to 15:	Install filter drain — backhoe, operator, and laborer.

If you know your crew and are familiar with equipment production rates, you won't have any trouble coming up with a tentative work schedule. You should also review your own cost records for the jobs you've just finished, and crosscheck the numbers with estimating tables and bid tabulations.

If you don't know your crew and you're not familiar with equipment production rates, get the best numbers you can from other sources. The *National Earthwork & Heavy Equipment Estimator* (a database available at www.craftsman-book.com) could prove to be a valuable cost resource for you. Several major equipment manufacturers publish production rates for the equipment they sell. Review production rates for the equipment you plan to use. If you don't have any other source of information, talk to an experienced operator or superintendent. Form an opinion on how much work can be done in a day. The next chapter explains how to estimate labor and equipment productivity.

The next step is to get bids from subcontractors. The asphalt work, hydroseeding and concrete catch basin are all subcontract items on this job. Contact your subs and get their bids on these items.

The last step in this process is to prepare direct cost takeoff sheets. Remember that your material calculations *must be accurate*. Chapter 2 explains how to calculate quantities.

Now look back at Figure 1-3, the direct cost sheets for this road slide correction project. Let's take a detailed look at each of the nine bid items.

For clearing and grubbing 1.5 acres of light sagebrush, figure two days of chainsaw usage at $50 per day. For labor, figure two men operating the chainsaws for two days. This is the same as four days of labor at $240 per day.

Equipment for excavation and embankment includes an estimated 60 hours of dozer work at $500 per hour. For labor, estimate one operator for seven days at $320 per day.

The mobilization estimate includes four trips of 25 miles each, for a total of 100 miles. The rate is $6 per loaded mile. Note how mobilization is limited to 6 percent of the total bid for this job.

Road resurfacing is a subcontract item and is bid at cost. The sub quoted a rate of $3.50 per square yard for 800 square yards.

Road finishing is a subcontract item and is bid at cost. The sub quoted a rate of $5 per square yard for 800 square yards.

Catch basin installation is also a subcontract item and is bid at cost. The sub quoted $3,500 for the catch basin.

The seventh item is a 12-inch pipe with pipe bedding. This item includes the pipe, pipe fittings, pipe bedding, and the labor and equipment required to install them. Suppliers quoted on the pipe and pipe fittings. For pipe, estimate $40 per foot for 250 feet of pipe. For pipe fittings, estimate $30 each for 12 connecting bands and $50 for one pipe outlet.

To calculate the number of cubic yards of bedding required, multiply the trench length (in feet) by the trench width (in feet) by the bedding depth (in feet), and divide the result by 27. For our road slide project, that comes to 37 cubic yards of bedding. Notice that we've added 8 cubic yards for waste, bringing the total to 45 cubic yards at $5, which totals out to $225. If you're using small-diameter pipe, you can ignore the small amount of bedding displaced by the pipe. Just consider it waste.

EQUIPMENT FOR THE PIPE installation includes three days of backhoe use at $235 per day. For labor, estimate one operator for three days at $320 per day and one laborer for three days at $200 per day.

The eighth item on the list includes the 6-inch pipe, filter fabric, drain chips, and the labor and equipment to install them. For pipe, estimate 250 feet at $20 per foot. To figure the square yards of filter fabric required, multiply the length (250 feet) by the width (15 feet), and divide by 9 (the number of square feet in a square yard). This gives you 416 square yards of filter fabric at $9 per square yard.

To figure the cubic yards of drain chips required, multiply the length (250 feet) by the width (3 feet) by the depth (4 feet), and divide by 27. The total is 111 cubic yards of drain chips at $20 per cubic yard.

For equipment on this item, estimate three days of backhoe use at $235 per day. For labor, estimate one operator for three days at $320 per day and one laborer for three days at $200 per day.

Hydroseeding is another subcontract item and is bid at cost. The sub quoted $9,800 for 1.5 acres of hydroseeding.

The final page of the direct cost sheet shows totals of all your direct costs, other miscellaneous costs, and your percentage for profit and overhead. Before totaling the direct costs, it's a good idea to round off all your unit prices to whole dollar numbers. This makes the final calculations easier and cuts down on errors.

"If you're using small-diameter pipe, you can ignore the small amount of bedding displaced by the pipe. Just consider it waste."

Direct costs on the road slide project come to $80,129. Add on two weeks of supervision at $750 per week and a bid bond of 2 percent of the total bid. (Round the total bid up to $82,000 before you calculate the amount of the bid bond.) This brings our total costs to $83,269.

Now add on 20 percent for profit and overhead. You can spread markup evenly over all of the bid items or load all markup on a couple of items. If you're going to pad a couple of bid items, the mobilization and dozer rental rates are probably your best bets. But remember that you're taking a chance if you do this. The owner has control over the actual number of hours the dozer will be used on this job. If he wants to cut back on dozer work, it comes out of your pocket.

Bid Openings

Plan to be at the bid opening well before the deadline. At the appointed hour for opening, you'll sit in suspense along with the other bidders. Each bid will be opened and read publicly. Every bidder wants the job, of course. There'll be a lot of tension in the air.

Bid openings can be very frustrating. If your bid is a great deal lower than the next lowest bid, the difference is money left "on the table." You'll be giving away some of your profit. If your bid is too high, a trimmed margin might have won the contract.

If your bid isn't the lowest, you may still get the job if the lowest bidder isn't responsive to the invitation to bid. For example, the low bid may omit some items or be based on substitute materials. That gives you the right to raise objections. If there are valid objections to the lowest bid, the engineer may either award the contract to the next lowest bidder or throw out all bids and call for new bids. If the job is rebid, expect that all numbers will come in at least a little lower than the original low bid. That's just simple human nature.

There's usually a delay between the bid opening and the awarding of the contract. If you're the low bidder on a large job, material suppliers will contact you during this interim period. Don't make any commitments. You could tell them you're reviewing quotations and you'll give the order to the lowest bidder. You may want to invite quotes from other subcontractors too. But remember that it's neither ethical nor smart to reveal one supplier's (or sub's) quotes to another. If you got the job using his bid, and then you don't allow him to do the portion of the project that he bid, there will be hard feelings. My advice would be to contact all of the bidders and tell them where they stand. They'll all appreciate your honesty and will respect you for it.

You're the Winner!

Once you've got a contract, review your estimate and talk to the people who'll be in charge on site. Ask your superintendent, "This is how we bid the job — what do you think? What's the most cost-effective way of doing the project?"

Be especially careful when you review your equipment and material selections. The materials and equipment you use make a big difference in terms of the final cost — and your profit. If alternate materials are allowed, check out every possible cost saving option.

It's a good feeling to review a well-prepared estimate and find that all your costs are covered. And it's even better when you find some cost savings. After you've reviewed the project with your superintendent, you'll select your suppliers, subs and crews.

The next step is a pre-construction meeting with the engineer and owner. The engineer usually opens the meeting by expressing his requirements and making some general comments. Then it's up to you to ask any questions you have, and to provide the engineer with a work schedule. Don't leave this meeting without answers to all your questions. Serious problems or potential problems should be covered in written memo or letter form.

When the meeting is over, the fun begins. You and your superintendent will try to put the plan into action. If your estimate was accurate, there's a good chance that you can do the work for less than the bid price. In the next chapter, I'll explain how that's done. But before we leave estimating, I want to cover two subjects that are important to every utility line estimator: cost keeping and bonding.

Controlling Costs

You can make two bankable profits on every job. The first is your estimated profit. The second is the extra profit earned by cutting costs below the estimate. Cutting costs isn't easy, but there are material, labor and equipment inefficiencies on every job. Your task is to find these and reduce them to a minimum. And the best way to find waste is with a good cost keeping system — a practical, detailed system of cost recording.

I'm not going to describe how to set up and run a cost keeping system. That would take more space than I'm willing to devote to this topic. Anyway, several good books have been written on the subject. But I want to emphasize how important cost keeping is to your utility line contracting business. Every large, successful utility line contractor I know has some type of cost keeping system. I'm sure some of that success was due to the way they monitor costs on every job. If you want to run a prosperous, growing utility line contracting company, I'd advise you to do the same.

A contractor who has little or no payroll and who personally watches every part of every job may feel that he has complete control of all his costs. In fact, he may be right. But as his business grows, he has to adopt some system for controlling costs. No one can watch every part of every project when several jobs are going on at once in several parts of the county. No one can remember every detail of jobs that were finished months or years ago. The important cost facts have to be collected, organized and compared. That's what a cost keeping system does for you.

"The basic document for every cost keeping system is the daily production report your supervisor prepares."

If you have good cost records, you can compare one job to the next, one crew to the next, and the productivity of one piece of equipment to the next. You can tell when things are going right, and make corrections when they aren't. You can do more of what works best and stop doing what doesn't work — long before it puts you out of business. You don't have to rely on hunches or opinions about what works best. You know. You've got the cost facts.

Contractors who don't keep cost records will know something is wrong because they're not making any money. But they may not discover exactly what's wrong until it's too late to fix it. Contractors with good cost keeping systems can often anticipate trouble, or discover potential problems while there's still time to avoid a major loss.

The basic document for every cost keeping system is the daily production report your supervisor prepares. It should show the quantity of materials installed or work done, the working conditions (including weather), the crews used and hours expended, overtime authorized, and materials and equipment used.

From these daily reports, you can determine the actual cost for each unit of work done — labor, material, equipment, subcontract and overhead cost for installing each foot of pipe, for example. Compare current costs to previous costs for similar work to identify materials waste, inefficient labor, poor supervision, time lost (due to delays, equipment breakdowns, poor planning, padded payrolls, or "dead men" on the payrolls) and any of a hundred factors that can inflate your costs unnecessarily.

Cost keeping is like bookkeeping in some ways. But the two aren't the same. Cost keeping deals with costs on a unit basis. Bookkeeping deals with accounts, directly with profits or losses. Cost keeping is an engineering function. Bookkeeping is a clerical function. The cost keeping viewpoint is that of the engineer, dealing with unit costs and quantities of materials. The bookkeeping viewpoint is that of finance, dealing with cash balances and net profits. Because the two are so different, you shouldn't rely on a bookkeeper to record costs. It should be done by someone who's familiar with both construction and estimating.

That's all I'm going to say about cost record keeping. But I hope you're curious about this powerful cost cutting, profit building tool. And I hope you're convinced that every growing utility line contracting business needs a cost keeping system to stay profitable.

Getting Bonds

If a project requires a bond and you can't get one, you're closed out. Utility line contractors who can't get bonds are left to scramble for the crumbs, while bondable contractors dine at a table spread with the more profitable work. That makes getting bonded one of your highest priorities if you want to handle public works projects.

Fortunately, there's a lot you can do to get the bonds you need. This section explains what your bonding company is looking for and how to meet its requirements.

Establishing a line of bonding credit can be your most important single step along the road to success in the utility line contracting business. Practically all public work is now bonded and more and more private work requires performance, labor and material bonds.

It's in your interest to develop a good working relationship with your bonding agent — a relationship based on confidence and cooperation. It should resemble the relationship you have with your bank. Your bonding agent puts together a presentation to the bonding company. It introduces your company, tells them who you are, what your experience in construction has been, and includes such information as:

- Your personal financial condition.
- Your company financial condition.
- The names of material suppliers who extend credit to you.
- A description of projects completed.
- The names of personal references who know your reputation.

You can make the job of your bonding agent much easier by supplying all the material he needs to present your case. Letters from satisfied customers, photos of completed projects and detailed resumes of key personnel are all considered when establishing your bonding capacity.

A typical cost for performance, labor and material bonds is between 1 and 2.5 percent of the contract price. Rates vary depending on the size and type of work and the contractor's experience and financial condition.

Your bonding company may suggest that you not bid any more jobs for a while. It's usually wise to consider this advice carefully. Bonding companies know that a prime cause of contractor failure is taking on more work and larger contracts than you can handle. Also, remember that bonds aren't like insurance. If you can't complete the job, the bonding company pays the loss. But they have the right to come after you for reimbursement. Your interest and the bonding company's are the same. They want to see you succeed as much as you do.

At one time or another you'll probably need the following types of bonds: bid bonds, performance bonds, payment bonds (labor, material and subcontract), combination performance and payment bonds, and maintenance bonds. Let's look at each of these bonds in detail.

Bid Bonds

Almost all public work requires that the bidder be bonded. This means that, along with your bid, you must submit either a certified check or a bid bond for a fixed percentage of the total bid.

The bid bond is the bonding company's guarantee that your bid is genuine, that you'll enter into a contract if your proposal is accepted, and that you'll furnish performance and payment bonds if granted the job. Your penalty for failure to do these things is either the total amount of the bid bond or the difference in price between the lowest bidder and the second lowest bidder, whichever is smaller.

> ***SOME OWNERS*** won't accept a bid bond. Instead, they require a bid security in the form of a certified check, negotiable securities, or cash. The amount can vary from 5 to 33 1/3 percent of the total bid. The bid security is returned after the contract is signed.

Performance bonds assure completion of the contract according to its plans and specifications and within the time allowed. Payment bonds guarantee payment of labor and material bills.

Obviously, bid bonds and performance bonds go together. Requirements for the bid bond are the same as requirements for the performance bond. No bonding company issues a bid bond to a contractor unless they're also willing to issue a performance bond on the same job.

There's a dangerous trap here for the unwary. Bid bonds are usually small — sometimes only a few thousand dollars. Suppose you're in a hurry and include a cashier's check with your bid instead of a bid bond. Assume further that you get the job. Now here comes the problem. What if no bonding company will give you a performance bond? You're stuck, and you'll probably lose the cashier's check submitted with the bid. That's why it's always best to qualify for the performance bond before bidding a job that requires one.

Even when either a certified check or a bid bond is acceptable, it may be best to use the bid bond. Otherwise, your money is tied up in outstanding bids. And most bonding companies provide bid bonds free!

You'll have to meet certain standards set by the surety company before being considered for any bond. I'll explain prequalification later. But once you've qualified, requests for bonds are considered on the basis of the merits of each contract.

On public contracts, both the amount and the form of the bond are specified by law. On private work, they're specified by the owner.

Performance Bonds

Once a qualified contractor is selected, the project is awarded and the contract documents are signed. At this point, the contractor has to provide a bond to guarantee his performance. The performance bond guarantees that if the contractor fails to complete the project, the surety company will get the job done at no additional cost to the owner. Sometimes that's not easy. Before issuing the bond, the bonding company will want to be very sure of your finances and professionalism.

If you don't do the work, the bonding company has to finish the job. But what if you claim you've finished, and the owner claims you haven't? Then the question becomes "What did the contract require?" In some cases, it's just doing the work according to the plans and specifications. Other contracts may require that you "promptly and faithfully perform the contract." Or that you "faithfully perform all of the undertakings, terms, conditions and agreements of the contract." Although each of these phrases implies the same thing, the courts have distinguished between them. Simple performance of the work under contract is one thing. The last phrase (sometimes called the *broad form*) requires performance of every condition of the contract, many of which aren't even remotely related to your work.

Under this broad form contract language, your obligations include *all* contract commitments. For example, you could be held liable for a manufacturer's failure to meet warranty provisions in the contract, or for failure to provide the required insurance coverage. That's why the broad form bond requires more study by your surety company.

Maintenance Bonds

Some of your contracts will require a warranty against defective workmanship and materials for one year after completion and acceptance of the project. This maintenance period guarantee is usually included in the performance bond, in which case no additional bond is needed. But some owners request a separate maintenance bond. If the only warranty is against defective materials and workmanship for one year, there's no additional premium charge even if a separate maintenance bond is required. But if the warranty is more broad, or for a term longer than one year, an additional premium is required.

Check the specifications for warranty provisions before you bid. And advise your agent if the coverage is beyond the minimum. That covers your extra risk and lets you include a maintenance premium cost in your bid.

Payment Bonds

An owner needs assurance that the contractor will pay in full for his labor, materials and subcontracts in a timely manner. Any bill you don't pay becomes a lien against the owner's property. Contracts require that you pay all bills for labor, equipment, and materials used — and that you discharge any liens filed by workers or suppliers against the project. Payment bonds guarantee that all your bills will be paid.

Combination Performance & Payment Bonds

Under this type of bond, there's a potential conflict between claims of the owner and claims of suppliers of labor and materials. For example, suppose there's a large loss. The face value of the bond may not be enough to satisfy the claims of both the owner and the material suppliers. That's why separate performance and payment bonds are usually the way to go, and they cost the same, or just slightly more.

Contract Pitfalls to Avoid

Most of the contracts you sign are carefully drafted by government, municipal or private attorneys to guard the owner against every possible loss. Most of these protective clauses are in the general conditions. Many utility line contractors have been tripped up by what you'll find there.

Don't sign contracts that are so one-sided that no one could make a reasonable profit on the job. Read the general conditions carefully, and question your bonding agent about language you don't understand.

There's no standard agreement for all construction work, though the *American Institute of Architects* (AIA) forms are used by many architects and may be considered fair. *Construction Contract Writer*, an affordable contract-writing program kept up-to-date and legal in all states, is available at www.craftsman-book.com. It makes it easy to draft legal contracts that protect the contractor.

> ***IF THE CONTRACT*** is unfair, but can't be renegotiated, your bonding company may be able to write a tailor-made bond that provides coverage that's more limited. Since this doesn't help you solve your problem of an unfair contract, surety underwriters are reluctant to amend bond forms under these circumstances.

Your bonding company will usually spot an unfair or poorly-worded contract. They won't let you get in over your head. They protect themselves as much as they protect you. If the contract is unfair, maybe they can help you get the provisions changed so it's less one-sided. After all, if the owner requires a bond, but no bonding company will write one for the job, the work's never going to get done.

Even if your jobs don't require a bond, you need to read and understand the contract. Unfair contracts have ruined many utility-line contractors. Know what you're signing. Don't let some obscure sentence in a routine little contract wipe you out financially.

First, be sure the work to be done is described accurately. Normally, the contract will say that the work to be done is identified in the plans and specs. But the contract itself may require other work that isn't in the plans and specs. If you're bidding the plans and specs, it's easy to omit what's described only in the contract. Don't make that mistake.

No responsible owner will demand that you sign a contract that's clearly unfair — especially if you point out the offending clauses. It's perfectly acceptable, and legally sufficient, to line through unfair contract clauses. If you do, make sure you line out the same language on all copies, and have all parties initial the change.

Getting Paid

A fair contract provides progress payments for work completed. These payments should be based on a percentage of the work done to date. Generally, payments are made monthly. Payments should be based on a schedule of values for various portions of the work. If it's a unit price contract, payment will be based on quantities of work completed to date, as computed by the engineer.

An agreed-upon percentage of each progress payment is withheld by the owner for his protection, until the job is completed and accepted. This *retention* is usually 10 percent of each progress payment. Better contracts provide that retainage be withheld from only the first half of the contract amount. Contract provisions different from these may be unfair.

When you feel that the work is "substantially completed," there should be a procedure in the contract for getting paid. Usually you'll send the owner a notice of completion. Final payment should be due 30 days after the owner gets this notice. This 30-day period is called the "lien period." Material suppliers, tradesmen and subcontractors have 30 days to file a lien if they haven't been paid. If no liens are filed, the owner should make the final payment.

"When you feel that the work is 'substantially completed,' there should be a procedure in the contract for getting paid."

Be sure that your contracts with subcontractors provide that they'll be paid only if, and when, you receive payment. That passes most of your risk of nonpayment to the subs. If there's a dispute between you and the owner and payment is withheld, you shouldn't have to pay your subs before you get paid.

Warranties

Your contract probably includes the following language: "Contractor warrants to the owner and the engineer all materials and equipment furnished under this contract will be new unless otherwise specified and that the work will be of good quality, free from faults and defects, and in conformance with the contract documents." The contract probably also requires that you remedy defects found by the owner "within one year after the date of substantial completion or within such longer period of time as may be prescribed by law or by the terms of any applicable special guarantee required by the contract documents."

These two quotes together are the basic warranty under most construction contracts. Your responsibility is limited to defective workmanship and materials, and to a reasonable period of time.

Warranties become unfair when they extend for an unreasonable time. Courts have held contractors liable for defects discovered many years after construction, but only for defects that weren't obvious, or if fraud was involved. You aren't running an insurance company or a maintenance outfit. Your job is to do the construction. If what you do meets code, complies with the plans and specs, and no defects are discovered for 12 months, your liability should end. If the owner doesn't see it that way, maybe you shouldn't bid the job.

The basic warranty described above has been interpreted by the courts to require only that the work you do is suitable for the purpose intended. You have to install materials according to plans and do the work in a workmanlike fashion. You're not liable for damage resulting from errors and omissions in the plans. The engineer's mistakes aren't your responsibility. Yet engineers are often reluctant to take this responsibility. Beware of disclaimers engineers may add to an approval.

Also, watch out for other warranties. They may be buried in technical specifications. For example, the contract may require that you provide a five year warranty on some piece of equipment. That's absurd! You're not in the equipment repair business. A fair contract would require only that you provide the owner with a written guarantee from the manufacturer.

Contract Duration, Delays and Damages

A fair contract states how long the job should take, in either calendar days or working days. It should also give acceptable reasons for extending the completion date, such as:

- Acts or omissions of the owner or architect
- Delays caused by separate contractors employed by the owner
- Delays caused by changes ordered in the work
- Delays caused by labor disputes, fire or weather
- Any delay beyond the control of the contractor

But some contracts offered by agencies of city and county government go on for pages trying to make you responsible for all delays that aren't entirely the owner's fault. That's clearly unfair. You should be responsible for your own delays and none other.

Many contracts provide for liquidated damages. You have to forfeit a certain amount for each day of unauthorized delay in completing a project. If work runs past the time limit, that amount is deducted from the final payment. If this amount is reasonable — meaning the owner can prove what it will cost him for each day that the project is completed late — the courts will probably enforce the contract provisions against you. That isn't necessarily unfair. In fact, it's to your advantage if it limits your liability for delay. But be sure the time period allowed is reasonable, and legitimate reasons for delay extend the completion time. If there is, in fact, a delay that's your fault, keep in mind that the owner must still prove that he actually incurs damages because of a delay before he can collect for it.

Don't take these provisions lightly. They can turn an otherwise attractive job into a sure loser.

Changes and Changed Conditions

The owner's normally given the right to add or delete work from the project during the construction period. Changes should be made only with a written change order. Never agree to make a change without a written authorization. You won't collect for changes made without the owner's written OK, especially if the owner and engineer aren't in complete agreement. Again, beware of engineer's disclaimer clauses. Look for something like this:

> *We approve the use of this material providing the contractor or manufacturer fully guarantees it.*

The AIA contracts, and most federal government contracts, spell out what'll happen if *changed conditions* are encountered at the jobsite. You're entitled to extra pay for changed conditions. Conditions are considered changed, for example, when the soil type isn't what was indicated in the contract documents, or isn't normal for the type of work you're doing.

Owners and engineers have written volumes of contract language, excusing themselves from liability for test borings and the 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. Be sure there's a changed conditions clause in the contract so you get paid if conditions aren't what the test borings showed, or are very unusual for the type of work being done.

By the way, big change orders can be very profitable since the owner will allow you to add overhead and profit to the change, which is usually greater than you used in bidding the job. However, small change orders can be losers if you consider the time it takes to process them in the office and get them signed by the owner.

Indemnity Provisions

Most of your contracts will include an indemnity provision that requires you to reimburse the owner for some losses. Suppose, for example, that one of your employees is driving your truck away from the jobsite, and runs down a pedestrian. You're responsible for the negligent acts of your employees. You'd be liable for the accident. There's nothing unfair about that.

Now, suppose the pedestrian sues the owner of the site and wins. By law, you aren't responsible for the owner's negligence. The pedestrian collects in full from the owner and you're off the hook. That's unfair. Your truck caused the damage in the first place, even though the accident happened at the owner's site.

It was to remedy this kind of problem that owners, many years ago, began to require that contractors agree to reimburse them for certain losses. That's known as *indemnity*. Indemnification clauses in construction contracts make you assume the liability of the owner.

The "limited form" indemnification provision holds the owner harmless for your negligence or the negligence of your subcontractors. Unfortunately, things have gone far beyond this "limited form" of indemnification. Even the AIA indemnity clause is questionable, because it provides the owner with indemnity for losses due to joint negligence of the contractor and owner. Most contractors have come to accept this provision. It's now called the "intermediate form" of indemnification.

But there's no excuse for the "broad form" indemnification clause sometimes found in construction contracts. It puts you in the position of holding the owner harmless against losses due to the owner's sole negligence. That makes you an insurance company, insuring the owner, the engineer, and all their employees and agents. That isn't your business. Don't sign a contract that includes a broad form indemnification provision.

Prequalifying for Bonds

Before you need your first bond, go to the insurance agent or carrier that handles your liability and worker's compensation insurance. Ask about getting construction bonds. If he doesn't handle bonds, he'll refer you to someone who does. If all else fails, the Internet or phone book yellow pages list bonding companies under "Bonds, Surety and Fidelity."

If you've never had a construction bond, the first step is to prequalify. Once you've prequalified, your requests for bid and performance bonds can be processed routinely. Plan to prequalify before you request the first bond. It may take several weeks to get your account set up. Allow plenty of time.

Getting prequalified is like getting acquainted. If you haven't worked together before and you haven't been bonded before, your agent will have some basic questions:

- About your business. How long in business? Principal owner's experience? Form of organization? Key staff members and their experience?

- About the work you've done. Type of work completed? Geographical area where you operate? Size of jobs undertaken?
- About the work you want to do. Type and size of projects? Number of jobs in progress at one time?
- About your reputation. How's your reputation with subcontractors, suppliers, owners, architects, engineers and your banker?
- About your history of meeting financial obligations.
- Do you get good professional advice from your banker, accountant, lawyer, and insurance agent?
- Have you been successful?

The Basic Financial Documents

Here's where you get into financial statements – balance sheets and income statements. A balance sheet shows that you're solvent, and likely to remain solvent for the duration of the contract. An income statement (profit and loss statement, or P & L) shows the profit for a particular period. Both should be prepared by a certified public accountant (CPA).

Bond underwriters aren't like accountants. They don't follow rigid guidelines when making decisions about bonding capacity. They're more like gamblers. They're betting on your ability and professionalism. They're always looking for growing, profitable construction companies that'll become good, steady customers. If they can see a bright future for you, they're anxious to do business with you. That's the good news.

The bad news is that you'll be judged primarily by the quality of your paperwork. Bond underwriters tend to think that contractors make good decisions when all the information is in front of them — usually in written form. If you don't have good accounting records, if you can't supply a current balance sheet and P & L, if you don't have cost records for previous jobs, and if you can't show a professional-quality estimate for the job you're bidding, they're going to be reluctant to write the bond you need.

Your bonding company will want you to use the "percentage of completion method" for reporting income. True, this calls for some estimating. But accurate estimating is your business. If you can't supply financial reports based on percentage of completion accounting, you're admitting that you have poor cost records, or little estimating ability.

Many contractors and accountants prefer the "completed contract" method of reporting income because it avoids paying tax on profits that may never be earned. But the percentage of completion method gives a better picture of your current condition, especially if completion percentage estimates are conservative. It also reduces the chance that you'll pay excess income tax.

Your Financials

Here's what your bond underwriter will want to see when you prequalify for bid and performance bonds:

- CPA-prepared financial documents for the three most recent years. These should include balance sheets, income statements (P & L), capital reconciliation and the source and application of funds. The financial report should be audited, supported by an unqualified opinion by the CPA, and should include the accountant's footnotes. This report must disclose the scope of the CPA's involvement, and should identify the basis of reporting income.
- A list of projects completed during the most recent year, and a schedule of jobs in progress showing profit estimates.
- A schedule showing the cost of owned equipment, depreciation of that equipment, and all liens against that equipment.
- A list of overhead expenses for the current year.
- A supporting statement describing any joint ventures reflected in the financial report.

Your bond underwriter will probably suggest that you keep his file of financial documents current, even if you aren't bidding more work right now. Do it. That'll make it easier to process your bond requests and avoid missing bid dates because you won't be scrambling around trying to get the paperwork in order.

Other Information You'll Need

Besides these basic financial documents, your bonding company will want to know your:

- Bank accounts by bank and account number.
- Accounts receivable by name, address and date due.
- Notes receivable by name, address and date due.
- Inventory value.

- Stocks and bonds if listed on a national exchange.
- Real estate owned and rental income produced.
- Accounts payable by name, address and date due.

Unless your statement is prepared by a CPA and is certified, it'll have to be verified either by phone or mail. That's why your financial statements have to be accurate and detailed.

When the prequalification process is complete, your bonding company will tell you the bonding capacity they recommend. The amount they give you will be a total for unfinished work on hand and, possibly, a maximum limit for any single job. This is your guide to the size of jobs to bid. Once your bonding limit is established, bid, performance, labor and material bonds will usually be issued promptly.

To maintain your bonding account, keep your bonding agent up to date on bid results and the amount of work on hand. File new financial statements with your bonding agent at the end of each accounting year.

Bonds for Specific Jobs

Once you have a line of bonding credit, you'll usually be able to get the bonds you need, within your dollar limit and for the type of work you've been doing. But sometimes a bond request will be turned down because of some special risks in the contract. A difficult site problem, short working season, material shortages, restricted working conditions or natural hazards might discourage your bonding company. Or perhaps an unfair contract or labor-management relations problems will make the job too risky. Decisions like this are based on two judgments: first, that there's a serious risk; second, that you can't afford to assume it.

Usually, when your bond underwriter turns you down, his explanation will be that the contract would leave you overextended. That means he feels you're biting off more than you can chew. For example, you're overextended if you take on too many jobs, take on jobs over too wide an area, take on work that you aren't used to handling, or simply take on too much work for your financial condition.

Other Bond Risk Factors

Some other factors can make the risk unreasonable in the eyes of your bond underwriter.

Owner Financing — Doing business with some developers and promoters can be risky. If your owner runs out of money, you're not going to get paid. That can put a big hole in your bank account. Your bond underwriter will usually want to see money set aside in a special construction account for the benefit of contractors. This money should be paid directly to you, without actually passing through the owner's hands. This protects you against an underfinanced owner who might divert contract funds for other purposes.

The Engineer — There's risk in faulty plans and specifications and poor project design. An underwriter's judgment here will be only as valid as his knowledge of the engineering firms in his area. It's generally a good sign if you've done previous work with the engineers involved.

Subcontractors — You reduce your risk by subcontracting part of the work to responsible subs. The underwriter will be interested in the amount of work subcontracted and in the quality of the subcontractors selected. That's why your bonding company will want a list of subcontractors showing the name and location of each sub, the nature and amount of the work and whether or not a subcontract bond will be required. Sometimes your bond underwriter will require that major subcontractors post a bond. That's why you should check on the bonding capacity of your sub *before* using his bid.

Is the Price Right? — Your bonding company wants to be sure there's enough profit built into your bid. If there are other bids at about the same price as yours, that's good confirmation that your price is right. A spread greater than 10 percent between your bid and the next lowest bid may worry your bond underwriter. By then it's too late to turn down the bonding request, of course. But it's not too late to turn down your *next* request for a bid bond.

Strengthening Your Bonding Capacity

Your bond underwriter may not agree that the jobs you want are the jobs you should be handling. But don't give up without considering some other alternatives. In this section, I'll discuss the most common ways to make your bond underwriter reconsider their decision.

Additional capital can be brought into the business, either by selling shares or by taking on a partner. This provides more cushion between the bonding company and a loss. But it isn't a substitute for management skill, and it doesn't eliminate risks in the job.

Subordination of debt gives the bonding company a prior claim against company assets if there's a loss. Subordination works when a small corporation owes money to its stockholders. The stockholders give the bonding company's claim priority over their claim. It's also used when a big debt is owed to a supplier.

Additional indemnity uses the pledge of some financial backer. He agrees to reimburse the bonding company if there's a loss on the bond. Getting additional indemnity makes sense if the financial backer has an interest in your company or stands to profit from the contract.

Joint venture partners reduce the risk of failure by combining resources on a given project. If you enter into a joint venture, be sure the agreement covers the obligations of all partners on all important topics, including:

- Advancing working capital.
- The percentage interest of each participant.
- Division of profits.
- Sharing of losses.
- Specific responsibilities and contributions.
- Details of administration and project management.
- Procedure in case of default by a partner.
- Termination of the agreement.

Assuming these items are worked out, a joint venture makes sense if your joint venture partner can add whatever is needed to make you qualify for a bond.

Here's Your Bonding Checklist

I want to conclude this chapter by reviewing the do's and don'ts that go into qualifying you for the bonds you need.

1. Set up and use an adequate cost-keeping system.
2. Keep up-to-date financial statements on file with your bonding company. Have a CPA audit your books and prepare your financial statements at least annually. Both your banker and bonding company need these documents.
3. Advise your bonding company as soon as you begin to cost a job. It takes time to underwrite even a bid bond. Try to give them an accurate breakdown of projected job costs. You can usually estimate your labor, material and equipment, but subcontractors may not give you a bid in time for the bid bond. Take care not to underestimate an unfamiliar subcontract item. Tell the bond agent that you're guessing on some items, and make sure you're conservative. It's better to ask for a $200,000 bid bond for a $160,000 job than be stuck with a $160,000 bid bond for a $200,000 job.

4. Keep your bonding company informed about the progress on key jobs. Don't surprise them with bad news after it's past. They deserve to be the first to know, not the last.

5. Get good professional advice. Be sure the quality of your legal advice is at least as good as the quality of your construction.

6. Subcontracts shouldn't always go to the lowest bidder, nor material purchases to the lowest-priced supplier. Pick the sub who'll help you earn the best profit and complete the contract promptly.

7. Never take on work that you don't have the reserves to carry. Don't count on profits from the current job until they're in the bank. Have enough cash available even if the current job doesn't earn a cent.

8. Don't waste cash on non-construction purchases. Your business is utility line contracting. Stick to it.

9. Many utility line contractors load themselves down with too much equipment. That cuts your financial strength. Keep your investment in equipment as low as possible. Never take work at no profit just so your equipment stays busy and cash keeps flowing in. That's a prescription for disaster.

Finally, remember what I said at the beginning of this chapter. Rome wasn't built in a day. Crawl before you walk, and walk before you run. Go from small jobs to somewhat larger projects. Get your experience on little jobs where making a mistake won't bankrupt you. After you've built your financial muscle, move on to larger jobs. Be patient. You'll never join the ranks of the biggest contractors if your company goes belly up because you tried to expand too fast.

2

Crew & Equipment Productivity

Every utility line job is unique. You'll never have two that are exactly alike. The job you're bidding today is different in a dozen subtle ways from any other job you've ever had, even if you're using the same equipment and installing the same materials. That tends to make even experienced utility line estimators humble — and give them more than a few gray hairs before their time!

Estimating utility line crew and equipment productivity is an inexact science. It's hard to sort out what's important from what may only *seem* important. Any one of several dozen variables can have a dramatic impact on production rates and profit; other variables may be irrelevant in the big scheme of things.

But don't give up hope. We'll explore most of the important variables in this chapter — and I'll offer some advice that will help you avoid the worst estimating mistakes. I'll also show you how to quantify equipment costs so you don't have to guess at them.

The most important cost variables on every job include equipment cost and labor performance. If you do your takeoff correctly, you're not going to make a big mistake when estimating material quantities — and the difference between your highest and lowest material bid will probably be less than 10 percent. But selecting the wrong equipment, not using equipment to good advantage, or tolerating poor performance from your crews can cost you plenty — far more than 10 percent of your total job cost. This chapter is about predicting how much work your crews and equipment can do, and then making sure actual and estimated productivity match up.

Your own cost records will always be your best guide when estimating equipment and crew performance. That's why collecting and saving crew and equipment productivity data is so important. But what if you don't have cost records on previous jobs? You'll have to use published data like the kind you'll find in this chapter. Also, the *National Earthwork & Heavy Equipment Estimator* (a database available from Craftsman Book Company at www.craftsman-book.com) has manhour estimates and cost data that are updated annually.

Before I begin on crew and equipment productivity, I'm going to explain how to calculate trench excavation quantities. You have to know the amount of material being moved before applying any production rate. The cost of excavation is the cost per unit times the number of units plus the cost of mobilization and demobilization. Mobilization is sometimes itemized as a separate cost on your bid. If it isn't, you'll need to include it in your equipment cost calculations. For example, if a unit price bid for a trench excavation is turn-key (including material, supervision, labor, mobilization and demobilization), you'll have to determine the total cost for all of these items and then divide the total cost by the total length of trench to obtain an accurate unit price.

After reviewing how to calculate trench quantities, we'll look at optimum hourly production rates and the factors that affect these rates. Then we'll walk through three sample estimates. Finally, we'll consider how to compare equipment and crew costs to select the appropriate equipment and crew for each job you're bidding.

All the calculations in this chapter can be done on an inexpensive hand-held calculator. A ten-key printing calculator is better, and a computer is best. One of the advantages of using a computer is that you can make a template for a sample job containing every possible cost item. When you bid a new job, save the sample job as a new file and just delete all line items that don't apply to the current job. Then enter unit totals for the surviving line items. You can set up most programs to automatically calculate the total cost for each item when you enter the number of units.

Trench Excavation Quantities (Volume)

Soil (and all fill material) is commonly measured in cubic yards. When you're measuring soil, you'll want to identify the *state* of the soil, as well as the number of cubic yards. They're significantly different. Here are the three common soil states:

1. Bank cubic yards (BCY): This measurement refers to soil resting in its natural, undisturbed condition.

2. Loose cubic yards (LCY): When soil is excavated or in some way disturbed from its natural state, it swells, increasing in volume.

3. Compacted cubic yards (CCY): When soil is compacted, it shrinks, decreasing in volume.

You can use *soil conversion factors* to convert soil volumes back and forth among the three soil states. Figure 2-1 shows swell and shrinkage factors for various soil types. Each row in the figure shows how many LCY and BCY there are in one CCY. For each soil type, there are several factors listed, based on different moisture densities and soil testing standards. The moisture density percentage number indicates the density as a percentage of maximum dry density. The Standard Proctor Test (Std. Proc.) and Modified Proctor Test (Mod. Proc.) refer to two techniques for determining soil moisture content. I'll discuss soil testing in more detail in Chapter 6.

Why would you want to calculate loose cubic yards? One reason is that hauling unit capacities are measured in loose cubic yards. For example, let's say you need to export 1,000 BCY of dry common earth from a jobsite, and the truck capacity is 14 LCY. To find out how many haul trips will be required, you'd first need to convert the 1,000 BCY figure to an equivalent LCY figure. Referring to the 1.32 conversion factor in Figure 2-1, shown with a bold box around it, 1,000 BCY of dry common earth equals 1,320 (1,000 × 1.32) LCY. With a hauling unit capacity of 14 LCY, you'll need 95 (1,320 LCY ÷ 14 LCY) haul trips.

I'll carry this example one step further: When you compact this 1,320 LCY, placed at 100 percent Standard Proctor density, it becomes 857 (1,320 ÷ 1.54) CCY. See the 1.54 conversion factor in Figure 2-1, also with a bold box. Notice that the compacted soil volume is less than the original bank cubic yard volume; that's because the compacted soil is denser than the in-place soil.

You can see how important it is to allow for swell and shrinkage when calculating the volume of material. If you don't consider the state of the soil, you may be comparing apples to oranges, and your estimates won't be accurate.

Import and Export

Export *(spoil)* is any excess excavated material that must be removed from the site. Import *(borrow)* is the term for any acceptable material that's hauled onto the site for use as fill material. Export or import quantity is the difference between the total cut and fill volumes. In other words, subtract total fill from total excavation volume. If total fill volume exceeds the excavation volume, your project requires import. If total fill volume is less than excavation volume, your project requires export.

There are				per	of
LCY		BCY			
1.13	---	1.00	1.00	BCY	
1.32	---	1.17	---	CCY (95% Std. Proc.)	Dry Sand
1.39	---	1.23	---	CCY (100% Std. Proc.)	
1.38	---	1.22	---	CCY (95% Mod. Proc.)	
1.45	---	1.28	---	CCY (100% Mod. Proc.)	
1.13	---	1.00	1.00	BCY	Damp Sand
1.16	---	1.02	---	CCY (95% Std. Proc.)	
1.22	---	1.07	---	CCY (100% Std. Proc.)	
1.21	---	1.06	---	CCY (95% Mod. Proc.)	
1.27	---	1.12	---	CCY (100% Mod. Proc.)	
1.14	---	1.00	1.00	BCY	Damp Gravel
1.23	---	1.07	---	CCY (95% Std. Proc.)	
1.29	---	1.13	---	CCY (100% Std. Proc.)	
1.32	---	1.16	---	CCY (95% Mod. Proc.)	
1.39	---	1.22	---	CCY (100% Mod. Proc.)	
1.31	---	1.00	1.00	BCY	Dry Clay**
1.18	---	0.90*	---	CCY (85% Std. Proc.)	
1.25	---	0.95*	---	CCY (90% Std. Proc.)	
1.39	---	1.06	---	CCY (100% Std. Proc.)	
1.39	---	1.06	---	CCY (90% Mod. Proc.)	
1.54	---	1.18	---	CCY (100% Mod. Proc.)	
1.32	---	1.00	1.00	BCY	Dry Common Earth
1.31	---	1.00	---	CCY (85% Std. Proc.)	
1.39	---	1.05	---	CCY (90% Std. Proc.)	
1.54	---	1.17	---	CCY (100% Std. Proc.)	
1.45	---	1.10	---	CCY (90% Mod. Proc.)	
1.61	---	1.22	---	CCY (100% Mod. Proc.)	
1.28	---	1.00	1.00	BCY	Moist Common Earth
1.17	---	0.91*	---	CCY (85% Std. Proc.)	
1.23	---	0.96*	---	CCY (90% Std. Proc.)	
1.37	---	1.07	---	CCY (100% Std. Proc.)	
1.29	---	1.00	---	CCY (90% Mod. Proc.)	
1.43	---	1.11	---	CCY (100% Mod. Proc.)	

*Indicates that the material in the bank has a greater density than the required for the compacted material.
**Due to clay's ability to retain such a wide range of moisture contents, it is difficult to define "wet" clay; therefore, dry clay only is considered here.

Soil volume conversion factors
Figure 2-1

As an example, let's assume that a project requires 4,000 cubic yards of cut and 4,000 cubic yards of compacted fill. The soil is dry common earth placed at 100 percent of Standard Proctor density. At first glance, you might think this is a balanced site, requiring neither import nor export. Or you might account for swell during the cut stage, but fail to shrink the (compacted) fill volume. Here's what the tally sheet would look like in the latter case, using conversion factors to calculate the swell from BCY to LCY:

$$\text{Cut} = 4{,}000 \text{ BCY} \times 1.32 \text{ LCY/BCY} = 5{,}280 \text{ LCY}$$

$$\text{Fill} = 4{,}000 \text{ CCY} \times \text{no factor} = 4{,}000 \text{ CCY}$$

You may already recognize that there's a problem here. If we subtract the fill from the cut, the result is 1,280 CY. But what's the state of the soil? Since we've subtracted compacted cubic yards from loose cubic yards, the resulting quantity has no legitimate meaning. The fill calculation needs to be converted into loose cubic yards. Here's the correct tally sheet:

$$\text{Cut} = 4{,}000 \text{ BCY} \times 1.32 \text{ LCY/BCY} = 5{,}280 \text{ LCY}$$

$$\text{Fill} = 4{,}000 \text{ CCY} \times 1.54 \text{ LCY/CCY} = 6{,}160 \text{ LCY}$$

So the correct import quantity is 6,160 LCY minus 5,280 LCY, which equals 880 LCY.

Calculating Trench Volume

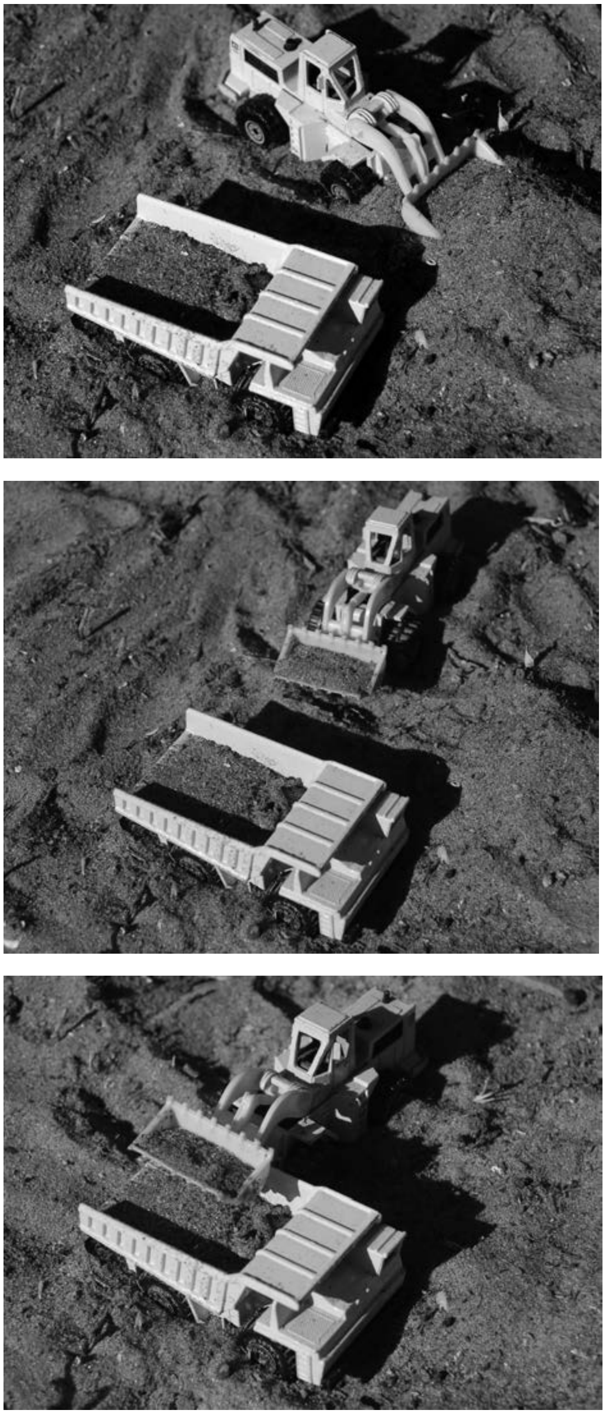
To calculate the volume in cubic feet of trench material to be moved, multiply the trench length by the width, in feet, by the *average* depth, in feet. Then divide the outcome by 27 (the number of cubic feet in a cubic yard) to get the number of cubic yards.

> ***AS A PRACTICAL MATTER,*** the depth of a trench will vary when pipe is laid across uneven ground. At different points, a trench may be anywhere from 5 to 7 feet deep, or even 10 feet deep. When the depth varies, it's acceptable estimating practice to find the average depth and then base volume calculations on that average.

Let's say you're digging a trench 100 feet long by 2 feet wide by 5 feet deep. Multiply the length (100 feet) by the width (2 feet) by the depth (5 feet) to get 1,000 bank cubic feet (BCF). Dividing by 27 yields a total volume of 37.04 BCY of material. I recommend that you round off the final volume calculations. A decimal point used in a total quantity is an accident waiting to happen, and it's absurd to think that any earthwork quantity will be accurate to within tenths (much less hundredths) of a cubic yard. So in this case we'll round off the answer to 37 BCY.

Here's how to get the average depth: From the plans, measure the depth at regular intervals along the ground where the trench will be dug. Then add the depth measurements together and divide by the number of measurements taken. For example, assume you're digging a 100-foot trench. Measure every 20 feet along the length of the trench. The depths you find in this example are 5, 5, 6, 7 and 10 feet. Add the depths together to get a total of 33 feet. Now divide by the number of measurements taken (five) to get an average depth of 6.6 feet. The more depth measurements you take, the more accurate your average depth figure will be.

Now let's calculate the volume of material to be moved from this trench, assuming it's 2 feet wide. Multiply the length (100 feet) by the width (2 feet) by the average depth (6.6 feet) to get 1,320 BCF. Divide by 27 to get a (rounded) total volume of 49 BCY.



Basic loader cycle
Figure 2-2

Equipment Performance

Start the equipment production estimate by determining the maximum ideal production rate for each piece of equipment under perfect conditions. Of course, it's highly unlikely you'll be working in perfect conditions. But once you know the optimum production rate, you can allow for the actual conditions and operator ability.

Hourly Production Rate

The optimum hourly production rate for each piece of equipment is the number of completed *cycles* per hour times the volume of material moved in each cycle. Cycle time can mean different things for different pieces of equipment. For example, cycle time for a wheeled loader filling a hauling unit includes time required for loading, turning, dumping, four reversals in direction and a 15-foot haul or return distance. Figure 2-2 illustrates the process.

Some of the major equipment manufacturers have spec sheets that show cycle times for their equipment. These cycle times are based on tests done under ideal conditions: level land, easy soil, no crosslines and an experienced operator. Production rates on these spec sheets are often somewhat optimistic, to say the least.

Wheeled backhoe, 14 foot hoe, 4 foot deep trench

Description	Time (seconds)	Soil type
Fast	10	Hard dry loam
Average	12	Hard dry loam
Average	16	Hard pan or cemented gravel
Slow (hard digging)	20-30	Caliche

Wheeled backhoe, 14 foot hoe, 8 foot deep trench

Description	Time (seconds)	Soil type
Fast	12	Hard dry loam
Average	14	Hard dry loam
Average	18	Hard pan or cemented gravel
Slow (hard digging)	20-30	Caliche

Cycle times for wheeled backhoe
Figure 2-3

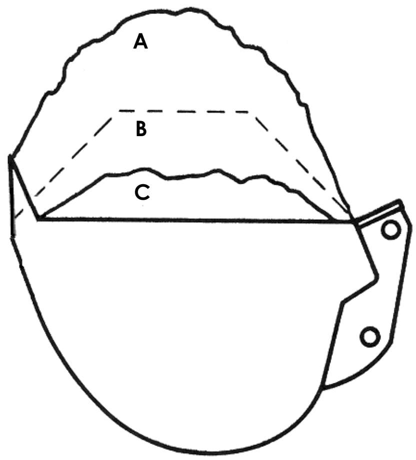
Figure 2-3 shows sample cycle times for a wheeled backhoe. It's OK to use these cycle times as a guide, but remember, *there's no substitute for your own data based on actual observation*. Collect cycle time data from the equipment on your jobs whenever possible.

When you have a reasonable estimate of your equipment's cycle time in seconds or minutes, convert it to cycles per hour. To convert seconds into hours, divide 3,600 (the number of seconds in an hour) by the cycle time. For example, if the average cycle time is 30 seconds, divide 3,600 by 30 to find the cycle time of 120 cycles per hour. If your cycle time is in minutes, just divide 60 (the number of minutes in an hour) by the number of minutes in the cycle. If the cycle time is 2 minutes, there will be 30 cycles per hour.

Now you've got the number of cycles per hour. To calculate hourly production, you also have to know the volume of material moved in each cycle. Volume per cycle varies with equipment capacity and soil swell.

Equipment Capacity Factors

Most earthmoving equipment comes with spec sheets showing equipment capacity. Bucket capacities are described as "heaped" or "struck." *Heaped capacity* is the bucket's maximum capacity when the material is heaped above the edges of the bucket. *Struck capacity* represents bucket contents when filled to the level of the rim, with no material heaped over it. Struck capacity is the same as the water-carrying capacity of the bucket.



Average Bucket Payload = (Heaped Bucket Capacity) = (Bucket Fill Factor)	
Material	**Fill Factor Range (Percent of Heaped Bucket Capacity)**
Moist loam or sandy clay	A — 100 - 110%
Sand and gravel	B — 95 - 110%
Hard tough clay	C — 80 - 90%
Rock — well blasted	60 - 75%
Rock — poorly blasted	40 - 50%

Courtesy of Caterpillar, Inc.

Excavator bucket fill factors
Figure 2-4

On equipment spec sheets, the capacities shown are often heaped capacities. You won't have fully heaped buckets on most cycles on a job. It's impossible to get a heaped bucket load when working in saturated sand and gravel or poorly shot rock. If the manufacturer's specs show heaped capacities, reduce the numbers by 10 percent before you apply any adjustment factor.

Figure 2-4 shows equipment capacity (fill) factors for an excavator — use these factors to adjust your equipment performance estimate. For example, moist loam or sandy clay has a maximum adjustment factor of 110 percent. That means you'd multiply the struck bucket capacity claimed by the excavator manufacturer by 1.10 to find the amount of material moved per cycle. Then multiply that number by the cycles per hour to find the optimum hourly production rate.

Swell (%)	Load factor
5	.952
10	.909
15	.870
20	.833
25	.800
30	.769
35	.741
40	.714
45	.690
50	.667
55	.645
60	.625

Load factors for common swell percentages
Figure 2-5

Once you have the optimum hourly production rate, it's time to consider another facet of soil swell called *load factor*. Load factor converts loose cubic yards to bank cubic yards. That's important because excavation production rates are usually expressed in terms of bank cubic yards per hour, but by definition you're working with loose soil.

To find the load factor, divide the bank volume by the bank volume plus the swell percentage. For example, a soil that swells by 25 percent has a load factor of 0.80 (1 LCY ÷ 1.25 LCY). To adjust your optimum production rate to allow for soil swell, just multiply the hourly production rate by the load factor. Figure 2-5 shows the load factors for common swell percentages, and Figure 2-6 shows swell percentages for different soil types. Remember, these are averages. Soil condition and degree of compaction affect these percentages considerably.

WEIGHT* OF MATERIALS	LOOSE kg/m³	LOOSE lb/yd³	BANK kg/m³	BANK lb/yd³	LOAD FACTORS
Basalt	1960	**3300**	2970	**5000**	.67
Bauxite, Kaolin	1420	**2400**	1900	**3200**	.75
Caliche	1250	**2100**	2260	**3800**	.55
Carnotite, uranium ore	1630	**2750**	2200	**3700**	.74
Cinders	560	**950**	860	**1450**	.66
Clay — Natural bed	1660	**2800**	2020	**3400**	.82
Dry	1480	**2500**	1840	**3100**	.81
Wet	1660	**2800**	2080	**3500**	.80
Clay & gravel — Dry	1420	**2400**	1660	**2800**	.85
Wet	1540	**2600**	1840	**3100**	.85
Coal — Anthracite, Raw	1190	**2000**	1600	**2700**	.74
Washed	1100	**1850**			.74
Ash, Bituminous Coal	530-650	**900-1100**	590-890	**1000-1500**	.93
Bituminous, Raw	950	**1600**	1280	**2150**	.74
Washed	830	**1400**			.74
Decomposed rock —					
75% Rock, 25% Earth	1960	**3300**	2790	**4700**	.70
50% Rock, 50% Earth	1720	**2900**	2280	**3850**	.75
25% Rock, 75% Earth	1570	**2650**	1960	**3300**	.80
Earth — Dry packed	1510	**2550**	1900	**3200**	.80
Wet excavated	1600	**2700**	2020	**3400**	.79
Loam	1250	**2100**	1540	**2600**	.81
Granite — Broken	1660	**2800**	2730	**4600**	.61
Gravel — Pitrun	1930	**3250**	2170	**3650**	.89
Dry	1510	**2550**	1690	**2850**	.89
Dry 6-50 mm (1/4"-2")	1690	**2850**	1900	**3200**	.89
Wet 6-50 mm (1/4"-2")	2020	**3400**	2260	**3800**	.89
Gypsum — Broken	1810	**3050**	3170	**5350**	.57
Crushed	1600	**2700**	2790	**4700**	.57
Hematite, iron ore, high grade	1810-2450	**4000-5400**	2130-2900	**4700-6400**	.85
Limestone — Broken	1540	**2600**	2610	**4400**	.59
Crushed	1540	**2600**	—	—	—
Magnetite, iron ore	2790	**4700**	3260	**5500**	.85
Pyrite, iron ore	2580	**4350**	3030	**5100**	.85
Sand — Dry, loose	1420	**2400**	1600	**2700**	.89
Damp	1690	**2850**	1900	**3200**	.89
Wet	1840	**3100**	2080	**3500**	.89
Sand & clay — Loose	1600	**2700**	2020	**3400**	.79
Compacted	2400	**4050**			
Sand & gravel — Dry	1720	**2900**	1930	**3250**	.89
Wet	2020	**3400**	2230	**3750**	.91
Sandstone	1510	**2550**	2520	**4250**	.60
Shale	1250	**2100**	1660	**2800**	.75
Slag — Broken	1750	**2950**	2940	**4950**	.60
Snow — Dry	130	**220**			
Wet	520	**860**			
Stone — Crushed	1600	**2700**	2670	**4500**	.60
Taconite	1630-1900	**3600-4200**	2360-2700	**5200-6100**	.58
Top Soil	950	**1600**	1370	**2300**	.70
Taprock — Broken	1750	**2950**	2610	**4400**	.67
Wood Chips**	—	—	—	—	—

*Varies with moisture content, grain size, degree of compaction, etc. Tests must be made to determine exact material characteristics.
**Weights of commercially important wood species can be found in the last pages of the Logging & Forest Products section. To obtain wood weights use the following equations: lb/yd³ = (lb/ft³) × .4 × 27
kg/m³ = (kg/m³) × .4

Courtesy of Caterpillar, Inc.

Weights and load factors for various soils
Figure 2-6

Say your optimum hourly production rate is 250 LCY when working in soil with a 25 percent swell factor. Referring to Figure 2-5, the load factor is 0.800. Multiply 250 by 0.800 and you get an adjusted production rate of 200 BCY.

Operator Ability Factors

A highly skilled operator can handle equipment on virtually any type of terrain. He's equally at home in any type of soil, on any safe slope, and even the most congested site. But you won't find many operators like that, so don't count on superior production rates until you've seen your operator do superior work under varying conditions.

> *"Crew motivation has a major impact on crew efficiency. In fact, motivation may be the most important variable of all."*

Most equipment operators have more limited skills. Every time the soil or job conditions change from ideal, production rates decline and costs increase. Don't expect better than average production rates from average operators. The skill level of most operators will be about 75 percent of maximum on most jobs. Some will do better and some will do worse. Until you know the skill level of your particular operator, use a correction factor of 0.75. Take your optimum hourly production rate, adjust it to allow for equipment capacity and soil swell, and then multiply the result by 0.75.

In the previous example, we adjusted the production rate of 250 LCY to 200 BCY. Assuming the job is being done by an operator with average ability, you'd need to multiply 200 BCY by the correction factor of 0.75. That brings the hourly production rate down to 150 BCY.

Job Efficiency Factors

No one works at peak productivity for an eight-hour day. But this doesn't necessarily imply that your crew is slacking off. You'll lose some production time in refueling, maintenance and the usual construction delays.

Every job has its share of holdups — not all of which are the fault of the operator. Pipe layers can only lay pipe after the trench is excavated. Backfill can't be placed until the pipe is laid. None of this can be done until the job is properly laid out and organized.

When you consider all the variables, 50 minutes of productive work per hour is probably the best you can expect on most jobs. To account for job efficiency, divide the number of productive minutes per hour by 60. For example, the job efficiency factor for a 50-minute work hour is 50 divided by 60, which comes to 0.83. Picking up where we left off earlier, we'll multiply 150 BCY by the job efficiency factor of 0.83. That brings the realistic hourly production rate to 125 BCY.

When a machine has to spend a lot of time waiting on trucks or pipe laying, actual production time may be only 30 minutes per hour. Also keep in mind that there's a big difference between excavating an entire length of trench at one time and having to excavate, lay pipe and backfill as the excavation moves forward. In the latter case, your efficiency will suffer.

Crew motivation has a major impact on crew efficiency. In fact, motivation may be the most important variable of all. That's where a good superintendent can make all the difference. He provides the motivation. He must be experienced, and know the business from top to bottom. A good superintendent needs the maturity and personality to get the best productivity from his crew, and know how to put the right people in the right positions. He must provide all crew members with the incentives they need to do a good job.

The best operators and tradesmen are motivated by pride of accomplishment and a spirit of cooperation, teamwork and respect for the supervisor. Unfortunately, most people on your payroll probably aren't natural team players. They're independent individuals with their own values and opinions. If there are some of these people on your crew, a good superintendent will massage egos occasionally because it's vital that they be molded into a productive team.

An In-Depth Review

Let's go over the production rate calculation process again, and do a few more examples, because it's one of the most important elements of estimating. You may not be able to predict production rates precisely, but you should be able to tell what's impossible in a given set of circumstances. You'll be in trouble if you base a bid on an overly optimistic projected production rate. The projected production rate is the basis of your bid — the foundation on which you base your other calculations.

With experience, you can begin to "ballpark" production rates. Experience may show that a certain size loader and skilled operator can load out 15 truckloads an hour. Experience may tell you that you can get a trenching rate of 100 feet an hour from a certain backhoe-operator combination, or a pipe installation rate of 300 feet a day. Such proven production data is invaluable.

The danger lies in oversimplification. If a job was profitable at a footage installation rate of $30 a linear foot last year, that doesn't mean you can base a bid on those same numbers today. Unless today's job, material, equipment, fuel, and labor prices are comparable, that information is irrelevant.

Wheeled backhoe loader
Figure 2-7

The basis of a bid is how long it'll take and how much it'll cost. So use production calculations to estimate how long it'll take. Then compare your estimates against your previous production records. Finally, compare them against previous bids of your competitors. If there's a vast difference between your projections and the competition's, there's either a faulty premise, a miscalculation, or your competitors are going broke!

Now let's apply what you've learned. We'll estimate the equipment performance rates for a handful of equipment types.

Wheeled Backhoe

Our first sample production estimate involves excavating for sewer service using a wheeled backhoe like the one in Figure 2-7. The average depth of the trench is 9 feet. The average width is 2 feet. The length of the trench is 30 feet. This project is in a developed area, and there will be several crosslines. Water, phone, power and gas lines run parallel to the sewer main.

The backhoe has to excavate the trench and supply pipe bedding from a nearby stockpile. A pipe layer follows with the service pipe. A follow-up backhoe (fitted with a trench compactor) will handle the backfill. The soil type is hard, dry loam.

Volume of Material

The first step is to use our formula to calculate the volume of material. Multiply the length of the trench (30 feet) by the width (2 feet) by the depth (9 feet) to get 540 BCF. Divide by 27 to get a total volume of 20 BCY.

If you want to know how many bank cubic yards of material there are in each linear foot of trench, just divide the total volume (20 BCY) by the length of the trench (30 LF). This comes to 0.66 BCY per linear foot of trench. Another (and perhaps simpler) way to do this calculation is to divide the end area of the trench, 18 SF, by 27.

Hourly Production Rate

Using the formula for calculating optimum hourly production rates, we'll multiply the number of cycles per hour by the volume of material moved in each cycle.

Look again at Figure 2-3. The cycle time for an operator of average ability digging in hard, dry loam is 14 seconds per cycle. To convert this to minutes per cycle, divide 14 seconds by 60. This comes to 0.23 minutes per cycle.

To calculate the number of cycles per hour, divide 60 minutes by the number of minutes per cycle (0.23). This gives you 261 cycles per hour.

Now let's find the volume of material moved in each cycle. Assume that the majority of material excavated will be primarily in a loose state after being disturbed. Go back to Figure 2-4 and look at the bucket fill factors. For loam, the bucket fill factor is 1.1 (110 percent). To find the bucket volume, multiply the bucket fill factor by the struck capacity. Struck capacity for this bucket is 6 loose cubic feet. Multiply 6 by 1.1 to get 6.6 loose cubic feet. Then divide by 27 to get the number of cubic yards. That brings the volume of material in each bucket load to 0.24 LCY.

Now let's apply the load factor. Assume the swell percentage for this type of soil is 35 percent. Figure 2-5 tells us that 0.741 is the load factor for a 35 percent swell rate. Multiply the bucket volume (0.24 LCY) by the load factor to get a more accurate load estimate. In this case, the volume of material in each bucket will be 0.18 BCY.

Now that we have the number of cycles per hour and the volume per cycle, we can calculate the hourly production rate. Multiply the number of cycles per hour (261) by the volume per cycle (0.18 BCY) to get a production rate of 47 BCY per hour.

Let's convert this hourly production rate by volume to an hourly rate per *linear foot*. This will tell us how many linear feet of trench we can dig in an hour. Here's the formula: Divide the hourly production rate (47 BCY) by the volume of material in each linear foot of trench (.66 BCY). In this example, it comes to 71 LF per hour.

Correction Factors

But this isn't our final estimate. We still have to incorporate operator ability and job efficiency.

We'll assume an operator with average ability. That tells us to use the 0.75 factor. Multiply the number of linear feet per hour (71) by the factor (0.75) to get a new linear foot production rate of 53 LF per hour.

For job efficiency, start with the 50-minute work hour and the correction factor of 0.83. Multiply the linear foot production rate (53) by 0.83 to get 44 LF per hour.

If your operator can dig 44 LF per hour, how long will it take him to do the entire 30 feet of trench? Just divide the trench length by the number of linear feet per hour to get a total production time of 0.68 hour. To convert this to minutes, multiply 60 minutes by 0.68. The answer is 40.8. Round that to 41 minutes for this trench.

On this job, other delays should be included in your calculation. This will be a stop-and-start operation. The area around the riser pipe (or tee) in the main line will have to be excavated by hand. If a grademan works along with the equipment operator, production will move faster and there'll be less chance of damage. But there'll still be considerable delay.

Crosslines will slow production too. If the soil allows easy digging, the delay will be about 10 to 15 minutes per crossline. If the soil is hard and the crosslines are difficult to locate, the delay may be 20 to 30 minutes per crossline. The time required to locate crosslines depends primarily on how accurately their locations are shown on the plans. Special care must be taken around gas lines and telephone or electrical cables. Hauling and placing the pipe bedding will also delay production.

Suppose the total of these delays comes to about 45 minutes. That makes the total production time for this task about 86 (41 + 45) minutes, or 1.43 (86 ÷ 60) hours.

"Most utility line contractors try to avoid leaving a trench open *overnight in a high traffic area."*

Keep an eye out for other factors that may affect your production rate. Street traffic, excavating under sidewalks, curbs or gutters, asphalt removal and avoiding damage to private property will all slow production. And don't forget to add time for startup in the morning and cleanup at the end of the workday.

Track excavator, 120-150 hp engine, 20 feet maximum digging depth		
Description	**Time (seconds)**	**Conditions**
Fast	18	Trench depth less than 10′ deep, good work room with few obstructions.
Average	22	Trench depth less than 12′ deep, underground utilities present, small dump target.
Hard digging	30	Trench depth in excess of 12′ deep, overhead obstructions.
Track excavator, 250-300 hp engine, 25-30 ft maximum digging depth		
Description	**Time (seconds)**	**Conditions**
Fast	20	Trench depth less than 10′ deep, good work room with few obstructions.
Average	27	Trench depth less than 12′ deep, underground utilities present, small dump target.
Hard digging	33	Trench depth in excess of 12′ deep, overhead obstructions.

Cycle times for track excavator
Figure 2-8

Most utility line contractors try to avoid leaving a trench *open* overnight in a high traffic area. You may not want to start any new excavation near the end of the workday. Keep this in mind. If your crew is working an 8-hour day, you'll probably get only 7 or 7½ hours of productive work; not 8.

Track Excavators

You can calculate trenching production for a track excavator the same way you would for a wheeled backhoe. Track equipment cycle times will be longer, however, because it takes more time to maneuver around obstructions like trees and power lines.

Figure 2-8 shows average cycle times for a track excavator under the three most typical working conditions. Use the procedures and formulas described earlier to determine the volume of material and hourly production rate for your project. Evaluate the delays you'll face, and then calculate your final estimated trenching production.

Crane used to lower pipe into trench
Figure 2-9

On some jobs you'll use the track excavator for laying pipe or loading the spoil into trucks. A track excavator isn't always a good choice for loading trucks, however. The production rate is generally lower, especially when trucks can't get close to the work, or when maneuvering room is restricted. It may be better to use a loader for spoil removal, and leave the excavator to excavate. But if you do end up using a track excavator, be sure to include pipe laying or truck loading delays into your excavation time.

Production will be delayed further when a track excavator is used to provide pipe bedding. A wheel loader is a better option, but it won't always fit in the work space. Again, it's better to let the excavator do what it does best. Figure 2-9 shows a project where a crane is used to lower the pipe into a trench, allowing the excavator to continue excavating.

Loaders

On a loading job, there are actually four separate operations: excavation, loading, hauling and backfilling. Ideally, the production rate for the four operations match perfectly and all equipment works at top efficiency for the project duration. I've never seen a job like that, and you won't either. Usually one operation sets the production pace. The others work at less than peak efficiency.

In a hauling job, loader capacity usually sets the work pace and dictates the number of trucks needed. In utility work, excavating equipment usually sets the work pace. Try to synchronize the excavator and loader, and select backfilling equipment that can keep pace with other equipment. For example, if a track excavator generates 100 LCY of spoil per hour, you'll need a loader that can handle 100 LCY per hour.

To determine the required loader bucket capacity, divide hourly volume requirement (100 LCY) by the *corrected cycles per hour*. To find corrected cycles per hour, first look up the optimum loader cycle time in Figure 2-10. Then convert this to optimum cycle times per hour. Divide the number of seconds in an hour (3,600) by the number of seconds per cycle. If the average cycle time is 35 seconds, that equals 103 optimum cycles per hour.

Struck Capacity (C.Y.)	Basic Cycle Time (Minutes)
Up to 4	0.45 to 0.50
4 to 6.75	0.50 to 0.55
6.75 to 7.1	0.55 to 0.60
7.1 to 11.2	0.60 to 0.75

Cycle times for wheel loaders
Figure 2-10

Material	Fill Factor as a Percentage of Heaped Bucket Capacity
Loose material	
Mixed moist aggregates	95-100%
Uniform aggregates up to 3mm (1/8 in.)	95-100%
Uniform aggregates 3mm (1/8 in.) to 9mm (3/8 in.)	90-95%
Uniform aggregates 12mm (½ in.) to 20mm (¾ in.)	85-90%
Uniform aggregates 24mm (1 in.) and over	85-90%
Blasted rock	
Well blasted	80-95%
Average	75-90%
Poor	60-75%
Other material	
Rock-dirt mixtures	100-120%
Moist loam	100-110%
Soil, boulders, roots	80-100%
Cemented materials	85-95%

Courtesy of Caterpillar, Inc.

Loader bucket fill factors
Figure 2-11

Next, convert this from optimum to corrected cycles per hour. Multiply the number for optimum cycles per hour by the job efficiency factor (0.83) and the operator ability factor (0.75). That comes to 64 corrected cycles per hour.

Since you're dealing with loose cubic yards, you won't have to convert from bank to loose. Now calculate the bucket capacity needed. Divide loose cubic yards per hour (100) by cycles per hour (64), which comes out to 1.56 LCY.

To keep pace with the excavation rate, the loader bucket must carry 1.56 LCY per cycle. Of course, loader bucket capacity depends on the type of material being handled. Look at the loader bucket fill factors in Figure 2-11. Use this formula to convert the specified bucket capacity to the appropriate type of material (in this case, moist loam). Use the high end of the moist loam fill factor range, 1.10. Divide 1.56 by 1.10 to get a 1.42 LCY heaped capacity requirement.

Just for practice, I'll ask you this question: What if you'd been working with well-blasted rock instead of loam? If that was the case, you'd use a bucket fill factor (from Figure 2-11) between 0.8 and 0.95. To be safe, use 0.8 as the fill factor. Dividing 1.56 by 0.8 results in a 1.95 LCY heaped capacity requirement.

Leave a margin of safety. When you have to make a choice, select a bigger loader with extra bucket capacity rather than a smaller loader barely big enough for the task. That increases the loader cost but will reduce overall job cost.

Track Loaders

In contrast to wheeled loaders, track loaders are best suited for projects where good traction and reduced ground pressures are required, and where the working surface is abrasive enough to cause excessive tire wear. However, a track loader must be transported on a trailer if the travel distance is substantial, or if crawler tracks are prohibited over the travel surface. Track loaders like the one in Figure 2-12 can travel along side slopes with grades up to 35 percent, and they can climb slopes with grades up to 60 percent.

Courtesy of Terry Newman

Track loader
Figure 2-12

Loader Production

Once you know the type of soil, the corrected bucket capacity and the cycle times, you can calculate loader production. Just multiply the number of cycles per hour by the volume per cycle. Continuing with the moist loam example from above, that's 64 cycles per hour times 1.42 LCY per cycle, which comes to 91 LCY per hour.

Determine how many trucks are required to service an excavator or loader by dividing the haul unit (truck) cycle time by the load time. Truck cycle time includes load, haul, dump, return and spot times. For example, if the truck cycle time is 30 minutes and the load time is 3 minutes, you'll need at least 10 (30 ÷ 3) trucks. To be on the safe side in case of mechanical problems, I'd suggest using one additional truck.

Cycle Times, Revisited

Figure 2-10 shows preliminary loader cycle times. Use this table only if you don't have better information from actual observations in the field. If bucket dumping requires precise placement of spoil or multiple dump targets, the cycle time will be longer. Other variables that affect the loader cycle time include soil type, pile type, truck size and truck availability.

When the loader has to carry loads over long distances, you have to calculate cycle times based on all the components of a loader's cycle: loading, traveling (including four reversals in direction), dumping, and returning to load.

Loading a bucket with up to 4 LCY capacity will usually take about 6 to 10 seconds. Dumping the bucket can range from 3 to 5 seconds to as much as 20 seconds when the loader must dump in several piles.

Travel speed depends on terrain, engine horsepower and the particular machine's gears. Two miles per hour is an average loaded travel speed over rough or steep terrain. Four to 8 mph may be possible on smooth surfaces with an empty bucket. To calculate travel time in feet per minute, divide the distance traveled in feet by the distance in feet traveled per minute. To convert speed in miles per hour to feet per minute, multiply by 88. For example, 2 mph × 88 = 176 feet per minute.

Here's an example of the steps required to calculate the total loader cycle time for longer carries. Assume a 200-foot cycle distance:

1. Load bucket: 7 seconds (0.11 minutes)
2. Reverse and forward: 10 seconds (0.17 minutes)
3. Travel time at 2 mph: 1.14 minutes
   (200 feet ÷ 176 feet per minute)
4. Reverse and forward: 10 seconds (0.17 minutes)
5. Bucket dumping time: 3 seconds (0.05 minutes)
6. Return to load at 4 mph: 0.56 minutes
   (200 feet ÷ 352 feet per minute)

The total cycle time comes to 2.20 minutes.

Bulldozers

Dozers range in size from 40 hp light utility dozers to very large machines weighing nearly 200,000 pounds that can move over 30 cubic yards in front of the blade. Dozer work includes logging, piling brush, and clearing land. Heavyweight dozer-ripper combinations can rip and remove fractured rock, sometimes making blasting unnecessary.

Each size and type of dozer has a range of appropriate uses and applications. The most common dozer models are those in the light utility and small production dozer class. Light utility dozers range from 40 to 80 hp and have a blade capacity of 1.25 to 2.25 cubic yards. Typical applications include residential and commercial foundations, fine grading, trench backfill, landscaping, light logging, and swamp dozing. Figure 2-13 shows a light utility dozer.

Mid-sized production dozers of 80 to 200 hp have a blade capacity of 2.75 to 5 cubic yards. Typical applications include trench backfill, logging, road building, leveling land, light duty ripping, tree and stump removal and short distance production dozing.

Light utility dozer
Figure 2-13

Heavyweight dozers of 200 to 700 hp have blade capacities up to 25 cubic yards. They're primarily production dozers but are also widely used for ripping, push scraper work, and road building.

Dozer Operations

The basic concept behind dozer operation is simple: The machine pushes dirt in front of a blade. But productive dozing requires more than just pushing dirt around. Cutting and moving dirt efficiently is an art. If the operator doesn't lift, tilt and angle the blade just right, he'll lose most of the load before he gets where he's going.

Crawler tracks convert engine power and machine weight into pushing power more efficiently than rubber tires could on dirt surfaces. And the width and length of the tracks distribute machine weight over a larger area of ground. That lets the dozer work in soft soil where a wheeled machine would bog down.

In this section, I'll explain the keys to effective dozing. Then we'll examine the dozer skills needed most often: basic dozing technique, dozing spoil piles, angle dozing, forestry work, and ripping.

Dozing Skills and Techniques

Blade position and depth of cut have the biggest influence on dozer efficiency. Other variables include direction of the dozing pass, gear selection, travel speed and the slope on which the machine is working. We'll consider each of these, one at a time.

Blade Position

There are two common blade positions in dozing. One is the bulldozing position, with the blade set at 90 degrees to the line of travel. The other is the angle dozing position, with the blade angled to one side.

Most small dozers are equipped with full hydraulic angling and blade tilt controls. A common dozer blade control is a four-way joystick for controlling blade lift and tilt, with a separate control lever for blade angling.

Depth of Cut

The appropriate depth of cut varies, depending on the job and the size of the machine. In either case, depth of cut shouldn't exceed what the machine can handle. A cut that's too shallow doesn't move enough soil. A cut that's too deep causes slipping tracks and inefficient use of power.

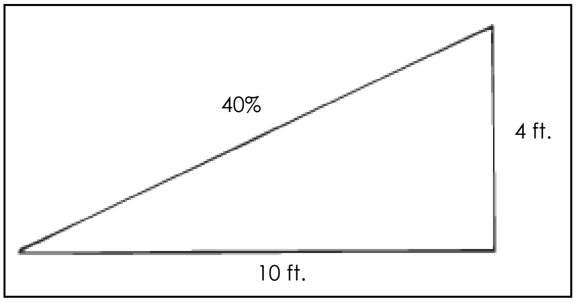
Direction of Dozing Pass

Wherever possible, the operator should align the direction of dozer travel with the blade dump area before beginning a pass. Of course, some dozers can turn a load easier than others. Even so, turning will cause loss of part of the load. Don't allow it unless it's absolutely necessary.

Gear Selection and Travel Speed

Gear selection and travel speed are influenced by engine hp, blade load, soil type, and grade. Using the right machine for the job, your operator should have no trouble achieving maximum load and travel speed.

You can't control the soil type and grade, but you *can* plan the job efficiently around them. A common mistake is operating a dozer too fast during the initial phase of a dozing pass. The most critical phase of the work cycle is when the dozer is traveling forward, picking up a blade load. The operator should take the time to cut the material smoothly and accurately. If he hurries across a bumpy or uneven area, the blade will create a washboard surface that's likely to get worse with each pass. Direct him to travel slowly when he loads the blade and removes the dirt in small slices. Speed will come later when he's transporting the blade load and making the reverse pass.



40 percent downgrade doubles dozer's load
Figure 2-14

A travel speed around 1.5 mph is ideal for initial blade loading. Although dozing speeds can be as high as 5 to 6 mph, the 1.5 to 4 mph range is normally the practical maximum.

Gear changes take a little time but reduce travel time. It's usually better to change gears in the middle of the dozing pass rather than start in a gear that's too high or travel slower than necessary. There's no set rule on which gears are best or what travel speed is right for a given application. Every job is unique.

Here's the rule of thumb I use: The motor should be turning smoothly and not lugging. An engine is lugging when it's losing speed even when the operator's trying to accelerate. Lugging causes excessive wear and overheating. Typically, a diesel engine will turn at about 2,000 rpm. A 10-20 percent drop in rpm is a comfortable loading. More than that and the engine is lugging, so a lower gear needs to be selected.

For fine grading where blade adjustments are made constantly during a dozing pass, the maximum speed practical for the travel portion of the dozing cycle should be used. A slow speed is needed to load the blade and an increase in speed for transporting the blade load.

Reverse travel offers another opportunity to minimize cycle times. As the dozer approaches the beginning of the next pass, the operator needs to steer it into position to make the pass without further steering adjustment. This lets him concentrate on speed control and blade adjustment as he begins the next dozing pass.

As he works an area, rows of spoil are left as part of the load is lost off the blade. These rows are called *windrows*. Crossing a windrow too fast can bounce the operator around in the cab. That can be dangerous. While I stress speed and efficiency, safety always comes first. Expect your crew to be reasonable and careful.

Downgrade Dozing

In earthmoving, it's common to use the percent of grade method to describe a slope. For example, a slope which rises 50 feet in 100 feet of horizontal distance is a 50 percent grade. A 100 percent slope is the same as a 45-degree angle. It rises 30 feet in 30 horizontal feet. Figure 2-14 illustrates a 40 percent grade.

A positive grade is an uphill slope. A negative grade is a downhill slope. Downgrade dozing increases the dozer's blade capacity and increases available pushing force. Gravity helps in both cases. The advantage is dramatic. *The blade load capacity of a dozer doubles if the load is pushed down a negative 40 percent grade.*

Dozing uphill is just the opposite. A positive grade has a negative effect on dozer production. When a dozer has to push its blade load up a 40 percent slope, the blade capacity is cut in half.

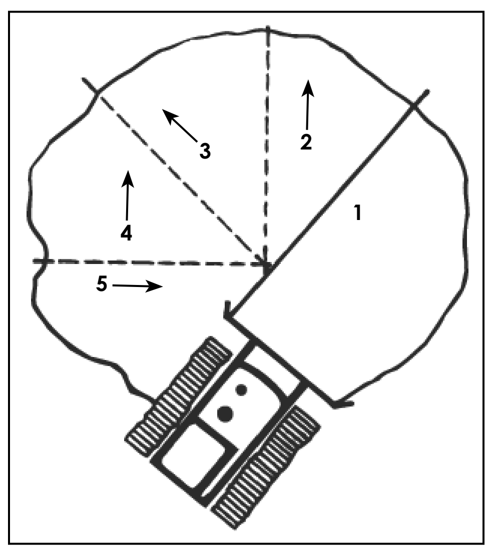
How many times have you seen dozers struggling to backfill large sewer trenches by working from the base of the spoil pile? A better way is to make an access ramp and level out the top of the pile. Then the operator can push spoil downgrade to the trench.

Here's another thing to keep in mind: A dozer blade tends to lose its load as the dozing distance increases. The blade load is triangular. As the machine moves forward, the load is gradually lost to each side and under the blade. Eventually there's nothing left of the original load.

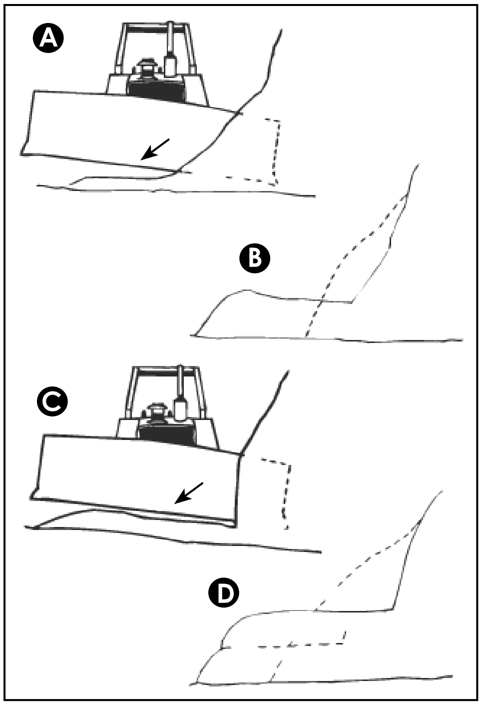
Slot dozing is one technique that can reduce the amount of load lost in transit. When slot dozing, the dozer works within a roughly 2-foot-deep trench that's the same width as the blade. Pushing soil in the slot keeps the load from slipping away. Additional slots, spaced at regular intervals, leave narrow uncut sections between the slots, which are eventually cut away. It's possible to create nearly the same result by having two dozers work in tandem, pushing the same load side by side. Another alternative is to use a dozer equipped with a U-shaped blade. U-blades are most efficient for dozing long distances, and can be fitted to many large dozers.

Dozing Spoil Piles

When your operator is spreading spoil, he must plan the work carefully. There are good ways and bad ways to spread a pile of earth. The key is getting maximum capacity from each pass while keeping maneuvering and direction changes to a minimum. Assuming the pile is to be moved and placed in the same vicinity, that usually entails breaking the pile down in a circular, clockwise or counterclockwise direction. Figure 2-15 illustrates the latter. The operator follows the sequence of cuts numbered 1 through 5 in the drawing.



Breaking down a spoil pile
Figure 2-15



Sidecasting
Figure 2-16

Angle Dozing

Most dozers can angle the dozer blade. On small utility dozers, the operator may be able to angle the blade hydraulically. On other machines, the angle has to be adjusted manually. In either case, blade angling increases the versatility of the machine. Angled blades can *sidecast* material, positioning it at 90 degrees to the line of travel. This is important, since it's often impossible for the operator to position the tractor directly behind the material he needs to bulldoze. Angle dozing lets the operator move the soil when there's no way to attack it from the rear.

To sidecast material, the operator uses the blade tilt control in combination with the angle control. On a small slope, he'll start sidecasting at the bottom of the slope and work upward, as illustrated in Figure 2-16. Part A shows the first cut. In Part B, the first cut has been finished. Notice that the spoil has been pushed out of the cut to form a ramp. In Part C, the dozer is making the second pass a little higher up the slope, again depositing spoil to the left. In Part D, the second pass has been made, preparing the ramp for the third pass.

As the forward edge of the blade slices into the pile, resistance of the soil tends to pull the blade deeper into the cut. That, in turn, tends to *slew* the machine into the bank. Under these circumstances, it's easy to make a cut that's too deep, which is something he wants to avoid.

Where the operator is cutting right-of-way across a steep slope, starting at the bottom may cause spoil to fall away too far, leaving the machine without a ramp to work from. In that case, it's often faster for him to reverse the process by starting at the top of the pile.

Dozer Safety

Your dozer operator is responsible for the safety of those working around him. Nothing on the job is worth the life of someone on the pipeline crew. Don't compromise safety on your jobsites for better production. When you consider the mass of soil and rock or the size of logs a dozer can move, the human body is frail in comparison. Don't forget that. Make sure you and your crews use common sense.

When your crews are working in the woods, make sure they keep the work area clear of trimmed branches so as not to obstruct the operator's vision. The operator must be especially alert when backing up.

Track equipment can work on steep ground, especially if the dozer is facing directly up or down a slope. But the operator needs to be cautious on side slopes, especially if the surface is wet or spongy. Rollovers can be fatal.

For operators inexperienced at working dense woods, they need to be especially careful. Brush can conceal old stumps that will drastically alter a dozer's center of gravity with little warning. Small poles and branches have a way of getting into the operator's platform, injuring the operator and interfering with the machine's controls.

When the operator is using a winch in his logging work, he should always line the machine up in the direction of pull before starting the winch. He can use a cable with a breaking strain greater than the winch capacity. And he should never start winching until the ground workers give him an "all clear" signal.

Working on Steep Slopes

Slopes greater than 60 percent are usually called *knee shakers*. A dozer can remain relatively stable on slopes up to 100 percent (1 foot of rise in each 1 foot of horizontal distance), but it's rare to find a smooth and even 100 percent slope on natural ground. Usually the slope will be steeper in some places and shallower in others. A 100 percent slope may have sections that are well over 100 percent.

Most dozers will climb a 100 percent slope. The problem will be in maneuvering, turning and stopping. A crawler equipped with a conventional transmission is the hardest to control on a steep slope. To turn left while traveling forward requires the left track to be slowed or braked. When the transmission is clutched, the dozer will stop. Unless the operator immediately applies the brakes, the machine will begin to travel backward down the slope. If the left brake is still applied, the front will slew rapidly to the right. Give the operator this control sequence to use to avoid this: throttle down, apply the main brake, then release the left brake as he pushes in the clutch.

Maneuvering a dozer over the lip of a drop-off can also be dangerous. If done incorrectly, it can cause the operator to be thrown around in the cab, probably lose control and maybe suffer some injury. It's important for the operator to reach the point of balance very slowly, and then ease ahead until the dozer slowly falls into position on the slope.

Dozer Blade Capacity

Not all equipment manufacturers list bulldozer blade capacity, so I'll show you the formula I prefer to use. The first step is to square the blade height in feet. Squaring is accomplished by multiplying the quantity

	Grade	Factor
Uphill (– grade)	20%	.66
	15%	.875
	10%	.916
	5%	.95
Downhill (+ grade)	5%	1.08
	10%	1.16
	15%	1.25
	20%	1.39
	30%	1.50
Slot dozing	25%	1.41
	30%	1.58
	35%	1.75
	40%	2.00

Blade capacity factors for dozers
Figure 2-17

by itself. Next, multiply the result by the blade width. Finally multiply that outcome by 0.022, and you've got the blade capacity in loose cubic yards. For example, say you have a dozer equipped with a blade that's 3 feet high and 10 feet wide. The height (3 feet) squared equals 9. Nine times 10 (the blade width) equals 90, and 90 times 0.022 equals 1.98 LCY blade capacity.

Grades affect both blade capacity and dozer pushing power. To account for varying grades, multiply a blade's capacity by correction factors. Figure 2-17 shows approximate blade capacity correction factors for a variety of uphill and downhill grades, as well as for slot dozing. As you can see, slot dozing (which I discussed earlier in this chapter) and downgrade dozing will increase production substantially.

Dozer Power and Speed

Formulas for calculating dozer-pushing power are too complex for practical application. I prefer the following rule of thumb: Assume that a dozer will push a blade load up a 20 percent grade at a speed slightly less than its maximum travel speed in first gear.

Dozing speeds range from 1 mph (88 feet per minute) up to 4 mph (352 feet per minute). But it's hard for the operator to adjust blade depth and tilt fast enough to keep pace at high travel speed. Most dozers have a fast travel speed of 6 to 7 mph. This is strictly a travel speed, not a working speed. But the fast travel speed in reverse gear can be used when reversing for the next dozing pass.

Dozer speed depends on many variables, including engine hp, but as a rule of thumb, average dozing speed under load is 2 mph. Average travel speed when the machine isn't under load will be 4 to 5 mph.

Bulldozer Cycle Time and Dozing Distance

A dozer's cycle time is made up of travel time forward under load plus return time. Return time is usually about half of travel time under load. In restricted work areas, however, the operator will spend more time maneuvering into position. Shorter dozing distances and confined work areas reduce travel speeds. In crowded or congested conditions, add spot and delay times to the total cycle time. *Spot time* is the time required to maneuver and get into position between passes.

Courtesy of Dymax Construction Equipment

Semi-universal blade
Figure 2-18

A dozer moving earth an average of 100 feet will have a higher production rate than a similar machine moving earth 200 feet. That's mainly because more travel time is involved. Another reason is that soil tends to drift away from the blade as the dozer moves. This reduces blade load at the end of the pass.

On a long dozer push, it's much more efficient if the operator uses one of the special purpose U-shaped blades available for large machines. As a rule, a semi-U blade fitted to a mid-sized dozer increases capacity by about 40 percent over that of a straight blade. Figure 2-18 shows a semi-U blade. Going one step further, full-U blades have about 20 percent greater capacity than semi-U blades of comparable height and width. Small utility dozers — 50 to 150 hp, with blade capacities from 1.5 to 4 LCY, can be fitted with straight multipurpose angling blades. These machines aren't a good choice for long distance dozing, however.

Dozer HP	Blade	Average distance (in feet)
50-70	6′-8′ W, straight blade	75
70-150	8′-12′ W, straight blade	100
150	12′ W, semi-U blade	125
More than 150	U or semi-U blade	150

Note: Hourly LCY production rates decrease by approximately 20% per 100 LF beyond efficient average dozing distance.

Efficient dozing distances
Figure 2-19

Figure 2-19 shows practical dozing distance. Hourly loose cubic yard production rates will decrease by about 20 percent per 100 LF beyond the efficient average dozing distance. If material must be pushed beyond the average distance, use loaders and trucks or scrapers instead.

Estimating Dozer Production

To calculate optimum dozer production rates, multiply the number of cycles per hour by the number of loose cubic yards per cycle. Let's run through an example. Suppose your operator is using a 70 hp dozer with a blade that's 3 feet 6 inches high and 8 feet wide. He's drawing from loose stockpiles to backfill a 100-foot-long, 8-foot-deep trench in an open area. The average trench width is 4 feet. Assume the soil swells by 30 percent when it's disturbed, and the average dozing distance is about 50 feet. Also assume a dozer speed of 1 mph (88 feet per minute) under load, and 3 mph (264 feet per minute) on the return.

The first thing to do is calculate the amount of material in the trench. The length (100 feet) times the width (4 feet) times the depth (8 feet) equals 3,200 BCF. To convert to bank cubic yards, divide by 27 to get 119 BCY.

The next step is to account for 30 percent swell, so multiply 119 by 1.30, which equals 155. Since the trench is 100 feet long, divide 155 by 100 to find the number of loose cubic yards per linear foot of trench. In this case, it's 1.55 LCY.

After calculating the trench figures, turn your attention to the dozer calculations, starting with cycle time and cycles per hour. Travel time equals the travel distance (50 feet) divided by the distance traveled per minute. Since 1 mph is 88 feet per minute, the forward travel time equals 0.57 (50 ÷ 88) minutes. Similarly, the return pass, at 3 mph (264 feet per minute), will take 0.19 minutes. That brings the total cycle time, combining forward and return, to 0.76 minutes. Dividing 60 by 0.76 gives us 79 cycles per hour.

The next step is to calculate blade capacity. Using the formula I discussed earlier, with a blade that's 3 feet 6 inches (3.5 feet) high and 8 feet wide, you come up with 2.16 (3.5 × 3.5 × 8 × 0.022) LCY per cycle.

If the dozer can move 2.16 LCY per cycle, and perform 79 cycles per hour, then its *optimum* production is 171 (2.16 × 79) LCY per hour. To put this in more realistic terms, adjust for efficiency and operator ability. Assuming a 50-minute hour and an operator with average skills, the

	Net HP	Blade size in feet Height	Blade size in feet Width	Capacity in L. CY	Distance in feet	Cycles per hour	L. CY per hour (flat)	L.CY per hour (on grade) -20%	-30%	-40%	+20%
Straight blade	80	3.0	8	1.6	50	85	136	166	217	272	108
	120	4.0	10	3.5	75	65	227	295	363	454	181
	160	4.5	12	5.4	100	50	270	351	432	540	216
	230	5.5	14	9.4	150	35	329	427	526	658	263
	350	6.5	15	14.0	250	21	294	382	470	588	235
Semi-U blade	120	10	4.0	4.9	75	60	294	382	470	588	235
	160	12	4.5	7.5	100	50	375	487	600	750	300
	230	14	5.5	13.0	150	35	455	591	728	910	364
	350	15	6.5	19.6	250	21	411	535	658	822	328
Full U blade	160	4.5	12	9.0	100	50	450	585	720	900	360
	230	5.5	14	15.8	150	35	553	719	885	1,106	442
	350	6.5	15	23.5	250	21	493	640	788	986	394

Optimum hourly production rates for dozers
Figure 2-20

adjustment factors are 0.83 and 0.75, respectively. Multiplying optimum efficiency (171) by these factors yields 106 LCY per hour. To convert 106 LCY to linear feet per hour, divide it by 1.55 (the number of LCY per linear foot for this trench), and you get 68 LF per hour.

Keep in mind that trenches are usually backfilled in lifts and each lift must be compacted (and often tested for density) before the next lift can be installed, which reduces backfill production substantially.

Figure 2-20 is a dozer production table to use as a guide, unless you have more accurate information. The table assumes a dozing speed of 1.25 mph and reverse travel speed of 6 mph. It also assumes the soil is easy loading and the operator has above-average skills. Grade figures with a negative percentage indicate favorable downgrade dozing. Those with a positive percentage indicate unfavorable upgrade dozing. The variables in your project can make a big difference, so if you do use the table, be sure to make adjustments for soil type and operator ability where appropriate.

Motor-Graders

Motor-graders (also called road graders), like the one in Figure 2-21, can work to very close tolerances. Some graders are towed behind a tractor, but most are self-propelled. Graders are used for bank sloping, road maintenance, ditching, backfilling, scarifying (loosening) and ripping, but they're primarily used for trimming the cut and fill area and processing material. There are two kinds of processing:

1. Mixing and stirring material to evenly blend added water
2. Spreading out material that's too wet, so it will dry

Motor-grader
Figure 2-21

Finish blading is the hardest part of a grader's work. A competent finish blade operator can cut and trim earth to the tolerance of a few hundredths of a foot. When a road base or site is approaching the correct grade level, engineers place hubs at the exact finish elevation. These hubs are usually blue and are often called *blue tops*. Obviously, these have to stay in place during finish grading. The grader operator has to cut just to the top of the hub and no farther. Hitting the hub with the blade would move the stake and require resetting. It's amazing how some operators can work right to the blue tops without hitting them.

Finishing and Trimming

Finishing operations include balancing and trimming. *Balancing* consists of cutting down high spots while filling in low areas, and *trimming* consists of shaping the road surface to a specified elevation. Some motor-graders are equipped with a precise automatic blade control sensing system that follows an established surface line by automatically raising and lowering the blade.

Material Blending and Spreading

Motor-graders are so versatile because the blade *(moldboard)* is adjustable. Blade adjustments can be made manually or with hydraulic controls. The blade can be tilted to a forward pitch position, which imparts a dragging action for blending soils, or it can be adjusted to a backward pitch position to increase cutting action for fine grading. Some graders are equipped with a second blade mounted on the front of the machine.

The moldboard's concave shape imparts a rolling action to the soil for spreading and mixing material. When spreading material, the blade is normally set perpendicular to, or at a slight angle from, the direction of travel. There are many situations where soil requires blending and mixing. Some soil mixing takes place as the grader spreads the soil during leveling and grading operations. Wet, unstable areas can be bladed and mixed with dry soil, then bladed back in place as suitable material.

Sidecasting and Backfilling

Soil can be moved laterally *(sidecast)* by setting the blade at an angle relative to the direction of travel. When sidecasting properly, the operator sets the blade so that the resulting windrow (longitudinal soil pile) doesn't form in the path of the rear wheels, since this increases rolling resistance and decreases traction. Sidecasting can be used for backfilling ditches and trenches, or for creating windrows of ripped asphalt to be crushed by a compactor.

Even when the blade is set perpendicular to the direction of travel, material will spill beyond the ends of the blade, forming windrows on each side of the motor-grader. Attaching wings to the ends of the blades will reduce the amount of spillage by keeping more material in front of the blade.

Ditching

A motor-grader can be used to cut ditches up to 3 feet deep. Beyond this depth, it's normally more economical to use a more productive excavator such as a scraper. Graders can be equipped with an elevating conveyor belt to help remove graded material.

Scarifying and Ripping

Scarifier teeth can be mounted behind and between the front wheels to aid the motor-grader in loosening tough or frozen soil, ice or gravel, and for breaking up asphalt paving. For light-duty applications, rippers can also be mounted at the rear of a motor-grader. This kind of versatility comes in handy, since subgrade material is normally trimmed to 0.10 foot above final subgrade elevation, and then ripped prior to compaction.

Motor-Grader Production

Motor-grader production is a function of effective blade length, average speed, job efficiency and the number of passes required. *Effective blade length* is the length of the blade measured perpendicular to the direction of travel.

To calculate production on a square-foot-per-hour basis, multiply effective blade length by average speed in mph times 5,280 (the number of feet in a mile) times the job efficiency factor times the operator ability factor. Then divide the result by the number of required passes. To convert to square yards per hour, divide the square foot figure by 9.

Let's try an example using a 30,000-square-yard site that's to be finish-graded and requires five passes. Assume two passes at 3 mph, two at 4 mph and one at 6 mph, and an effective blade length of 12 feet. Also assume a job efficiency factor of 0.83 and an operator ability factor of 0.75.

Start by calculating the only unknown component: average travel speed for the five passes. Multiply the number of passes by their three respective speeds, add them together, and divide by 5 (the number of passes). The average speed comes to 4 mph.

Now multiply the blade width (12) × average speed (4) × 5,280 × job efficiency (0.83) × operator ability factor (0.75). That comes to 157,766. Divide by the number of passes (5) to get 31,553 square feet per hour, which equals 3,506 square yards per hour. Dividing 30,000 (the square yards of the site) by 3,506 (the square yards per hour) gives your operator 8.6 hours to complete.

Scrapers

With the exception of extremely large excavators, scrapers *(pans)* are the most cost-efficient earthmovers available. Scrapers combine the ability to excavate with a proficiency at hauling material economically over great distances. Generally, scrapers are most effective when the haul distance ranges from 500 feet to 2 miles.

If you're using an excavator with a hauling unit fleet and the excavator breaks down, production stops completely. A scraper fleet doesn't pose that kind of risk. In addition, a scraper can dump its payload in uniformly thick layers, whereas trucks can't. That improves compaction productivity. Also, scrapers are precision finishing machines that can help maintain haul roads by filling in low areas during the haul trip and cutting down high spots during the return trip.

Scraper Varieties

The type of scraper to use depends on the size of the cut area, haul distance, soil type, rock size, total resistance, traction, underfoot conditions and other aspects of the jobsite. Some scrapers have an open bowl and are towed by tractors *(trailer scrapers)*. Figure 2-22 shows a pair of bowls being used in tandem formation for improved production. A scraper pulled by a crawler tractor is economical for short haul distances,

SCRAPERS ARE BUILT with a sturdy push block located at the rear of the machine which allows them to be assisted by a pusher tractor.

Courtesy of Miskin Scraper Works

Trailer scrapers
Figure 2-22

Courtesy of Terry Newman

Open-bowl scraper
Figure 2-23

especially on extremely steep grades, poorly-maintained haul roads, and in slippery conditions. For longer haul distances, scrapers pulled by wheel tractors or wheel tractor scrapers are better choices.

Elevating (paddle wheel) scrapers are equipped with a ladder-type mechanism called an elevator. The ladder reduces loading resistance and assists during loading by lifting and distributing material into the bowl. Elevating scrapers usually don't require loading assistance, and are referred to as self-loading scrapers. If the operator uses a pusher to assist a self-loading unit, he needs to push cautiously to avoid damaging the elevator. Elevating scrapers can't be used to load rock, sticky soil, or extremely hard or large pieces of material. They're also not very useful if the cut area is short, because they can't cut deep enough to get a full load. In such instances, an *open-bowl* scraper is used, often aided by a tractor pusher, like the one in Figure 2-23.

Scraper Payload

Payload is the load that a scraper can carry, exclusive of the vehicle weight. Payload can be expressed as weight capacity in pounds or tons, struck volume capacity in loose cubic yards, or heaped volume capacity in loose cubic yards. Regardless of the volume capacity, the rated weight capacity should never be exceeded. To do so will increase operating costs due to higher fuel consumption, reduced tire life, frequent failure of mechanical parts and higher maintenance costs. All of these items also equate to lost time and production while the vehicle is repaired or undergoing maintenance.

Struck capacity of a scraper is the volume of material that can be filled to the top of the bowl; therefore, struck capacity remains constant for any given scraper. Struck capacity is a useful measure when you need to limit spillage.

Heaped capacity will vary, depending on the height that the soil can be extended above the sides of the bowl. Heaped capacity is normally based on the heap having an angle of repose of 26.57 degrees, or a slope (run:rise) of 2 to 1 (2:1). As a rule of thumb, you can estimate the heaped capacity under normal conditions as being midway between the manufacturer's struck and heaped capacity ratings. For example, the estimated heaped capacity of a scraper with a rated 14 LCY struck capacity and 20 LCY heaped capacity would be 17 (14 + 20 ÷ 2) LCY.

Scraper Cycle Time

The total scraper cycle time is the sum of the load, haul, maneuver, dump and return times. Load, maneuver and dump times can be combined into what's referred to as *fixed* time. Similarly, haul and return times can be thought of as *travel* time. Therefore, total scraper cycle time is the sum of its fixed and travel times.

Load Time

Scraper load time is dependent upon many variables, including:

- the size, power and type of scraper
- the amount of pusher power that's available
- soil condition, traction, and total resistance
- traffic at the cut
- operator skill

If your operator has a short haul distance, he'll reach the point of diminishing returns if he completely loads a scraper. Have him use full loads only for long haul distances.

Load time can be reduced by loading downgrade, since this will reduce the total resistance and the amount of pusher power required. When a scraper is excavating a hill, the operator should start the cut at the top of the hill and make the cut as deep as possible, raising the bowl as the cut proceeds down the slope. This will flatten the hill and increase production rates.

Straddle loading is another way to reduce load time. Straddle loading involves spacing cutting at intervals, leaving ridges between the cuts. Eventually, the ridges are cut away and removed.

Direct your operator to load at a rate that doesn't cause the tires to spin, since that will cause excessive (and expensive) tire wear. If the loading rate is excessive, he needs to lift the bowl and make a lighter cut. Sometimes it's more productive to make a shallow cut in a faster, higher gear than to make a deep cut in a slower, lower gear. Ripping hard, cohesive soil prior to scraper excavation will reduce load time. Raising and lowering the scraper bowl will speed up loading when soft, non-cohesive soil is being loaded.

Using pusher assistance will increase the loading rate. Pushers should be powerful and heavy enough to push the scrapers through the cut and accelerate, or boost, the scrapers as they leave the cut. Adequate boosting will allow scrapers to spread the soil remaining in front of the bowl as it's lifted.

Pushers are normally crawler tractors weighing at least 20 tons. Since the speed of both vehicles is limited by the speed of the pusher, it's important for the operator to keep pusher speed limitations in mind. The pusher normally pushes in first gear, limiting track-mounted pushers to about 1½ mph and wheel-mounted pushers to 3 or 4 mph.

Some pushers are equipped with a fixed push plate while others use a reinforced dozer blade. Since a dozer blade can be equipped with rippers that engage only when the dozer is backing up, a dozer can be put to work back-ripping or cleaning up while waiting for a scraper to push.

Use an adequate number of pushers to service all of the scrapers, and if congestion occurs, reduce the loading time of some of the scrapers so that they're more evenly spaced.

Pushers are often used in tandem to increase the loading rate. Generally, each pound of push (including the scraper's effort) loads one pound of soil into the bowl per minute of load time.

Maneuver and Dump Time

Maneuver and dump time is the time required to properly position the scraper and off-load at the fill area. Some contractors allow scrapers to drive over previously dumped soil to help compact it. This increases overall dump time and reduces compaction time.

Maneuver and dump time can be reduced by dumping downgrade. When the operator keeps the cutting edge of the bowl high enough off the ground, that'll help keep wet, cohesive soil from becoming clogged as it passes through the front of the bowl. Provide pushers if the scrapers require additional power to dump their loads and be boosted out of the fill.

Minimize dump time by providing an adequate number of graders and compactors to keep the fill smooth and compacted, and by giving scrapers the right-of-way. When the scraper dumps its load, have it start by placing the fill in the lowest spots. This will produce a more level surface and will increase production rates.

Spot and Delay Time

Spot and delay time is the time required for the scraper to maneuver into the proper position and wait for pusher assistance at the cut. Spot and delay time can be reduced by providing an adequate number of pushers to service the scrapers, and by using either the chain- or shuttle-loading methods with the pushers. The *chain-loading* pushing technique involves the pusher transferring from one scraper to another without having to return to its original position. This assumes a second scraper is waiting near the end of the first scraper's pass, and is ready to begin its own scraping pass. *Shuttle-loading* pushing involves the pusher taking turns transferring from one scraper to another that's moving in the opposite direction — again, without having to return to its original position.

Travel Time

Travel time depends primarily on round-trip distance, engine power, payload, and surface resistance created by the road and grade. Some manufacturers publish travel time charts for their equipment.

Grades and road surface conditions can vary along the haul road. Scrapers may have to slow down for curves — not only for safety, but to preserve tire life, which is a particular concern in hot weather. Scraper traffic on narrow roads can become bottlenecked, especially when graders, dozers and water trucks are maintaining the haul road. One slow scraper can dictate overall production when passing is dangerous or impossible.

Bad weather conditions such as wind, rain and blowing dust can affect visibility and slow production. Rain can change a relatively hard-surfaced dirt road into a quagmire, and adverse haul road conditions will require that scrapers haul less than their rated payloads.

Figure 2-24 shows travel times for a variety of short haul distances that a scraper is likely to encounter. Unassisted scraper haul speeds vary from 4 to 6 mph in difficult conditions to as high as 20 to 30 mph over a well-groomed haul road. Remember that a scraper moving at 12 mph on an empty return travel will average much less than that for the entire return trip. Some time is wasted in acceleration and deceleration. The best way to estimate cycle time is to observe several jobs under varying conditions.

Scraper Production Rates

Some equipment manufacturers provide production curves for use in estimating scraper production, but here's how you can calculate it for yourself. Once you have estimates for all the cycle time components, add them together to determine total cycle time. Then calculate cycles

Speed (in mph)	Distance (in feet) 100	150	200	250	300	400	500	600	1,000	5,280
1	1.14	1.70	2.27	2.84	3.41	4.55	5.68	6.82	11.36	60.00
2	.57	.85	1.14	1.42	1.70	2.27	2.84	3.41	5.68	30.00
3	.38	.57	.76	.95	1.14	1.52	1.89	2.27	3.79	20.00
4	.28	.43	.57	.71	.85	1.14	1.42	1.70	2.84	15.00
5	.23	.34	.45	.57	.68	.91	1.14	1.36	2.27	12.00
6	.19	.28	.38	.47	.57	.76	.95	1.14	1.89	10.00
7	.16	.24	.32	.41	.49	.65	.81	.97	1.62	8.57
8	.14	.21	.28	.36	.43	.57	.71	.85	1.42	7.50
10	.11	.17	.23	.28	.34	.45	.57	.68	1.14	6.00
12	.09	.14	.19	.24	.28	.38	.47	.57	.95	5.00
15	.08	.11	.15	.19	.23	.30	.38	.45	.76	4.00
20	.06	.09	.11	.14	.17	.23	.28	.34	.57	3.00
25	.05	.07	.09	.11	.14	.18	.23	.27	.45	2.40

Travel time in minutes — short haul
Figure 2-24

per hour by dividing 60 (minutes) by the cycle time in minutes. For example, a 4.2-minute cycle time equals 14 (60 ÷ 4.2) cycles per hour. A machine's production rate equals its payload multiplied by the number of cycles per hour.

Comparing Crew and Equipment Costs

Spend some time selecting the right equipment. It's an important decision. The best way to be sure you've got the right equipment is to make up an estimate for each equipment combination that might be practical. That's what we're going to do in the remainder of this chapter.

If using bigger equipment and a larger crew will double the production rate while increasing the daily cost by only 50 percent, do it. But bigger isn't always better. Larger crews and more or bigger equipment won't always boost the work rate enough to make up for the increased cost. There's no advantage to using a $100-an-hour machine if the work can be done as quickly and easily with a $50-an-hour machine.

Think in terms of balances and tradeoffs. A higher daily cost will often pay off in lower unit costs … but not always. You might end up with "too many cooks in the kitchen." A crew that's too large may require additional supervision and can create crowded conditions that cause delays.

> ***THE DAILY OPERATING COST*** of a piece of equipment is only part of the picture. Don't fall into the trap of assuming that the equipment you own is right for every project. That's ignoring reality. You're most competitive when you're using the right equipment. When appropriate, rent your equipment out to someone who can use it productively while you use a rented machine to do what you need to get done.

Most utility line contractors are fairly conservative and very cost-conscious. But you can increase efficiency and profits by finding new and better ways to get the job done. Be open-minded. Look at all the options and alternatives before you decide.

Think of earthmoving as volumes of material to be moved within certain time spans and at a certain dollar cost. When you change the volume of material or the time allowed to move it, you change the cost. While it's almost impossible to estimate precise production rates, it's fairly easy to estimate *maximum* rates. Compare the calculated maximum with your actual production in the field. Chances are you'll be shocked at how much less actual production is from what you believe is possible.

For example, watch a track excavator load a truck. If your stopwatch shows 15-second cycles and it takes 12 cycles to load a truck, the trucks could theoretically be loaded in 3 minutes. But actual loading will take longer. Why? Because there will always be delays as each truck moves into place. Is the truck driver positioning the truck poorly or too slowly? Are there enough trucks to service the excavator? Is the operator slowing production with poor bucket loads or slow cycles? Is the material hard to load? Identify the problems that are lowering production rates on your jobs. Then either allow for them in production estimates or take steps to correct them in the field.

When you have all the data to make your production estimates as accurate as possible, you're ready to compare production rates for various crew and equipment combinations. If your numbers are accurate, it'll be easy to pick the best combination.

Volume of Material

Let's look at an example. We'll compare crew and equipment options for a 1,230-foot-long, 2-foot-wide urban storm pipeline that's installed under an existing asphalt street. There are quite a few crosslines, but soil conditions are relatively good. Assume the soil swells by 25 percent.

The first step is to find the cubic yards to be excavated. Calculate the volume of material from the plans. Average the trench depth by taking measurements on the plans every 200 feet along the line. Scale off the distance from the surface to the bottom of the trench. Remember, the formula is length times width times depth, divided by 27. The answer is in bank cubic yards.

Assume you've calculated the average trench depth to be 5 feet. That means the trench volume is 456: (5 × 2 × 1,230) ÷ 27 BCY. To account for 25 percent swell, multiply that number by 1.25 to get 570 LCY. Dividing 570 by the trench length, which is 1,230, gives you 0.46 LCY per linear foot of trench.

Notice that this estimate ignores the extra excavation needed around the shallow manholes. You could calculate manhole excavation volume from the dimensions on the plans. In our sample estimate, however, the volume of the manhole excavation is insignificant. We can safely ignore it. But if the work included a deep sewer in poor soil, manhole excavation and shoring could be a major cost; it would be worth your time to make the calculations.

Once you've calculated volume, think through the job step by step. First you'll have to remove the asphalt. It's usually best to do this before trenching begins, since removing it during trenching slows the work. If you excavate both at once, asphalt and spoil have to be piled separately. That takes up more space than may be available on a busy street.

On this project, you'll cut approximately 2,400 linear feet of asphalt. That's enough to make a mechanical cutter economical. A good choice in this case would be a cutting wheel mounted on a grader, loader or backhoe. It's probably best to price the asphalt removal as a separate item, adding the cost as a unit price after you've selected the best equipment and crew combination.

Once you've got your head wrapped around the project requirements and quantities, you can calculate production rates for crew and equipment combinations that could be used on this job. Follow the steps described earlier in this chapter. Find the optimum production rate for each piece of equipment. Reduce optimum rates to realistic rates by applying correction factors. Use 0.75 for operator ability, 0.83 for job efficiency, and an additional 0.6 factor for difficult site conditions, including an allowance for crosslines.

Wheeled Backhoe – the Best Option?

One option for this trench project is a wheeled backhoe. Suppose your observations indicate that the average bucket load is 7 cubic feet and average digging cycle time is 12 seconds (5 cycles per minute). That means the backhoe can move 35 LCF per minute, which equals 2,100 LCF per hour. Divide by 27, and you'll get an optimum production of 78 LCY per hour.

Then reduce this to a realistic production rate by applying the correction factors:

78 LCY × 0.75 × 0.83 × 0.6 = 29 LCY per hour.

OK, you've estimated hourly production for a wheeled backhoe. Think about that and ask yourself if it seems reasonable. While you're at it, here are some other questions to consider:

- How does it compare with past production records?
- How many hours per day can the backhoe trench?
- How will traffic control affect daily production?
- Will daily backfill and cleanup reduce production further?
- What are the alternatives?
- Will larger equipment yield a better trenching rate?
- What's the mobilization cost?

Other Options

Trenching machines offer high foot-per-hour rates. But the number of crosslines on this job would make a trencher more trouble than it's worth. Other than the wheeled backhoe, the only other serious contender is a larger track excavator. You know that your crew, using a 1 CY track backhoe, will have an average bucket load of 0.75 CY and a cycle time of 20 seconds (3 cycles per minute). That equals 2.25 LCY per minute, or 135 LCY per hour. Factoring in efficiency (0.83), operator skill (0.75) and difficult conditions (0.6), realistic productivity comes down to 50 LCY per hour. That's better than what we calculated for the wheeled backhoe, but will the size of the project warrant transporting the machine to and from the job? It's up to you to decide.

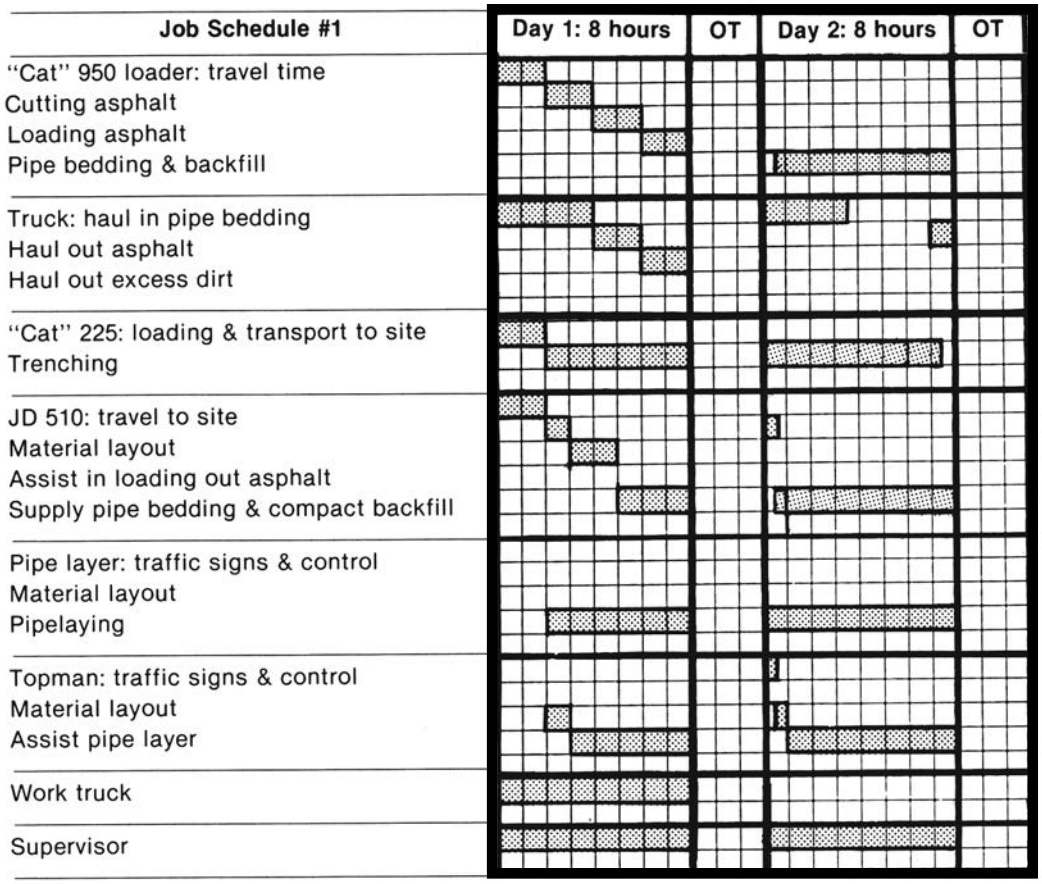
Job Schedules to Compare Costs

Job schedules can help you visualize how the project will unfold and also lets you convert these hourly trenching rates into daily production estimates. For the job schedules, you'll have to plan out the complete job and determine what equipment and crew you'll use for each option. Once you have the complete crew and equipment cost, add the cost of mobilization. Divide by the linear feet of trench to arrive at a cost per linear foot for each option.

For this 1,230-foot storm pipeline project, we'll create and analyze job schedules for three different equipment scenarios.

Job Schedule 1

Figure 2-25 shows one possible scenario. This is the high-productivity option, as it only requires 2 days of work. Our choice would be influenced



Mobilization:

"Cat" 950	2 hours @	$50.00 =		$100.00
"Cat" 225	2 hours @	$60.00 =		$120.00
Transport	3 hours @	$60.00 =		$180.00
JD 510	2 hours @	$40.00 =		$ 80.00
				$400.00

Estimated production rate: 7½ hours @ 111 LF per hour = 832 LF per day.
Estimated duration of trenching & pipe installation: 2 days with full crew, not including cleanup and asphalt work.

		Hour	Day
Dump truck and driver	@	$ 35	$ 280
Cat 950 and operator	@	50	400
Cat 225 and operator	@	60	480
JD 510/hoe pack and operator	@	40	320
Supervisor	@	20	160
Pipelayer	@	15	120
Laborer/topman	@	15	120
Work truck and tools	@	4	32
		$239	$1,912
Mobilization	@	$ 400	$ 400
Crew and equipment, 2 days	@	$1,912	$3,824
		Total cost	$4,224

$$\frac{\$4{,}224}{1{,}235} = \$3.42 \text{ per LF}$$

Job Schedule 1
Figure 2-25

by equipment availability and its distance from the work site. It wouldn't make sense to ship the equipment in from across the state for a 2-day job. If the machines happened to be nearby, the mobilization cost would be much less. Of course, the same is true of the other schedules that we'll consider below, but not to the same extent. Loading and transporting heavy track-type machines is much more costly than simply driving a wheeled machine to a site.

Because of the small size of this job, mobilization costs (at roughly 10 percent of total job cost) make Job Schedule 1 an unattractive option. A project of longer duration might make the mobilization cost seem more reasonable.

Job Schedule 1 also requires a tight work schedule. You need near perfect synchronization and no delays. A broken water main, bad weather or equipment breakdown could disrupt the entire schedule. If that happens, the cost per foot would skyrocket. Overrunning the time schedule by just half a day could blow your profit. A highly experienced contractor can avoid some problems, some of the time — but not all problems all of the time! If you're not that experienced, or not that lucky, why take the risk?

Job Schedule 2

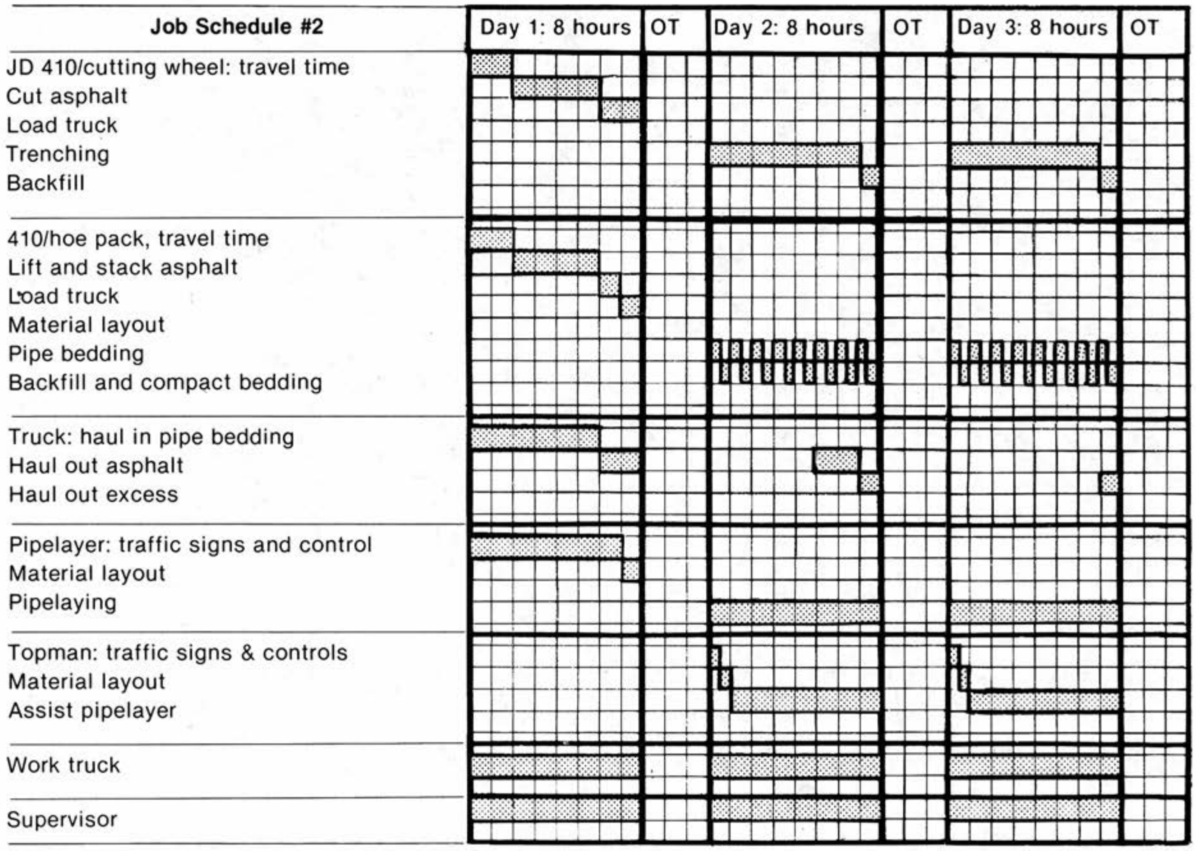
Figure 2-26 shows Job Schedule 2, which offers a good balance of crew and equipment. Estimated total duration is 3½ days, including cleanup and asphalt work, but mobilization costs are reasonable. Matching the digging hoe and the backfill hoe allows virtually full-time trenching after asphalt has been removed.

Job Schedule 3

Job Schedule 3, shown in Figure 2-27, requires a lot of movement by the John Deere (JD) backhoe. The hoe does the excavation, supplies the pipe and bedding and does the backfilling. A variation of this method would be to have a small wheel loader share the supplying and backfilling chores so the JD 410 has more digging time.

Note that this schedule requires overtime work for at least two employees. In this case, the extra cost wouldn't be significant. The mobilization cost is also small. Day one uses only a partial crew, costing a total of $400. But, ultimately, Job Schedule 3 is the least efficient and most costly of the job schedules we're considering.

Of course, these schedules are only estimates; they won't be completely accurate. However, they *do* let us compare work rates. Each can be changed, of course. The dump truck is included in all three schedules, even though it won't be required all of the time. Renting a truck occasionally or bringing one in from another project when needed



Mobilization:

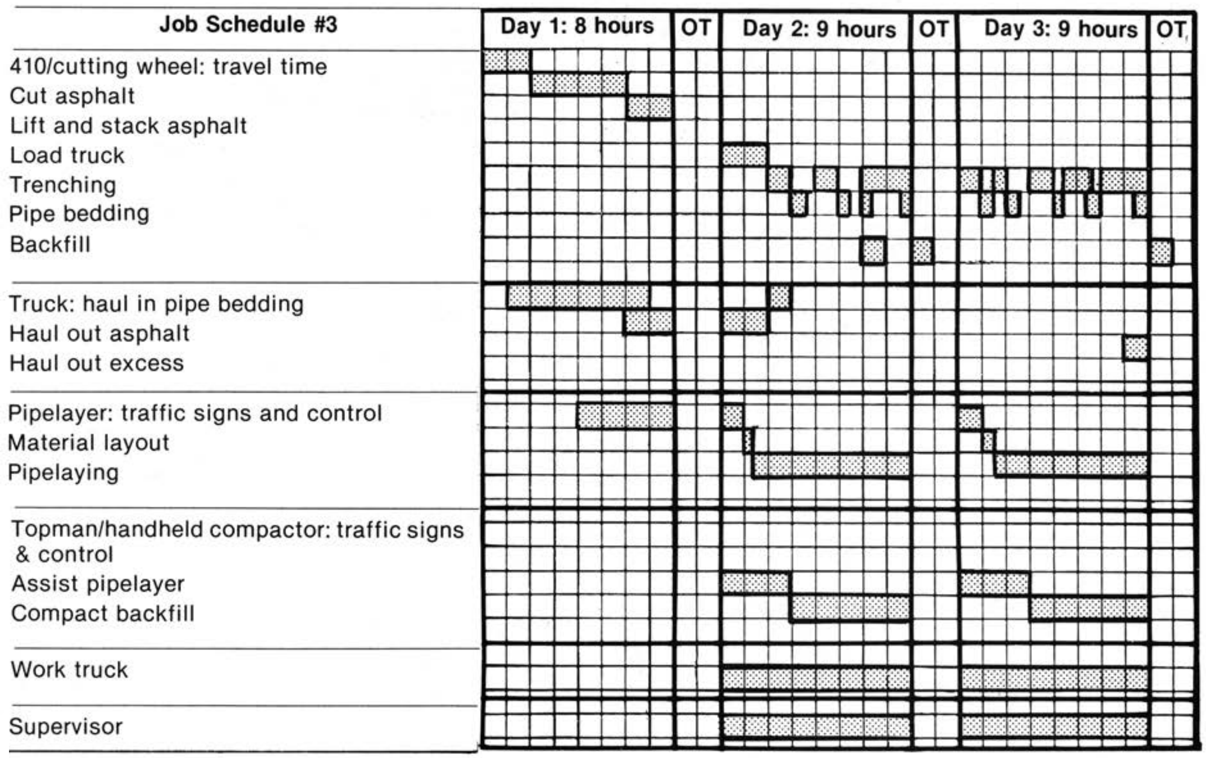
JD 410	2 hours @	$35.00 =	$ 70.00
JD 410	2 hours @	$35.00 =	$ 70.00
			$140.00

Estimated production rate: 7 hours @ 62 LF per hour @ 434 LF daily.
Estimated duration of trenching & pipe installation: 3 work days, not including cleanup and asphalt work.

		Hour	Day
Dump truck and driver	@	$ 35	$ 280
JD 410	@	35	280
JD 410 and packer	@	37	296
Supervisor	@	20	160
Pipelayer	@	15	120
Laborer/topman	@	15	120
Work truck and tools	@	4	32
		$ 161	$1,288
Mobilization	@	$ 140	$ 140
Crew and equipment, 3½ days	@	$1,288	$4,508
		Total cost	$4,648

$$\frac{\$4{,}648}{1{,}235} = \$3.69 \text{ per LF}$$

Job Schedule 2
Figure 2-26



Mobilization:
JD 410 2 hours @ $35.00 = $70.00

Estimated production rate: 4 hours trenching @ 62 LF per hour = 248 LF daily.
Estimated duration of trenching and pipe installation:
5 days + 1 day preparation work = 6 days, not including cleanup and asphalt work.
(This schedule involves paying two hours overtime, increasing the cost slightly).

		Hour	Day
Dump truck and driver	@	$ 35	$ 280
JD 410	@	35	280
Supervisor	@	20	160
Pipelayer	@	15	120
Topman/hand compaction	@	16	128
Work truck and tools	@	4	32
		$ 125	$1,000
Mobilization	@	$ 70	$ 70
Preparation work, 1 day	@	400	400
Crew and equipment, 5 days	@	$1,012	$5,060
		Total cost	$5,530

$$\frac{\$5{,}495}{1{,}235} = \$4.47 \text{ per LF}$$

Job Schedule 3
Figure 2-27

would yield some savings. If the truck driver will be on the job every day, he may be able to flag traffic or handle other chores when not actually driving.

The choice is really between Job Schedule 1 and Job Schedule 2. Based on the available machinery, the projected overall work schedule at the time of the project date, and the availability of the necessary personnel, Job Schedule 2 is probably the right choice. I would base my estimate on these figures, remembering to add material costs and the cost of removing and replacing the asphalt.

In the last two chapters, we've estimated and bid the job and produced a production schedule. At the bid opening, if we were low bidder, we would get the contract. And this is where it gets interesting. We'll start by surveying the site in Chapter 3.

[Blank Page]

3

READING PLANS & SURVEYING

The job plans (also known as *prints*) show both the existing features where you'll be doing the work, and the work you'll have to do. The engineer's responsibility is to provide plans and specifications that explain all job requirements. Your responsibility is to install exactly what the plans and specs show.

You don't have to be an engineer to read and follow plans. Nor do you have to be a surveyor to lay out the job correctly. But you *do* need to understand some basic plan reading and surveying concepts. This chapter is intended to provide you the background to interpret the plans and lay out the work for nearly any underground utility job.

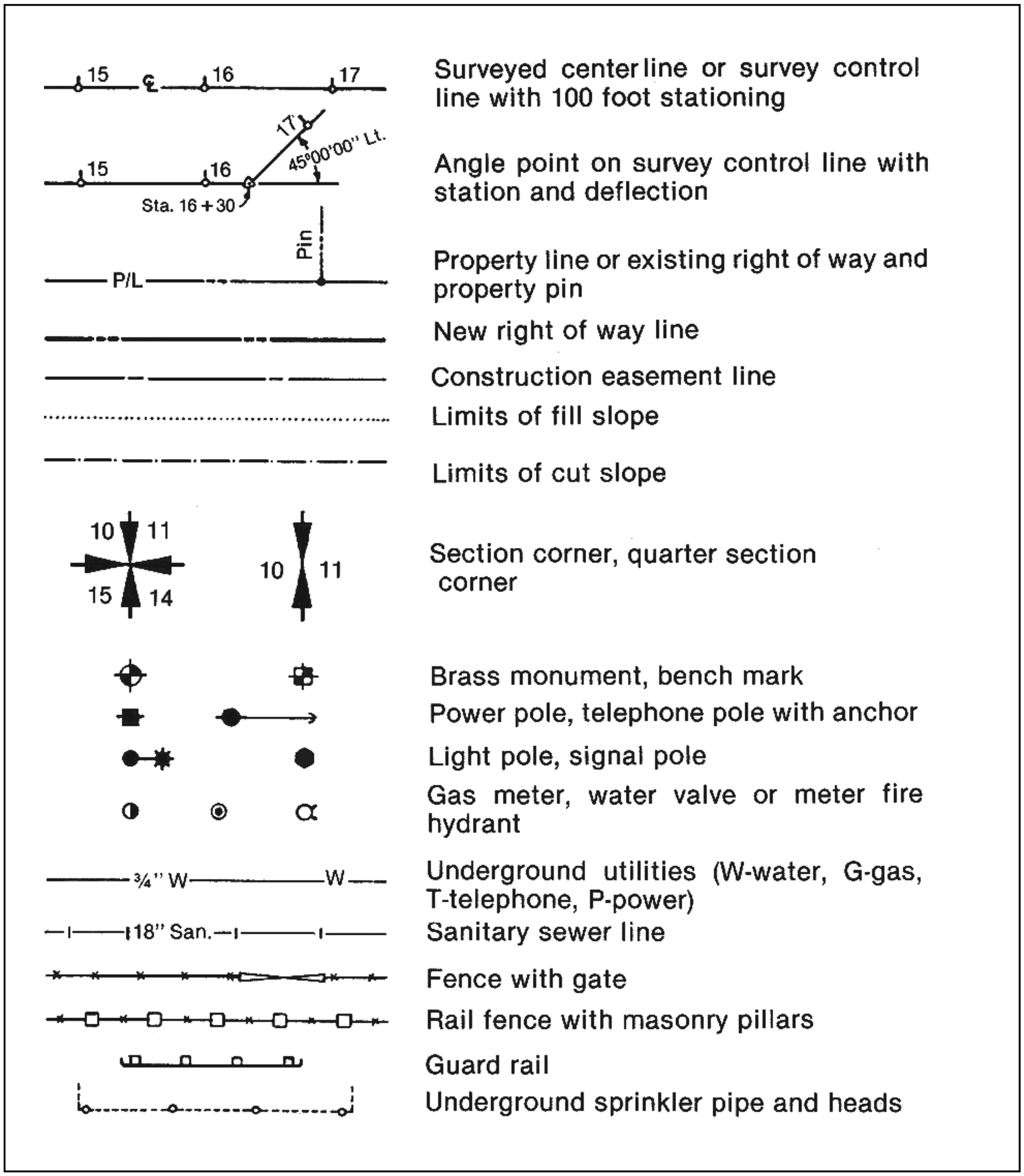
Let's start by looking at a typical project: Several developers have been active on the west end of your town. The existing sewer system will have to be extended to the proposed tracts. The city council hired an engineering company to study the problem and draft plans for expanding treatment capacity and extending the existing collection system. Acting on the engineer's recommendation, the city council approved the project, arranged funding and authorized the engineers to begin planning the project.

The engineering company sent a survey team into the field to record the actual lay of the land where the sewer line will be extended. This is important information for the design engineer. Without it, he can't calculate the falls and slopes in the pipeline. With the surveyor's data in hand, an engineer designed the project.

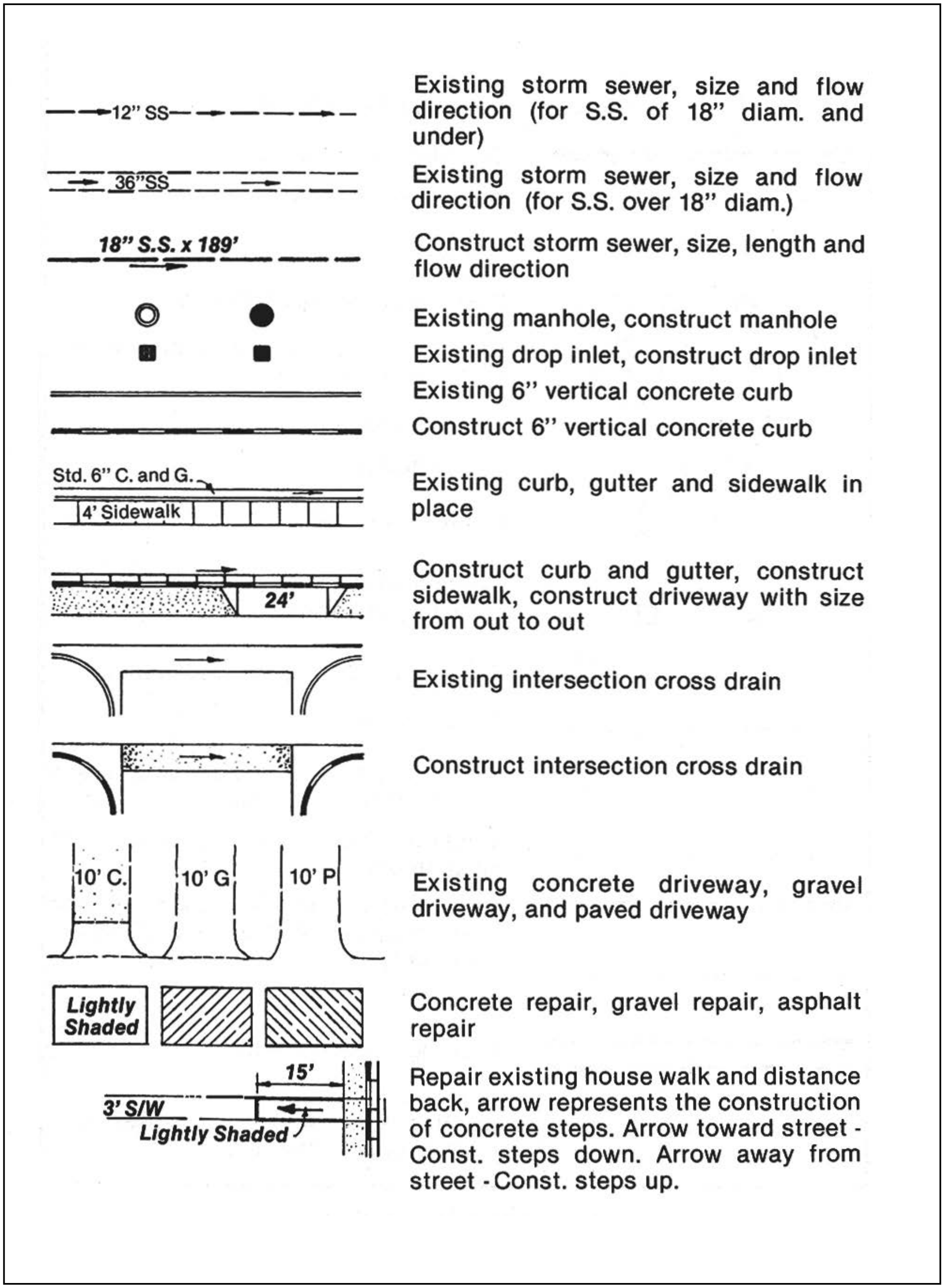
Next, a draftsman drew up plans showing details of the engineer's design. These plans showed the intended work in two different views: the *plan view*, which is a bird's-eye view of the area, and the *profile view*, which shows a horizontal cut-away view of the work.

Reading Plans

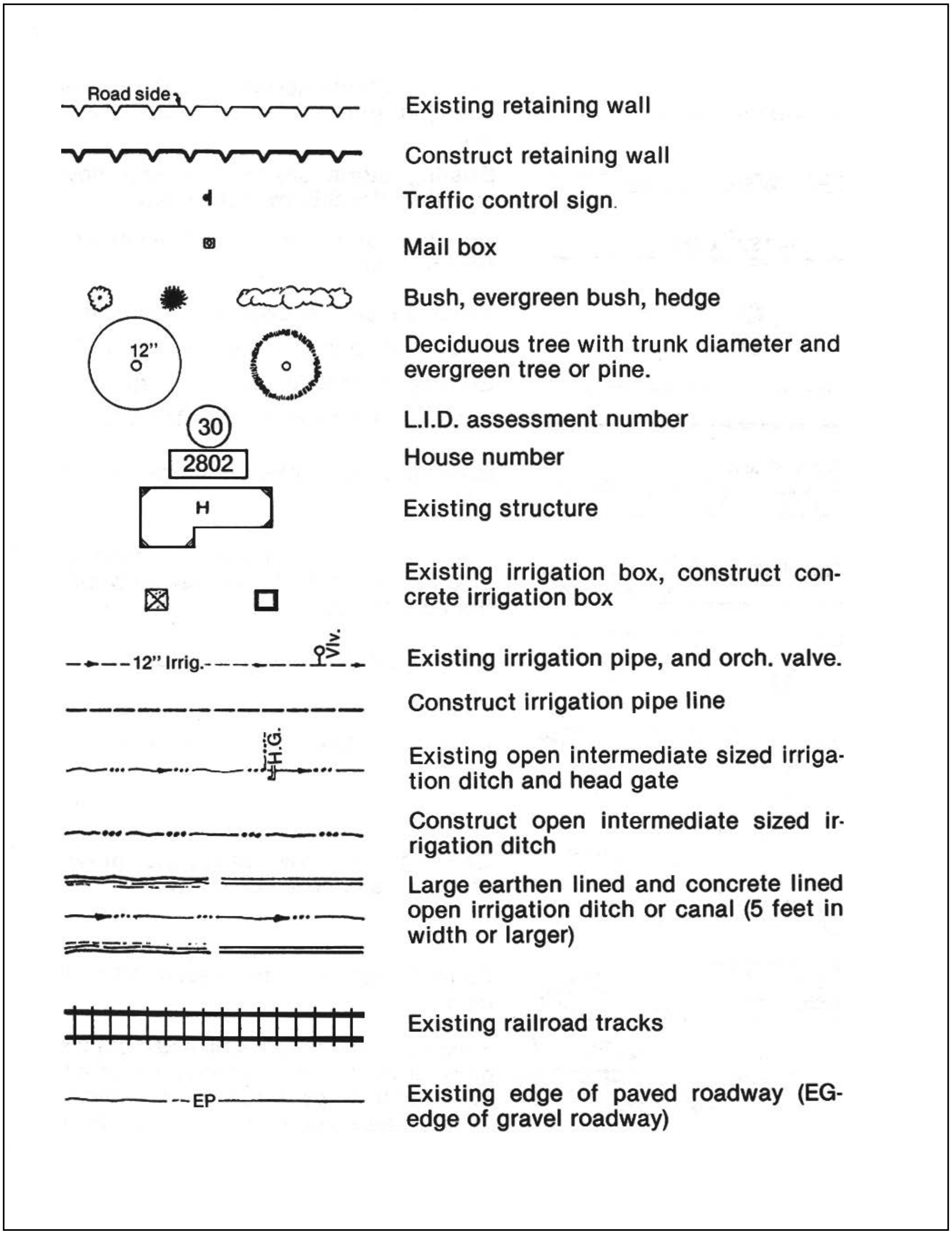
Figure 3-1 shows common plan symbols for underground utility work. These are like a draftsman's "shorthand." Different draftsmen may use slightly different symbols, but most sets of plans include a key like this one explaining the symbols used — much like the legend on a map.



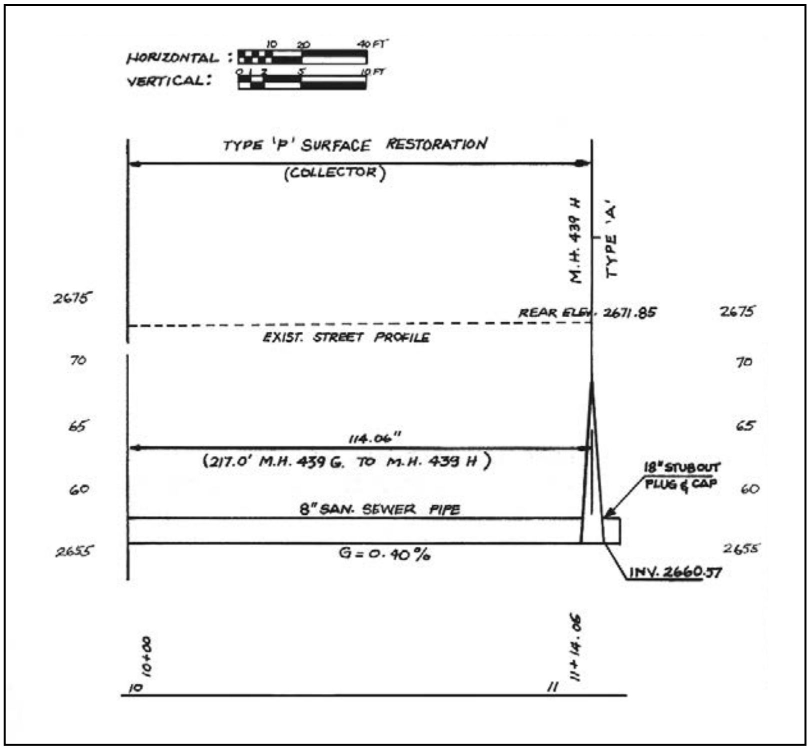
Common plan symbols
Figure 3-1



Common plan symbols
Figure 3-1 (continued)



Common plan symbols
Figure 3-1 (continued)



Typical two-scale plan
Figure 3-2

Scale in Utility Plans

Imagine a set of plans 1,000 feet long for a 1,000-foot sewer extension! For obvious reasons, nearly all plans are drawn to scale. Many house plans use a scale of ¼ inch to the foot, for example. One-quarter inch on the plan is equal to 1 foot on the actual house. That wouldn't be practical for most utility plans. A 1,000-foot sewer extension would still require a plan sheet over 20 feet long. A scale of 1⁄16 inch to the foot would require a plan sheet only 5 feet long. But if the sewer line was 10 feet deep, the scale of 1⁄16 inch to the foot would be a vertical height of 10⁄16 inch, too small to show sufficient detail.

The challenge is to draw the plan so that no detail is lost and, at the same time, fit the site onto one sheet. To make your job easier, most utility site plans you use will be drawn in two scales with the use of an engineer's scale. One scale is used for horizontal distances and another for vertical distances. Usually the horizontal scale is ten times the vertical scale. One inch may represent 50 feet horizontally and only 5 feet vertically. This lets the engineer show the entire horizontal length of the project in a compact drawing and still include the detail you need for vertical measurements.

Look at Figure 3-2. Elevation numbers run vertically up the side of the print. Both the horizontal and the vertical scales are indicated at the top. In this case, 1 inch represents 40 feet horizontally and 10 feet vertically. Reading two-scale prints takes some practice. Slopes and grades are exaggerated and appear much steeper than they really are.

Some sites are so big, however, that it takes several sheets to show the entire site. Match lines, drawn on each sheet, help you align the sheets accurately. I use a digitizer board to do takeoffs, so I take plans to a print shop to have them reduced so that I can tape them together and fit the entire project on the board.

Engineers often show existing conditions and elevations on one sheet, and proposed conditions and elevations on another. To handle this situation, I tape the top of the existing conditions sheet to a large sliding glass door. I then overlay it with the proposed conditions sheet, line up both drawings and tape them together along the left side to create a "hinge." Next, I secure the existing conditions drawing to the digitizer board and flip the proposed conditions drawing over and out of the way while I digitize the existing elevations. When I'm done with that, I flip the proposed conditions sheet over the existing conditions drawing and digitize the proposed elevations.

In some cases, existing and proposed condition plans are drawn at different scales. That will require a trip to the print shop to enlarge or reduce one of the drawings so that both are at the same scale.

To those of you who have earthwork estimating software that allows you to "marry" several drawings, regardless of how many sheets are involved or the scales used, it might seem like I'm a little old fashioned. But to do this on a computer, you have to line up match points (points you can locate on both drawings being linked). And if you're not 100 percent correct when you locate and digitize these points, your takeoff won't be accurate. And it's difficult to correct the error once it's made.

Surveying

Accurate measurements and precise installation mark professional utility line work. As a professional underground utility line contractor, you'll want to do nothing but precision work. "About right" shouldn't be good enough on your jobs. The engineer won't approve it and you shouldn't tolerate it. If it isn't right on the money, it isn't right. To do accurate work, you'll have to use a surveyor's level correctly.

There are good reasons to follow the plans exactly. Pressure pipelines work best when laid to even, uniform grades. Gravity flow pipelines must be laid very precisely if they're to work as designed. A slope or fall of as little as 1 foot per 1,000 linear feet is common in some pipelines. Usually, the larger the diameter of the pipe, the smaller the fall required to maintain a water velocity great enough to prevent solids from settling out.

Take the plans seriously. Never assume that the engineer will approve anything different from what the plans show. What you install should give a lifetime of trouble-free service — if installed correctly. Make precision work your company's trademark.

Surveyor's Codes and Abbreviations

Everyone in the underground utility business has to understand the common codes and abbreviations used by surveyors. The way some terms are used may vary slightly from area to area and from company to company. But the basic meaning will be the same no matter where you work.

- *Elevation*, abbreviated El, is the height of a point above sea level. If you know the elevation of two points, you can calculate the difference in elevation between them. If you know the elevation of a certain fixed object, you can calculate the elevation of other points by measuring the vertical distance between the two points.

  If the elevation of the outfall of a pipeline is 700.55 feet, and the invert is 706.35 feet, you can calculate the fall in that section of pipeline by subtracting 700.55 feet from 706.35 feet. The fall is 5.80 feet.

  It's important for you to understand elevations. Here's another example. Let's say the threshold at your front door is exactly 700 feet above sea level. If you have a 6-foot, 6-inch door opening, the elevation of the top of the opening is 706 feet, 6 inches. In engineering measurements, that's El 706.5. We've added the height of the opening to the known elevation of the threshold to find the elevation at the top of the opening.

- We've used the threshold as the *benchmark*, the point of known elevation. If your garden path is 3 feet lower than the threshold, you can calculate its elevation: BM (benchmark) El 700.00 minus 3 feet equals El 697.00.

- Two other important surveying terms are *cut* and *fill*. A cut (C) is always lower than the reference point. A fill (F) is always higher. Surveyors sometimes calculate cuts and fills.

- It's standard practice to show horizontal distance in multiples of 100 feet. These distances are shown as station numbers. A *station number* (Sta) gives a stake's position in relation to the starting point of the line. The starting point is Sta 0 + 00. The number to the left of the plus sign indicates the number of hundreds of feet. The number to the right of the plus sign indicates feet in units of one. Sta 2 + 50 means that the stake is located 250 feet from the starting point, Sta 0 + 00.

Measuring Feet Using Decimals

Engineers measure vertical distances (in feet) in terms of decimals. Two feet, 6 inches is 2.5 feet in engineer's measure. It's easier to add and subtract decimals than it is to add and subtract in terms of feet, inches and fractions of an inch. For example, it's harder to add 18 feet, 4¹³⁄16 inches to 37 feet, 9½ inches than it is to add 18.41 feet to 37.79 feet.

But don't confuse decimal feet with metric measurements, which are a completely different system of measure. Engineer's measure uses the good old foot but substitutes decimals of a foot for inches and fractions of an inch.

In engineer's measure, a foot is divided into tenths and hundredths. Notice that a hundredth of a foot is very nearly ⅛ inch. Rarely will you see measurements expressed to the nearest thousandth of a foot (0.001 foot). Generally, that's more accuracy than is needed in this type of construction.

Engineer's measurements are expressed two ways. For example, a plan will show an elevation as El 1,520.67, using the decimal point to show the portion of a foot. On survey stakes, the same elevation will be written like this:

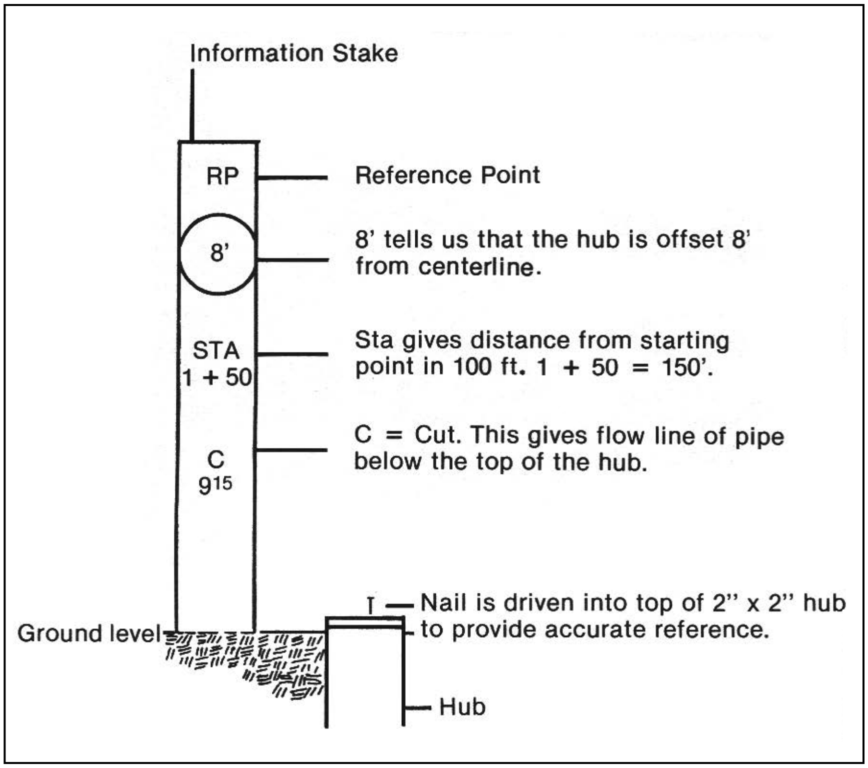
El 20^{67}

Notice that the first two digits of the elevation have been omitted and the denominator (bottom number) of the fraction 67⁄100 isn't shown.

> *"In engineer's measure, a foot is divided into tenths and hundredths."*

Here's a suggestion that'll simplify doing an earthwork or pipe excavation takeoff: If all elevations are given within a restricted range of values, you can disregard the first two or three digits of each elevation. For example, if you have an elevation of 1,520.66 feet and all the remaining elevations are between 1,500 and 1,600 feet, you can omit the first two digits of each elevation and express the elevation as 20.66 feet. Had all the elevations been between the range of 1,520 and 1,530 feet, you could omit the first three digits of each elevation and express the elevation as 0.66 feet.

Be aware that some engineers will express site elevations relative to the top-of-slab (TOS) elevation of a new building, set at 100 feet. So if the actual elevation at the TOS is 1,527.25 feet, but it's expressed as 100 feet, then another elevation on the site whose actual elevation is 1,524.5 feet would be expressed as 97.25 feet. That's because 1,524.5 is 2.75 (1,527.5 — 1,524.5) feet lower than the TOS elevation, and 100 minus 2.75 feet equals 97.25.



Typical reference stake
Figure 3-3

Hubs and Reference Stakes

The engineering company that designed the project will probably lay out your reference stakes. This survey team should stay just ahead of your work, providing hubs and reference stakes with the information necessary to install the pipeline. A *hub* is a small stake driven into the ground to identify some reference point. Near the hub will be a *reference stake*, which identifies the hub's elevation and situation in relation to the pipeline. Figure 3-3 shows a typical reference stake.

Sometimes reference stakes will show only station numbers, omitting any other data. In this case, the information that's normally given on the stake itself will be on a *cut sheet.* A cut sheet is a form showing elevations, cuts and horizontal distances to a fixed point.

Reference stakes along a sewer trench will refer to the depth, in decimal feet, from the reference hub to the flow line of the pipe. For example, a reference stake might read:

Sta	2 + 50
El	$2{,}500^{47}$
C	9^{63}

Courtesy of CST/berger

Optical level
Figure 3-4

This means the reference hub is 250 feet from the starting point, and the flow line of the pipe is 9.63 feet below the hub. The hub's elevation is 2,500.47 feet, which means the elevation of the flow line of the pipe at this point is 2,500.47 feet minus 9.63 feet, or 2,490.84 feet.

Surveying Instruments

You're not a surveyor. You don't have to be. But you, and key employees on your crew, should understand a surveyor's job and the instruments he uses.

The surveyor's main job is measurement. Horizontal distances can be measured easily with a steel tape measure. Vertical measurements are more difficult. To measure vertical distances (elevations), the surveyor depends on the optical level and the transit. Let's look at each of these.

The *optical level* in Figure 3-4 is a telescope that mounts to a tripod. Using the fine adjustment controls on the instrument, you can set it up so your line of sight is exactly level no matter how the scope is rotated.

Looking into the optical level, you'll see cross hairs similar to those in a rifle scope. If you sight through the level and line up the cross hairs on an object several hundred feet away, the scope's cross hairs will be on exactly the same level as the object you see. Pivoting the scope so the cross hairs fall on some other object assures you that the second object is at the same elevation as the first.

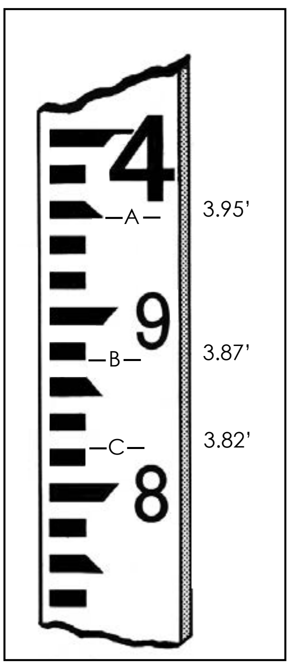
Because the instrument is mounted on a pivot, you can rotate the line of sight through a full 360 degrees. This gives you a level plane, which can be used as a reference point over a wide area, and for a distance of several hundred feet.

Let's go back to the example of your threshold for a minute. If you set up the optical level in your front doorway and look across at your garden fence a hundred feet away, the point where the cross hairs intersect is level with the instrument. If the instrument is 3 feet above the level of the threshold, the point you're sighting on the fence is also 3 feet above that level. If you mark that point on the fence and measure from it to the top of the fence, you'll know how much higher the elevation of the top of the fence is above your threshold.

An optical level lets you project a horizontal line over considerable distances. It gives you a reference point from which you can calculate the elevation of all points within view *if you know the elevation of the scope.*

Courtesy of CST/berger

Transit
Figure 3-5



Reading a grade rod
Figure 3-6

That's the key. Once you know the elevation of the optical level, it's a simple matter of addition and subtraction.

Surveyors find the height of the instrument by reading a measuring rod held on a benchmark. They add that reading to the known elevation of the benchmark to determine the height of the instrument, which is abbreviated HI. If the elevation of the BM is 250 feet, and the rod reading is 2.25 feet, the notation will look like this:

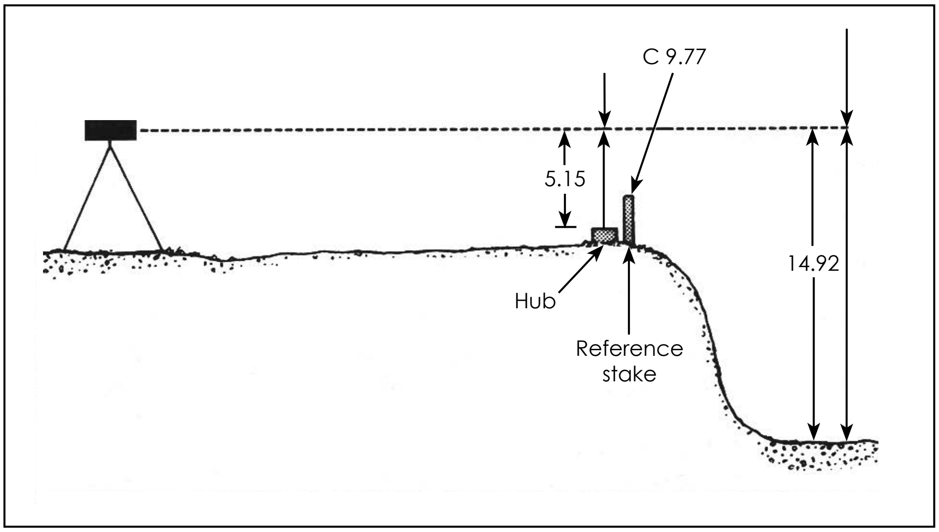
BM	250.00
Rod reading	+ 2.25
HI	252.25

The *transit*, shown in Figure 3-5, is a more complicated instrument because it's both an optical level and a device for measuring angles. If you remember any of your high school geometry, you'll recall that if you know two angles of a triangle, you can calculate the third. A surveyor uses the transit to measure both vertical and horizontal distances. We won't go into the method here. That's surveying, and you don't need to know surveying to install underground utilities. Nearly all the layout you need to do on the site can be done with an optical level, a grade rod, and a notebook. You might need to use a transit to align a pipe laser, but we'll discuss that later.

A *grade rod* is like a big "yardstick" that shows feet and decimals of a foot above the end of the rod. Look at Figure 3-6. The long black line with the large 4 next to it marks the 4-foot point. Each of the shorter black lines and the white spaces between them measure one $\frac{1}{100}$ of a foot. The lines with the bottom right corner cut away mark tenths of a foot. Each line with the top right corner cut away signifies a decimal ending in a five.

If the cross hairs of the level intersect at Point A in Figure 3-6, the reading is 3.95 feet. Point A is five segments below the 4-foot mark, and five segments above the 3.9-foot mark. Point B reads 3.87 feet (two segments above the 3.85-foot mark) and Point C reads 3.82 feet. Count the segments between the 5 mark and the 10 mark to find the rod reading. If possible, practice taking rod readings with someone who's familiar with using a grade rod.

To get an accurate reading, it's essential that the grade rod be absolutely vertical. If it leans away from the vertical, you'll get a false



Measuring a cut
Figure 3-7

reading. To avoid this, have the person holding the rod slowly lean it toward and away from you while you're taking readings through the level. The lowest rod reading is the correct one when you use this method.

Using the Optical Level

An optical level is a precision instrument and must be set up correctly. If the line of sight isn't level, the readings taken off the grade rod will be inaccurate. Set up the tripod so it's reasonably level to start. Then finish leveling the instrument with the adjusting screws in the instrument base. Centering the bubble in the vial levels the scope. Then tighten the adjusting screw just finger tight when the scope is level.

Figure 3-7 shows a typical job situation. The reference stake by the hub is marked C 9.77, showing that you're to make a cut 9.77 feet deep. First, take a reading with the grade rod held on the hub to establish the HI. The reading is 5.15 feet. Add this to the cut figure (9.77) to find the HI above the required elevation of the finished cut. Here's what you'd write in your notebook:

Rod reading	5.15
C	+ 9.77
HI	14.92

Always note where you took the reading and an explanation of the calculations you used to arrive at the revised cut figure. This reduces the chance of error. A notebook and pencil are as necessary as the level itself for accurate, verifiable surveying. You'll use the level primarily for checking cuts from reference stakes. But sometimes you'll need a level to survey a long distance or a steep slope. If the distance or slope is so great that you can't shoot all points from one setup of the level, you'll have to move the instrument one or more times.

An optical level can only transfer elevations within view. If you can't see some point along the line, set the level up at a new position that has a view of both your reference point and the obscured point. You'll have to establish the elevation of that new position. A quick way to do this is to have the rod holder hold the rod in place while you reposition the level and take a new reading. Then the difference between the two readings is added to or subtracted from the previous HI, giving the new HI.

Surveying Using a Global Positioning System (GPS)

Most surveyors are now taking advantage of satellite technology for locating positions on the earth by using a *Global Positioning System (GPS)*, a worldwide navigation and positioning system developed by the U.S. Department of Defense. Depending on the receiver and signal processing technology, a GPS can determine the location of an object on earth within a few millimeters of accuracy.

For centuries, surveyors have used optical instruments and physical measuring devices, such as tape measures or chains. But optical instruments require a direct line of sight from the instrument to a target. Measuring tapes or chains require that the survey crew pass through all the terrain to measure the distance between two points. The big advantage of a GPS is that you don't have to have a line of sight between two stations in order to determine a given location on a site. This means that surveying can be done in almost all weather conditions or on opposite sides of an obstruction, such as a mountain. Another advantage is that the accuracy of the collected data doesn't require a skilled instrument operator. Because line of sight doesn't have to be established between GPS stations, the survey team can be smaller and work more quickly. Data collection devices, like the one shown in Figure 3-8, collect positioning information, which can then be downloaded to a computer. Using surveying software, you can then create a map of the site.

Despite its obvious advantages, the GPS is seldom used for determining elevations on a site. That means the prism pole must be in sight from the base station (also called robotic total station — see Figure 3-9), because elevation data is only accurate when the reference satellites are in very specific positions in their orbit.

Data collector
Figure 3-8

Robotic total station
Figure 3-9

Grades or Slopes in Pipe Laying

Grade describes the slope of the ground. The term probably comes from the more descriptive word *gradient*. As used in underground utility contracting, it means the desired slope of a pipe, trench or surface.

There are several perfectly good ways to describe the incline of any surface. That can cause some confusion if you're not alert to the problem. I'll cover the common ways of describing slopes, and then offer some examples to test your understanding.

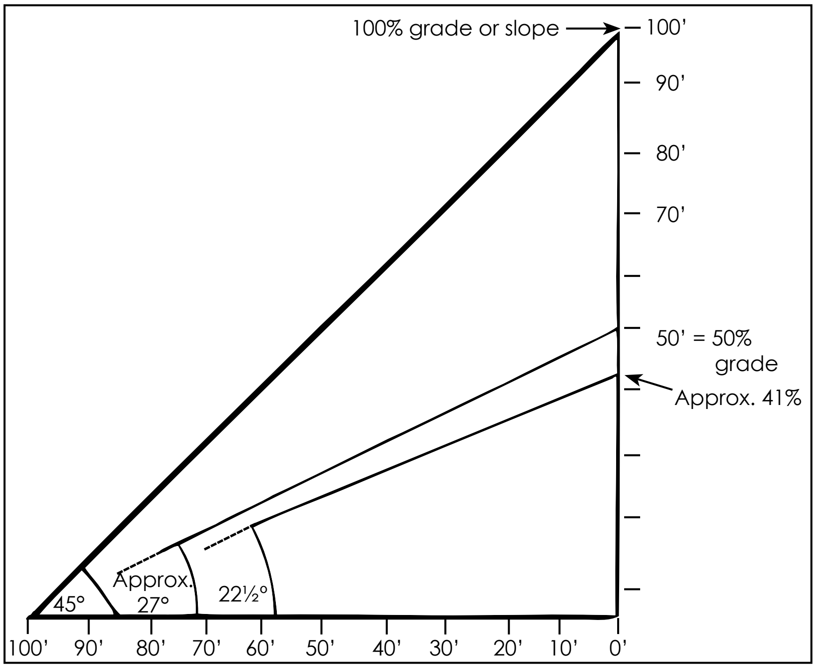
Slope in Degrees

A circle can be divided into 360 degrees. Each degree is further divided into minutes (60 to each degree) and seconds (60 to each minute). This allows very precise measurement of angles. But, because of the complex mathematics involved and the precision required of the instruments, this method is seldom used by contractors in the field. Surveyors can measure slope in degrees, but you'll probably never see it on a set of plans.

Slope as a Ratio

Expressing slope as a ratio is the second method of measuring inclines, and is often used for steeper slopes. The horizontal distance is given first, then the vertical distance. So 3:1 means the vertical fall is 1 foot in each 3 horizontal feet.

You may be aware that carpenters and plumbers turn the ratios around, expressing the vertical rise first. Plumbers refer to slope in a drain line of ¼ inch to 1 foot. Carpenters describe roof pitch as 3 in 12,



Slopes expressed in percents and degrees
Figure 3-10

meaning the roof rises 3 inches in each 12 inches measured horizontally. This ratio method is easy to misunderstand and isn't precise enough for utility line work.

Slope as a Percent

Many inclines for excavation work are described in percentage terms. The vertical rise is always expressed in units compared to a horizontal distance of 100 units. For example, a 50-percent slope will rise 50 feet in a horizontal distance of 100 feet. A 1-percent slope rises 1 foot in each 100 feet measured horizontally. Sewer pipe laid at 0.5 percent rises ½ foot (6 inches) each 100 feet.

Here's an easy way to remember how to calculate slope in percentage terms. A 45-degree slope is a 100-percent slope. If the vertical rise is equal to the horizontal distance, the slope is 100 percent. Figure 3-10 shows some equivalent slopes expressed in degrees and percents.

To calculate the slope as a percent, divide the vertical rise by the horizontal distance, then multiply the answer by 100. For example, if a hill rises 83 feet in a horizontal distance of 227 feet, then (divide 83 by 227 to get 0.365. Multiply 0.365 by 100 and you get 36.5 percent.

Slope as a Decimal

Many underground utility line plans will show pipe grade expressed as a decimal. Percent grades always describe rise in each 100 units. Decimal grades show rise or fall in units as designated by the decimal fraction:

.1	= 1/10
.01	= 1/100
.001	= 1/1,000
.0001	= 1/10,000

Plans usually use 4-place decimals to express grade. Let's look at a few examples. Plans showing a pipe grade of 0.0046 indicate a rise or fall of 46 feet in each 10,000 feet of pipe, 4.6 feet in each 1,000 feet, 0.46 foot in each 100 feet. By definition, percent is based on a rate per hundred, so this pipe grade of 0.0046 equals 0.46 percent.

Given the slope or grade in decimals or percent, you may have to calculate how much a pipe or trench needs to rise or fall within a given distance. For example, suppose you're laying a 20-foot length of pipe at a 0.0025 grade. How much must it rise in 20 feet? We can reduce the 25-foot rise per 10,000 feet to 0.25 foot per 100 feet and 0.025 foot per 10 feet. Since it's a 20-foot length of pipe, we double the 0.025 for 10 feet to find that, for 20 feet, the pipe must rise 0.05 foot. That's $^5\!/_{100}$ on the grade rod, or approximately $^5\!/_8$ inch.

For practice, let's determine the invert elevation of the sewer pipe, shown back in Figure 3-2, at Station 10 + 00. The pipe rises (or falls) at a 0.40 percent grade, which is a 0.004 (0.40 ÷ 100) grade. Since the total run is 114.06 feet, the total rise at Sta 10 + 00 is 0.456 (0.004 × 114.06) feet. So the invert elevation at that station is 2,661.03 (2,660.57 + 0.456) feet.

Checking Grade with an Optical Level

Pipe layers have to understand how pipe grades are measured. Flow rates in gravity pipelines depend on two factors: the inside diameter of the pipe and the pipe grade. The greater the diameter of the pipe, the flatter it can be laid. Engineers understand these principles and plan carefully to use just the right grades. If you don't lay pipe exactly on grade, it won't function correctly.

High and low spots along a pipeline reduce the carrying capacity. A low spot collects fluids and solids. That increases the friction when material passes through the low spot. A line that isn't on grade may have *backfall* (reverse flow), which reduces the pipeline's carrying capacity, or it may rise too quickly, causing backfall at another point. And any significant backfall will cause your engineer to reject the line. He'll probably accept minor deviations from a true straight line, but will demand precision in grade alignment.

The easiest way to check grade is with an optical level. Sight over from each cut stake provided by the surveyors. Measure down from the line projected by the scope to find the correct elevation at that point. In most cases, it's enough to check grade every 50 feet.

Remember, the cut figure on each stake identifies the flow line of the water — that's the bottom of the pipe's interior. Obviously, you can't hold a grade rod vertical if it's placed on the bottom of the pipe. It's common practice to set the grade rod on top of the pipe. This works fine, as long as you allow for the diameter and pipe wall thickness. To calculate HI, add the rod reading on the hub and the cut (C) quantity. Then, from that sum, subtract the pipe diameter and the pipe wall thickness.

For example, when using a 15-inch plastic pipe, the difference between the flow line and the top of the pipe is 1.25 feet. If the cut stake indicates a cut of 12.66 feet and the rod reading is 4.78, the HI would be 16.19 (4.78 + 12.66 − 1.25).

Lasers

LASER is an acronym for "light amplification by stimulated emission of radiation." The science behind it is complex, but I'll discuss some basics that may come in handy. Laser beams are essentially amplified light waves. Laser light differs from normal light in the following three ways:

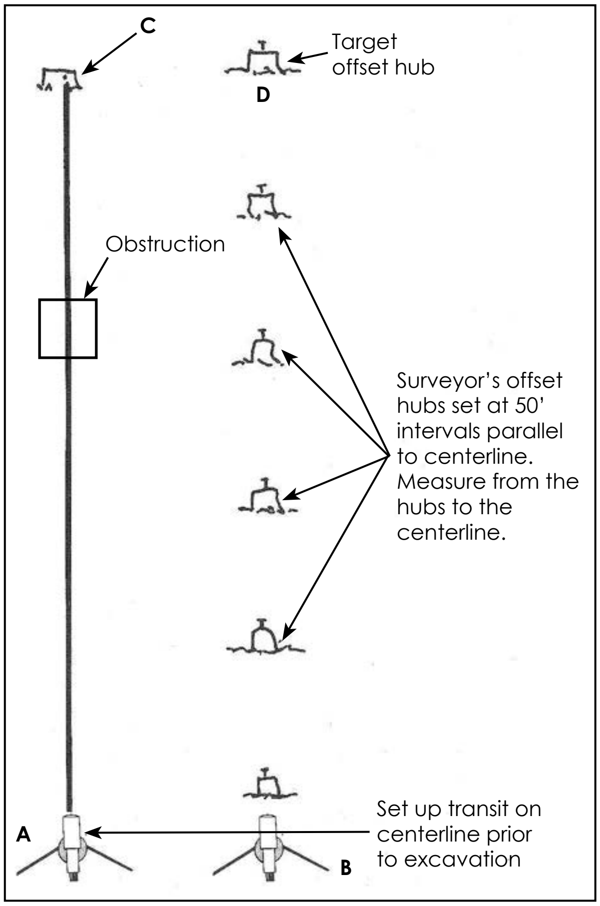
1. The light released is monochromatic, which means the light has the same wavelength and color.
2. The light is coherent (organized) because the photons' wavefronts are launched in unison.
3. The light is extremely directional, which means the light forms a tight beam that's strong and concentrated.

Laying Pipe with Lasers

Pipe laying requires exact measurement, and pipe lasers offer that kind of precision. Lasers can project a concentrated beam of light in a straight line for several hundred feet. The beam is visible to the naked eye when it shines on a solid surface. Using controls built into the laser, you can direct the beam very precisely along the desired grade.

I've had more arguments over how to set up lasers than over anything else in the pipe laying business. Like any precision instrument, accuracy depends on the skill and knowledge of the user. I'll talk about laser setup a little later. But first, let's see why even this modern instrument isn't infallible.

Light has different characteristics as it moves through air of different temperatures and densities. You've seen heat waves rising off hot asphalt in the August sun. A beam of light actually bends or refracts in response to temperature changes. This problem is worst during extremely hot or cold weather. Pipe that's been in the ground for a while will have about the same temperature all along the line, but the temperature of newly-buried pipe can vary quite a bit. This causes air currents and heat waves, which distort the laser beam as it passes through the pipe. That makes the beam an unreliable reference.



Establishing the centerline from hubs
Figure 3-11

One solution to this distortion problem is to use a fan or blower to blow air through the pipe. This evens out temperature variations and extends the distance at which the laser is reliable.

Check the laser as pipe laying progresses, and make sure it didn't get bumped or disturbed. That happens easily on a busy construction site. If the beam moves, you can bet that there are temperature differences in the pipe. If the beam seems to be enlarged, there's probably water vapor in the pipe or near the laser. I've found the practical maximum range of most lasers to be about 400 feet.

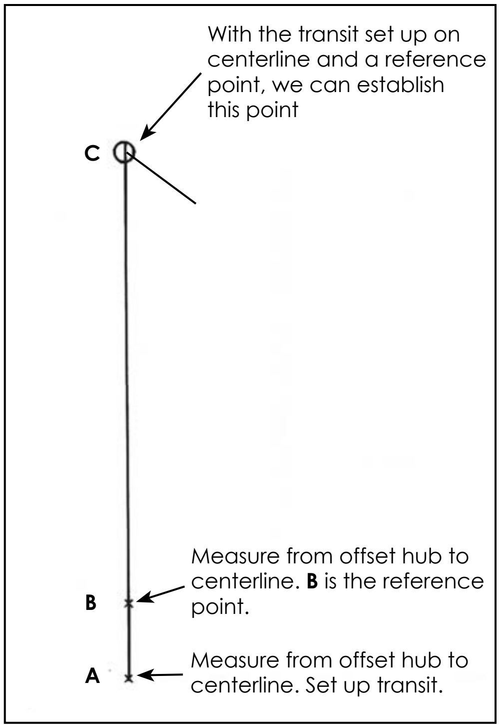
Laser Alignment

A great deal of time is spent aligning pipe lasers. Much of this time is wasted because the operator doesn't understand the process. Alignment can be very simple. There are several fast and easy ways of doing it.

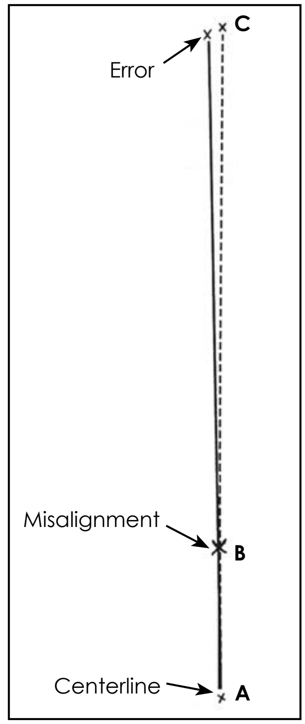
It would be a snap to set up a pipe laser on a level surface, with good light and lots of working room. In practice, however, your laser setups will be in cramped and dark manholes several feet underground. Further complicating matters, your target will be an object that isn't in view.

To project a straight line under these conditions, you need a reference point between the laser and the target (usually a manhole several hundred feet away). One way to do this is to use the offset hubs to record the precise *centerline* and then transfer it to the laser. For example, in Figure 3-11 let's assume there's a tree or other obstruction between the pipe's starting centerline location of the laser (A) and the target (C).

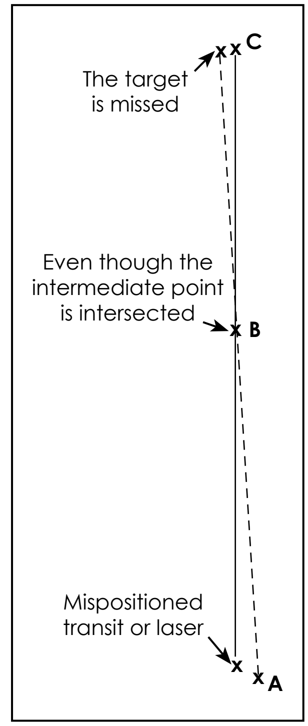
Begin by offsetting the laser and target equal distances far enough (to the right, in this case) so that the laser (B) can see a target offset hub (D). Next, place intermediate hubs between the laser and the target offset hub, forming a line that's parallel to the centerline you're trying to define. Then use the offset hubs to define the centerline reference points: At each offset hub, measure back toward the trench by the original offset



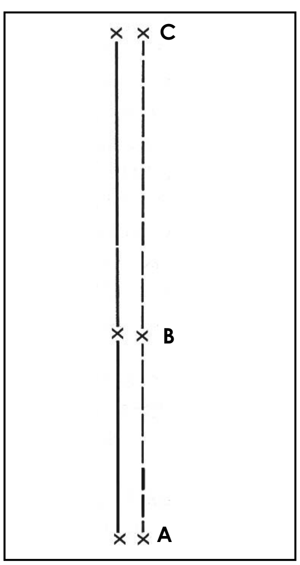
Establishing the centerline with one reference point
Figure 3-12



Misalignment of centerline at point B
Figure 3-13



Misalignment of centerline at transit or laser
Figure 3-14



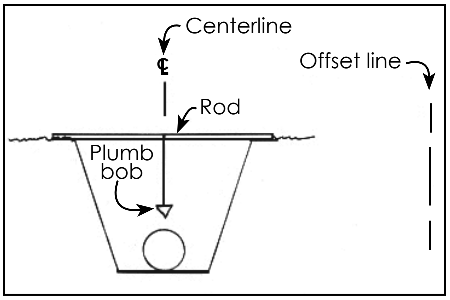
Misalignment of centerline at both points
Figure 3-15

distance. This must be done at right angles with respect to the offset hubs. If you've done this correctly, you'll establish the proper centerline for excavation.

Suppose we know at least one intermediate point along the line from the starting point to the target. We can save time by projecting a straight line along the two points to find the centerline. See Figure 3-12.

This takes a precise measurement, however, and several things can go wrong. Figures 3-13, 3-14 and 3-15 illustrate possible alignment errors. In all of these figures, Point A represents the laser, Point B the intermediate reference point, and Point C the target.

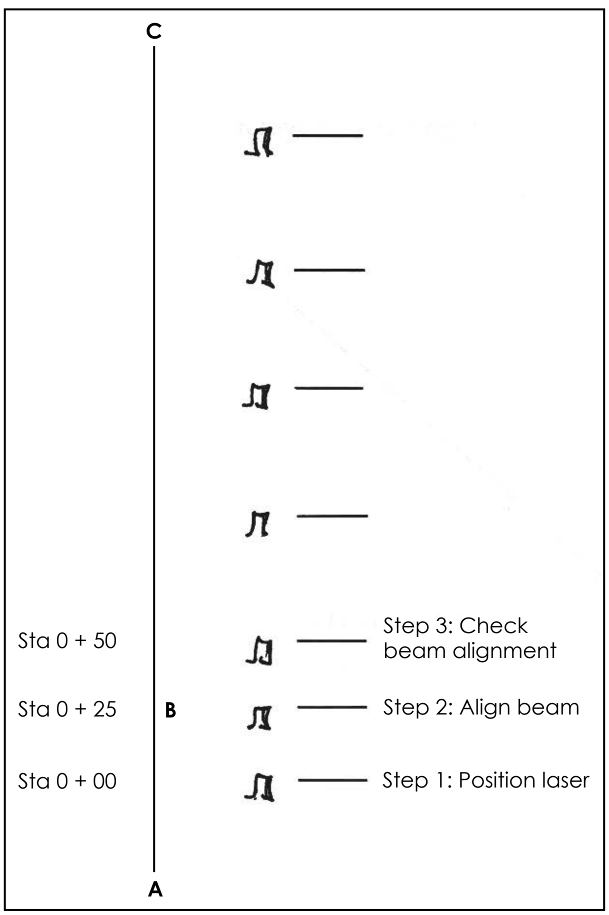
Figure 3-13 shows what can happen if the reference point is out of alignment. Figure 3-14 illustrates an error in positioning the transit or laser. Just a small error in the placement of the instrument or laser, or in the position of the reference point, will cause a large error at Point C. This is particularly true in pipe laying because we're projecting the line several hundred feet. If the laser and reference point are offset but parallel to the centerline, as shown in Figure 3-15, you'll miss the target by the distance between the parallel lines.



Trench cross section
Figure 3-16

You can see why it's important to set up the laser very carefully and precisely. But good setup shouldn't take more than about 15 minutes. Your setup time for the pipe laser is an important and controllable production cost. If you prevent 10 minutes of wasted time on each setup, you'll save tons of time on a sewer line, for example, where a new setup is needed at every manhole.

Even experienced operators make mistakes when setting lasers — not because they don't understand the principles or methods, but just out of haste or carelessness. Try to avoid your operators becoming discouraged with the method you've chosen, or challenging the use of this equipment.



Aligning a laser with grade rod and plumb bob
Figure 3-17

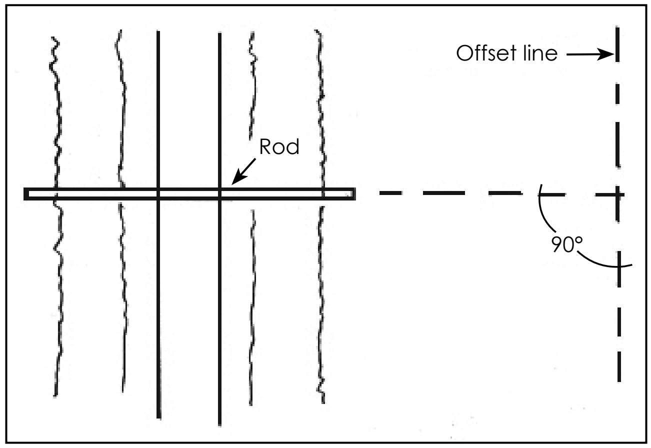
Using the Laser to Check Pipe Placement

I've explained how to use a transit to locate the centerline prior to excavation. Once excavation has started, you can use the laser to be sure the pipe is laid precisely on that centerline.

After part of the trench is dug, use a grade rod and plumb bob to transfer the offset line to the pipe centerline, seen in Figure 3-16:

Step 1: Place the grade rod on the manhole offset hub and lay it flat across the trench. As shown in Figure 3-17, suspend the plumb bob over the centerline at Point A and place the laser there.

Step 2: Next, move the grade rod to the next hub and suspend the plumb bob on center Point B. Align the laser beam to the plumb bob at Point B.



Plan view of trench
Figure 3-18

Step 3: To check placement, move the grade rod and plumb bob to the next hub and check beam alignment again.

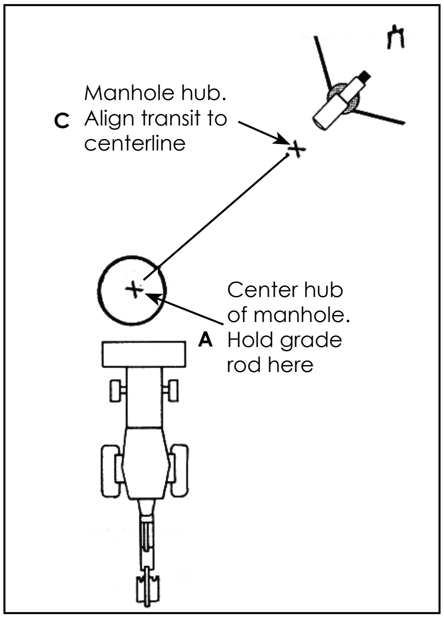
I like to recheck beam alignment by suspending the plumb bob about 50 or 75 feet from the manhole. The further away from the manhole the beam is checked, the more accurate the projected line.

No matter how you set up the laser, there's a potential for error. In this method, the most likely error is in failing to hold the grade rod at exactly 90 degrees in relation to the offset line. See Figure 3-18. If the rod isn't at 90 degrees, you'll get a false reading.

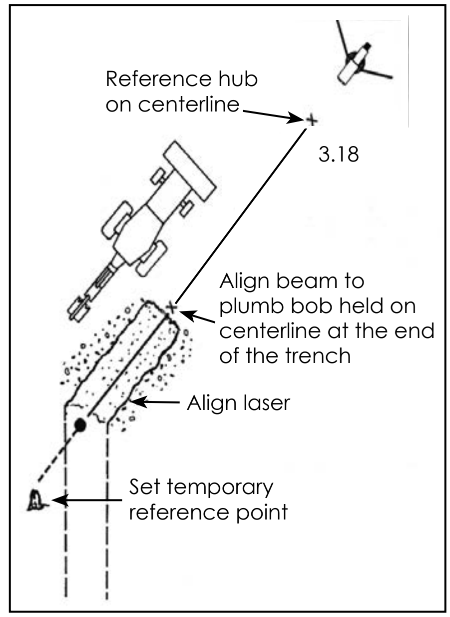
Rushing your setup can also lead to inaccurate alignment. If the excavator must be moved off line to set up the laser, production stops while you're measuring. With a large crew and several pieces of equipment, a 15-minute delay can cost you hundreds of dollars. Your best bet is to choose a setup method your crew understands and stick with it.

Using a Transit to Align the Laser

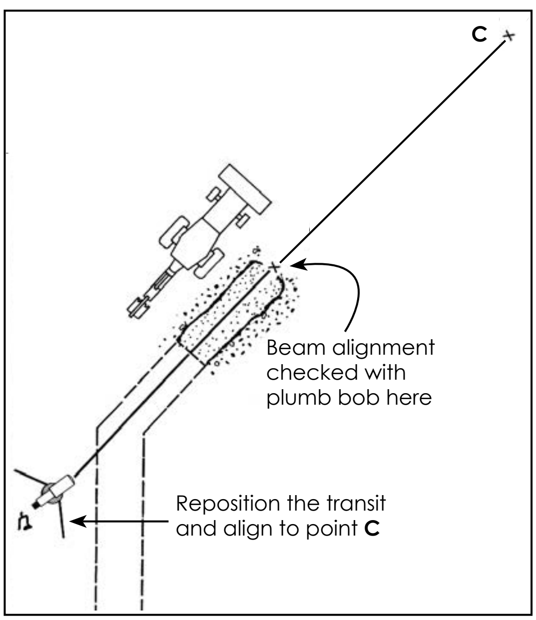
A transit can speed your laser setup *if* the transit is properly aligned to the pipe's centerline. Before excavation, all manholes are given centerline hubs. Set up a transit on the manhole hub upstream from the next manhole to be excavated, as illustrated in Figure 3-19. The transit is set up at the manhole hub, Point C, and aligned to the center hub of the manhole to be excavated, Point A. When the transit is perfectly aligned to the pipe centerline, lock it on line.



Setting a transit on centerline
Figure 3-19



Aligning the laser
Figure 3-20



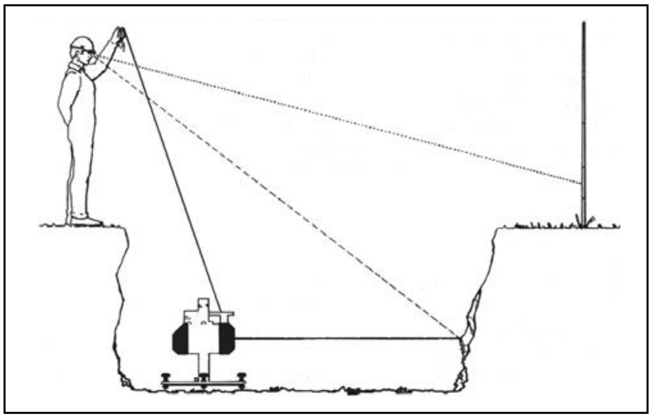
Setting the transit to check the laser
Figure 3-21

After the excavator has dug the manhole and a short section of trench, move the excavator off the centerline. Suspend a plumb bob over the center of the manhole and set up your laser as shown in Figure 3-20. Before resuming trenching, set a temporary reference point downstream from the laser.

Resume trenching and reset the transit behind the laser. See Figure 3-21. If you move the excavator off the line a second time, lock the transit on the centerline. Then use the transit to check on the laser as pipe is installed.

The drawback with this method is that the plumb bob swings too much in deep trenches and windy weather, making it difficult to find the correct centerline position. Getting the precise position is essential, because every small error is magnified by the longer distance between manholes.

The surveyors will usually stake the pipeline at 50- or 100-foot intervals. To use this plumb bob method, you'll need hubs at the manhole and at 25-foot and 50-foot intervals out from the manhole. The surveyors will usually provide the extra hubs if you request them in advance.



Setting the laser by string line
Figure 3-22

A variation of this method is to set up the transit behind the laser at the beginning. The drawback is that it's hard to set up the transit precisely behind the laser without having an established reference point. You have that reference point in the method described previously.

It's the user's responsibility to position the transit in the right spot. You might want to consider specialized equipment, such as a special transit from AGL Corporation (www.agl-lasers.com), that eliminates the need for plumb bobs. This instrument allows you to align the transit and the laser in a single operation.

Newer lasers are smaller and will fit in small diameter pipe. Some operators try to set the first pipe with a transit and then set the laser in that first length. I don't recommend doing it that way. It slows the process of setting the first length, and any movement of the first pipe during construction will jar the laser out of position.

There's one more alignment method I want to discuss briefly. It isn't perfectly accurate, but it's fast and may be accurate enough for large diameter pipe. It's called *string line setup*. See Figure 3-22.

- First, dial the percent of grade into the laser and establish the proper elevation for the laser light. Then adjust the laser on line.
- Position a 3-meter range rod at the center of the next manhole, making sure that it's plumb.
- Attach a string line in the slot on the handle of the laser, then position the laser in the trench on the centerline of the proposed pipeline.
- Next, position the string line on the centerline of the pipe, on the same plane as the range rod, and, using the remote control, adjust the laser light to be on line with the range rod.

Whichever method you use, always check both grade and alignment as laying progresses. Check alignment using a plumb bob and rod to establish the centerline from the hubs situated between manholes. Check the grade with a builder's level. If you've carefully followed the methods described here, you should get accurate results.

4

SITE PREPARATION

Nearly every job requires some site preparation before underground utility work can begin. Preparing the site may be as simple as clearing out some dry grass and weeds that present a fire hazard. Other times you'll have to remove dense undergrowth or trees, or level or grade slopes. If you're working in a developed area, you can count on removing pavement and possibly even existing structures. If you need to tear up the pavement before doing any excavation, you'll have to replace it when you're done. In any case, be sure to include the cost of site preparation and restoration in your bid.

In this chapter, we'll examine five common site preparation tasks, including clearing grass and brush, clearing trees, preparing the jobsite, removing pavement and existing structures, and material layout.

If you work in Kansas, Nevada or Southern California, there's more information in this chapter on felling trees than you're likely to need. I go into detail on removing trees because it's a major issue for underground utility contractors in the Northwest. If that isn't the case where you live and work, feel free to skip these sections.

Clearing Grass and Brush

Clearing dry grass and brush is simple work. But you know how important it is to remove dry grass if you've ever had a grass fire break out in the middle of your job. Under certain conditions, one spark from a metal cutting tool can start a blaze. Provide firebreaks around both the

Courtesy of Dymax Construction Equipment

Rake blade
Figure 4-1

Courtesy of Rome Plow Company

Disk harrow
Figure 4-2

perimeter of the job and around your stockpile of materials. Protect yourself and your investment, and get rid of the fire hazards on your jobsite.

For small brush, with trunks less than 2 inches in diameter, use a dozer equipped with a rake blade (Figure 4-1) or make two or three passes with a heavy disc plow or harrow, shown in Figure 4-2.

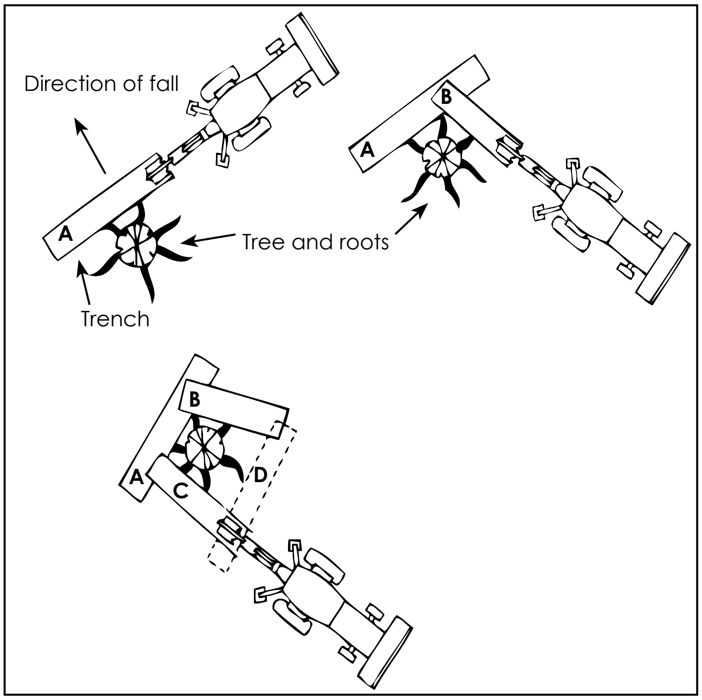
If you're working in an area where further development is planned, the specifications may not allow you to doze the brush into the ground. But you may be able to doze brush into large piles and burn it. A burning permit may be required. Some states, such as Florida, won't allow citrus trees to be burned. But if there's a fire hazard, burning won't be an option. In that case, you may need to rent a chipper and use hand tools to get the site cleared.

For dense brush with trunks greater than 2 inches in diameter, special equipment may be required. You may want to subcontract the job to someone who has the tools and experience to deal efficiently with the underbrush.

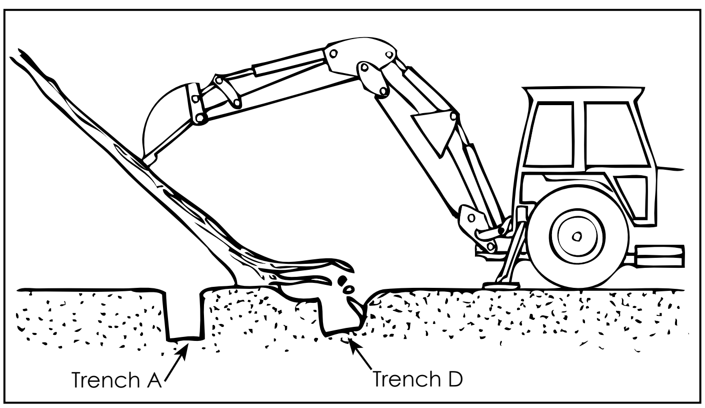
Clearing Trees

If your utility project is in a wooded area, clearing trees may be one of the most expensive items in your bid. Include timber salvage rights in your bid if possible. Salvage rights to commercial grade timber can increase your profit.

Felling and logging trees isn't for amateurs, and can be extremely dangerous. If there are a lot of trees on the property, consider getting a bid from a specialist. But if there are only a few trees, you may not be able to find a logging contractor willing to do the work at a reasonable cost. If possible, try to have someone on your payroll who can handle removal of an occasional tree.



Excavating trenches around a tree
Figure 4-3



Using hoe dipper to push tree over
Figure 4-4

You can remove small trees using a dozer equipped with a V-blade or stinger blade. But the two pieces of equipment you'll use most often for tree removal are the backhoe and the chain saw. I'll provide some tips for using them safely and efficiently.

Removing Trees with a Backhoe

The best way to remove a tree is to remove the *entire* tree, including the roots. You'll need a midsize wheeled backhoe for this. There are three important steps to follow:

1. Excavate four trenches (A, B, C & D) around the tree, as shown in Figure 4-3. The trenches should be deep enough to cut through the tree's root system. Notice the position of Trench D. Dig this trench farther away from the tree than the other three trenches, leaving a platform of dirt between the tree and Trench D. The extra dirt will prevent the tree from falling in that direction.
2. Place the hoe dipper against the tree and push the tree over, as shown in Figure 4-4. The higher up the trunk you place the dipper, the more leverage you'll have.
3. Once the tree is down, use a chain saw to cut the tree into manageable sections.

Use an excavator bucket equipped with a thumb to move trees once they've been felled. Since the felled trees' roots leave voids, it's a good idea to count the number of large trees on the existing site plan and add at least a cubic yard of fill to your takeoff for each.

Removing Trees with a Chain Saw

The modern chain saw is a light, powerful, safe, and highly efficient wood-cutting tool. But that doesn't mean that anyone can operate one. A chain saw is like a rifle — harmless by itself or when handled properly, but potentially fatal when handled carelessly.

The two main causes of chain saw accidents are improper handling of the saw, and making incorrect cuts that result in unexpected falling timber. Here are some tips on how to eliminate chain saw accidents from your site clearance work.

Know and understand *all* of the information in the user's manual before you press the "on" switch. Know how to use the safety devices on the saw and *pay attention to your work every minute the saw is running*. Don't take safety for granted. The saw may be small, but one slip can cost you an arm or a leg.

"There's a big difference between sawing up firewood and felling and bucking trees in the woods."

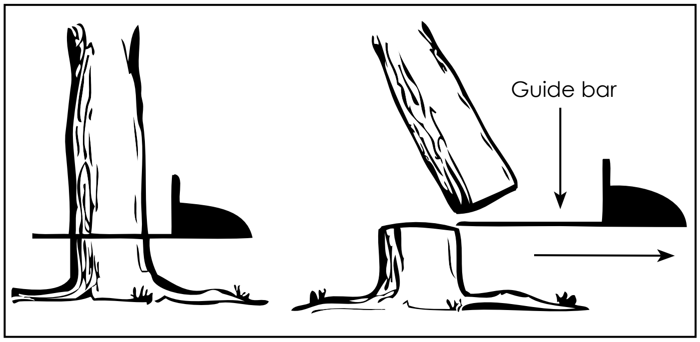
Before making your first cut, take a few minutes to observe the tree and its surroundings. Which way is the tree leaning? Are any limbs rotting or otherwise hazardous? Also, consider your escape route, wind direction and speed, and any overhead hazards such as power lines.

There's a big difference between sawing up firewood and felling and bucking trees in the woods. Every tree is a complex balancing act. Nearly all trees have a natural lean. If you could instantly slice a tree off at its stump, it would fall in the direction of the lean (unless some mechanical force or the wind pushed it some other way).

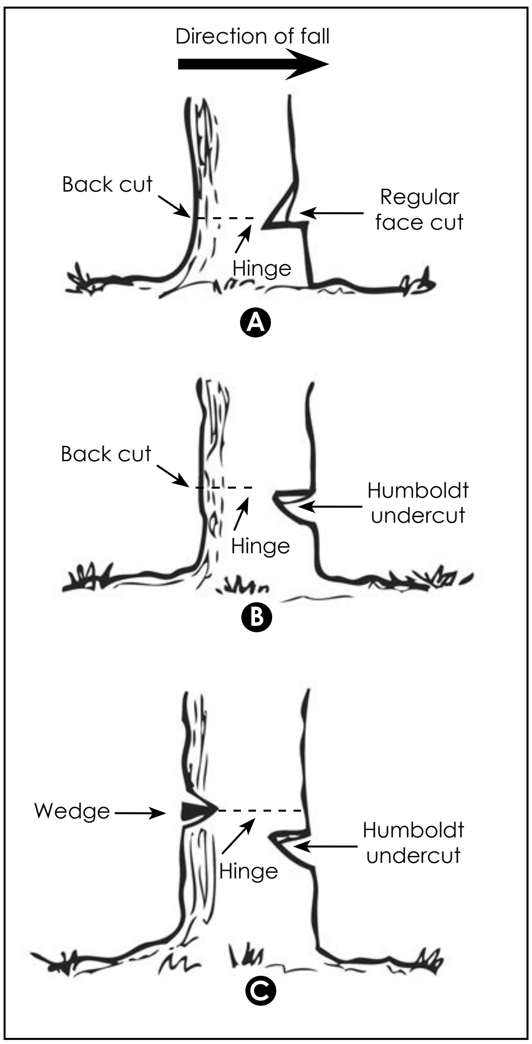
But "instant slicing" isn't possible with a chain saw. Cutting takes time, and the balance and lean change during cutting. The size, placement and angle of each cut affect how the tree falls. To control the direction of fall, you have to know how each cut you make is going to affect the tree's natural lean. Let's look at four types of cuts and how each affects the line of fall. We'll also cover how to cut up the trees once they're on the ground.

Single Cut

A single cut is the standard technique for felling small trees that are up to 6 inches in diameter at breast height (DBH). This method is useful where small trees are growing close together.



Single cut
Figure 4-5



Humboldt undercut
Figure 4-6

Use a single cut to slice the small tree off at the stump. As the saw cuts through the tree, jerk the saw back toward you. See Figure 4-5. The small tree will settle onto the guide bar of the saw, which will pull it off its stump.

Humboldt Undercut

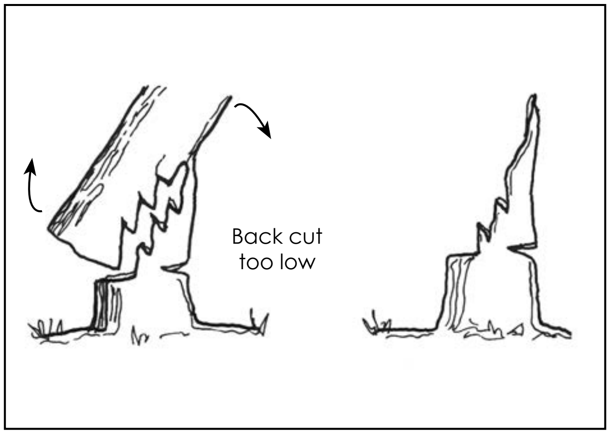
The Humboldt undercut is the conventional method for felling trees larger than 6 inches in DBH. This method allows you to influence the tree's center of gravity to make it fall in the direction you choose.

The first step is to use a face cut to remove a chock of wood from the stump of the tree. Removing a chock unbalances the tree. Note how a standard face cut takes the chock of wood from the trunk of the tree (Figure 4-6 A), but a Humboldt undercut (Figure 4-6 B) takes the chock of wood from the stump rather than from valuable timber.

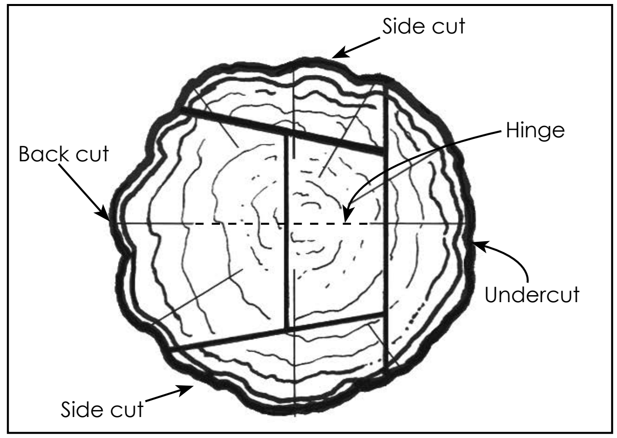
Next, make a back cut on the side of the tree opposite the face cut. The back cut allows the tree to fall in the direction of the face cut. It's important for the back cut to be on the same horizontal plane or slightly higher than the face cut. It's also important to leave a *hinge* of uncut wood running across the stump between the back cut and the face cut. This hinge guides the falling tree, preventing it from slewing sideways or falling in some unpredictable direction. Without the hinge, it may even fall over backward on top of you.

If the tree isn't leaning heavily in any particular direction, a wedge inserted at the back of the cut can be helpful in guiding the tree past its center of balance. See Figure 4-6 C.

When using the Humboldt or conventional undercut, *you must cut accurately*. If your face cut is too shallow, the tree can't fall all the way over. The weight of the tree and the leverage of its height are pulling the tree toward the ground. Something's got to give. So the tree splits. If the face cut and back cut aren't on the same horizontal plane, again, the tree



Barber chair
Figure 4-7



Side cut
Figure 4-8

may split while falling. This is called a *barber chair*. When a tree barber chairs, the back of the tree swings out and up, pivoting on the top of the split. Figure 4-7 shows a tree that barber chaired because the back cut was too low.

Don't take the barber chair phenomenon lightly. An experienced tree feller can usually direct the line of fall to any point in a 360-degree circle using the lean, wedges and accurate cutting. But even professionals have been injured or killed by barber chairs. Study the lean carefully. Make accurate cuts. Use the wedges and your equipment correctly. Most of all, be alert when you work.

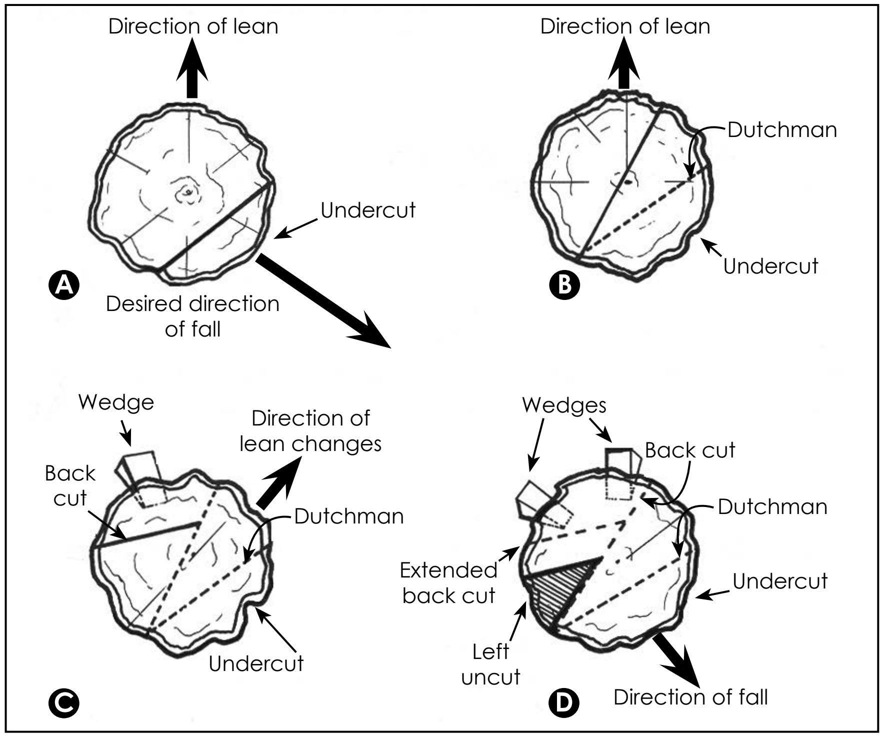
Another serious timber-felling hazard is called the *widow-maker*. A widow-maker is any loose, broken or rotten part of the tree, which can fall during felling and hit the feller. Inspect the tree for such hazardous branches *before* you begin felling.

Side Cut

If you use the conventional Humboldt method on a heavily-leaning tree, it may barber chair even if your cuts are accurate. An extreme lean often causes the tree to fall before the back cut is deep enough. In this case, side cut the tree before you begin your back cut. Figure 4-8 illustrates how to side cut the heavily-leaning tree.

Dutchman Cut

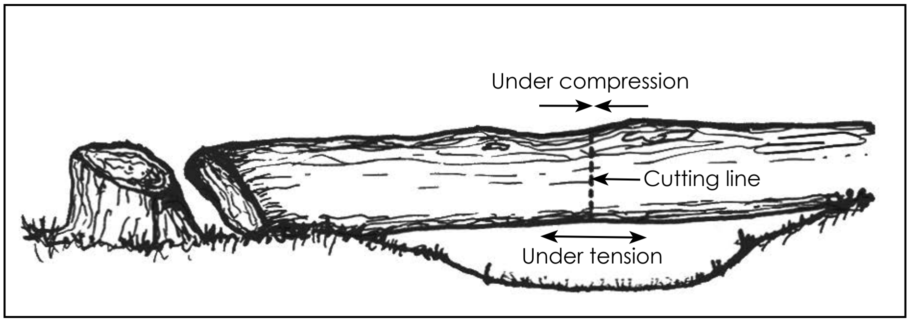
A Dutchman cut is useful when you need to fell a tree *against* its natural lean. Let's look at an example. Assume you're trying to fell a 10-inch diameter tree at a 135-degree angle with respect to its natural lean.



Dutchman cut
Figure 4-9

Using a single wedge isn't practical because it won't lift the base of the trunk enough to compensate for the natural lean. A Dutchman cut offers a solution to this problem. Refer to Figure 4-9 as we take a step-by-step look at the Dutchman.

- Use an undercut to notch the tree as shown in Figure 4-9 A. Make the cut at a 90-degree angle to the desired direction of fall.
- Extend the face cut using Figure 4-9 B as a guide. This extension is called a Dutchman.
- Use a back cut to cut away the hinge section on the side of the tree that has the natural lean. The wood here is under compression, so the cut will try to close up, preventing the tree from falling in the direction of the natural lean. Insert a wedge to keep the tree from slewing sideways, as shown in Figure 4-9 C.
- Now extend the back cut, seen in Figure 4-9 D. The tree will begin to pivot on its stump and fall in the desired direction. Use additional wedges to help it along.



Log spanning a dip
Figure 4-10

When you extend the back cut, be sure to leave enough *holding* (uncut) *wood*. If the holding wood isn't strong enough to hold the weight of the tree as it pivots, the tree will fall back in the direction of natural lean.

This is precision work, and all of these steps need to happen in a short period of time. Correct placement of the cuts and wedges is important. If your cuts are slightly off or the wedges aren't inserted properly, the tree may fall in the wrong direction. If your crew doesn't have the skills to perform a complicated felling technique, *don't ask them to do it*. Bring in someone who can do the work safely and efficiently.

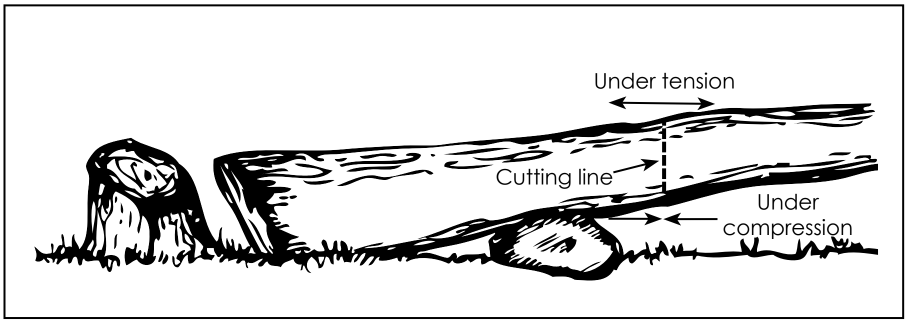
Cutting Logs

Once the tree is down and limbs have been trimmed off, the log has to be moved out of the work area. Some trees can be hauled out whole. Others should be cut into pieces first. This is an easy task as long as the log is fully supported along its length. But usually there will be rocks or other obstacles under some part of the log, while other parts won't be supported at all. In both cases, part of the wood in the log will be under compression and part of the wood will be under tension.

When a log spans a dip in the ground, the wood on top of the log is under compression; the wood at the bottom of the log is under tension. See Figure 4-10. If you try to saw this log through from the top, the compression will cause the cut to close up and trap your saw blade while you're cutting. There are three ways to handle this situation:

1. Make two cuts so the saw can't become trapped.

2. Use wedges to keep the cut from closing up. Insert the wedges after you cut about one-third of the way through the top of the log. Then continue cutting the rest of the way through.



Log resting on obstacle
Figure 4-11

3. Cut one-third of the way through the log from the top. Then move your saw to the bottom of the log. Finish cutting through from the bottom. This is the simplest and most efficient way to cut a log that's compressed at the top.

When there are rocks or other obstacles under a log, the compressed wood will be on the bottom of the log and the wood under tension will be on top. This situation is illustrated in Figure 4-11. In this case, your cutting method will be reversed. Cut the first third of the log through from the bottom. Then move your saw to the top of the log and finish cutting through from the top.

Site Preparation and Material Layout

Site preparation and material layout are important steps in a well-planned job. In any developed area, your first priority should be locating existing underground utilities. These may include underground power and phone lines, natural gas, storm drains, irrigation lines, cable TV, and water and sewer lines. You can usually locate these in the building drawings or by using pipe-locating instruments. But here's the easy way to do it: Most local utility companies provide a locating service at no cost. Keep in mind, however, that they only want to do it once, and you need to give 24- to 48-hours advance notice.

Take the time to record these underground utility locations on a set of plans, or establish an offset or reference point. For example, you can mark a phone line location on the plans as being 15 feet west of the storm drain inlet.

Spray cans of fluorescent paint are cheap. Use the bright paint to highlight important structures and existing features. In many cases, the water meter may be the most accurate reference to the water service line. If it's painted bright orange, the hoe operator will be less likely to forget it as the trenching proceeds.

Demolishing Existing Structures

Having marked and referenced the existing utilities, the next task is asphalt removal. Cutting wheels mounted on a loader, grader or hoe bucket work well on shallow asphalt. If the asphalt is more than a couple of inches deep, saw cutting may be required. A "thumb" fitted to the hoe's dipper helps grasp the slabs and makes loading easier. When using a loader to remove asphalt, ripping the asphalt prior to loading generally increases overall productivity. If the job involves working on hilly terrain, it's well worth the time and money to build pioneering roads, tracks and stockpile areas.

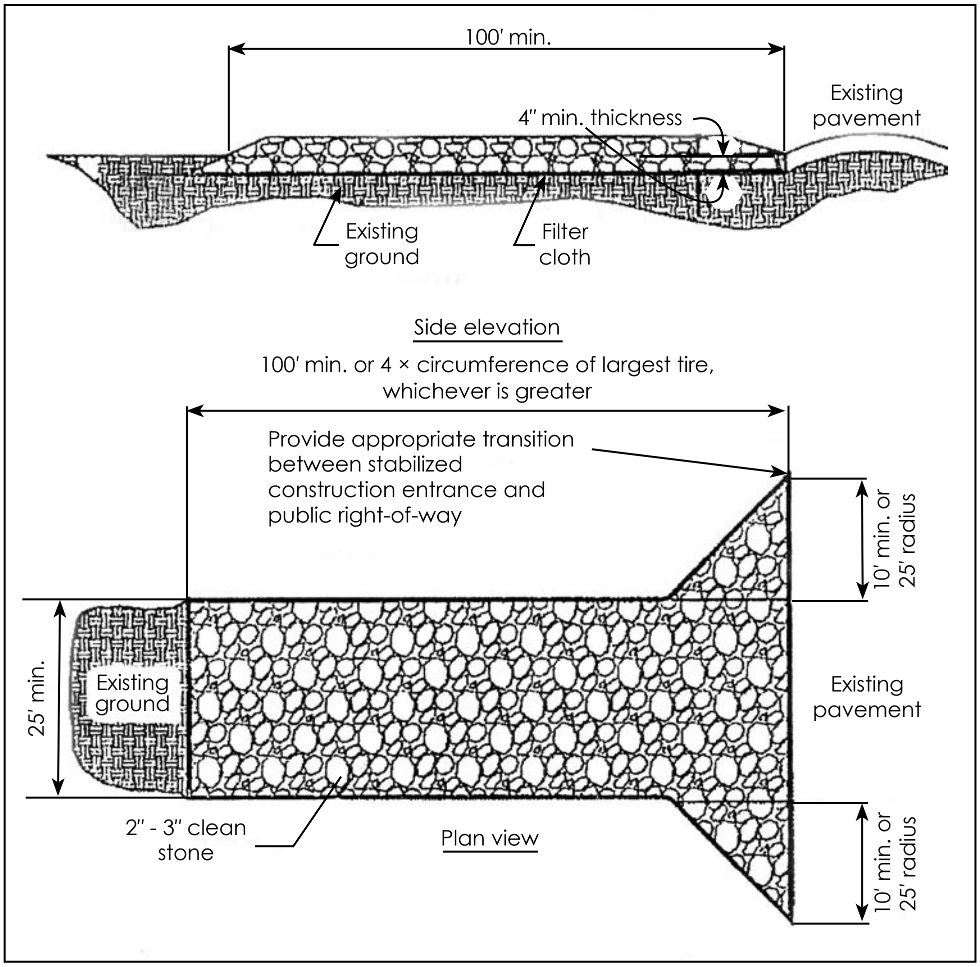
Asphalt and concrete slabs are bulky, even after they've been cut. Once they're ready for loading onto trucks, remember to always allow for a swell factor of 1.7 from in-place volume to loose disturbed volume. In other words, if your project requires the removal of 1,000 bank cubic yards of asphalt or concrete, you'll actually be handling 1,700 loose cubic yards once it's cut up. And, besides being bulky, the asphalt and concrete slabs are hard to handle, so that slows down production.

Beyond the costs of demolition, keep in mind that the existing grades may need to be lowered after a structure is removed. In areas previously paved with asphalt, the base and sub-base material can be left intact and reused on the site. On home sites, however, assume a lowering of at least 10 inches after both the slab and footings are removed. Expect additional lowering on a commercial building with two or more floors, or a heavy industrial building with footings designed for heavy loading.

Sediment Control

Some projects require a stabilized construction entrance, like the one diagrammed in Figure 4-12. This generally consists of construction fabric laid beneath a layer of aggregate, the purpose of which is to reduce mud and sediment transfer from the site onto public roads.

Similarly, silt fences may be required to provide slope protection and prevent storm water from carrying sediment away from the site. See Figure 4-13. Install silt fencing along the site boundary and on contours where you'd expect runoff accumulation. Silt fencing end points should turn upslope, forming a J- or smile-like shape, so it can retain water. A silt fence is like a chain — it's only as strong as its weakest link. Post spacing generally shouldn't exceed 6 feet, and post depth should be at least 12 inches.



Stabilized construction entrance
Figure 4-12

Silt fence
Figure 4-13

Material Layout

Material layout may be as simple as stringing out the pipe to be installed. But it can be much more — and it can save you time and money on almost every job. When you're installing water systems, there are often fittings such as valves, crosses and tees that could be assembled and laid out by two men and a wheeled backhoe before you move in the main crew and equipment. If they spend a day or so assembling and laying out materials beforehand, it could cut a significant amount of time off the main crew's schedule. That saves money.

What's another advantage to laying out material ahead of time? Material shortages and omissions can be discovered and corrected before they delay a \$600-an-hour crew. At that rate, a \$10 gasket can cost you \$200 if it delays your crew by 20 minutes.

Try to have all the required materials, tools and equipment on hand before trenching begins. And by "on hand" I don't mean just anywhere on the jobsite. Each material, tool and piece of equipment should be laid out so it's as close as possible to where you'll be using it. If your materials aren't laid out properly, your crew may come to an expensive halt while you run down some missing part.

Sharing tools can also cause production delays, so here's one last piece of advice for this chapter: Don't be penny wise and pound foolish. Give each crew a full set of hand tools, and assign someone on each crew the responsibility of keeping track of them. This will help prevent excessive breakage and loss. As in all construction work, a little planning can yield big dividends.

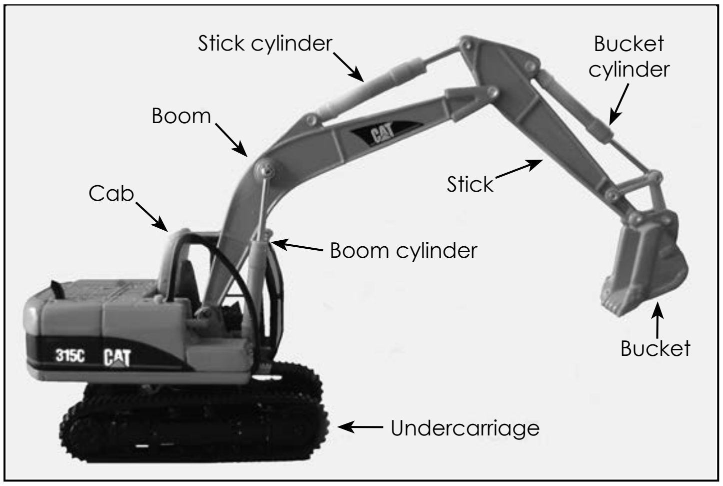
5

OPERATING A BACKHOE

A backhoe can be the most versatile piece of construction equipment on your underground utility line jobs. This versatility makes backhoes a popular choice for utility line jobs, but it also makes them challenging to operate, because every task requires variations of the different skills and techniques.

Depending on the size of the excavator, operator skill and overall job conditions, most excavators have an ideal cycle time ranging between 10 and 40 seconds. The loader backhoe can complete a digging cycle in less than 10 seconds — if the operator can make a complex series of precise moves without wasted time or motion. It's important that *each* work cycle be efficient. Ten wasted seconds may not seem worth worrying about, but multiply that ten seconds by several thousand times each working day and you're talking a lot of money.

In this chapter, I'll discuss how to get the most out of your backhoe. We'll look at the parts of a backhoe and how they work. I'll cover the precision skills your operator needs and suggest ways to develop those skills. I'll recommend a good way to calculate backhoe production rates. Then we'll look at the two backhoes normally used: the wheeled backhoe and the track excavator. I'll describe what I feel are the keys to operating these two machines both efficiently and profitably. Finally, I'll discuss some trenchless alternatives to consider when traditional trench excavation isn't a practical option.

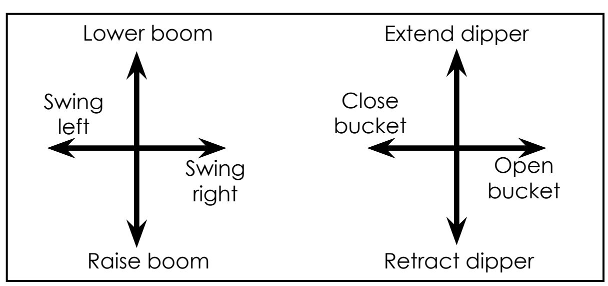


Basic backhoe components
Figure 5-1

How Wheeled Backhoes and Trackhoes (Excavators) Work

Backhoes have four main components: cab and undercarriage (or swing mechanism), boom, dipper (or stick), and bucket. The latter three components have hydraulic rams and cylinders that provide control and mobility. See Figure 5-1. The operator has eight different ways he can move these components using the control levers on the operator's platform. Figure 5-2 shows the most common wheeled backhoe controls.

Efficient backhoe operation is more complex than just making eight separate maneuvers. The table at the top of the next page shows how the control maneuvers combine in a typical *digging cycle* for a wheeled backhoe.



Common hoe controls
Figure 5-2

Digging Cycle Component	Control Maneuver
Load bucket	Retract dipper Lift boom Adjust bucket angle
Lift load	Lift boom Adjust dipper Adjust bucket angle
Swing & prepare to dump	Swing Adjust dipper Adjust bucket angle
Dump bucket load	Dump bucket Extend dipper Lower boom
Return to dig	Return swing Adjust dipper Adjust bucket angle

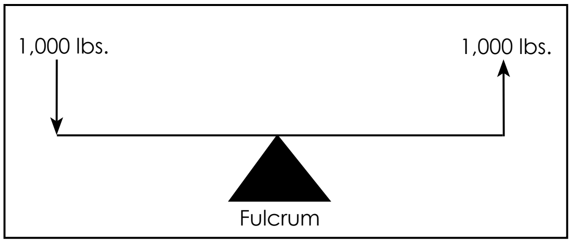
These control maneuvers don't take place independently of each other. The operator combines them to create a smooth digging cycle.

Understanding Hydraulics

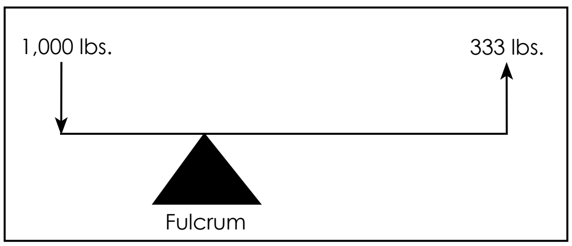
Regardless of control lever layout, the operating principle of the backhoe is the same. The engine drives a hydraulic pump. The pump sends high-pressure hydraulic fluid to the control box where valves direct the fluid to the hydraulic rams. The rams act like a piston and move the hoe's components.

Hydraulic rams exert tremendous force. How much force depends on the end area of the piston and the pressure of the oil against that piston. To calculate the force of a ram, multiply the area (in square inches) of the piston by the pressure (in pounds per square inch, or psi) of the oil against that piston. For example, if the piston has an area of 10 square inches and the oil is pumped into the cylinder at 2,000 psi, the force generated is 20,000 pounds.

Hydraulics is an efficient means of transferring power. There's hardly any loss of force due to friction along the hydraulic lines. If the hydraulic fluid pressure is 3,000 psi in one part of the system, the hydraulic pressure will be very nearly 3,000 psi at every other part of the system. Pressures in backhoe hydraulic systems usually range from 2,000 to 3,000 psi.



Equal leverage: 1/1 ratio
Figure 5-3



Leverage disadvantage: 1/3 ratio
Figure 5-4

Because of the tremendous hydraulic pressure, no one should ever go beneath the bucket while the machine is in operation. If a hydraulic hose breaks, the fluid can drain quickly, causing the bucket to fall suddenly.

Regulating Control Response Time

The control valves allow precise control of the oil flowing into each cylinder. By controlling the rate of flow, equipment response time can be fine-tuned without affecting the power of the ram. Reduced oil flow into a cylinder will cause the ram to move more slowly — *but with the same force*. Opening the control valve all the way increases oil flow, causing the piston to move faster and extend the ram quicker.

The operator should always use the control valves to regulate response time. *He should not reduce engine speed to slow his response time*. The backhoe engine is designed to run at a specific speed. It's less efficient if he runs it below the design speed during excavation operations. And the backhoe design assumes a certain hydraulic pump output at a given engine rpm. Reducing the rpm can cause the hoe to "misbehave" because the pump output is insufficient.

Using Maximum Power

The ram is most efficient near the middle of its travel. That's because all of a backhoe's rams operate at a *leverage disadvantage*: A small movement of the ram results in a larger movement at the end of the lever. Figure 5-3 illustrates equal leverage. If the leverage is equal, and there's 1,000 pounds of force applied to one end of the bar, the same amount of force is transmitted to the other end of the bar. Notice the position of the fulcrum. When the fulcrum is in the middle of the bar, the leverage is equal.

In Figure 5-4, the fulcrum is no longer in the middle of the bar. If 1,000 pounds of force is applied to one end of the bar, only 333 pounds of it is transmitted to the other end. This is a leverage disadvantage of 1/3rd. The leverage disadvantage of a backhoe dipper changes as it moves, but usually ranges between 1/3rd and 1/6th, depending on the length of the dipper.

Points of maximum leverage disadvantage: excavator fully extended
Figure 5-5A

When the stick cylinder is at either endpoint of its travel (fully extended or retracted, as shown in Figures 5-5 A and 5-5 B, respectively), the leverage disadvantage is at its greatest. Note in each figure that the stick cylinder is at the beginning or end of travel. The backhoe is most powerful when the ram has the least leverage disadvantage. This is usually when the stick cylinder is near the middle of its travel.

Points of maximum leverage disadvantage: excavator fully retracted
Figure 5-5B

There are times when you may need to use the maximum reach of your backhoe. But a skilled operator will keep most work within the maximum efficiency zone. When work is outside the easy reach of your equipment, it's time to reposition the hoe. It's more productive to reposition your equipment than to struggle with work at the end of the reach.

Calculating Backhoe Production Rates

In production trenching, the backhoe excavates one *set* at a time. A set is the length of trench that a hoe can excavate from one position, and can be broken down further into digging cycles.

Here's how to calculate the time required to excavate a set. First, divide the volume of dirt in the set by the dirt moved per cycle. This gives you the number of digging cycles required per set. Then multiply the number of digging cycles per set by the average cycle time to get the total length of time it takes to excavate a set.

Here's what the formulas look like:

$$\text{Volume of dirt in set} \div \text{dirt moved per cycle} = \text{digging cycles per set}$$

$$\text{Digging cycles per set} \times \text{average cycle time} = \text{time required to excavate a set}$$

Time spent analyzing backhoe performance is worthwhile because it helps point out inefficiencies. The most common problem is not fully loading the bucket, which reduces production significantly.

When you're calculating production rates, it's important to remember that dirt swells when disturbed from its natural *bank* condition. Loam, for example, swells by about 30 percent. Let's say you're excavating a 2-foot-wide by 4-foot-deep trench in loamy soil, and you want to find the production rate. In this example, assume that a set is 8 feet long. Start by calculating the number of bank cubic feet of dirt per linear foot of trench; multiply the depth of the trench by the width of the trench. In this case, the trench contains 8 BCF of dirt per linear foot.

Now multiply the number of bank cubic feet by 1.3 (the factor for loam) to get the number of loose cubic feet — 10.4 LCF. Next, multiply the number of loose cubic feet by the number of feet in a set. This gives you the total *loose* volume of dirt in the set. In this example, that comes to 83.2 LCF per set.

Before we compute the final production rate, let's look at bucket capacity. Depending on the soil type, the heaped capacity is usually about 130 percent of the struck capacity. For example, a 2-foot-wide hoe bucket has a struck capacity of 5 to 6 LCF. So the heaped capacity would be 130 percent of this amount, or about 6.5 to 8 LCF.

> *"Time spent analyzing backhoe performance is worthwhile because it helps point out inefficiencies."*

Assume your operator is a real pro and gets heaped capacity bucket loads of 8 LCF per bucket. His cycle time is fast, averaging 12 seconds, and it takes him 15 seconds to move his machine into position for the next set.

With 83.2 LCF per set, it will require 10.4 (83.2 ÷ 8) digging cycles per set. At 12 seconds per cycle, 10.4 cycles will take 124.8 (12 × 10.4) seconds. Add in the 15 seconds required to move the machine, and you end up with 139.8 seconds for the total time required to excavate a set. That's equal to 2.33 (139.8 ÷ 60) minutes.

To calculate how many sets can be excavated in an hour, divide 60 (minutes in an hour) by 2.33 minutes (time to excavate each set). That equals 25.75 sets in this example.

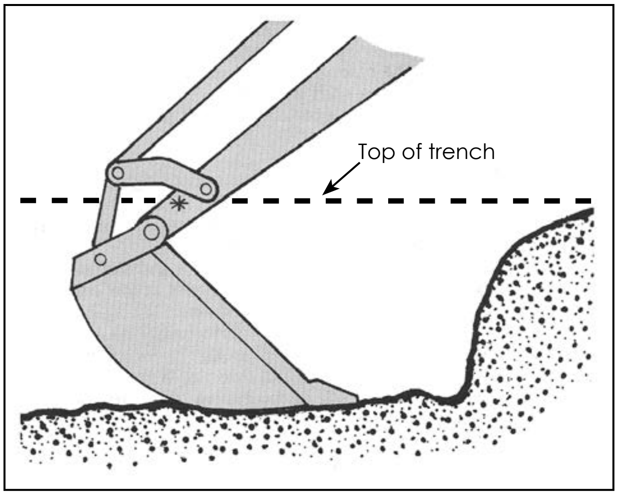
Finally, to convert the sets per hour figure (25.75) to linear feet of trench per hour, multiply it by the number of linear feet per set (8). That comes to 206 linear feet in this case.

For practice, try plugging some different figures for cycle time or bucket load into the formulas above. You'll notice how small increases or decreases in heaped capacity, cycle time or moving time can cause dramatic increases or decreases in productivity. That goes to show how important it is to hire good equipment operators.

Operator Ability

Anyone can operate a backhoe. It's just a matter of moving the levers. Given a little time, anyone could find a way to scratch the ground and dig a hole. But that isn't what a professional operator gets paid for. A good operator has control so precise that he could open a soda can with his bucket. He's aware that good control, proper positioning of his machine and maximizing the amount of material per cycle leads to efficient, productive work. Even a perfectly-executed cycle is a wasteful one if the hoe bucket isn't filled to capacity.

The operator's control levers open valves that allow hydraulic fluid to flow to the rams that activate the hoe. The wider he opens a valve,



"Eyeballing" an even grade
Figure 5-6

the greater the flow to the ram, and the faster the ram will operate. Reducing the flow slows the speed of the ram. A skilled operator will always use the control valves — *not the engine speed* — to increase or decrease the speed of the rams.

Highly skilled operators can use a hoe almost as an extension of their body. They develop a "feel" for obstructions in the soil or changes in ground condition. Of course, it's impossible to "feel" a steel crossline before you get to it. But a skilled operator *will* feel the slightest pause in the progress of the hoe on first contact. When the bucket strikes a solid object, the tractor will pull toward the obstruction.

When the hoe hits a fragile crossline, it usually happens too quickly for even the most skilled operator to prevent damage. Cutting through a 50-pair phone cable is virtually imperceptible. But if the operator knows the general location of a crossline, he may be able to detect a difference in soil resistance as the line is reached. In certain soils, soil resistance is usually greater in undisturbed earth than in an existing trench line. The key is to pay attention to the work, looking for trench lines or soft spots in otherwise firm soil. It results in fewer surprises and less damage to crosslines.

It's essential that the operator be able to keep the trench at the correct depth. That's called *holding grade*. Nearly all trenching work requires that the excavator maintain a specific grade. For example, water pipe installation specs may demand an even grade and a minimum cover over the entire length of the pipeline. Sewer service lines have to flow toward the main line, so the trench bottom must have a precise grade. The operator has to deliver the grade called for in the specs.

Overdigging is a waste of both time and material. And leaving humps or a rough, uneven trench bottom makes hand-grading necessary. A good operator will minimize the handwork and make the hoe do as much of the work as possible. A highly-skilled operator can keep the trench bottom straight, even without constant directions from the grademan.

A good operator can also "eyeball" an even grade. He does this by noting the position of the dipper and its relation to the top of the trench as he draws it toward the machine. See Figure 5-6. When the bucket is at the correct depth, the operator eyeballs a spot on the dipper and makes sure that spot stays parallel to ground level as he continues to dig. This keeps the trench bottom parallel to ground level.

The Wheeled Backhoe

The advantage of a wheeled backhoe is that it's easy to maneuver and can double as a loader. If any piece of equipment deserves the title of all-around workhorse, it's the tractor-loader-backhoe. Its specialty is digging trenches up to about 8 feet deep.

First, we'll look at the three types of transmissions fitted to the wheeled backhoe. Then we'll look at some key pointers for positioning the wheeled hoe. Finally, I'll describe five specialized tasks wheeled backhoes usually handle in underground utility work.

Wheeled Hoe Transmissions

There are three types of wheeled backhoe transmissions. The older style direct drive transmissions are being replaced with power shift transmissions and torque converter transmissions. Let's look at the pros and cons of each type.

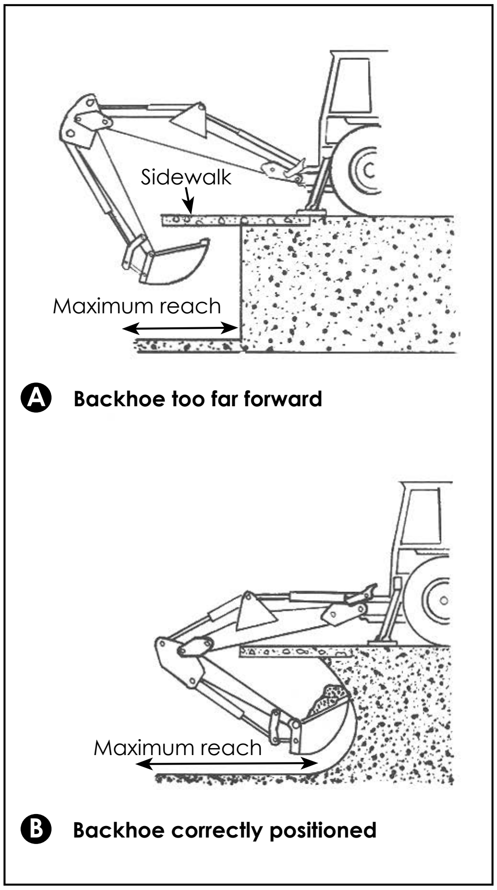
Direct drive has a conventional clutch, and six to eight closely-spaced gears. The travel speed ranges from 1.5 to 20 miles per hour at full engine speed. This type of transmission has low-speed first and second gears. This allows full-power hydraulic response at low travel speeds. But constant double-clutching and gear shifting is required to get maximum front loader performance out of this type of transmission. Shifting gears is usually easier when the motor is spinning fast, at or near full throttle. When using these machines, set the hand throttle at the desired rpm. Save the foot throttle for road travel.

Power shift has all the advantages of the direct drive transmission plus the ability to shift gears at any engine speed without using the clutch.

Most new backhoes are fitted with *torque converter* 4-speed transmissions. The torque converter is a fluid coupler. There's no direct contact between the engine flywheel and the transmission. Engine torque is transmitted through the transmission fluid.

There are two advantages to the torque converter transmission. First, it reduces wheel spin. Second, it can reduce loader cycle times when the machine is doing shuttle work such as truck loading.

In my opinion, the drawback to torque converter transmissions is that first gear may be too fast for certain types of work. There are times when the operator needs a low travel gear — no greater than 1 to 2 miles per hour. For example, when the backhoe is stuck in deep mud or trying to climb a steep or slippery slope, he may need to use both the



Digging under a sidewalk
Figure 5-7

dipper and the transmission to push the hoe forward. If the machine is fitted with a 3- to 4-mph first gear, the transmission either stalls, or minimum travel speed is simply too fast to do any good.

Selecting the Right Size Hoe

A backhoe is most efficient when working within 70 percent of its maximum digging depth. To determine what hoe is best for the job in terms of maximum digging depth, just divide the trench depth by 0.70. For example, if you're excavating a trench that's 10 feet deep, you'll need a hoe with a maximum digging depth of about 14 (10 ÷ 0.70) feet. This isn't to say that the backhoe can't be used to dig deeper trenches. It's just more efficient in this range.

The typical wheeled backhoe has a maximum digging depth of 14 feet and a horizontal reach of 16 to 17 feet, measured from the swing post of the hoe. This size backhoe can excavate a 6- to 9-foot section of trench in one position.

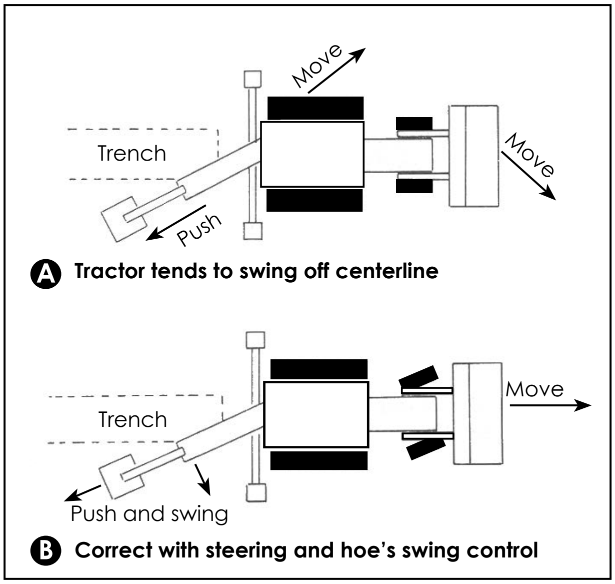
If the soil is loose sand and gravel, the backhoe may not have enough reach to place the spoil far enough away from the trench. An extending dipper will increase both the digging depth and reach for spoil placement. Or consider the possibility of a track excavator. You're usually better off paying extra for the most suitable equipment rather than suffering slow production rates.

Once you've selected the right-size backhoe for the job, it's time to decide how to position it for maximum efficiency.

Positioning the Hoe

When digging around or under obstacles, it's vitally important to have the hoe in a good position. It's better to have to change the position of the hoe several times rather than work from a bad position. This is especially true when excavating under a sidewalk or working around crosslines.

If the backhoe is too far forward, it can't reach all the way under the sidewalk, as shown in Figure 5-7 A. Moving the machine backward a few feet lets the hoe reach completely under the sidewalk. A backhoe that's positioned correctly (Figure 5-7 B) can tunnel all the way under a 4-foot-wide sidewalk.



Setting dipper off to side of trench
Figure 5-8

Using the Hoe to Move the Tractor

Quick, accurate positioning will increase your trenching production rate. Sometimes it's best to use the hoe to push the tractor forward. This can be done by raising the front bucket and lowering the hoe bucket to lift the rear wheels and stabilizers off the ground. The tractor will then roll forward on its front wheels. Another way is to leave the rear wheels on the ground and lift the stabilizers just enough so that the tractor can roll on all four wheels. Fully retracting the stabilizers is only necessary when the operator needs to lift them to clear an obstruction.

One disadvantage of moving the tractor with the hoe is that it may disturb the trench bottom — especially in soft ground. If that could be a problem, the dipper could be set off to the side of the trench. But the operator needs to be aware that this maneuver will tend to swing the tractor off the centerline, as shown in Figure 5-8 A. He can steer the wheels to counteract this tendency, and use the hoe's swing control (Figure 5-8 B) to offset the push away from the centerline.

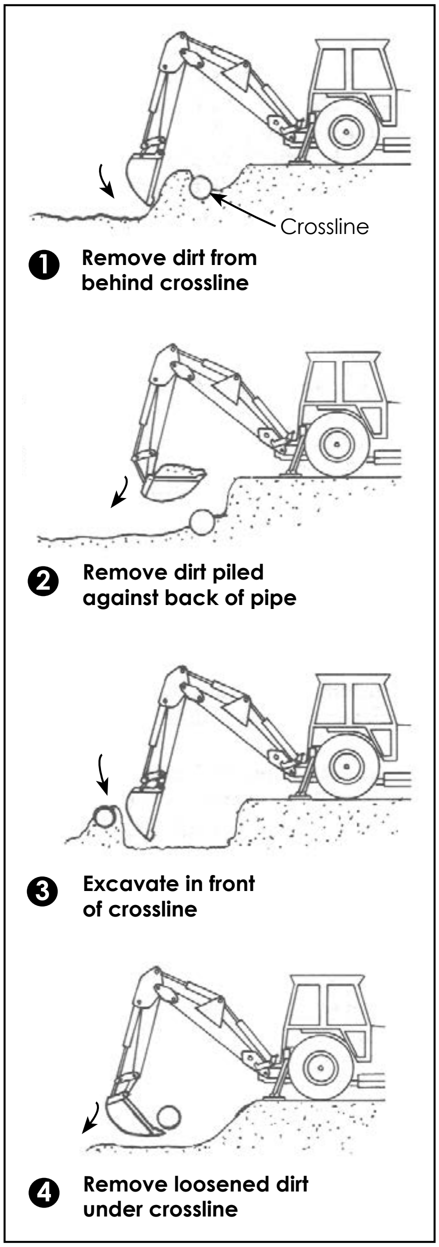
Using the Transmission to Move the Hoe

Most backhoes have shuttle levers mounted near the steering column. The transmission can be engaged with the operator facing toward the rear. But it may be hard to control the machine in this position. It's best to stay in the driving position when using the transmission to move the hoe.

Backhoes fitted with torque converter transmissions require throttling down the engine rpm to achieve a slow travel speed. Backhoes with direct drive or power shift transmissions will creep ahead at 1 to 2 mph at full throttle.

Working Around Crosslines

When working in developed areas, you're going to have to deal with crosslines. Some are just a nuisance, while others are dangerous. But all of them are expensive to repair. Using a grademan to locate crosslines *before* they can be hit prevents unnecessary damage.



Excavating around crosslines
Figure 5-9

If there are a large number of crosslines, locating all of them can be a full-time job. You'll need to hire someone to do just that. If there are only a few crosslines and the pipe laying work isn't too heavy, the pipe layer can double as grademan.

Most crosslines have been laid in a trench. By carefully watching the walls of the ditch, the grademan can often spot the old ditch line. Look for darker spots of topsoil mixed in with lighter-colored subsoil. The soil in the old ditch will usually be easier digging than undisturbed soil. Crossline damage is tougher to avoid in rocky soil. The hoe hits rocks regularly, which causes the machine to momentarily freeze up or pause. From the operator's seat, it's hard to distinguish a rock from a crossline when he first hits it. He may be encountering existing utility lines; or he may just be running into natural rock.

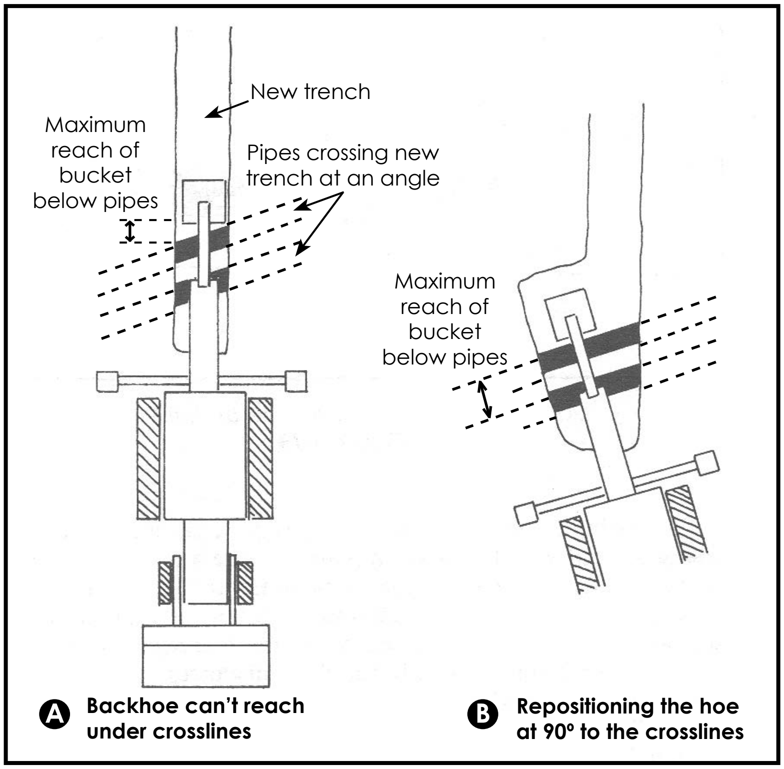
Some cables and flexible pipe are ploughed into the soil without any trenching. There won't be many clues to their whereabouts. But most utility companies will locate and mark their lines. *Always* take advantage of this service. And mark the location of known crosslines on your blueprints. You can use these to refresh your memory if one of the utility company's markers gets wiped out.

If a utility company marker does disappear, have them come mark it again. An additional safeguard is to paint an offset reference mark in a position where it's unlikely to be covered up or destroyed. Some utility companies have a "guaranteed" safe area, usually one foot beyond their paint mark. If they mismark the location and the crossline is in fact outside this area, they'll pay for any crossline damage. If missed locations are common, report it to the construction department of the utility company. Be sure everyone understands that the fault is theirs and not yours.

Modern pipe detectors are useful for locating metal pipe from above ground. But nonmetallic water and sewer lines can't be located with metal detectors. Fortunately, these are the cheapest pipes to repair.

Finding the crossline is only the first step. The next is to excavate around it. The best technique is to excavate underneath the line, using the four basic steps shown in Figure 5-9.

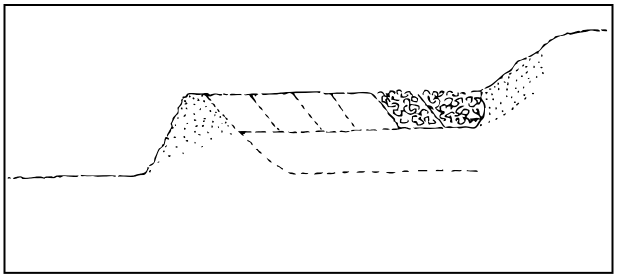
1. First, the operator removes the dirt from the area *behind* the crossline. He needs to keep the pipe in view the entire time he's working near it. The line is treated as though it were made of glass. Even pressing dirt against an old pipe may make it snap.



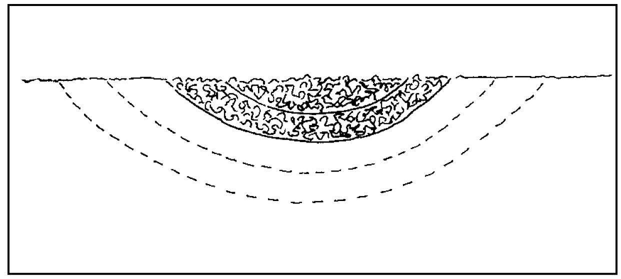
Crosslines crossing new trench at an angle
Figure 5-10

2. The operator removes the dirt that has been piled up against the back of the pipe. He shouldn't put it in toward the pipe. Instead, he shoves the dirt back and away from the pipe.
3. The backhoe needs to be moved ahead. Then the operator quickly excavates *in front of* the crossline. He should make sure the hoe is positioned to make this as easy and precise as possible before beginning.
4. The operator moves the backhoe into a position where it can easily reach under the crossline. He removes the loosened dirt under the line. The soil should always be flicked down and away from the crossline. He may be able to excavate a tunnel under the crossline for his new line. He shouldn't remove any more dirt than necessary. Remember what I said before: It's better to reposition the backhoe than dig from an unfavorable position.

When the crosslines cross the new ditch at an angle, the backhoe may not be able to reach far enough to excavate underneath them, as shown in Figure 5-10 A. In that case, the operator must reposition the backhoe at 90 degrees with respect to the crosslines before he excavates. See Figure 5-10 B. Careful positioning of the hoe is crucial.



Applying downward pressure on hard soil
Figure 5-11



Removing hard soil in arcs
Figure 5-12

As you've probably noticed, excavating around crosslines may require several position changes. When moving just a few feet at a time, it's best to use the hoe to move the tractor forward. It's a waste of time to switch back and forth between the driver's seat and the hoe operator's seat when the hoe needs to be moved several times for short distances.

Hard Digging

Under normal digging conditions, the bucket is loaded by pulling it toward the machine. In hard ground, the operator has to use other techniques.

One way to break hard material is to force the bucket downward into the soil, breaking off and loosening a section of material with each thrust. Figure 5-11 illustrates what those sections might look like. The operator begins in the section of trench nearest the machine. Once that material is broken up, he uses the conventional pickup technique to remove the soil.

Another hard digging method is to remove the material in arcs, slicing off a few inches of material with each pass. See Figure 5-12. This pulls the new material toward already-loosened earth.

Whether your operator uses downward thrusts or an arc motion depends on what works best for that particular situation. Both techniques involve pulling the hard material towards broken soil. It's more effective than simply tugging at the hard-to-move earth.

No backhoe can dig in solid rock. But your operator should be able to handle softer materials, such as caliche, cemented sand and weathered rocks. Some operators use what I call the "drop and smash" method for these materials. They use the dipper as a ram, crushing the material into fragments. I won't claim that this doesn't work. It does. But it also tends to cause cracks and breaks in the boom and dipper. Backhoes aren't designed to take this kind of abuse. Use it in an emergency, but understand that drop and smash will shorten equipment life.

Sewer System Work

Your operator will usually dig trenches from the low end to the high end. Most of the time, it's easier to stay on grade when the trench slopes up toward the machine. But sometimes he'll have to dig a falling grade. For example, if you dig a sewer line from the property line to the main line, grade will slope down toward the machine. Let's look at an example:

We're installing a 4-inch PVC sewer service. Assume it's 35 feet from the main to the property where the service is required. A well-kept lawn prohibits taking the backhoe onto the property. At the property line, the pipe needs to be 5 feet deep for the specified minimum grade of 0.02 foot. This means the pipe has 2 vertical feet of fall for every 100 horizontal feet of run.

> *"Your operator will usually dig trenches from the low end to the high end."*

To determine how deep to install the riser, multiply the distance from the main to the property line (35 feet) by the vertical rise required (0.02 foot) to get a depth of 0.7 foot. This means that the riser must be installed at least 0.7 foot *deeper than the pipe at the property line*. Assuming level ground, with a 5-foot starting depth, a 0.7-foot fall, and allowing for 0.5 foot of bedding gravel, the trench needs to be 6.2 feet deep at the riser.

Always use a grademan for this type of trenching. He'll indicate when your operator reaches the 5.5-foot depth and will monitor the depth as he proceeds toward the main line. If the ground is fairly level, the grademan can use the ground as a reference point. If not, he should use a small hand sighting level.

We know the trench needs to be 0.7 foot deeper at the riser pipe. Let's divide the trench up into thirds and check our progress along the way. The first checkpoint is at about 12 feet out from the property line. The depth at this point should be 0.23 (0.7 ÷ 3) foot deeper than at the property line, or 5.73 (5.5 + 0.23) feet deep. The second checkpoint is at 24 feet out from the property line. Here the trench should be 5.96 (5.73 + 0.23) feet deep. The third checkpoint is the riser pipe, and here the trench should be 6.2 feet deep. You can see how important the grademan is in this type of work.

Water System Work

Whether you're installing a system in a new subdivision or repairing an existing system in a developed area, you'll most likely use the wheeled backhoe to install water services. You'll need a trench from the main to the property line and an enlargement around the meter box. The water main will need a tap or saddle, requiring working room around the main.

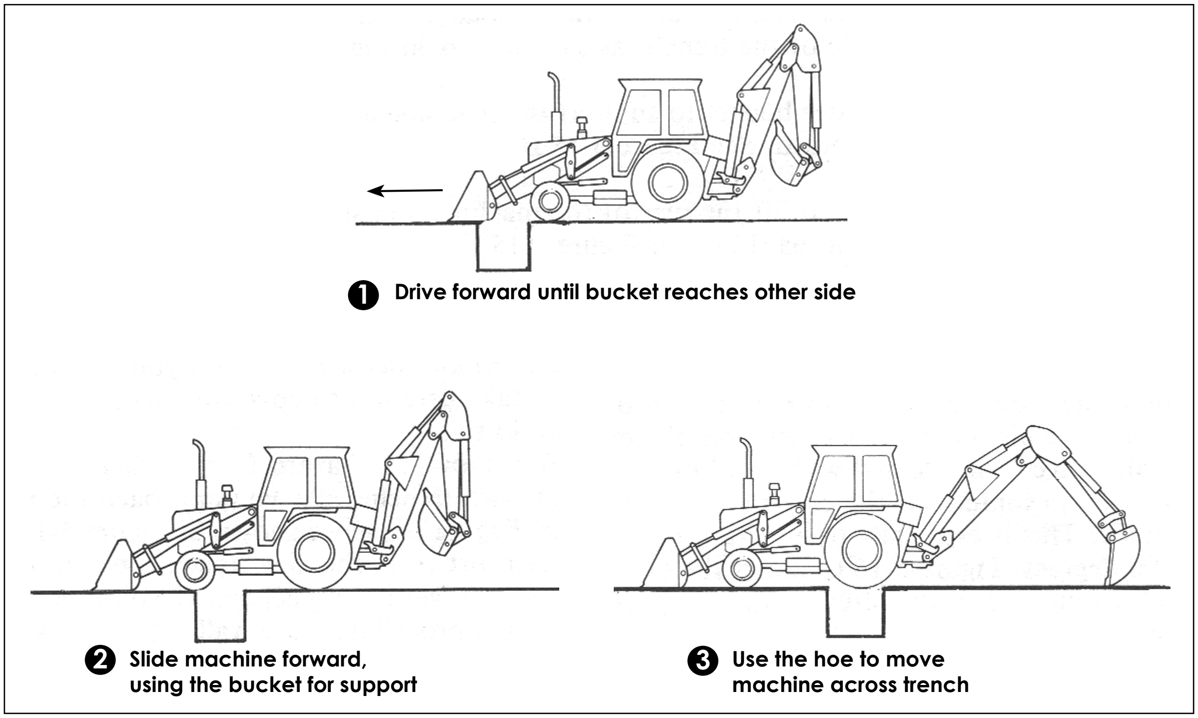
In a new subdivision, your excavation work may simply involve digging a trench from the main to the property line. Encroaching on someone's property won't be a problem when you're working on undeveloped lots. But if you're doing replacement work in an area with existing homes, your work area may be limited by the surrounding private property. If you need access, get permission *in writing* from the property owner (you'll still have to repair any damage). But it's better to stay off private property entirely if you can manage it.

"Enlarging the work area around an existing meter box can be tricky."

You may also have to contend with an existing meter box and service. These will probably be in use (under pressure) and will feed off the existing main line. Enlarging the work area around an existing meter box can be tricky. The existing service pipe may be laid in a direction you wouldn't expect. Give your operator time to excavate this area, and use a grademan.

Specialized Tasks

If you work back from the property to the main, it may involve specialized tasks such as moving a hoe across an open trench, excavating toward an open trench, punching holes for pipeline, and excavating the work area for a saddle or tap.



Moving the hoe across an open trench
Figure 5-13

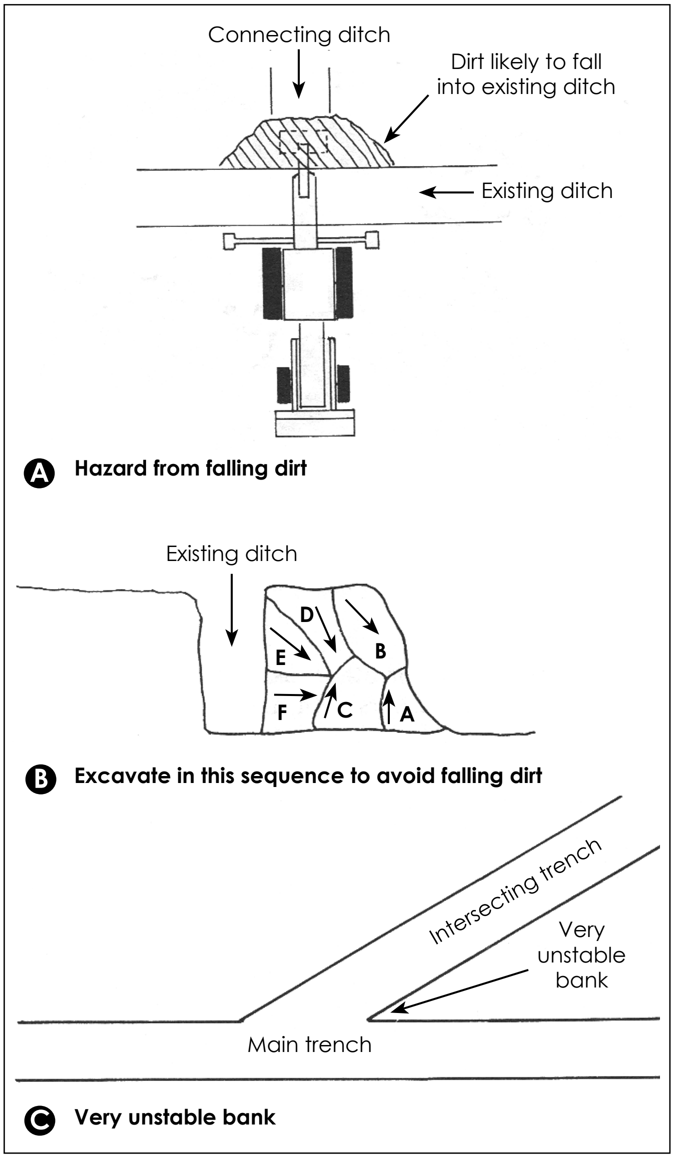
Moving a Hoe Across an Open Trench

Figure 5-13 illustrates the three steps involved with moving a backhoe across an open trench:

1. First, the operator drives the machine forward until the loader bucket reaches the opposite side of the trench.
2. Next, he uses the loader bucket to support the machine as he slides the machine forward.
3. Finally, he uses the hoe to lift the rear of the machine and pushes it across the trench.

Excavating Toward an Open Trench

As the operator excavates toward the new main, he must take care not to cover the main pipe. Figure 5-14 A illustrates the potential hazard from falling dirt at the junction of the two trenches. If he excavates this area using conventional procedures, the walls of the new trench are likely to cave in toward the existing trench and bury the pipe. Cave-ins usually have to be cleared with hand excavation.



Excavating toward an open ditch
Figure 5-14

As he approaches the junction point, the digging sequence shown in Figure 5-14 B is used to excavate the last dirt from the new trench. The final strokes will push the dirt down and away from the existing pipe. He must be careful not to exert a direct pull toward the machine.

Where two trenches intersect, the corners of the bank can become unstable. This is especially true if the trench intersects at less than a 90-degree angle. Figure 5-14 C shows the extremely unstable bank formed when the intersecting trench comes in at an acute angle. This is another situation that requires caution and deliberate digging movements to avoid cave-ins.

Punching Holes for Small Diameter Pipe

When you come to a crossline, don't bother tunneling all the way under it. Instead, stop the trenching at the crossline and have your operator begin the trench again on the other side of the line. Then have him punch a hole through the bank of soil under the line and thread the pipe through the hole. Most water service pipe is flexible and can be threaded under crosslines.

A good tool for punching holes through a bank of soil is a 2-inch diameter steel bar about 5 or 6 feet long with a point on one end and a plate welded on the other end. This can be shoved under obstructions in soft soil. It leaves a neat 2-inch diameter hole when it's withdrawn. A midsize backhoe can push or pull a 2-inch bar through several feet of soft soil without any problem.

Steel bars are useful for other tasks too. Some utility line contractors have sets of bars with male and female threaded ends that can be joined together into a single long bar. If soil conditions are right, a bar like this can be punched under the entire width of a street. Steel bars and other underground piercing devices, such as the Hole-Hog® shown in Figure 5-15, can save a lot of time and money because they eliminate

Courtesy of Allied Construction Products, LLC

Hole-Hog® underground piercing device
Figure 5-15

most excavation and nearly all street repairs. *Trenchless* construction has become a popular technique. I'll discuss trenchless construction in more detail at the end of this chapter.

And remember, you don't need to dig a 2-foot-wide trench for a ¾- or 1-inch water service pipe. A 12- or 18-inch bucket will do the job and reduce street restoration. In some cases, the main pipe will be backfilled prior to excavating the water service. This means you'll have to expose the buried main pipe.

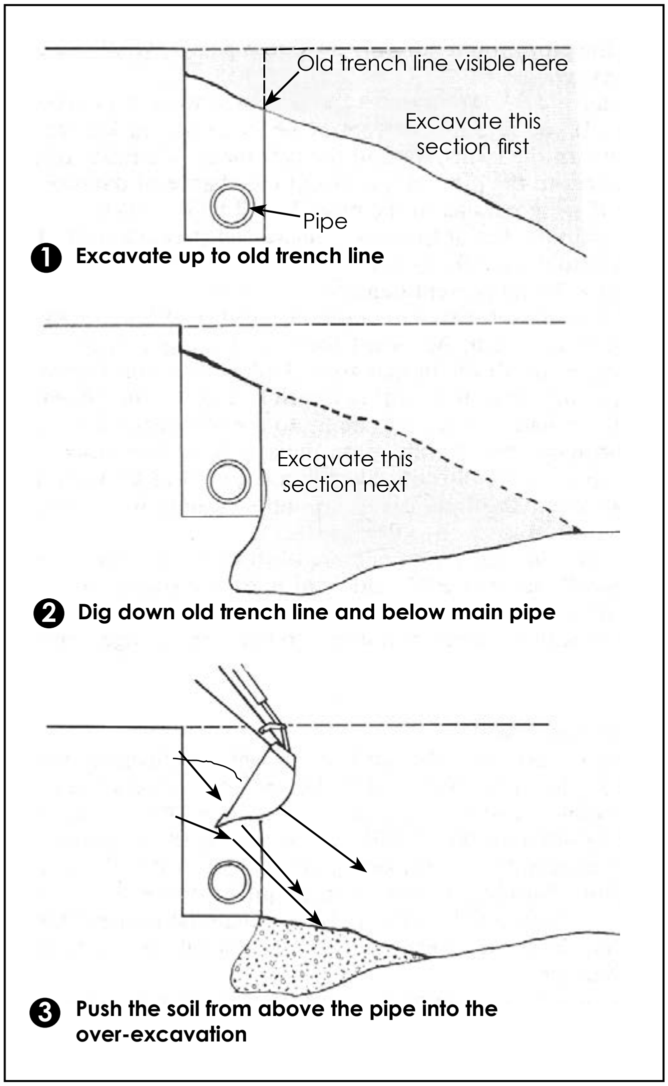
Excavating the Work Area for the Saddle or Tap

Where a lateral joins the water main, you'll usually have to install a saddle or tap. Have your operator cut a small hole in the main line and tap into the main with a special fitting. The problem is that he'll be doing this with the main under full operating pressure. If he damages the pipe, you'll not only have to repair it, you'll have a flooded excavation to add to your troubles.

To install the tap, first the operator excavates a work area around the main. If he's using a bucket that's 1 foot to 18 inches wide, he'll have to widen the trench around the new main. It's faster to dig at 90 degrees to the pipe. But to avoid damage to the pipe, consider having him dig parallel to it. He'll be less likely to damage it, but at the cost of increased street repairs. If you decide to have him dig at 90 degrees to the main, the following technique will help him prevent damage.

If the main has just recently been installed, he'll know its exact minimum depth. Allow a 1-foot safety margin all around the new pipe. Don't let him dig in that zone. Follow along on Figure 5-16. First, the operator digs to the existing trench line, well above the known depth of the main. Second, he excavates up to the old trench line and below the main pipe. Third, the remaining dirt is pushed from above the main, down and away from the pipe, into the space he just excavated. Have the grademan locate the pipe by hand. A little cleanup with the hoe will finish the excavation.

Remember that some pipe is more damage-resistant than others. But small-diameter PVC and transite are fragile. So have the grademan spend a little time shoveling if you need to. It's always easier to locate pipe with a shovel than it is to repair the damaged pipe.



Excavating a service trench to expose buried pipe
Figure 5-16

Using the Front Bucket

The front bucket on a wheeled backhoe will get plenty of use on most utility line jobs. Wheeled backhoes are both versatile and highly productive machines. But using the front bucket requires an entirely different set of skills. For example, the operator has to understand how bucket loading affects weight distribution on his machine. Pushing the loader into a pile of material transfers weight to the rear of the tractor. Lifting material in the front bucket has the opposite effect. It transfers weight to the front of the machine.

Lifting material in the bucket of a 2-wheel drive backhoe reduces traction on the rear wheels. Carrying a load downhill reduces traction even more. If the grade is steep enough and the load heavy enough, the hoe loses all traction, becoming a runaway. The operator can compensate for these weight and traction shifts by manipulating the positions and weights of the hoe and loader buckets. When your operator is climbing or descending a steep grade, he needs to keep the hoe pointed upgrade. This means he'll ascend in reverse gear. If he points the loader bucket uphill while ascending grade, he needs to partially fill the loader bucket with dirt to help transfer weight to the front wheels. He can also use this technique while hauling a heavy object such as a tree trunk using the curled hoe bucket. If he points the loader bucket downhill while descending grade, he can extend the hoe bucket to help transfer weight to the rear of the machine.

Avoid using a 2-wheel drive backhoe for heavy material handling and loader work. A 4-wheel drive front loader is better suited for these tasks. Use a backhoe's front loader for smaller tasks when a large front loader isn't available.

A midsize hoe's front loader shouldn't be called on to lift more than about 3,000 pounds. But even with this limited capacity, a backhoe's ability to backfill its own trenches make it a versatile dual-purpose machine.

Front Bucket Tasks

Your tractor-loader's front bucket will handle seven different tasks: picking up material from a stockpile, picking up spread material, dozing, spread dumping, sprinkle dumping, fine grading and smoothing, and supporting the tractor in muddy ground.

Picking Up Material from a Stockpile

Here's the key to picking up a good bucket load when you don't have the advantage of 4-wheel drive: Have your operator charge into the pile at a reasonable speed (about as fast as a brisk walk), and roll the bucket up just as forward momentum stops. That should fill the bucket to capacity.

When the operator is cutting into the stockpile, he must be sure the toe plate and the floor of the bucket are level. Most machines have a bucket angle sight gauge to help him judge the angle. Some machines have a plate welded on the back of the loader bucket. The plate is parallel to the bucket floor. This arrangement helps the operator to level the bucket or judge the bucket angle.

Picking Up Spread Material

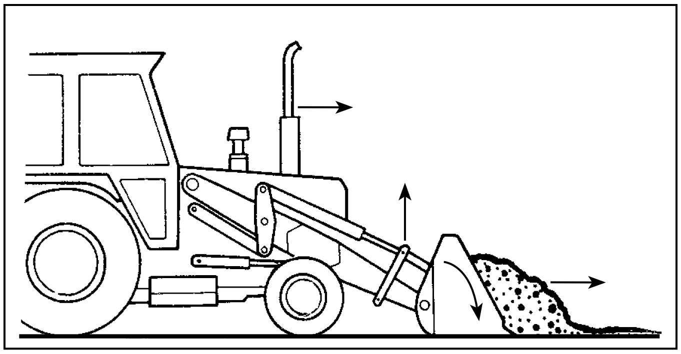
When picking up soil, the operator should angle the bucket down so it can cut into the material. As soil builds up in front of the machine, he rolls the bucket back. When he's picking up the last of the material, he needs to approach it at 90 degrees with respect to the previous passes.

Dozing

A backhoe may not be as precise as a grader, but it can still clean up and do minor finish grading. When using the backhoe as a dozer, have your operator consider using the independent brakes for direction control if the backhoe has separate brakes for each wheel. Also note that the foot throttle on some backhoes is located in a position that interferes with operation of the independent brakes.

During normal front loader work, engine power is needed for both hydraulic power and wheel turning power. Using the independent brakes for direction control places extra load on engine power. Your operator should watch the engine speed and avoid running the backhoe under load at low engine speeds.

The operator needs to select a gear low enough so the tractor works without stalling or lugging. Zipping around at high speeds and in high gear makes the operator look efficient. But constant downshifting is hard on the machine and a lugging engine slows hydraulic response. It's better to slow down and work in a lower gear.



Spreading the load while dumping
Figure 5-17

Some backhoes have an *instant* forward-reverse shuttle lever. Equipment manufacturers claim this shuttle lever allows you to shift from forward to reverse at full engine speed. Some operators, however, still prefer to use the foot clutch or reduce engine speed when changing direction. This makes for a smoother ride.

Your operator should use the bucket at a steep angle when he's working on firm ground. This results in a cleaner pass.

Spread Dumping

If later spreading is required, it makes sense to spread the material as it's dumped. This is done by making a pass in low gear while simultaneously raising the load and dumping the bucket. See Figure 5-17.

Sprinkle Dumping

Sprinkle dumping is useful for accurate placement of granular material such as sand or gravel for bedding material in a trench. This method involves raising a full bucket load to a height above the operator's eye level so the operator can see material as it falls from the bucket. Dumping should start as the operator approaches the spread area. He should use the dump control lever to shake the material out of the bucket during travel. An expert operator can spread a fairly even layer this way. Note, however, that quick hydraulic response is required, so the operator needs to keep the engine speed high.

Fine Grading and Smoothing

There are several ways to smooth out dumped material with a backhoe. Let's look at two of them. The first is to use the bucket in a slightly rolled-back position to doze the material. The second is to drag the bucket backward so the toe plate cutting edge or the angled rear edge of the bucket floor smooths the material.

A backhoe doesn't do very well as a fine grader because there's no way to adjust the horizontal angle of the front bucket. If the rear wheels aren't level, the front bucket won't be either. If the front bucket isn't level, then your fine grading won't be very precise. The only practical solution is for the operator to level part of the area with the hoe, and then work from that area.

Supporting the Tractor in Muddy Conditions

The operator should use the front loader to support the front of the tractor when working in mud. This is similar to the support system I described earlier for moving across an open trench.

The Track Excavator (Trackhoe or Track Backhoe)

Track excavators, sometimes called trackhoes or track backhoes, are much more difficult machines to operate than wheeled backhoes. Experienced operators can sometimes "hot dog" while operating the smaller wheeled backhoes, getting speed and precision from the relatively small, compact machines. But they can't do this with the larger machines. The typical trackhoe has a 30- to 40-foot horizontal reach and the ability to revolve 360 degrees. Its operating range is perhaps 50 vertical feet. Within these operating parameters, there's a great potential for destruction.

The trackhoe operator must be constantly aware of three areas for possible disaster. First, his main focus must be what's happening in the trench. Second, he must watch for overheads such as cables, trees and structures. Third, he must be aware of the machine's counterweight, which rotates in the opposite direction of the boom and dipper. It's easy to simply focus on digging a trench. But when you have to divide your concentration among all three components while preventing damage to crosslines and maintaining a profitable production rate, you've got a real job on your hands. This isn't for the inexperienced operator.

In a typical urban sewer installation project, the trackhoe operator will be dealing with all of these pressures for 8 to 10 hours a day. To further complicate matters, the hoe may be used to install heavy pipes, place pipe bedding, move shoring, load and work around trucks, move dewatering equipment, and coordinate with auxiliary equipment such as loaders or dozers.

Attention to Safety is a Must

Safety must be stressed by everyone on the jobsite. If you've worked around heavy equipment, you probably have a few horror stories you could share. The potential for injury and death is ever-present. Injury from rock or spoil falling from an overloaded hoe bucket or a spoil pile too close to the trench is a real, but avoidable, hazard.

The responsibility for maintaining a safe work place should be shared by the whole crew. The ground crew can see whether or not the counterweight will clear an obstruction. They can make it a point to remain in sight of the operator, alert for problems and signaling requirements.

A competent pipe crew and operator will have a system of hand signals to communicate over distance and noise. These hand signals aren't standardized, but in most cases a closed fist means *stop*, and an open hand with the thumb and index finger forming a circle means *OK*. Circling a vertical index finger means *raise*. Showing the operator a certain number of fingers pointing up or down means to move that many tenths of a foot up or down, while pointing to your foot means the measure is a foot instead of tenths of a foot.

Every crew will have variations and additions to these hand signals. It's not important which signals your crews use, as long as *every member of the crew* understands them and uses them to communicate visually.

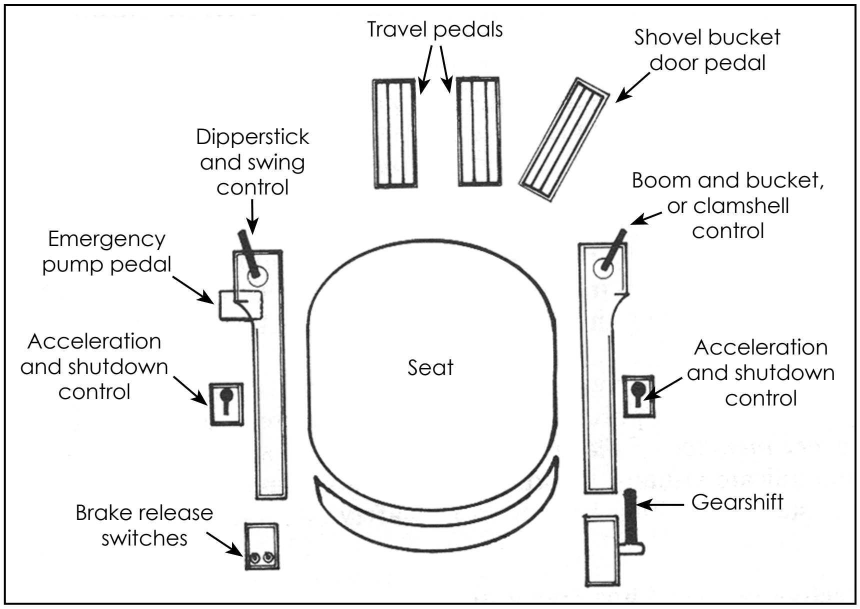
Selecting the Trackhoe Operator

Your trackhoe operator is one of your most important crew members. Previous experience with deep utility installation is important. However, experience with other kinds of equipment, or in using trackhoes for other applications, is largely irrelevant. And even if the operator has the experience, avoid anyone who's immature, a showoff, or just plain unstable. He'll cost you money and maybe hurt or kill someone. If there ever was a need for a drug-free work place, this type of work calls for it.

The trackhoe operator's job is more than just operating a piece of equipment. He also needs to anticipate changing conditions and allow for them. That includes awareness of hazards, and planning spoil placement to allow subsequent work on the job to be done efficiently and safely. For instance, when wet sandy spoil from the bottom of a trench is piled on the banks, the water will drain out of the wet spoil quickly and seep down into the banks. This added water will lubricate the soil in the bank, possibly causing an otherwise stable bank to slip. An experienced operator should be able to foresee this, and avoid it.

"If there ever was a need for a drug-free work place, this type of work calls for it."

Trackhoe operation is a job where experience, maturity and safety consciousness are as important as the mechanics of operating the machine. This point is often lost on young, ambitious operators. There's a saying in utility work: "If you ain't smart enough to operate a number 1



Cab layout of track backhoe
Figure 5-18

hand shovel, you sure ain't smart enough to run a hoe!" That means that the best possible operator experience is groundwork, pipe laying, or other work around the crew. Having worked in a 20-foot-deep trench will increase an operator's safety awareness a lot faster than any safety program, book or speech.

Safety on the job is a subject I feel strongly about, but my lecture is over. Let's discuss when you should use a trackhoe, and how to use it efficiently to make money on a job.

When to Use the Track Backhoe

For trenches deeper than 8 feet, or in extremely hard digging, the track backhoe should be your first choice. It's designed especially for deep trenching and truck loading. With the right kind of bucket, a track backhoe can also be used for material rehandling and site cleanup. Figure 5-18 shows the cab layout of a track backhoe.

Some contractors avoid using track backhoes because they're big and expensive to operate. And if your operator is slow or inefficient, it's even more expensive. But remember that it's the capacity of a track backhoe that makes it so productive. While the hourly or daily cost may be high, a skilled operator can *save* you money by moving large quantities of dirt in a short period of time. Used wisely, a track backhoe can increase your production rate and your profits.

Contrasting Track Backhoes with Wheeled Backhoes

Track backhoes differ from wheeled backhoes in their size, equipment rotation, field of vision, counterbalance, extra-sensitive controls, and cycle times.

Size

Some track backhoes are so big that the operator can look in a second-floor window while seated in the cab. That makes it more likely that a careless operator will accidentally damage people and property. The boom and dipper can easily come too close to high-voltage cables. Keep in mind: *You don't have to actually touch an electric line to attract a deadly charge*. High-voltage electricity will jump several feet from the cables to the backhoe. When this happens, the machine conducts electricity to the ground, possibly electrocuting anyone nearby if the ground is flooded or saturated. Keep your equipment at least 10 feet from high-voltage power lines.

Equipment Rotation

Wheeled backhoes can only rotate 180 degrees. Track backhoes can revolve a full 360 degrees. The operator's cab revolves with the turntable.

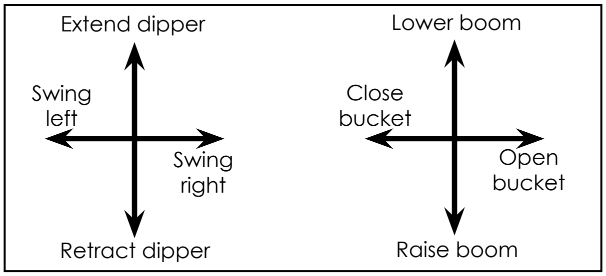
Field of Vision

Vision is restricted on the boom side of the cab. The operator's view to the rear (the direction of travel) is also severely restricted. Forward vision is usually excellent. On machines with the cab set on the left, the operator's blind spot is usually on the right. Cabs set on the right side of the machine have a blind spot on the left.

Working close to power poles, trees or existing structures can be hazardous. Have a spotter on the ground help keep the hoe clear of obstacles. Once the operator makes a mental note of the position of an obstruction, he won't need the spotter again until he repositions the hoe.

Counterbalance

Track backhoes, unlike wheeled machines, have counterweights. When you swing the hoe left, the counterweight at the rear of the machine swings right. It allows the machine to handle heavy loads, but it's also a potential hazard — the counterweight swings with enough force to down power poles or damage vehicles and buildings, not to mention people.



Common control lever layout on track backhoes
Figure 15-19

Sensitive Controls

The controls on a track backhoe are extremely sensitive. You'll hear operators say the machine is "jumpy" because it's so responsive. Twin joystick controls are most common, but some machines have combination hand and foot controls.

European countries have standardized the hoe control layouts, but in the U.S. there are still several different control layouts used on track excavators. Back in Figure 5-2, we illustrated the twin-lever layout found on many wheeled backhoes. Some track backhoes use it, too. Figure 5-19 shows the more common layout on track backhoes, with the dipper and bucket controls in different hands.

Various types of lever configurations work well under different conditions — and each design has its advantages. But the best control configuration for any job will be the layout your operator knows best. It takes time to learn precise maneuvers when doing complicated work. The operator has to learn what combination of moves will give him the desired response. And he has to learn these combinations so well that reactions become automatic, as though the machine were an extension of his body.

An experienced operator doesn't have to watch the panel. He doesn't even think about which movements are desired. He just senses the correct combination of motions. You can guess what'll happen if you switch machines on him. His perfectly tuned hands will try to go through all the usual moves — moves which won't work on the different lever configuration.

"An experienced operator doesn't have to watch the panel."

Like most operators, I'm inept at operating a hoe fitted with an unfamiliar control layout. Imagine driving a car with the clutch and brake pedals switched around. You'd certainly be hitting the wrong pedals until your habits slowly changed. It's the same with a hoe operator. Changing the controls means having to discard old habits and form new ones.

Any time you put an operator on an unfamiliar piece of equipment, give him a little training time. Let him practice on simple work in an open area, or loading trucks, before he takes on more complex work.

After a little practice, the movements will become automatic again. Also, you should know that most control lever layouts can be altered to suit the operator.

Track Backhoe Cycle Times

Wheeled backhoes have a minimum effective cycle time of about 10 seconds. A small ¾-yard trackhoe has a minimum effective cycle time of about 15 seconds. The larger the machine, the slower the cycle time. Large track excavators take as long as 30 to 40 seconds per digging cycle.

When digging cycles are slow, it's important that the operator get a full bucket load with each cycle. A good operator fills the hoe bucket to capacity at least 90 percent of the time.

Now that we've identified the distinguishing features of the track backhoe, let's look at the basic digging technique for this machine. Then we'll discuss five specialized trackhoe tasks your operator will perform in your utility line work.

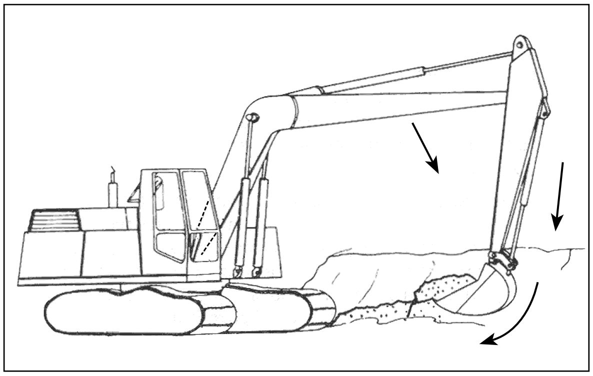
Basic Digging Technique

The key to digging with a track excavator is *feathering* the controls. The operator's small, precise movements are amplified many times by the hydraulic system. Fluid under pressure flows to the rams. The speed and movement of each ram is determined by the speed and direction of fluid flowing into each cylinder. Clumsy control movements force a lot of fluid into the ram suddenly. The result is sudden, jerky movement.

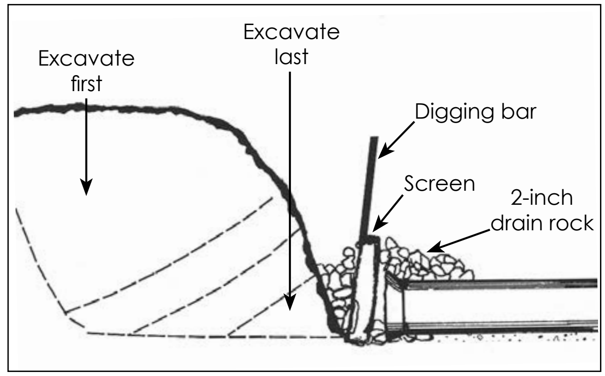
"Clumsy control movements force a lot of fluid into the ram suddenly."

On a wheeled backhoe, the operator often pulls the control levers wide open, allowing the hoe to operate at maximum speed and power. A trackhoe operator will sometimes do that, but only when raising the boom of his machine. He'll usually use several control functions simultaneously to slow the equipment, aiming for smooth precision. Remember that if you overextend a track excavator's ram by an inch, you'll overextend the bucket by about a foot.

The digging technique for a track backhoe is slightly different from that of a wheeled backhoe. On a wheeled backhoe, the operator usually



Curling force of a track hoe bucket
Figure 5-20



Excavating in groundwater
Figure 5-21

rakes the ditch bottom, scraping off soil to fill the bucket as he pulls it toward him. The great power of a trackhoe lets the operator scoop out a full bite in one go.

As he moves the dipper around the radius of the bucket, he curls the bucket to scoop up dirt. If he lowers the boom as he does this, it'll add to the curling force of the bucket. See Figure 5-20. This technique works especially well in clay.

The track backhoe normally uses a raking technique to spread bedding. Skilled operators can actually *throw* bedding rock from the bucket. Here's how it's done: As he extends the dipper, he drops the boom and opens the bucket. This is faster than sprinkle dumping. The control layout shown in Figure 5-19 works well when throwing bedding. This layout has the bucket and dipper controls in opposite hands, making the maneuver easier.

Excavating in Groundwater

Figure 5-21 shows how to excavate in high groundwater. To prevent water and mud from flowing against the pipe that's already been laid, the operator starts excavating some distance behind the end of the pipe, leaving a "dam" of unexcavated soil until the last. This helps stop mud and sludge from blocking the pipe.

Material Rehandling and Cleanup

A track backhoe fitted with the right bucket can be used for cleanup and material rehandling. It's possible to use the swing rams to sweep material sideways. But this isn't a very efficient way to do cleanup. And it stresses the machine. Allow it only when no other equipment is available.

You could use a larger bucket, but it probably wouldn't be cost effective to change it unless there's a lot of cleanup for the machine to do.

Working Around Crosslines

When working in developed areas, you're going to find underground power cables, phone cables, water pipes and gas pipes. Damaging these lines can be both expensive and dangerous. When you hit a power cable, circuit protection fuses usually blow and cut off power to the damaged cable. But if the fuses don't blow, you've got live wires in the trench. So if you suspect damaged power cables, make sure your operator moves with caution.

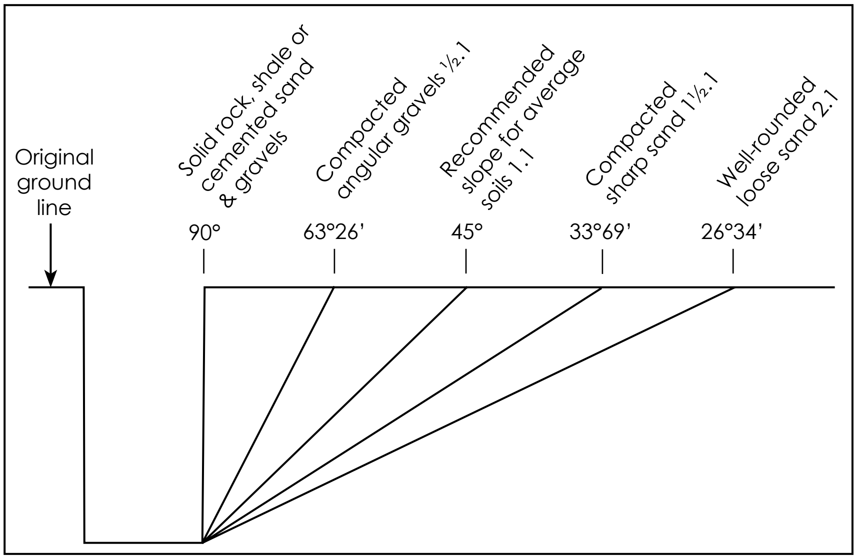
Damaged phone cables aren't dangerous, but they *are* expensive to repair. Broken gas and water pipes are the most dangerous. A spark or exhaust flame can ignite the gas, creating an explosion and fire. Ruptured water pipes will quickly flood the trench and can easily drown a trapped worker.

Crosslines present a special problem when your operator's working with a track backhoe. Large trackhoes often dig very wide trenches. Any crosslines will be suspended across this wide trench, especially if the line crosses the trench diagonally. Some are weak enough that they could collapse under their own weight. Occasionally a line will snap when the trench is backfilled. Transite, clay, small-diameter PVC pipe, and concrete pipe and duct are especially fragile.

Support the crosslines if the trench is wide. Lay a stout 8- x 10-inch timber across the ditch (an old utility pole works well). Suspend the crossline from the timber with chains or slings until the work is complete. After the pipe layers have passed under the crossline, compact fill under it by hand to reduce sag and the chance of breakage. Use a fine, easily-compacted material like sand for fill under fragile crosslines.

If your trench is deep and your crosslines are fairly shallow, a track backhoe can be used to good advantage. The long reach of the track backhoe lets it undermine shallow crosslines with ease. Once your operator has tunneled under the line, he should push the unsupported dirt down and away from the crossline.

Have a grademan direct the operator any time you're working around a crossline. Using hand signals, he can direct the operator's movements around the obstacle.



Angle of repose for common soil types
Figure 5-22

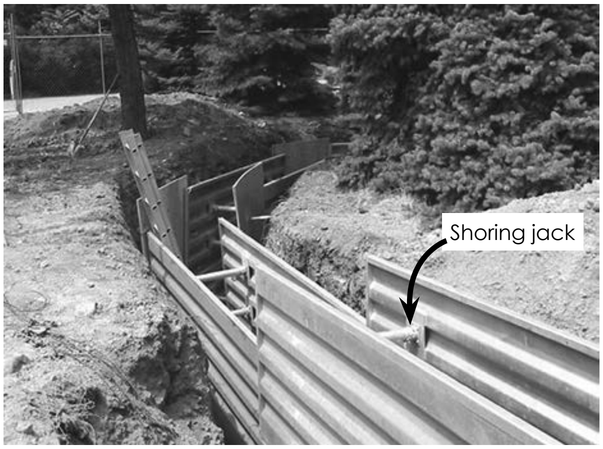
Working with Shoring Systems

It's dangerous and illegal to have anyone working in a trench that's over 5 feet deep unless the trench is protected with some kind of cave-in deterrent. Of course, the danger of collapse varies with the soil type. Some cemented soils are quite stable. But it's wise to consider all trench walls over 5 feet high to be dangerous. Any trench can collapse and bury your crew. Don't let that happen on your job. I have a friend who's a retired OSHA inspector. His favorite task was to look for unsafe excavations. He once said, "If a contractor gets a worker killed in an unsafe trench, he'll be doing government paperwork for the rest of his life."

The easiest way to protect against cave-ins is to slope the trench walls. Figure 5-22 shows the *angle of repose* of several common soil types. This is the maximum angle at which friction holds the soil stable. But don't rely on a chart to tell you when the soil is safe. There are other factors to consider:

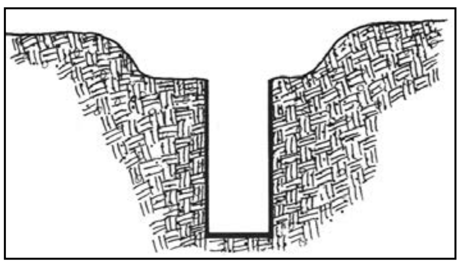
- Damp or saturated soil is much less stable than dry earth.
- Changing soil conditions can make a trench wall unsafe. A vertical trench wall may be quite safe when dug in cemented gravel. But if you run into a pocket of loose sand or heavy loam, the wall becomes dangerous.
- Earth that's disturbed can become unstable. For example, equipment digging another trench or nearby vibratory compaction equipment may make your digging area unstable.
- Piling spoil near the edge of the ditch can make the trench walls unstable.

Safety is always your top priority. No job, completion schedule or profit margin is worth the life of a crew member. But making every trench completely accident-proof isn't practical. In difficult conditions,



Courtesy of www.shoring.com

Adjustable shoring
Figure 5-23



Benching
Figure 5-24

sloping an open trench enough to make it safe can take a lot of time. When open trenching is impractical or impossible, select one of the three common shoring systems: shoring jacks, steel or aluminum sheets or the trench box.

Shoring Jacks

Shoring jacks are the best choice when working in firm soil that will stay in place long enough for the jacks to be positioned. They're easy to use — they can be placed and removed by hand without entering the trench. As the excavation proceeds, the pipe crew moves the jacks forward. Figure 5-23 shows shoring jacks being used in combination with aluminum sheeting.

If you use shoring jacks, the equipment operator has to keep the trench walls vertical and smooth. It lets the pipe crew position the jacks easily and accurately. Excavating one or more horizontal levels at the top of the trench, a technique known as *benching* or *stepping*, helps prevent cave-ins. See Figure 5-24.

Steel Sheets

Steel sheets are bulky and have limited use. But they're fairly simple to install and remove. Shoring jacks placed between 1-inch thick sheets support the trench walls.

Trench Boxes

Trench boxes, also known as *coffins* (shown in Figure 5-25), are the best shoring option when working in very unstable ground. The trench box requires less labor than shoring jacks but it takes a skillful operator to maneuver the box into place quickly and safely. It also takes a large, powerful trackhoe to pull the heavy box while it's being squeezed by the trench walls.

Pipe layers work inside the box while the hoe bucket is working in and immediately in front of the box. That can be dangerous. The hoe operator must work carefully, moving the bucket only when he's absolutely certain that no one is in the way.

Here are the steps for your operator to follow when using a trench box in stable soil:

1. Excavate a section of trench, beginning with an open cut down to pipe grade level.

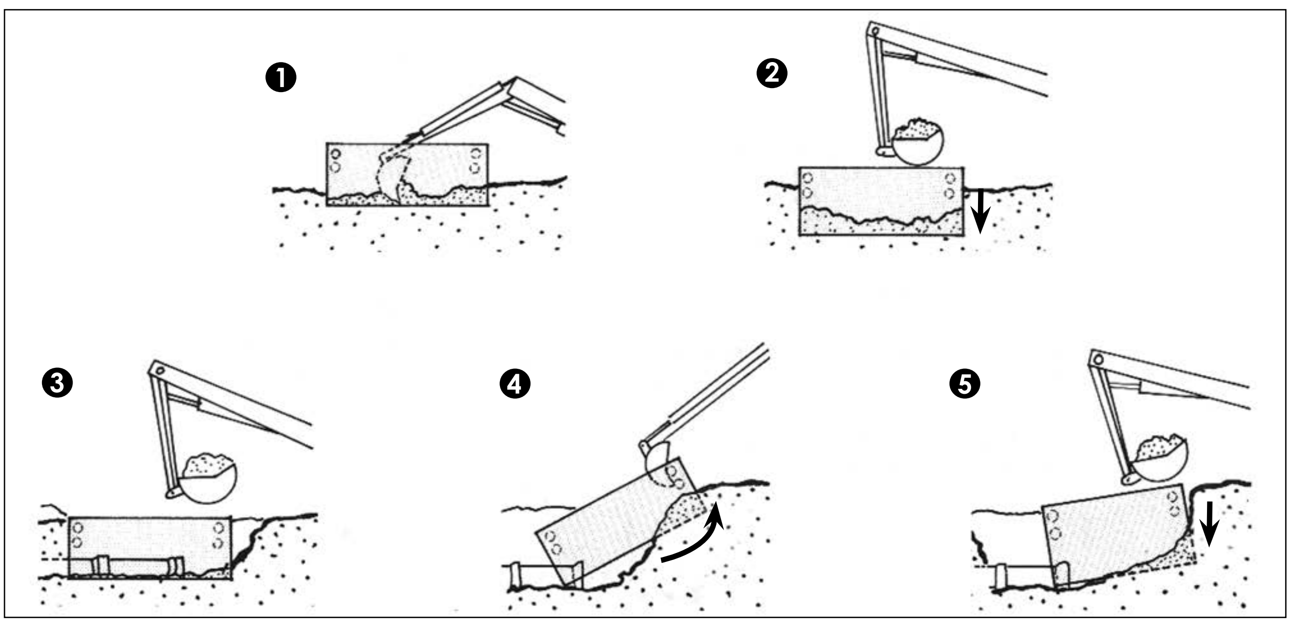
Courtesy of www.shoring.com

Trench box
Figure 5-25

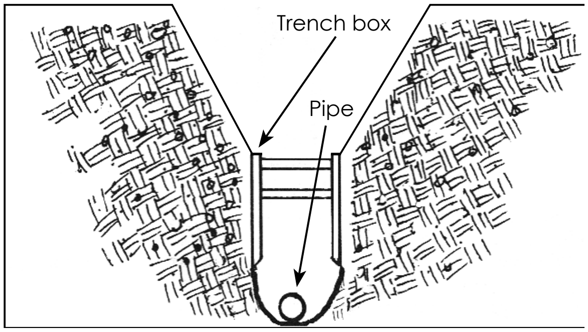
2. Lower the trench box into the trench.
3. Install the pipe.
4. Excavate ahead of the box for the next length of pipe.
5. Pull the box forward into the new excavation while backfilling behind it.

When working in unstable soil, the procedure (illustrated in Figure 5-26) is a little different:

1. Pull the box up so it rests over the area to be excavated. Dig the trench from inside the box.
2. Force the box down into the newly-dug trench as excavation proceeds.
3. When the box is at the right grade, install the pipe.
4. Pull the box forward and up at about a 45-degree angle.
5. Continue excavating inside the box and tamping it to grade so the next length of pipe can be set. As the box is pulled forward, backfill behind it.



Using a trench box in unstable soil
Figure 5-26



Positioning the trench box
Figure 5-27

This is slow work. But it may be the only thing that works in unstable ground. When positioning the trench box, it's essential that the box be centered over the pipe. The bottom of the trench box should sit higher than the pipe — 2 to 3 feet higher will usually be enough. See Figure 5-27. If the box sits too low in the trench, pulling the box may disturb the bedding and the newly-laid pipe. PVC and small diameter pipe can pull apart when a low trench box is moved forward. Of course, the operator needs to avoid positioning the trench box too high. If it's more than 5 feet above the pipe, the ditch will be unsafe.

In extremely unstable ground, pipe layers should climb in and out of the trench box as they lay each length of pipe. Don't let them stay in the box while the hoe is excavating soil or moving the box. It's common to have dirt fall into the box if the soil is unstable.

Using a trench box cuts the excavation required by at least a third. Figure 5-28 compares soil removal and machine cycles for the same trench, one 12 feet long and 18 feet deep, when excavated as an open trench (no trench box), a trench with one trench box, and a trench with two trench boxes. The soil condition is stable enough to allow a slope of ½ to 1. The excavator is using a 2-CY bucket.

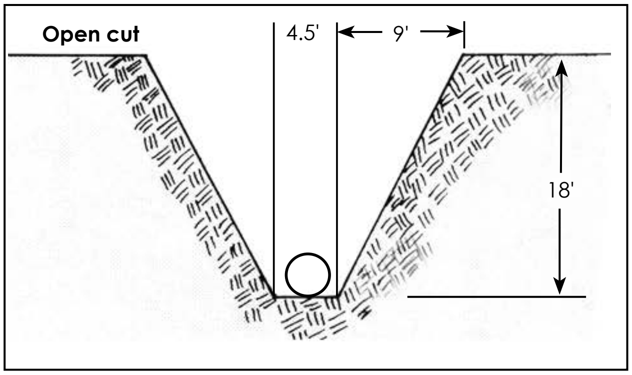
I'll discuss shoring in a little more detail in Chapter 8.

Working in Mud or Soft Ground

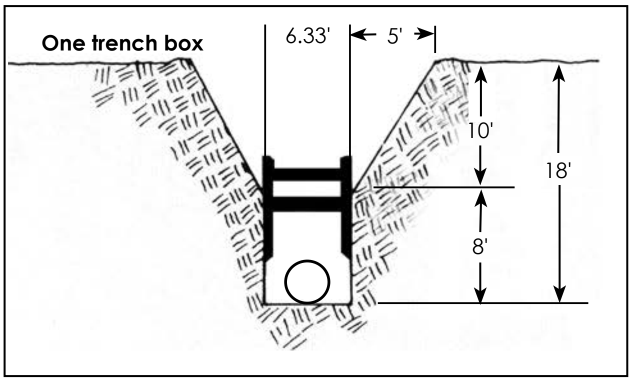
Track backhoes can work in several feet of slimy mud when necessary, but they can get mired down in deep mud. If a trackhoe gets stuck:

- Use the hoe to lift and pull or push the machine out of the mud. If depressing the travel pedals on the hoe leaves it without any hydraulic power, feather the pedal. This reduces the power needed for travel so more is available for the hoe.
- In extremely boggy conditions, your operator may need heavy timbers or excavator mats to get the trackhoe unstuck. If the timbers or mats don't work, a large dozer may be needed to pull the machine out. Renting a dozer for only one day, plus the cost of mobilization and demobilization, could become a very expensive cost item.

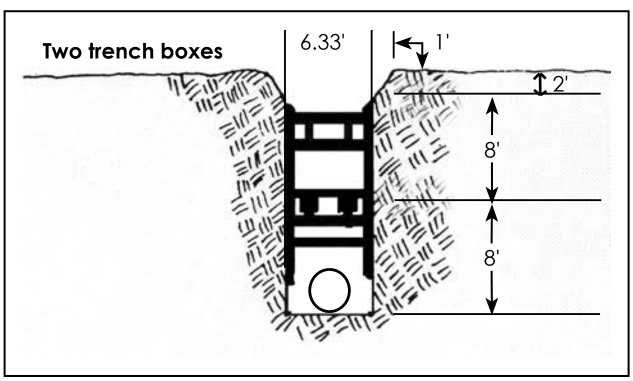
Never park your equipment in a basin. I've seen an entire fleet of equipment buried under water after a long, heavy rain.



Trench excavation - soil removed	36 cyds
Layback - soil removed	72 cyds
Total - soil removed	**108 cyds**
Total - machine cycles	**54**

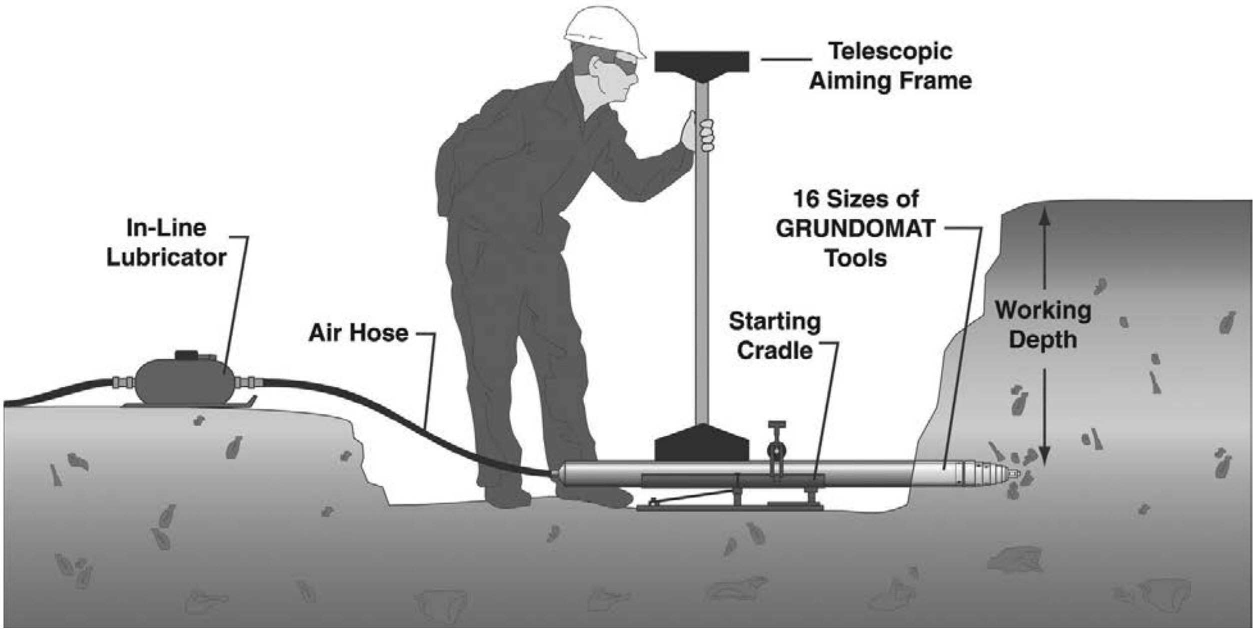


Trench excavation - soil removed	50 cyds	
Layback - soil removed	23 cyds	
Total - soil removed	**73 cyds**	**saves 32%**
Machine cycles - excavating	37	
Machine cycles - moving box	3	
Total - machine cycles	**40**	**saves 26%**



Trench excavation - soil removed	50 cyds	
Layback - soil removed	1 cyd	
Total - soil removed	**51 cyds**	**saves 52%**
Machine cycles - excavating	26	
Machine cycles - moving box	3	
Total - machine cycles	**29**	**saves 46%**

Spoil savings
Figure 5-28



Courtesy of TT Technologies, Inc.

Aiming a directional drilling tool
Figure 5-29

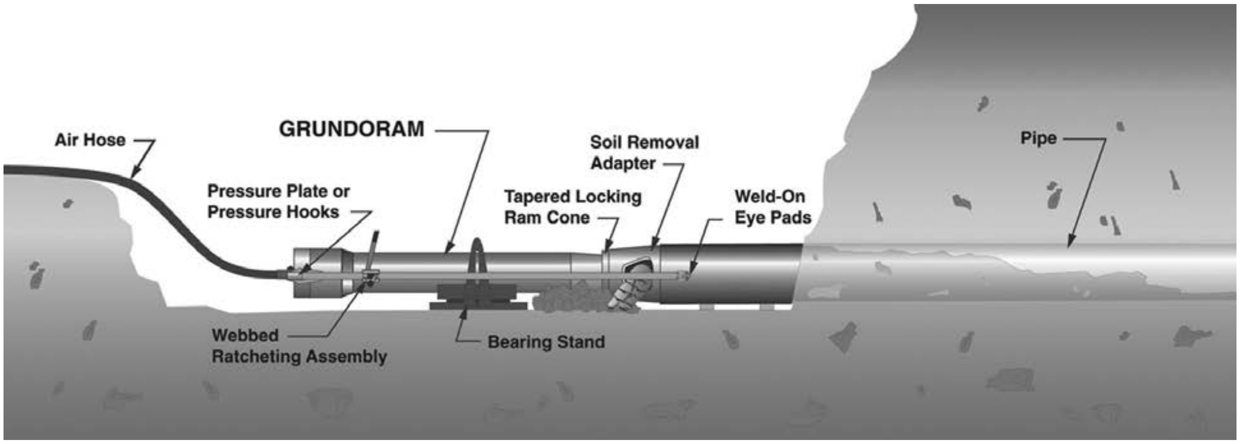
Trenchless Construction

Trenches are practical until you have to lay pipe in crowded urban areas, industrial complexes, environmentally-sensitive areas, or across waterways. That's when trenchless "no-dig" construction is a good alternative. Trenchless technology can be used for new construction and renovation or replacement of existing piping. I'll discuss a few options in this section.

Directional Boring

Directional boring pertains to boring a subsurface hole that will eventually have pipe passed through it. First, a worker hand digs a starting pit at the entry and exit points. Next, he bores from the entry hole to the destination hole, using a pneumatically-driven steel *torpedo* or *mole,* with a scope and level as guides. See Figure 5-29. After he completes the boring, he removes the torpedo and pulls the pneumatic hose back out of the entry hole. Holes bored using this method typically range from 50 to 150 feet, and accommodate pipes up to 6 inches in diameter.

Some directional boring machines are steerable, with sensors that provide pitch and roll information to the operator. An aboveground locator tracks the tool's position and movement. The operator can make



Courtesy of TT Technologies, Inc.

Pipe ramming tool setup
Figure 5-30

adjustments to the tool's course by rotating the air hose with a hydraulic tensioning unit called a torquer. A specially-designed, tapered steering head then guides the tool on course.

Auger Boring

Auger boring techniques utilize rotating augers inside a steel casing. The casing supports the hole as the hole is being drilled, while the augers cut through rock and soil and push the spoil back out through the entry hole. This method works well for bores as long as several hundred feet, and for pipe diameters as large as 48 inches, depending on soil conditions.

Pipe Ramming

Pipe ramming is accomplished by a large pneumatic rammer that literally pounds steel pipe through the earth. See Figure 5-30. After the pipe is in place, the remaining soil core is removed by using compressed air and/or water. Pipe ramming is a suitable option for a wide range of pipe sizes.

Directional Drilling

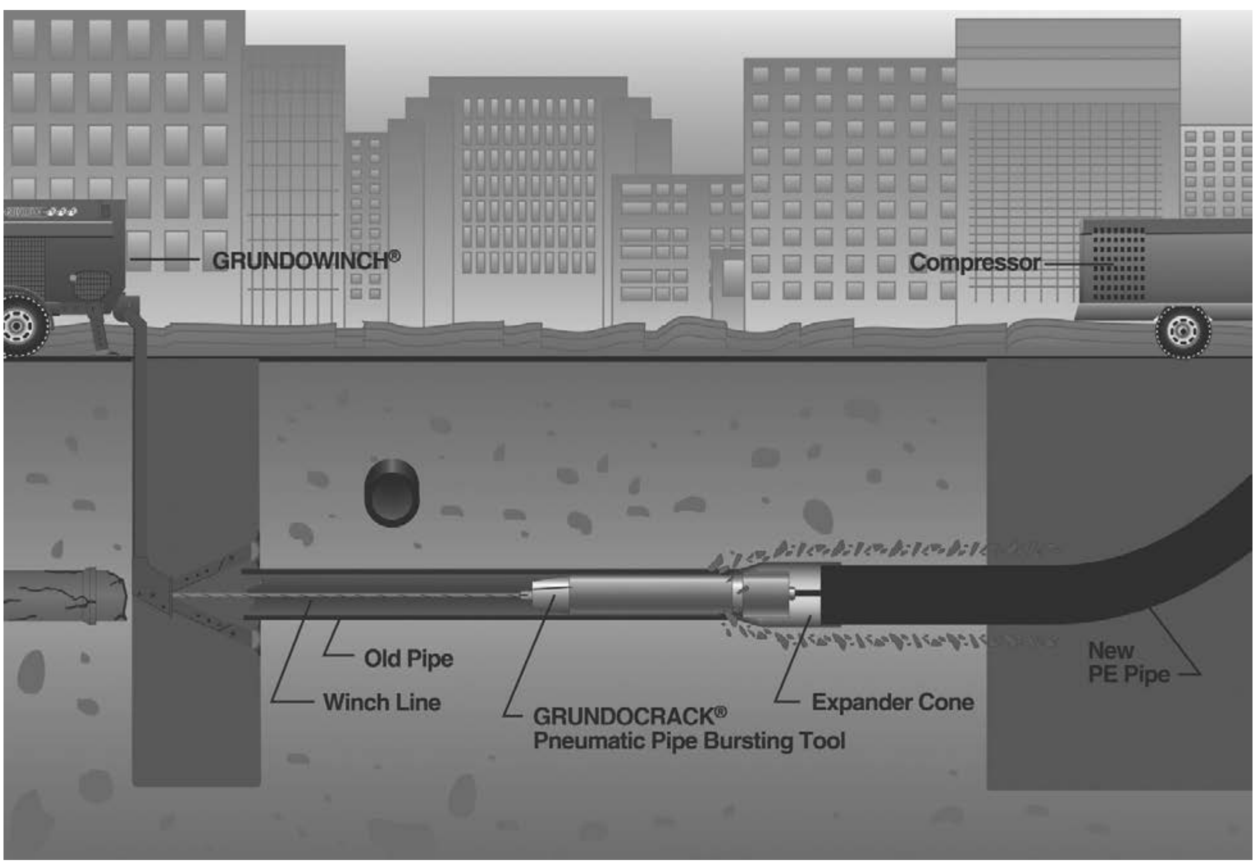
Directional drilling begins with a drill excavating a horizontal tunnel. The tunnel is reamed to remove spoil and then filled with a bentonite slurry to keep the tunnel stable. The pipeline is assembled aboveground and pulled or pushed into the tunnel. Directional drilling is a practical method for tunneling up to 2,200 feet for pipe ranging from 16 to 36 inches in diameter.

Micro Tunneling and Pipe Jacking

Micro tunneling and pipe jacking refers to pushing pipe into a tunnel as the tunnel is being excavated by a boring machine. For longer tunnels, friction around the pipe's outer edge may become a hindrance. *Overcutting* (cutting a tunnel that's slightly wider than the pipe's outside diameter) and/or lubricating with bentonite can help reduce friction. Micro tunneling is used for pipe from 12 to 84 inches in diameter.

Sliplining

Sliplining is a way of installing replacement pipe inside an existing host pipe that has structurally deteriorated or corroded. Insertion pits — usually 10 feet wide and 20 feet long — are excavated above the existing pipeline at 600- to 1,200-foot intervals. The existing pipe is removed within the pits and sections of fiberglass slipliner are lowered into the pit and pushed or pulled into place. Grout may be pumped between the host pipe and the slipliner to improve structural integrity.



Courtesy of TT Technologies, Inc.

Pipe bursting tool setup
Figure 5-31

Sliplining ultimately decreases the original pipe's inside diameter, but if the replacement pipe's inner lining is smoother than that of the original, it may actually increase flow potential.

Pipe Bursting

Pipe bursting, as the name suggests, involves the destruction of existing pipe — often because it has collapsed or become deformed. An expander or cutting tool is pulled through the existing pipe, using pneumatic percussion, which splits and expands the pipe. See Figure 5-31. Meanwhile, new pipe is pulled through to replace the original pipe.

Pipe bursting is the only trenchless replacement method that allows for the upsizing of the original pipe diameter. It can be used on many fracturable pipe materials — including cast iron, clay, concrete, RCP, ABS and some plastics — with diameters between 4 and 54 inches.

[Blank Page]

6

SOIL COMPACTION

Underground utility contractors obviously do a lot of excavation. And every trench they dig has to be filled back up after the utilities are installed. This seems like a simple-enough task. There's nothing easier than digging a hole and filling it back up again, right? If you believe that, you haven't worked in utility line contracting. Backfilling a trench can be a very complex and expensive operation. This chapter is intended to help you avoid some of the more common (and more expensive) mistakes.

Most soil in its natural state is pretty stable — at least when it's dry. It's probably been resting undisturbed for hundreds, thousands or even millions of years. But when your blade or bucket cuts into the soil, everything changes. It loosens up and *swells* because you introduce air cavities into the mass. Loose soil is unstable and has a poor load-bearing capacity. As uncompacted backfill, it shrinks and settles, which may eventually damage overlying surfaces. This can be a nightmare if the overlying surface is a road or asphalt parking lot. To protect against settling, the specifications for your job probably demand that you compact all backfill, restoring it as close as possible to its previously undisturbed density, or even greater.

In this chapter, I'll explain how to prevent backfill from settling. First, we'll look at the structure of soil: why it swells and why it compacts. Next, we'll look at soil density and how to test it. Finally, we'll look at the most efficient methods of soil compaction.

Soil Structure

Soil consists of rock particles, air voids and water. The particles vary in size from very fine, in silt or clay, to larger particles in sand and gravel. Under a microscope, you can see the particles resting against each other like rocks in a rock pile. They have irregular shapes and don't fit together very well. Spaces between soil particles are air voids. More air voids are introduced every time you disturb or excavate soil. Air voids mean decreased soil density and less stability. Reducing air voids is the goal of soil compaction.

> ***WELL-GRADED SOIL*** contains a wide variety of grain particle sizes, which minimizes air voids. This soil will compact to a greater density than poorly-graded soil containing a large percentage of grain particles of a similar size.

Here's what happens when you compact soil: Imagine you've put some disturbed soil in a press. The press crams the soil particles closer together. You'll reach a point where the particles are as close as they can get; they can't get any closer because of their irregular shapes. But since air voids remain, the continued pressure would break down the soil particles and result in a fine powder that still contains air.

But if you add water to this soil sample, it does two things:

1. It lubricates the particles so they slide together easily when you compress them.
2. It fills the remaining air voids, adding weight and density.

Water makes compaction easier. It's virtually impossible to compact soil without adequate moisture. But how much water is the right amount? If you use too little, it won't lubricate the particles enough or fill all the voids. And too much water will hold the particles apart, causing them to float. If you try to compact water-saturated soil, the soil will *pump* (become unstable) and move away from the compaction equipment.

The right amount of moisture for optimum compaction is called the *optimum moisture content* or *optimum percent of moisture.* It's usually expressed as a percentage of maximum dry weight.

Determining Soil Density

The closer the soil particles, the denser the soil. Reducing or eliminating air voids increases the soil's density and its load-bearing capacity, and minimizes the chance of future settling. The whole point of soil compaction is to increase soil density, essentially eliminating the air voids.

Density can be determined as a weight-to-volume ratio of the soil. The more soil particles per cubic foot, the greater the weight per cubic foot and the greater the density. Two methods for testing soil density

Passing the sample through a ¾-inch sieve
Figure 6-1

that we'll discuss here are the Proctor tests and the nuclear density meter.

Proctor Tests

The *standard Proctor test* was developed in the early 1930s by R.R. Proctor, a field engineer for the City of Los Angeles. It's now universally accepted throughout the construction industry. Proctor discovered the important relationship between soil moisture content and compaction effort, and how they affect soil density: When using an identical compaction effort on identical soil samples, varying the water content will vary the soil density.

It's important for you to understand the concept of the Proctor findings. Applying a heavy weight to a completely dry soil sample won't achieve much increase in density. When water is added, it's much easier to increase the density. Remember, the water acts as a lubricant.

Visualize a pile of dry flour and a lump of dough. What happens when you apply pressure to each? The dry flour displaces easily. But when water is added to form stiff dough, it's much more malleable and can be compressed. If too much water is added, it becomes sloppy and again displaces easily. Here's the point: It's impossible to compact soil unless it contains the correct amount of water.

Hand-operated standard
Proctor test
Figure 6-2

The Standard Proctor Test

The standard Proctor test is also known as AASHTO test designation T 99-70, or ASTM test designation D 698. Soil labs normally refer to this test as a "T-99." The standard Proctor test is usually specified for fill material designated for use under building slabs and sidewalks, and in utility trenches under grassy areas.

To perform the standard Proctor test, a sample of the proposed fill material is crushed so it can pass through a ¾-inch sieve. See Figure 6-1. Then a steel cylinder mold is filled with the sample in three layers. Each layer is struck 25 times with a 5.5-pound, 2-inch-diameter hammer before the next layer is added. The hammer can be hand-operated, as shown in Figure 6-2, or mechanical. The total compaction effort used in this test is 12,400 foot-pounds.

The Modified Proctor Test

The *modified* Proctor test is known as Modified AASHTO T 180-70, or ASTM test designation D 1557. Soil labs normally refer to this test as a "T-180." The modified Proctor test is usually specified for fill material designated for use under:

- nuclear power plants
- federal highways
- heavy-duty paved areas
- concrete drives
- airport runways
- any other area where high-design loads are anticipated

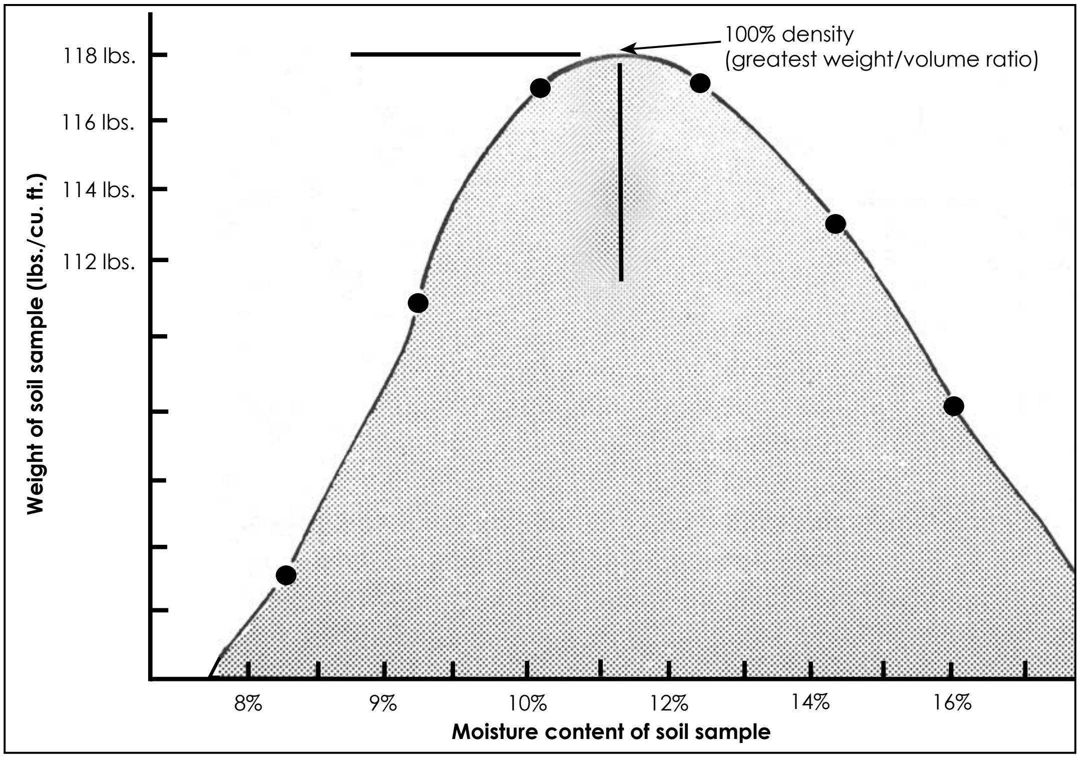
The testing procedure is similar to that of the standard Proctor test, except the sample contains five layers — and each layer is struck 25 times with a 10-pound hammer before the next layer is added. The energy imparted to each cubic foot of soil during the modified Proctor test is 56,250 foot-pounds.

Determining Maximum Dry Density and Optimum Moisture Content

Regardless of which Proctor test is used, the goal is to obtain information about soil density and how it varies with different moisture contents. Each test is repeated a few times, with varying amounts of water added to the soil. The densities and moisture content data are then plotted on a graph. Figure 6-3 shows a typical density curve. For this particular sample, the point of 100 percent density was achieved at about the 11 percent moisture content level — at a density of 118 pounds per cubic foot.

The engineer's specifications spell out the density required in the field. For example, if the density is specified at 95 percent of the lab-obtained density in Figure 6-3, you'll have to compact the soil to at least 112 pounds (0.95 × 118) per cubic foot. The engineer's specifications will depend on soil type and where it's to be placed. Soil placed as fill in a grassy area is usually specified at 85 percent of maximum dry density. Soils under building slabs, sidewalks, etc. are usually specified at 90 percent of maximum dry density for cohesive soils, or 95 percent of maximum dry density for non-cohesive soils.

During compaction, if the soil is too much above or below the optimum moisture content, you'll never get the right soil density. If the soil is too wet, it must be allowed to dry; if it's too dry, water must be added.



Curve showing 100 percent density and optimum moisture content
Figure 6-3

Remember that each soil type has a different weight-to-volume ratio and different optimum moisture content. The Proctor test finds the point taken at 100 percent density and optimum moisture content for the soil you're compacting. Each soil type will produce a different curve because each one has a different optimum moisture content value.

Nuclear meter
Figure 6-4

Determining Soil Density in the Field

The most convenient, accurate and relatively inexpensive method of determining in-place soil density and moisture content is to use a nuclear density gauge (*nuclear meter,* ASTM 2922). See Figure 6-4. An advantage to using a nuclear testing gauge is that it leaves the soil undisturbed. To perform this test, a steel stake approximately ⅝ 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 (denser soil absorbs a higher percentage of the radiation), while the remainder is transmitted to the gauge for measurement.

Another counter on the gauge determines soil moisture content. Nuclear testers can also be used to determine the density of asphalt paving.

When using a nuclear density meter, there are three important facts to remember:

1. Reflected gamma rays show the *average* density of material under the probe. If there are layers of high and low density under the probe, it may be hard to determine which you're measuring. For example, suppose the probe is set on soil that rests 8 inches above a very dense object like a rock or boulder. An artificially high count of gamma rays may be returned. If the probe is set on soil that's 8 inches above a very loose sub-layer, some rays may dissipate into the loose soil and not return to be counted.

2. If the soil being tested happens to be above the optimum moisture content at the time of testing, the excess moisture is deducted from the score. That makes it harder to get an acceptable compaction determination. Be sure the soil isn't above optimum moisture when you run the test.

3. A dried crust on the surface of the test area may reduce the count of returned rays. This will give a higher weight-to-volume reading than if the site were freshly excavated.

As with most other tools and instruments, the accuracy of the nuclear density meter depends on the skill and experience of the user. Some people, for example, have found that a nuclear density reading taken in the bottom of a narrow trench may not be accurate. And, as with any meter, the nuclear density meter must be regularly calibrated by testing it on a material of known density.

Compaction Methods

Soil type, required density, and moisture content all affect the choice of compaction method. Sand and gravel compact well with water and vibration. Silt and clay may require a precise combination of vibration, weight and moisture. The two most common methods of compaction are water settling *(puddling)* and a combination of weight and vibration.

Puddling

Puddling is the easiest soil compaction method. Simply flood the loose backfill with water until it's completely saturated. As the water floods the soil, air voids are driven to the surface. When the water drains or evaporates, it tends to draw the soil particles together.

An ocean beach offers a good example of how water compacts sand. Above the high tide mark, sand is dry and loose underfoot. Just below the high tide mark, the recently wet (but already drained) sand is damp and firm underfoot. Below this area, sand is still being washed by waves and is saturated to the point where it's unstable.

The success of the puddling method depends on the type of soil. This method is least effective in cohesive soils, such as silt and clay, which take a long time to drain. Water settling is most effective in sand, gravel and desert-type soils. When you do water settling correctly, you can sometimes achieve compaction of up to 80 percent of the Proctor density. To get more than 80 percent density, you'll have to use mechanical compaction in addition to puddling.

If you have fairly shallow trenches and hot weather, flood the trench, wait until the soil dries to near the Proctor optimum moisture content, and then mechanically compact. If you compact when the soil is too wet, the soil will pump away from your compacting equipment. This is not so much the case with coarse sand and gravel, but you'll still get the best results when the soil is near optimum moisture.

Whether you use water settling alone or combine it with mechanical compaction, let the soil dry out before testing the density. If you're working in sandy soil, you won't have to wait long. With silt and clay, you'll have to be patient. If you test too soon, the density won't be high enough to meet construction standards.

Because the subject of soils and soil engineering is so complex, it's hard to establish firm guidelines. Coarse-grained soils (like gravel) tend to withstand saturation very well. They drain quickly, and they can be worked while they're still quite wet. Fine-grained soils (such as sand) behave very differently. They'll only compact when they contain a specific moisture content. A fine-grained soil that's poorly compacted will be stable *until* the day it becomes saturated. Then it may collapse and sink dramatically.

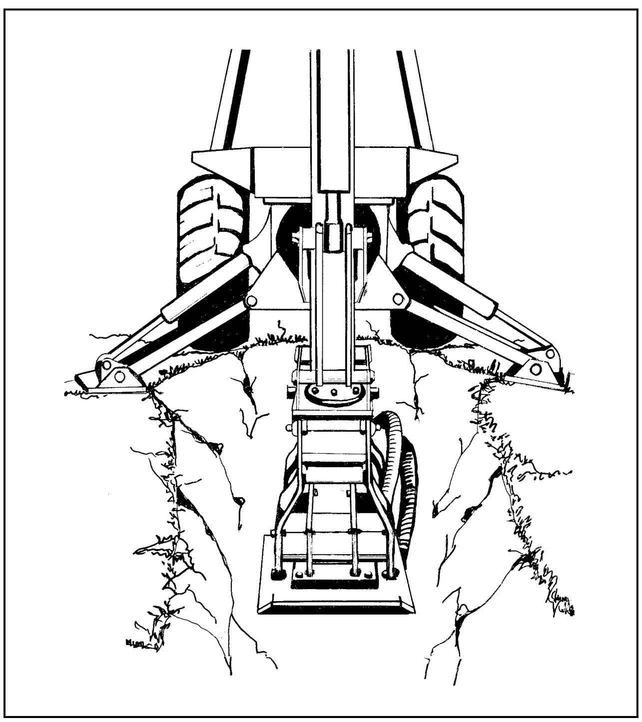
Even if you don't have to satisfy compaction specifications, it's important to pay attention to good compaction practices. This means close supervision and adequate training of your crew. Backfill material is more than just a pile of dirt. It's a specific type of soil that requires precise treatment and processing.

By training and necessity, your equipment operators are dirt movers. Their job is to move great quantities of earth quickly and efficiently.

Tamping foot roller
Figure 6-5

But you've got to make them understand that in building compacted fills, the treatment and processing of the fill material is as important as the quantity moved. They've also got to understand that a process that worked well on one job or on one area of a large project won't necessarily work on the next.

Successful compaction depends on skill, experience and judgment. Use the data generated by passing or failing soil density tests to find the best compaction methods. And pay attention to changing conditions. There probably won't be one final answer for the entire job.



Courtesy of Allied Steel & Tractor Products

Hoe-mounted vibratory plate
Figure 6-6

Weight and Vibration

Compression of most soils will increase the density, especially when weight is applied with high-intensity vibration. Vibration tends to shuffle the soil particles together as the weight compresses them. The two most commonly-used tools for this method are the tamping foot vibratory roller (Figure 6-5) and hand-held or machine-mounted vibratory plates.

If the compaction equipment you select doesn't get the desired result within a reasonable amount of time, something is wrong. You may not be using enough weight. Try a bigger roller or a hoe-mounted vibratory plate, like the one illustrated in Figure 6-6. You may be trying to compact a layer of soil that's too thick. Or the material may be above or below its optimum moisture content.

In rare cases, particularly when using hoe-mounted vibratory plates, the odd case of *over-compaction* can occur. The old saying: "If one is good, two are twice as good," doesn't always apply in compacting. Let's assume you can obtain good results by placing the plate on each section of spoil for 20 seconds. If the operator increases this time to 30 or 40 seconds, he decreases the production rate and may actually *decrease* the soil density.

How does this happen? Well, the vibrations that are so effective in arranging the soil particles into a dense mass can, after an extended period of time, actually rattle the soil particles apart again. Complexities like this add to the problems of compaction, reinforcing the need for an experienced, well-informed and well-supervised crew. Using high-performance equipment is great, but it's your *people* who'll make you money.

Soils that are Difficult to Compact

There are two situations where you'll find soil that's extremely difficult to compact. One is soil that's too wet in its undisturbed state. The other is a jobsite containing several different soil types. Each soil type has a different moisture requirement, so a single compaction technique won't work. Topsoil with a Proctor density of 110 pounds per cubic foot may overlay a heavier sandy soil with a density of 135 pounds per cubic foot. If these soils are partially mixed, you'll get widely-varying density results. In this situation, you'll need to get a Proctor for each soil type and mix of soil types. Try to avoid having to do this by keeping the soils separate. Then you can compare apples to apples (topsoil-to-topsoil Proctors, sandy-soil-to-sandy-soil Proctors and mixed-soil-to-mixed-soil Proctors) without repeatedly running the lab test.

Compacting Imported Fill

Where the excavated soil is known to be unsuitable for fill, imported fill will be specified in the contract documents. In many ways, this makes things easier, because you know in advance the exact cost of labor, equipment and materials needed to import fill, and can predict the compaction characteristics in advance. Compacting native fill, on the other hand, always involves some unknowns.

Compacting Soil with Limited Working Room

Lack of space complicates the compaction operation. If you're on a job where there's a lot of earthwork going on, you'll probably have plenty of room to mix soil, add and subtract moisture as required and then

Courtesy of Wacker Corp.

Courtesy of Wacker Corp.

Vibrating plate compactor
Figure 6-7

Impact rammer
Figure 6-8

bring in the large compaction equipment. If you're working in an urban area, you won't have this advantage. Dirt excavated from one section of trench may have to be returned to that section — often on the same day it was excavated.

When it's impractical or impossible to use large compaction equipment, hand-operated vibrating plate compactors (Figure 6-7) or impact rammer compactors (Figure 6-8) can usually do the job. They're available in gasoline, diesel, compressed air and electric varieties. Electric motors are useful where noise or fumes must be minimized. The gasoline-powered types are normally two-cycle engines with output of up to 10 hp. Two-cycle engines work well for this type of equipment because oil mixed with the fuel helps lubricate moving parts, and there's no engine damage caused when the machine is tilted. Also, the two-cycle engine is lightweight, since it has no valves. Manually-operated hand compactors weigh between 75 and 300 pounds, and deliver 50 to 9,000 cycles per minute. Remote-controlled compactors are also available for use when compacting soil in dangerous locations, such as the bottom of steep trenches.

Limited working room means you won't have room to mix soil. It may also mean you can't easily add the water necessary for wetting. In a narrow street, it's virtually impossible to wet the soil with a 4,000-gallon water tanker. The best way to wet backfill in a narrow right-of-way is to use 2-inch flexible fire hose tapped onto a fire hydrant or large water tanker. As the material is excavated and backfilled, have it sprayed with water. The hose man and the equipment operators must understand how to wet the material evenly, and carefully coordinate their work to obtain the desired results.

As the spoil is placed back in the trench, it must be spread into layers, called *lifts*. The lift may need to be as thin as 6 inches with difficult-to-compact material that has to meet a tough specification. With easily-compactable material, on the other hand, several feet of backfill may be compacted in a single lift. Judging the amount of water required and experimenting with the thickness of the lifts is largely a trial-and-error process. You'll probably have to test repeatedly to get progress reports on the success of the different methods and techniques. In difficult cases, it might be worth employing the services of an independent soil-testing laboratory.

A single pipeline may go through damp soil (near optimum moisture), dry soil, and overly wet soil. It's hard to establish a pattern, so you can't just instruct that a given amount of water be applied or that a given amount of compaction effort is adequate.

Failing the density tests can be a nightmare. Protect against it. Work cautiously. If necessary, test the compaction method you plan to use before production work begins. Be sure you have the right combination of equipment and methods before doing the lion's share of the work. And then, if possible, wait for wet soil to dry to below optimum moisture levels before making the density measurements required in the specifications.

Soil Testing Costs

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

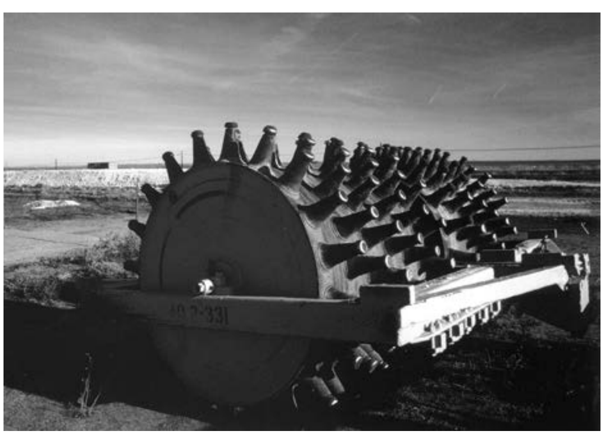
- *Number of tests required per lift:* Testing compacted fill is usually specified on a per-square-footage-of-fill basis, with a minimum number of tests required per lift. Therefore, testing costs will depend on the surface area of the fill, and the number of lifts placed.
- *Types of tests required:* Different types of tests require different methods, equipment, and time to perform, so costs vary accordingly.

- *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.
- *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 type of fill material, 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, and on holidays and 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.

Compaction Equipment Productivity

It's always hard to predict compaction equipment output accurately. Every soil type has unique optimum moisture content, compaction requirements and shrinkage characteristics as it changes from loose to compacted condition. Refer back to Chapter 2 for my discussion on soil volume conversion factors and how to use them.

Two machines are commonly used for trench compaction: sheepsfoot rollers and hoe-mounted vibratory compactors. We'll examine production rates for both.



Sheepsfoot roller
Figure 6-9

Sheepsfoot Roller

Sheepsfoot rollers, like the one pictured in Figure 6-9, are a good choice if you have a wide trench and no crosslines. Here's how to calculate sheepsfoot roller compaction ideal output on a CCY per hour basis: Multiply the roller width in feet times speed in mph times compacted lift thickness in inches times 16.3. Then divide the result by the number of passes necessary for compaction.

For example, suppose a 5-foot-wide sheepsfoot roller is working at 1 mph on 12-inch lifts of loose material. Assume each lift shrinks to 7 inches after compaction, and six passes are required. Using the formula above, divide 570 ($5 \times 1 \times 7 \times 16.3$) by 6 passes to get a 95 CCY per hour ideal production rate.

For the sheepsfoot roller, you might consider using a job efficiency factor of 0.83 and an operator ability correction factor of 0.9. That brings the corrected hourly production rate to 71 ($95 \times 0.83 \times 0.9$) CCY per hour.

This is a good first approximation, but it still comes in second to using real world experience in the field. Until you have such experience, I recommend overestimating the compaction equipment and time requirements. Don't get caught short with an overly optimistic estimate.

Hoe-Mounted Vibratory Compactor

The hoe-mounted plate is ideal for narrow trenches and for compacting around crosslines. In easily-compacted soils, 3 to 5 seconds of pressure on a 1-foot lift will provide adequate compaction. Difficult soils may require twice as long. If you can't get adequate compaction in 10 seconds, then something is wrong. Either the soil is above or below optimum moisture content, or the machine is too light for the soil being compacted.

To calculate the ideal production rate for a hoe-mounted plate, multiply the plate area in square feet times the compacted lift thickness in feet times the number of cycles per hour. Then divide the result by 27.

In this example, we'll use a 2-foot x 2-foot 6-inch plate, 7-inch compacted lift (0.58 feet), and 7 seconds per position, including repositioning time. Seven seconds per position means that we'll have 514 cycles per hour (3,600 seconds per hour, divided by 7). Here's how the equation would look:

$$\frac{2 \times 2.5 \times 0.58 \times 514}{27}$$

That comes to 55 CCY per hour. For hoe-mounted plates, assume a job efficiency factor of 0.83 and an operator ability factor of 0.8. That brings the corrected hourly production rate to 37 CCY per hour.

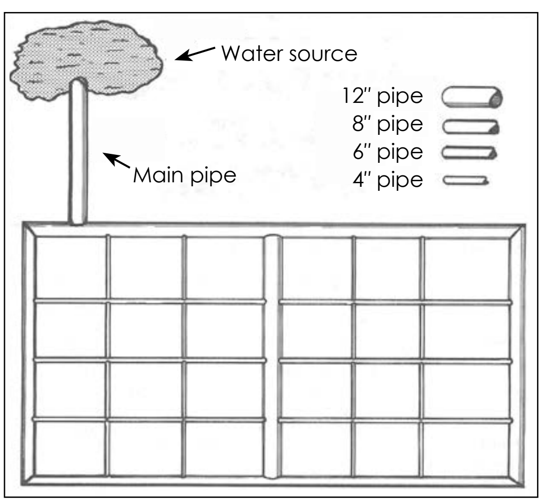
[Blank Page]

7

INSTALLING WATER SYSTEMS

As a nation, we can be proud of the coverage of our water systems. Virtually every town and city in the U.S. has a piped water system that provides water for drinking, cleaning, and fire protection. Replacing, extending and repairing these systems is the subject of this chapter.

Cities may draw their water from reservoirs, lakes or wells. Water not pure enough for human consumption is treated to make it safe, then distributed to the point of use through pressurized pipelines. When water is stored in a tank or reservoir that's higher than the distribution system, gravity creates pressure in the pipes. If the water source isn't higher than the distribution system, pumps are needed to create pressure so water will flow to the point of use.



Simplified water grid
Figure 7-1

The most efficient layout for a water distribution system is a *grid*, as illustrated in Figure 7-1. Note that the lines are interconnected, allowing water to feed any point of use from several different directions. When there's a sudden high demand for water in one area, the entire system responds and flow rates go up in all mains.

The grid layout is important when there's a fire, for example. A fire hydrant on a 6-inch dead-end (non-grid) pipeline can draw only what's available through the single line. A fire hydrant on a 6-inch pipeline in a water grid can draw water from two directions and several mains.

Grid layouts also help equalize pressure throughout the system and minimize *water hammer.* Water hammer occurs when a sudden demand is placed on a pipeline. Water rushes into the pipeline to replace the water being used, causing a water surge. This creates a vacuum. When the valve is closed, the momentum of rushing water hammers against the valve, increasing pressure momentarily at points throughout the system. Surges and vacuums are hard to remedy and can destroy pipes and valves. A grid layout reduces water hammer by reducing surges and vacuums.

Pressure pipe and a grid layout are the keys to every efficient water system design. But there are other points to consider, including: pipe materials, fittings and joints, and the effect of water pressure and thrust on the system. The efficiency of your equipment and crew and final testing of the completed work can also have an effect on system performance. Let's look at each of these key factors.

Water Pressure and Thrust

Every pipeline must be strong enough to withstand the maximum pressure of the water it carries. Water pressure is expressed as pounds per square inch, or *psi.* This means the water exerts a given number of pounds of force against each square inch of surface. Water pressures in municipal systems commonly range between 40 psi and 90 psi. Above 90 psi, the pressure is too great for most household plumbing. If the pressure is too high, a pressure-reducing valve must be installed in the pipeline to bring the pressure down to an acceptable level.

The three most common classes of water pipe are designed to hold water at 150 psi, 200 psi and 350 psi. A Class 150 pipe, for example, can hold water up to 150 psi. But keep in mind that water pressure will vary with demand, source of supply and layout of the system. In any gravity pressure system, for example, it's the *head* of the water that creates the pressure below the storage point. This means that the higher the supply point is above the point of use, the greater the pressure. Note that the system has to be designed so pipe at the lowest points can hold the most pressure.

Another factor that affects water pressure in the system is demand. Drawing water out of a pipeline will temporarily reduce the pressure. At night, when the demand goes down, pressure in the pipeline tends to increase.

The outward force of water pressure is called *thrust.* The effect of thrust against fittings, bends and dead-ends in a pipeline can be very powerful. Every pipe fitting you install has to be able to withstand the forces of water pressure and thrust. Proper installation of the pipe, fittings and joints is very important.

Pipe size in. (mm)	Fitting 90° elbow	Fitting 45° elbow	Valves, tees, dead ends
4 (100 mm)	1,800	1,100	1,300
6 (150 mm)	4,000	2,300	2,900
8 (200 mm)	7,200	4,100	5,100
10 (250 mm)	11,200	6,300	7,900
12 (300 mm)	16,000	9,100	11,300

A Thrust developed per 100 psi pressure

Soil type	Lb/sp. ft.
Muck, peat, etc.	0
Soft clay	500
Sand	1,000
Sand and gravel	1,500
Sand and gravel with clay	2,000
Sand and gravel cemented with clay	4,000
Hard pan	5,000

B Estimated bearing load of soil

Thrust forces and estimated bearing load of soil
Figure 7-2

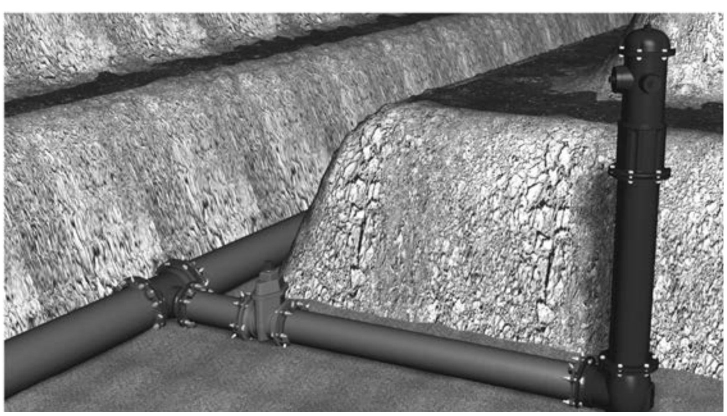
Thrust can create movement that damages the pipe. Installing concrete thrust block at points of direction change will prevent thrust from destroying the pipe fittings. Figure 7-2 lists some sample thrust forces and estimated bearing loads for various soil types. Bearing loads are measured in pounds per square foot, or *psf.* To calculate the thrust block surface area required to keep a fitting in place, divide the amount of thrust per 100 psi of water pressure by the soil bearing load. For example, say you need to install a thrust block in a 100 psi system for a 12-inch 90-degree elbow bearing against soft clay. Divide 16,000 lbs. of force by 500 psf, which equals 32 square feet. Likewise, that same fitting would require an area of 16 (16,000 lbs. ÷ 1,000 psf) square feet in sand and 4 (16,000 lbs. ÷ 4,000 psf) square feet in gravel cemented with clay.

Pipe Restraints and Adapter Flanges

Pipe restraint and adapter flange systems are an alternative to concrete thrust block. Pipe restraints can be used on any type of connection; some examples are shown in Figure 7-3. A wide variety of restraint system designs is available, and they have several advantages:

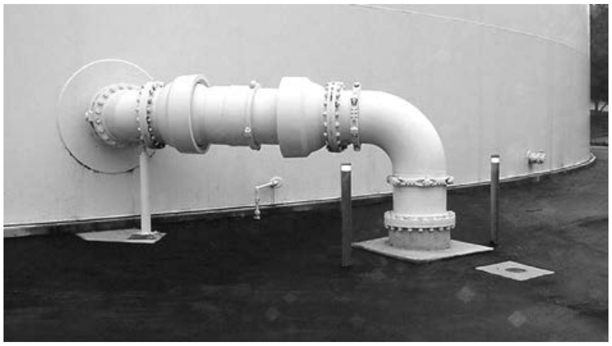
- They can be assembled in the field or shop and dropped into the ditch after assembly.
- There's no waiting for concrete trucks, or for the concrete to set up.
- No forms are required.

These restraints work with water or gas pipe. They're useful through a wide range of temperatures (–65 degrees F through more than 200 degrees F), but they're not good for use in pipe that's constantly conveying steam.



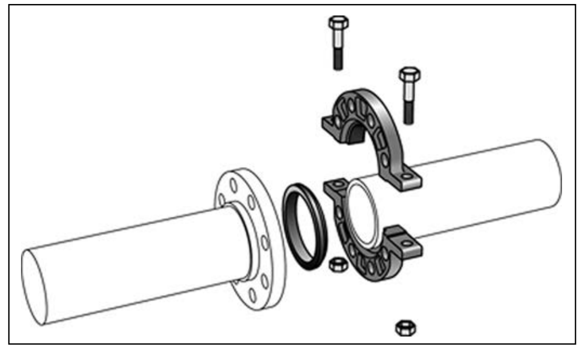
Courtesy of EBAA Iron, Inc.

Mechanical joint restraints
Figure 7-3



Courtesy of EBAA Iron, Inc.

Flexible expansion joint
Figure 7-4



Courtesy of The Ford Meter Box Company, Inc.

Pipe restraint for PVC
Figure 7-5

Since pipe restraints don't allow for expansion and contraction, expansion joints like the one in Figure 7-4 are recommended at various locations along the line. They're available for pipe ranging from 4 to 24 inches in diameter.

Pipe Restraints for PVC Pipe

Restraints designed for iron pipe aren't recommended for use on PVC pipe because the set screws can deform the pipe and affect the seal. Instead, use PVC-specific pipe restraints, as shown in Figure 7-5. This type of restraint has a two-part flange that's secured to the pipe with clamping bolts. An EPDM gasket inside the flange seals the pipe joint. T-bolts then secure a steel gasket over the opposite pipe. PVC pipe restraints of this sort are available for pipe ranging from 4 to 36 inches in diameter.

Pipe Materials

Since there are so many considerations and options when it comes to pipe materials, I've dedicated an entire chapter to the subject. See Chapter 11 for a detailed discussion of pipe materials, sizes, joints, fittings and uses.

Selecting Equipment

Water pipe is installed relatively shallow — just below the frost line. It may be as shallow as 2 feet in some areas. Four to 5 feet of cover is adequate for most climates, although in extremely cold climates, you may have to go down 6 or 7 feet and insulate the pipe. A small or midsize

Courtesy of Terry Newman

Loader equipped with forks
Figure 7-6

wheeled backhoe can easily handle a trench 5 or 6 feet deep. The versatility of this machine makes it the most popular choice for water line installation.

Another choice is the smaller track excavator. This is useful when the pipe has to be bedded and covered with imported fill material. Trenching machines excavate quickly when there aren't any obstructions. But they have a hard time maneuvering around utility crosslines, so they're not practical where crosslines are present. They're not the best choice for hilly terrain either.

On projects involving more than 5,000 linear feet, you'll probably want to use at least one loader backhoe. In some cases, you'll also use additional backfill and compaction equipment.

Production schedules vary with site conditions. Under ideal conditions, a wheeled backhoe trenching constantly in a developed street can handle about 100 linear feet of 4-foot-deep trench per hour. Traffic, asphalt removal and numerous crosslines may reduce that ideal rate by 50 percent or more.

Make sure your backfill and compaction equipment can realistically handle the trenching schedule. An excavation rate of more than a few hundred feet per day requires high-capacity compaction equipment. You may also need hand-held compaction tools for the smaller areas. A hoe-mounted vibratory compactor is a good choice for compaction in small areas.

If you need to trench over 1,000 feet per day, use a wheeled loader to do the backfilling. And get a loader equipped with a quick-detach front bucket that can also be fitted with forks to handle pipes, and pallets of fittings. See Figure 7-6. These attachments double the utility of your loader, letting it handle both the backfilling and material layout.

Some water pipe material is extremely heavy and requires machine laying. Figure 7-7 shows the weights of some commonly-used pipe

		Lbs. per lin. ft.
PVC pipe	Class 150	9.00
Fiberglass composite pipe	Class 350	4.55
Ductile iron pipe	Class 350	24.40
Reinforced plastic mortar pipe	Class 150	6.00

Typical pipe weights
Figure 7-7

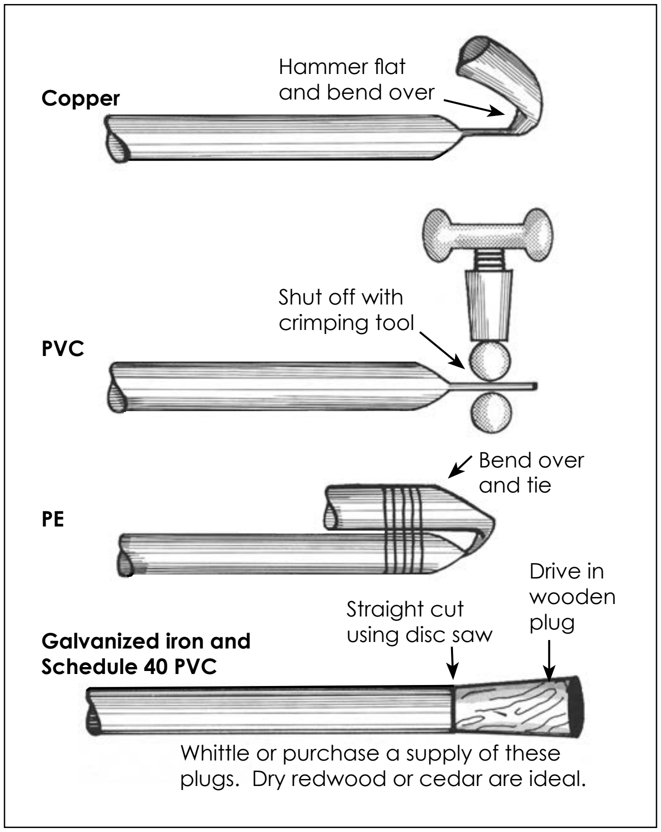
materials. You might be able to use your trenching equipment to lay the pipe, but it's often more productive to bring in specialized equipment. A side boom jib crane like the one in Figure 7-8 is ideal for laying pipe, although the versatile backhoe loader is a common alternative. A pipe-laying hoe can serve double duty with trench backfilling too.

Forming a Crew

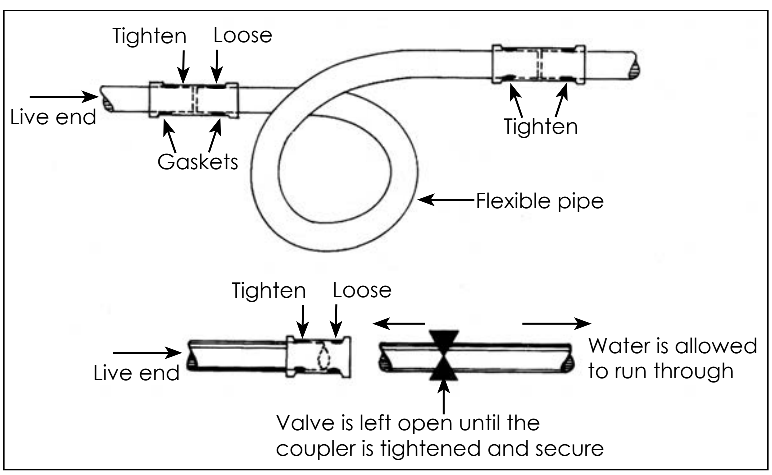
In addition to the equipment operator, the minimum crew required for installing a water system includes a superintendent, a pipe layer and a pipe layer's helper. To increase the production rate, hire additional laborers to assist with material layout, backfill compaction and damage repair. Let's look at the responsibilities of each of these crew members.

Courtesy of Terry Newman

Jib crane
Figure 7-8



Shutting off water in damaged service lines
Figure 7-9



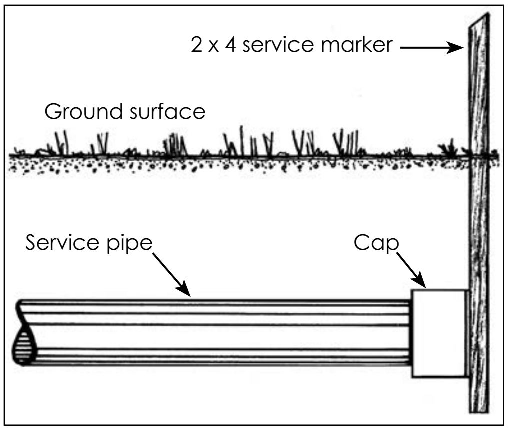
Repairing a live service line
Figure 7-10

The Superintendent

It's the superintendent's job to make sure the equipment and crew can meet the production schedule. He'll expand or reduce the crew to meet job requirements. Careful analysis of the jobsite is an essential part of this job. When work is being done in developed areas among existing lines, equipment operators have to be able to work around obstructions quickly and with accuracy.

If you're installing a replacement water system, sometimes you'll have to maintain service to customers while gradually replacing and transferring services to new sections of line. Old water systems are often in poor repair. Control valves may not work or may be lost or buried under street surfaces. The superintendent should know the position and condition of all valves before work starts. If any accidental damage occurs during the job, he'll need to know how to shut off the water supply to the damaged section of pipeline. And remember: If the old system is laid out in a grid, you'll need to shut off *several* valves to isolate one section of pipe. The superintendent must know exactly which valves shut down which sections of the line.

The crew needs good access to all necessary materials and equipment. This includes whatever materials might be required to repair unexpected damage. A shrewd superintendent stockpiles a supply of repair materials so that he doesn't have unnecessary production delays. Figure 7-9 shows several methods of shutting off water in damaged service lines. Figure 7-10 shows two ways to repair live service lines when it's not practical to shut off the water.



2 x 4 service marker placed against a cap
Figure 7-11

The Pipe Layer

It's the pipe layer's job to know how to install the parts and fittings quickly and efficiently. Pipe weighing over 100 pounds per joint (section) is usually laid with lifting equipment.

It's essential that the pipe layer measure accurately when cutting the pipe. Fittings, such as control valves, fire hydrants, tees and crosses, must fit onto the pipe perfectly at the specified interval.

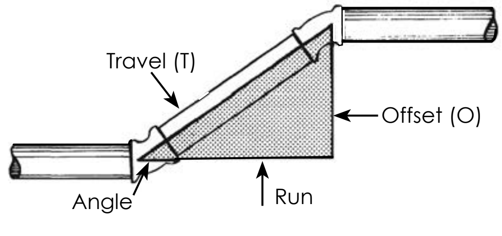
The pipe layer can boost the production rate by measuring and preparing the pipe and fittings for installation before the trench is excavated. Here's an example: Let's say that the crew is installing a cross-assembly consisting of the cross, two short lengths of pipe and two gate valves. The pipe stubs can be cut and prepared and the gate valves fitted to the cross before the trenching hoe reaches the intersection. When the hoe reaches the intersection, it can quickly swing the preassembled cross-assembly into position. The trenching proceeds without interruption. If the trenching hoe has to wait for the pipe crew to cut and assemble, productivity drops. Anticipating the need for cutting and assembling always boosts production.

Here's another way your pipe layers can save time: When you have to lay fittings that will need re-excavating and additional work, cap the open pipe end with a plug and mark its end position with a scrap 2 x 4 erected vertically. See Figure 7-11.

Water pipe must be laid to even grade. Some operators can "hold grade" without constant directions from a grademan. Others will require help to maintain the required trench depth. A pipe layer often acts as grademan for the operator.

The pipe laying crew may also be responsible for guiding the trenching hoe around crosslines and obstructions. A man in the trench immediately behind the hoe bucket can usually spot old trench lines more easily than the operator. It's always easier to avoid damage than to repair it after it happens. An attentive grademan will save the operator, the company and himself a good deal of trouble and expense by helping the operator avoid damage.

The pipe layer often has to calculate the precise position of trenches and pipelines for an *offset*. An offset is a combination of elbows or bends that brings one section of pipe into line with another section of pipe. See Figure 7-12. Notice that the displaced section of pipe remains parallel to the original pipeline. The angle of the elbows determines the *factor* to use for finding two other important dimensions: *run* and *travel*. Figure



Calculating the length of an offset
Figure 7-12

60°		
	Offset	= 1.73 x run
	Run	= .57 x offset
	Travel	= 2.00 x run
	Travel	= 1.16 x offset
45°		
	Offset	= run
	Run	= offset
	Travel	= 1.41 x run
	Travel	= 1.41 x offset
22½°		
	Offset	= .41 x run
	Run	= 2.41 x offset
	Travel	= 1.08 x run
	Travel	= 2.61 x offset
11¼°		
	Offset	= .20 x run
	Run	= 5.03 x offset
	Travel	= 1.02 x run
	Travel	= 5.13 x offset

Note: These figures are correct to two decimal places or have been rounded down to the second decimal place.

Factors for calculating offset-related distances
Figure 7-13

7-13 contains multiplication factors to determine travel distances.

To use the factors, you just need to know the elbow angles and either the run distance or the offset distance. Let's say we're using two 60-degree elbows to align two parallel pipelines that are 30 feet apart. The 60-degree section of Figure 7-13 shows that the run will be 0.57 times the offset. Since the offset is 30 feet, multiply 30 by 0.57 to get 17.1 feet of run.

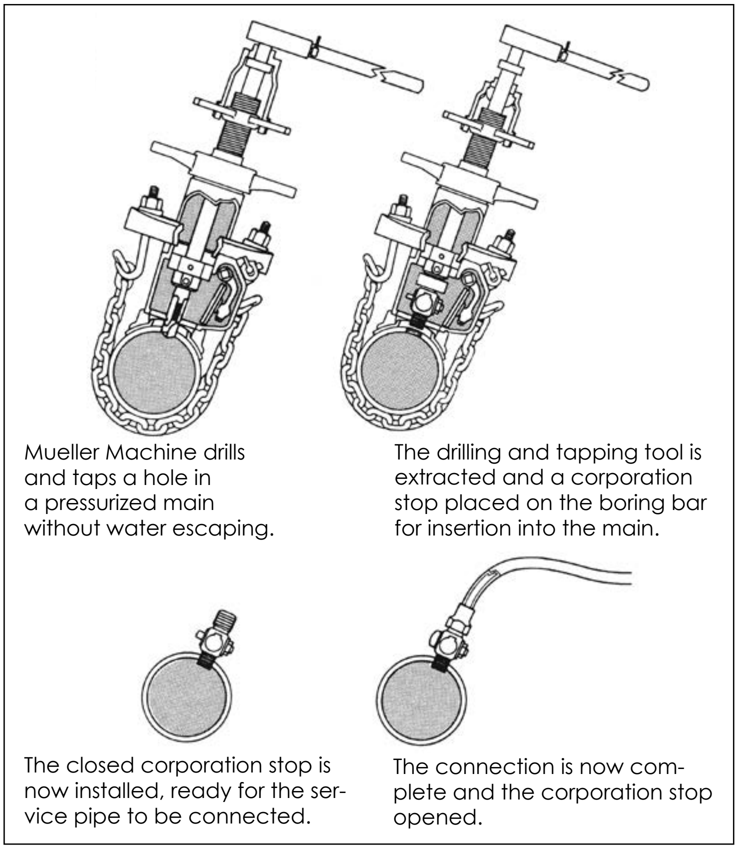
Let's look at another example, assuming the elbow angle is 45 degrees and the offset is 10 feet. To find the travel, multiply the offset by 1.41. The travel distance comes to 14.1 feet. Once the pipe crew has the run and travel distance, they can mark the trench line for the excavating hoe.

If the water must be turned on immediately after the offset is installed, partially open the feed valve. This will help reduce damage if the assembly blows apart under pressure. Reducing the water feed won't reduce the thrust, but it'll reduce the amount of water that escapes if a mishap occurs. It's important to brace the fitting against thrust immediately. You can do this with timbers and by pouring high early strength concrete. If possible, however, avoid putting immediate stress on the assembly.

We've discussed the equipment and crew we'll need for our water system work. Specifications usually demand that the new main line be tested and disinfected before hooking up the services. Before we examine how to run the final tests on completed lines, I'll discuss some important tips to remember when you're installing service lines.

Installing Service Lines

Once the main line is in place, installing the service lines comes next. Domestic service usually requires ¾- to 1-inch diameter pipe. Businesses may require 2- to 6-inch service lines.



Courtesy of Mueller Co.

Direct tapping
Figure 7-14

Joining the Main Line

The two methods of fitting domestic service lines into the main pipeline are the direct tap and the saddle tap. When you tap the main line, you'll also install the control fitting. Here's how.

Direct Tap

Use the direct tap method where the main line walls are thick enough to allow drilling and tapping. Thread the corporation *(corp)* stop directly into the wall of the main pipe. The Mueller Company manufactures a direct tapping machine specifically for this task. See Figure 7-14. This machine allows you to install corporation stops when water in the main pipe is under pressure.

Saddle Tap

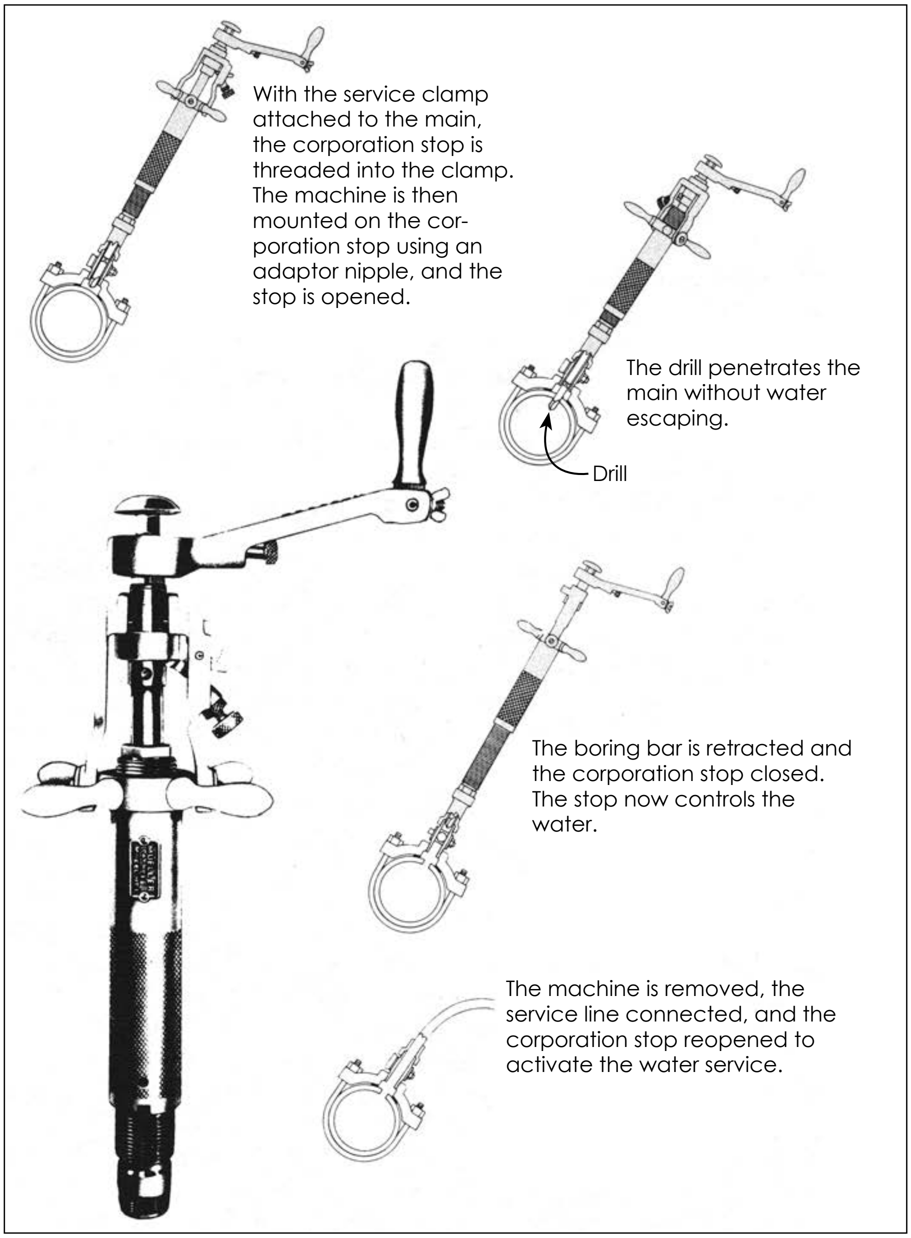
If the main line walls aren't thick enough to allow drilling and tapping, use the saddle tap. Figure 7-15 illustrates how saddle tapping works. This also allows corp stops to be installed when the main is under pressure.

In some cases you can install the saddle while installing the main line. Use an electric drill to make the hole in the main pipe. This method is usually practical only in undeveloped subdivisions where the main pipe can be left exposed and the service trench is excavated away from the main line.

When installing service lines in developed areas, you'll probably be trenching from the property line toward the main pipeline. If you install your saddle before installing the main line, it'll be difficult to locate the saddle after it's buried. It's easy to knock off the saddle and protruding corporation stop. Stay away from existing saddle installations when you're working in developed areas.

Control Fittings

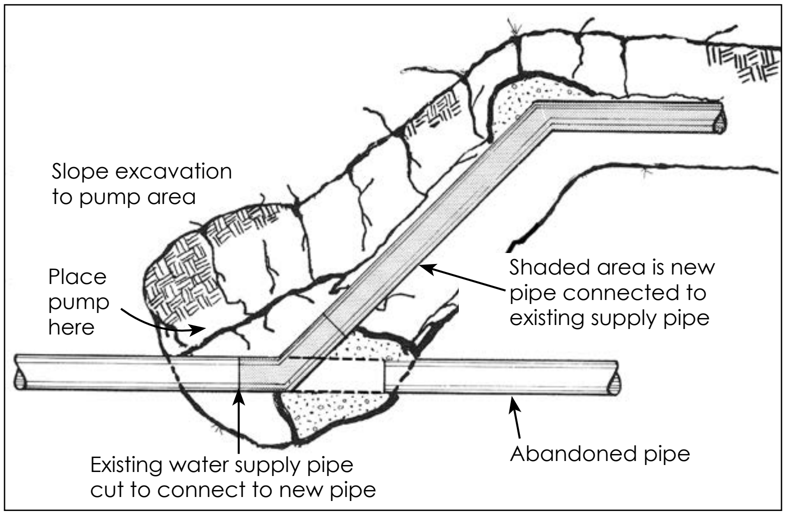
Specifications often require that you install the corp at an angle between 22½ degrees and 15 degrees off horizontal. This allows for some slack in the service pipe if trench settlement puts tension on the service line.



Courtesy of Mueller Co.

Saddle tapping
Figure 7-15

It's essential that *all* plumbing fittings be tightened securely. Every slight weep or drip will get worse. And if the line is holding relatively high pressure, escaping water can actually wear away parts of a metal fitting. Remember, it's easier to do it right the first time than to repair it later.



Excavating for a tie-in
Figure 7-16

Joining New and Existing Service Lines

A *tie-in* is a joint that ties a new section of main line to an existing section. Installing tie-ins requires meticulous planning. Once you start a tie-in, it has to be completed promptly because the water has to be cut off during installation. In a business district, you may have to do tie-in work during non-business hours. Always give advance notice to consumers who'll be temporarily without water.

The most common tie-in is the straight compression coupler, which allows you to join two pipes made of different materials. Be sure to select the correct gasket and follower for the new pipe.

Pipes made of different materials will have different outside diameters. Whenever you're in doubt about the outside diameter of a pipe, measure it. That's the only way to be sure you've got the correct gasket. To calculate the outside diameter of a pipe, start by measuring the pipe circumference with a flexible tape. Then, simply divide the pipe circumference by 3.14.

Excavating around a tie-in is a balancing act. Don't make the common mistake of excavating too small a hole around a tie-in. Cramped quarters will slow the job and increase labor costs. But also be sure never to over-excavate in the areas where thrust blocks will be required to hold the tie-in in place after assembly. An over-excavated area will require a lot of concrete, adding unnecessary material costs. Figure 7-16 shows how to excavate for a tie-in. Before beginning the tie-in, lay out your excavation carefully. Then shut down pressure to the line.

Pipe size (inches)	Gallons per linear foot
15	9.17
12	5.87
10	4.07
8	2.61
6	1.46
4	.65

Water capacity per linear foot of pipe
Figure 7-17

When cutting starts, the pipe will begin draining into the excavation. You'll have to pump it out. When you're cutting into a line that has several hundred feet of large-diameter pipe, there's a lot of water in there. Have enough pumping capacity to handle the water you need to remove. Figure 7-17 lists the water capacity, in gallons per linear foot, of the common pipe sizes.

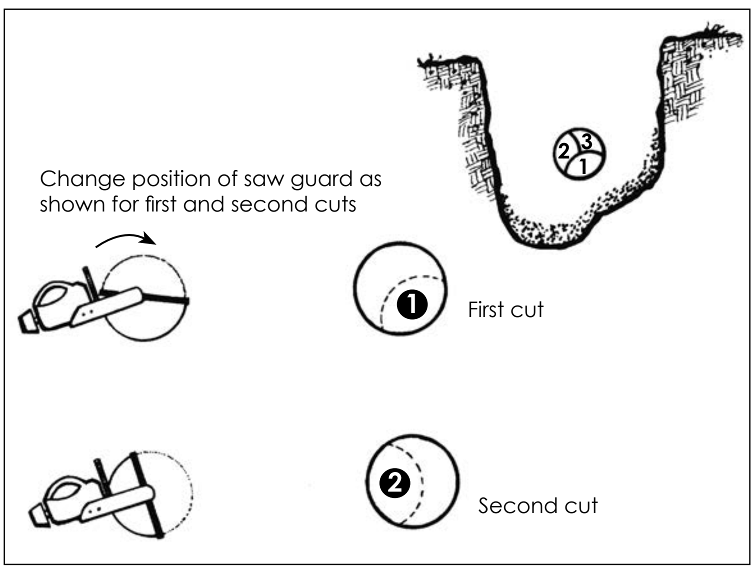
If you need to calculate pipe capacity for other pipe sizes, use the following two-step formula.

1. Calculate the cubic foot capacity per linear foot of pipe, keeping in mind that pipe radius is equal to one-half of the pipe diameter:

$$\frac{3.14 \times \text{Pipe radius (in.)} \times \text{Pipe radius (in.)}}{144}$$

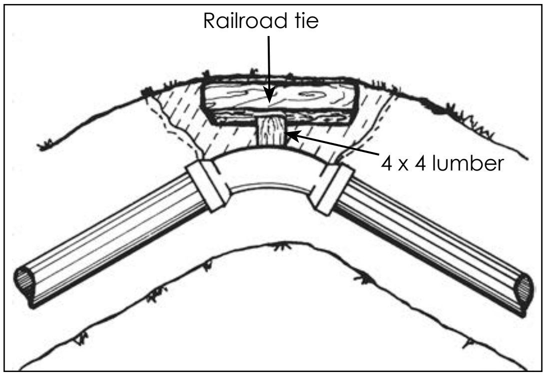
2. Multiply the outcome by 7.48 to convert it to U.S. gallon capacity per linear foot.

When cutting into a water-filled line, use the method shown in Figure 7-18. This will keep water from being thrown toward the operator. With the first cut, water is thrown up and away from the operator. Now the water can drain out of the pipe. With the second cut, the water is thrown down and away from the operator. Finally, the top of the pipe is cut. The operator will still get wet, but this technique will minimize the drenching. If there's a great deal of water in the pipe, cut a chock out of the pipe to speed draining. "Measure twice; cut once" is a good maxim not only for carpenters, but also for all pipe-laying work. This is especially true with tie-ins.



Cutting a water-filled pipe
Figure 7-18

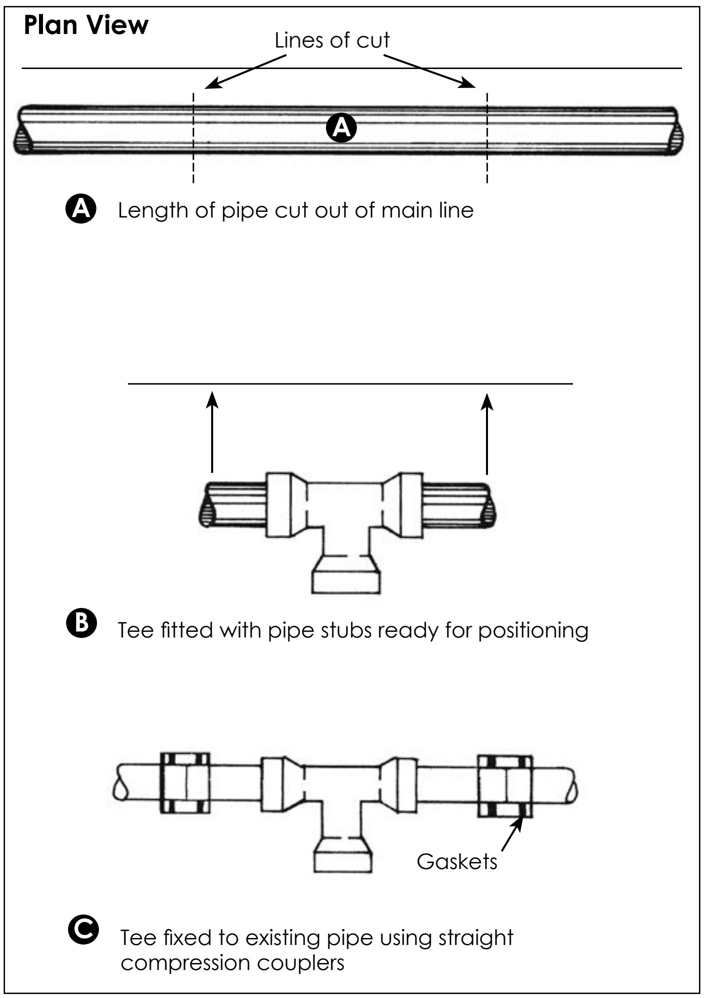
Look again at Figure 7-2 and review the thrust forces each 100 psi of water pressure places against pipeline fittings. For example, a 12-inch 45-degree elbow must endure 4.55 tons (9,100 lbs.) of thrust.



Temporary bracing
Figure 7-19

Thrust blocks are designed to resist that pressure. Concrete is the only acceptable thrust block. Use rapid-hardening concrete if the installation will be put under immediate pressure. While the concrete is hardening, support the tie-in with lengths of waste steel pipe about 4 to 8 inches in diameter. Stout lumber also makes an adequate temporary support. Figure 7-19 shows how a temporary bracing of railroad ties and 4 x 4 lumber is arranged before it's covered with rapid-hardening concrete.

Some tie-ins will be made with a tee. In Figure 7-20, the tee is fixed to the existing pipe with two straight compression couplers. If the pipe can be beveled for a slip joint or if you can use a mechanical joint, only one compression coupler will be needed. The drilling machine shown in Figure 7-21 is designed for work like this.

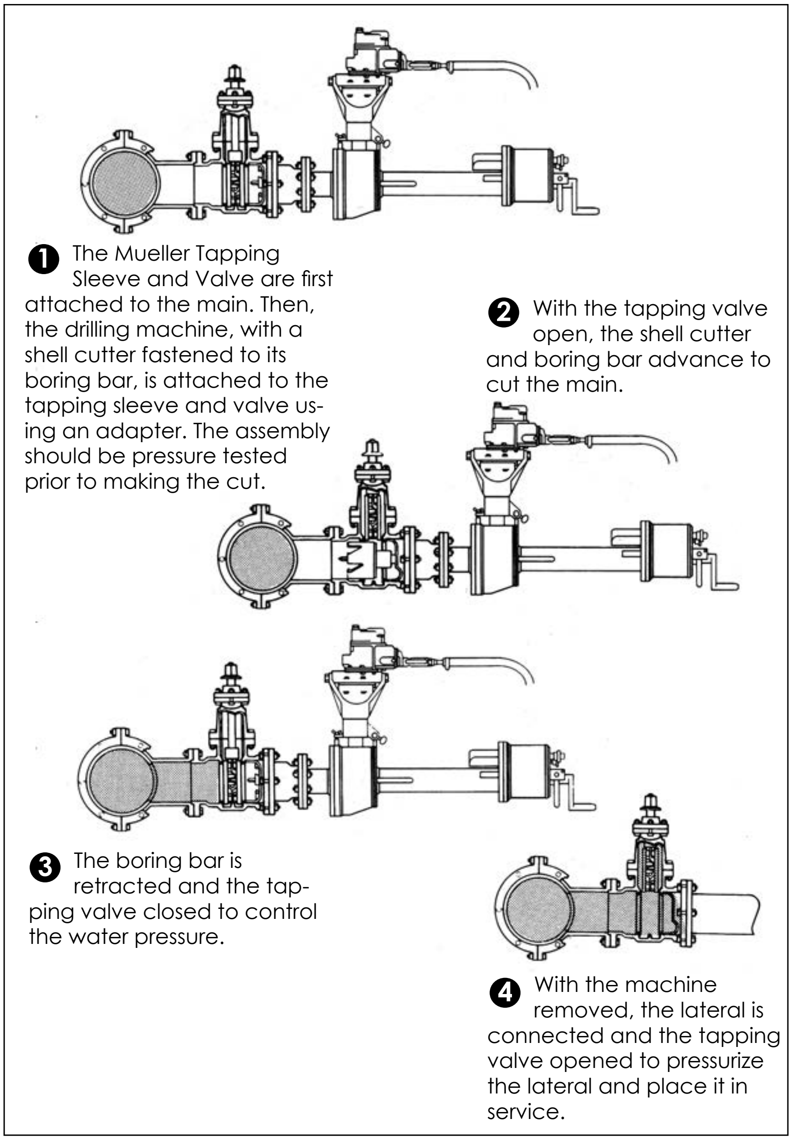


Cutting in a tee
Figure 7-20

Testing the Line

After installing the new service line or tie-in, it's standard practice to test each line under high pressure. You need to find out if the system will do what it was designed to do — hold water under any pressure condition. A system normally operating at 70 pounds per square inch may need to withstand pressures of double that when demand is low. The engineers should specify pipe and fittings that meet job requirements. For common operating pressures of 70 pounds per square inch, they'll probably specify materials designed for operation at 150 to 160 psi. Of course, the strength of the pipe material isn't the only consideration. Fittings have to be installed so they won't come apart.

You can test the pipelines one at a time, or you can test sections of a system together. Just isolate the section that you're testing. Shut off the main control valves and each of the meter setters. Use a high-pressure pump to send water through a service



Courtesy of Mueller Co.

Drilling machine
Figure 7-21

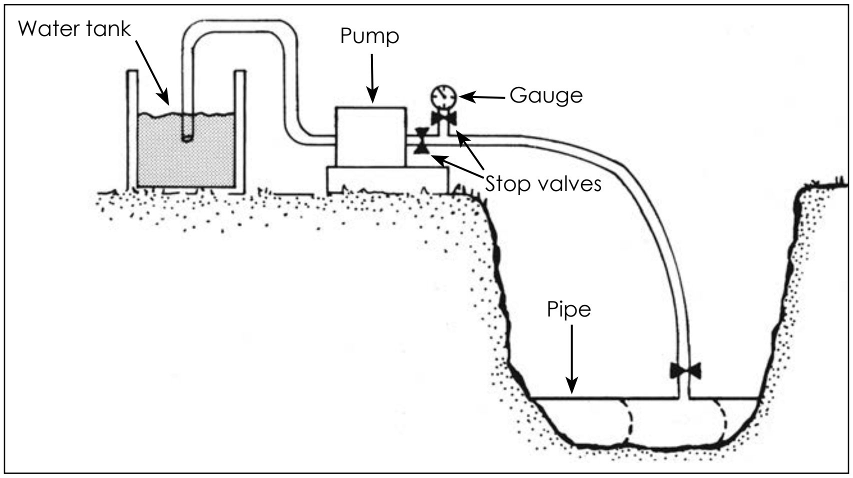
tap into the test line. See Figure 7-22. Forcing extra water into a line raises the pressure inside the line. The increased pressure is measured and monitored by a pressure gauge fitted into the feeding line. It's important to use a valve to isolate this gauge. The gauge can't withstand the full pressure of a working pump.

The test pressure will break apart any faulty fittings and assemblies. To measure the amount of leakage, let the lines hold the test pressure for a period of time. The pressure will drop due to the leakage. Then measure the amount of water you have to pump back into the lines to return them to the pressure they had at the beginning of the timed period.

A certain amount of leakage is considered acceptable. The specification for your job will explain how much leakage is allowed.

When you're conducting the high-pressure test, remember that *excess air in the line will make your test results inaccurate.* Air in the line will be absorbed by water when you increase the water pressure. Water can absorb some air without noticeably increasing in volume. For example, if a cylinder has 50 percent air and 50 percent water under compression, the air will compress (not the water) as pressure is increased.

Under enough pressure, the compressed air will even "disappear" into the water, leaving us with a volume approximately the same as the volume of the water by itself. When we reduce the pressure, air will slowly escape from the water. This means that if your pipelines contain a significant amount of air during the high-pressure testing, your test results will be wrong.



Pressure testing water lines
Figure 7-22

Water lines shouldn't contain any air at all. That's why it's important to lay the lines to grade and to install air relief valves at any high points where air might be trapped. Even correctly installed, well-designed systems may contain some air after the first filling. Just remember to expel all air prior to testing. You may even need to install a tap for the sole purpose of releasing trapped air.

If you're looking for a leak, flush the line to make sure you expel all air before you start excavating. Then retest and try to establish the amount of leakage. A small leak of a few pints an hour indicates a drip, probably from a service fitting. Larger amounts indicate a problem in the main line. There are sophisticated electronic listening devices available now that can pinpoint the problem by detecting the sound of escaping water.

Be aware of the danger of exploding plugs and caps. Internal line pressure can blow off a plug or cap with terrific force. So stay clear of fittings under pressure, especially when lines are fitted in vaults or manholes. And be sure that the pressure has been released before you remove any temporary braces.

8

Installing Sewer & Stormwater Systems

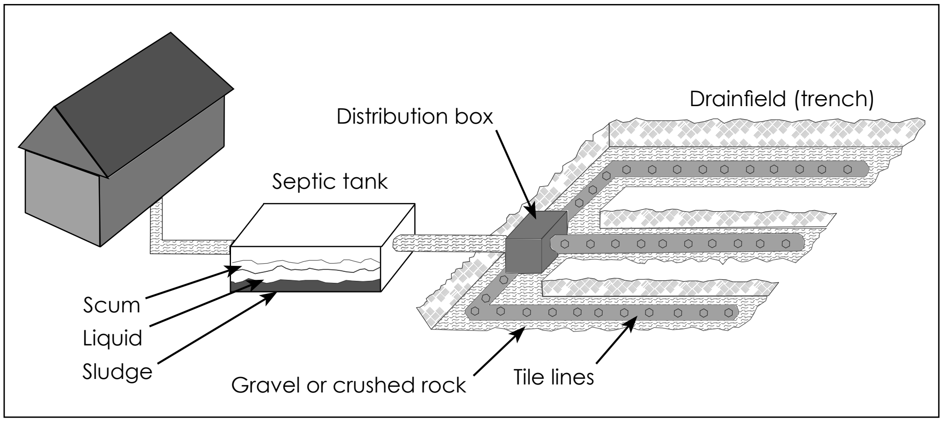
The sewage volume produced in most communities is about equal to its water use — about 40 gallons per person per day. This effluent must be collected, transported and treated. As a utility contractor, you don't need to worry about treating the effluent. Your job is to install the pipelines that collect and transport it to the treatment plant.

In this chapter, I'll explain how to install the pipes to meet the design specifications. We'll discuss the equipment and crew you'll need to do sewer system work. Then we'll go step-by-step through a sample sewer pipe installation.

Septic Tank Systems and Drainfields

Septic tank systems are used to hold and process sewage in rural areas and housing developments not served by municipal sewer systems. A septic tank is basically a settlement tank. The solids in the effluent settle to the bottom of the tank. The lighter fluids flow out of the tank and are released to underground pits and drains where they can be absorbed by the soil.

Effluent from a septic system isn't clean and potable. It's a definite health hazard if it filters down to an underground water table used for drinking water. That's not usually a problem in rural areas where homes are spaced well apart and most underground water is used only for agricultural purposes. But the quantity of sewage generated in towns and cities would poison underground water sources if the effluent weren't collected and treated properly.



Courtesy of the U.S. Environmental Protection Agency

Septic system components
Figure 8-1

Septic systems include the underground septic tank, header pipe or distribution box *(D box)* and the drainfield (also called leach field, absorption field or infiltration bed). See Figure 8-1.

A septic system will only function if all of its components are working properly. For example, if drainfield soil doesn't allow liquid to pass through, then the septic tank won't be able to discharge wastewater. That won't necessarily damage the septic tank, but sewage will eventually back up into the dwelling.

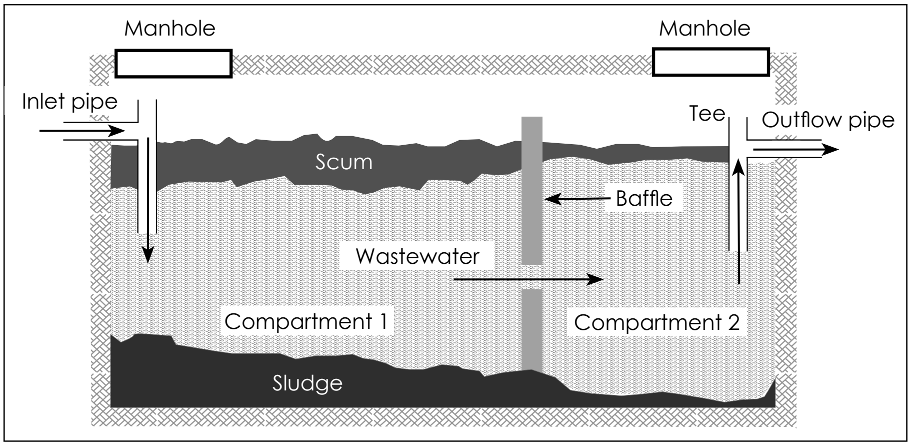
Septic Tanks

Septic tank and drainfield size requirements vary depending upon state and local codes. Minimum tank size is typically around 1,000 gallons. Bigger tanks allow longer retention times, which allow solids to settle to the bottom, grease to float to the top and solid wastes to decompose more completely. The object of septic tank sewage treatment is to retain the effluent in the septic tank for at least 30 hours.

Septic tanks can be constructed from precast concrete, fiberglass, polyethylene plastic or steel. Steel tanks may last only a decade because they're susceptible to corrosion problems. The other varieties, if properly maintained, should last about 50 years.

An inlet pipe coming from the dwelling enters one side of the septic tank with a ¼-inch per foot slope downhill. An output pipe exits the tank and is connected to the drainfield. The slope of outlet pipe should be 1/8-inch per foot downhill.

The tank itself is watertight and divided into two semi-compartments separated by a baffle or dividing wall near the center of the tank.



Septic tank with two compartments
Figure 8-2

This division allows for improved decomposition of the waste materials. When the waste *load* flows into the tank's first compartment, heavy solids settle to the bottom to form a layer of sludge. Lighter materials such as grease, fats and small food particles float to the surface, forming a layer of scum. Between these two layers is a mixture of suspended materials. The baffle helps prevent scum and other solids from entering the second compartment and the drainfield. See Figure 8-2.

When the second compartment receives its load, many of the solids have already settled in the first compartment. Also, there's less turbulence in the second chamber because the load enters more slowly than it does in the first chamber. Both of these factors allow finer suspended solids to settle in the second chamber.

Microbes from human digestive systems perform much of the decomposition in the septic tank, just as they perform digestion in our bodies. This process also produces similar gas byproducts such as hydrogen sulfide and methane. Up to 50 percent of the solids are converted to liquids and gases. The gases stir septic tank contents, promoting further decomposition of the solids.

When liquids in the second compartment rise to the level of the outflow pipe, they're discharged into the drainfield. Outflow pipes are equipped with a tee and filter to help capture any scum and solids before they exit the tank. See Figure 8-3. This filter should be removed and cleaned once a year, so it's a good idea to keep maintenance records. The outflow or effluent goes through a distribution box or non-perforated header pipe, and it's dispersed throughout the drainfield through a series of subsurface perforated pipes. All of the pipes must be sloped accurately to ensure that the wastewater is distributed equally throughout the drainfield. Final effluent treatment occurs as the soil absorbs and filters

Outlet tee with filter
Figure 8-3

the liquid and microbes break down the rest of the waste into harmless material. The clarified water either evaporates or returns to the groundwater through the soil.

Septic Tank Maintenance

Unfortunately, septic systems can't dispose of all the material that they encounter. Cooking oil, household cleaners and other common household wastes can interfere with the system's process. Solids that aren't broken down by bacteria begin to accumulate in the first compartment of the septic tank and eventually need to be removed. The most common cause of system failure is not having these solids removed on a regular basis.

Local codes may dictate how often to pump the tank. Most recommend pumping on a 3- to 5-year schedule, or when the combined scum and sludge layers exceed one-third of the tank's depth. Otherwise, sludge can build to the point where wastewater is released into the tank's second compartment, and eventually the drainfield, without being sufficiently treated. Always employ a licensed pumper and hauler to pump out a septic tank.

It's the homeowner's responsibility to maintain his septic system, but you'll be doing the customer a favor if you explain the potential problems associated with a septic system and how he can prevent them. Components, including the tank, baffles, inlet pipe, outlet pipe and filter, should be checked annually to ensure they're not worn or damaged.

Problems Leading to Contamination of the System

As I've already mentioned, many common household items can lead to septic tank contamination. Homeowners should be aware of what they put down their drains, and follow these suggestions:

- Refrain from putting any plastic, cloth, or unnecessary paper products into the sewage system.

- Use garbage disposals sparingly, as they increase accumulation of solids in the holding tank. Choose a good-quality disposal that grinds food into tiny particles.
- Avoid putting any grease or oil in the disposal or drain. These can clog pipes and the drainfield itself, making it impossible for soil to absorb liquids.
- Minimize the use of heavy-duty cleaners, as they kill beneficial bacteria in the septic tank.
- Never flush cat litter, disposable diapers, feminine hygiene products, condoms, paper towels, facial tissues, dental floss, coffee grounds, or cigarette butts and filters.
- Dispose of chemicals properly. Varnish, paint thinners, motor oils, gasoline, antifreeze, dry cleaning fluid, pesticides and photographic chemicals can ruin a septic system and are hazardous to groundwater.
- Avoid the use of additives. Generally, they won't extend the amount of time required between pumping, and they may do more harm than good. Some state legislatures even prohibit the use of septic tank additives.
- Avoid powdered detergents as they contain non-biodegradable fillers that can plug the septic system.
- Prevent washing machine lint from getting into the septic system. Install a reusable, inline filter on the washing machine's discharge hose.

Reducing Septic System Load

The average four-person household uses about 150,000 gallons of water per year. More than half of that is indoor water use, which means 205 gallons of water (plus wastes) goes into the septic tank each day. If the system is overburdened, water entering the drainfield will contain solids that eventually form a slime mat *(biomat)* under the field. The biomat acts as a barrier, reducing the soil's permeability.

Since toilets, washing machines, showers and sinks generate the majority of household wastewater, there are plenty of ways for homeowners to reduce septic system load:

- Check faucets and toilets for leaks.
- Use aerators on faucets and flow reducer nozzles on showers to help lower water consumption.
- Install water-saver (low-flow) toilets. Older toilets have 3.5- to 5-gallon tank reservoirs, while newer water-savers use 1.6 gallons per flush.

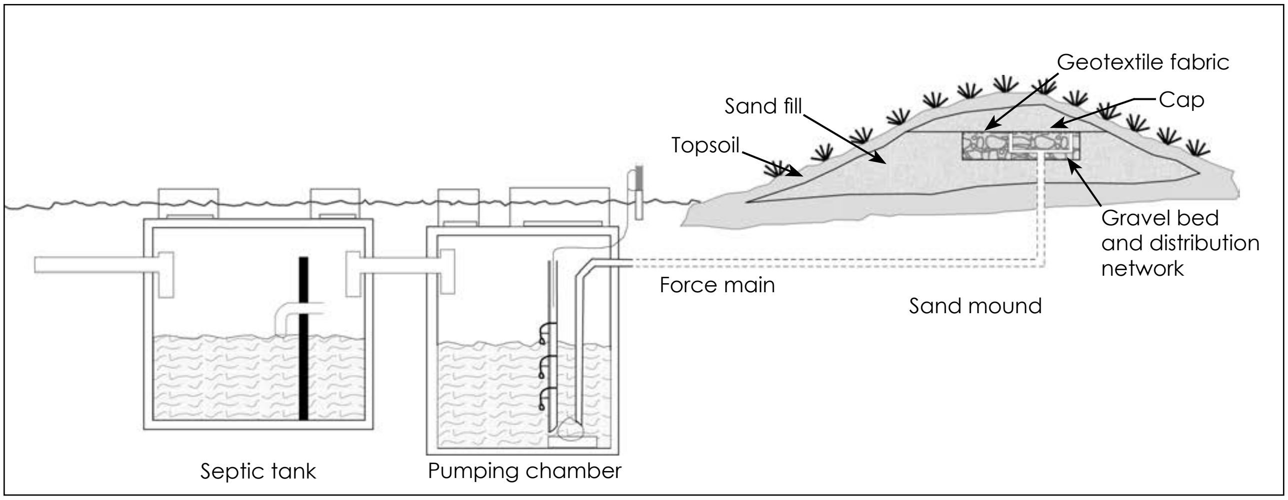
Drainfield with EZflow pipe
Figure 8-4

- Space showers or baths. Don't wash dishes or clothes after peak water-use times in the bathroom.
- Consider installing a recirculating pump in the hot-water line. This ensures an instant flow of hot water when any faucet is turned on, so water isn't wasted running the water till it gets hot.
- Direct roof downspouts and runoff away from the drainfield to avoid saturating the area. The excess water can actually fill the perforated pipe in the drainfield, causing it to back up into the septic tank and eventually into the dwelling.

Drainfields

In order for a septic system to function properly, the surrounding soil must be permeable. A septic engineer or health department official usually performs a percolation test (also known as a *deep hole* or *perc test*) to determine the soil's adequacy for supporting a septic system. Soil permeability may have an influence on the system's design too.

Most drainfields have the drainpipe installed on a 6-inch layer of ¾-inch rock or crushed stone. The drainpipe is then covered with 2 inches of stone. EZflow pipe, shown in Figure 8-4, is an alternative to the traditional rock bed setup. The pre-assembled EZflow drain units are 10 feet in length, with 4-inch perforated, corrugated plastic pipe surrounded by a synthetic aggregate. They're held together by polyethylene netting. Because EZflow units are lightweight and easy to assemble and transport, they save time, labor and transportation costs.



Courtesy of the U.S. Environmental Protection Agency

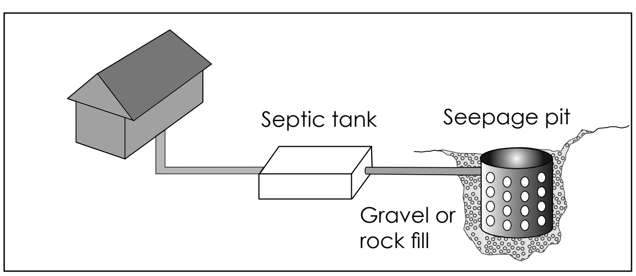
Sand mound
Figure 8-5

Sand Mounds

Drainfields must have adequate separation from the water table to keep contamination from occurring. Likewise, layers of impermeable soil must be well below the drainfield.

There are ways to convert a seemingly-unsuitable drainfield area into a perfectly good drainfield location. One such modification is known as the *Wisconsin*, or *sand mound system*. As the name implies, it involves placing a permeable soil mound on top of the natural soil surface. See Figure 8-5. The extra soil layer is thick enough to ensure adequate time and distance for proper treatment of the wastewater.

Sand mound systems also require a pumping station to pump the tank effluent up to the sand mound. The pumping station, electricity and extra maintenance costs make sand mound systems more expensive than traditional septic tank systems.



Courtesy of the U.S. Environmental Protection Agency

Seepage pit
Figure 8-6

Seepage Pits

Figure 8-6 shows a septic system with a seepage pit *(drywell)*, which is an alternative to a drainfield. Seepage pits have a perforated or open-jointed lining which allows septic tank discharge to seep into the surrounding soil. The pit is generally surrounded by sand, gravel or crushed stone. Depending on the water table, seepage pits may extend 35 feet or more below the surface.

Seepage pits require less land area than drainfields, but they're not as efficient. Seepage pits should only be used where drainfields aren't suitable and well water supplies won't be endangered by seepage pit effluent.

In a properly maintained septic system, the seepage pit can be expected to last 10 or 20 years. Eventually the pit walls become clogged, and a new pit is needed.

Protecting the Drainfield

If a drainfield fails, the septic tank will need to be pumped out and the drainfield lines cleaned. Homeowners can do a lot to protect and maintain their drainfield. Here are some suggestions you may want to pass on:

- Never park vehicles or place other large objects on the drainfield, as this will compact the soil and damage drainpipes within the field. Don't build any structure on top of the drainfield, or cover it with concrete or asphalt.
- Effluent from sump pumps and roof drains shouldn't discharge near the drainfield. Overly-saturated drainfield soil will turn into an environmental and health hazard.
- Check for depressions in the drainfield where surface water can collect. The drainfield should be level with the surrounding soil to discourage puddling.
- Aggressive tree root systems can cause septic system and drainfield problems. Keep trees at least 100 feet away from the septic system. Plant only grass on the drainfield to minimize soil erosion and accelerate evaporation.

Municipal Sewer Systems

Unlike septic tank systems, municipal sewer systems consist of laterals and mains that collect and transmit sewage to the point of treatment and eventual discharge.

Gravity flow is the cheapest and simplest method of transporting sewage. But gravity systems aren't always possible. Sometimes pumps and pressure pipe are needed to lift the effluent to a treatment plant. These are called *lift stations*.

Pressure pipe for sewer systems is laid about the same way as pressure pipe for water systems. It can be laid relatively shallow, but it must be laid to even falls and grades. Unlike pressure pipe, gravity lines must flow downhill regardless of the lay of the ground. Where gravity pipe has to run deeper than 30 feet, it may be necessary to tunnel or bore a hole for the lines. The alternative is to install lift stations and force mains (pressurized lines) for the sewage.

Whether the design uses gravity or pressure lines, every sewer pipe you install will have a specific carrying capacity or *rate of flow*. There are three factors that determine the rate of flow for a pipe: pipe diameter, slope, and pipe material.

Pipe Diameter

Carrying capacity increases with increased pipe diameter. When you double the pipe diameter, the carrying capacity nearly quadruples. This means that an 8-inch-diameter pipe has almost four times the carrying capacity or flow rate of a 4-inch-diameter pipe.

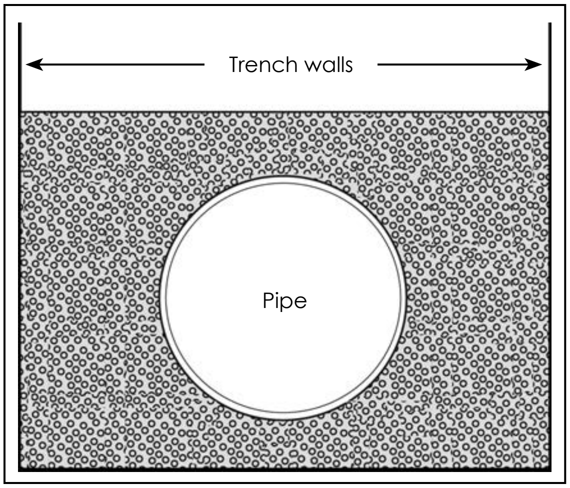
Slope

Slope or grade in a pipeline causes the fluid to flow. The slope of a pipe may be as little as 0.01 percent (0.0001) in a large diameter pipeline. Small diameter pipe is generally laid to a steeper slope: 0.24 percent is about the minimum for 8-inch-diameter PVC pipe. That's just 2.4 hundredths of a foot per 10 linear feet. One hundredth of a foot equals about $^1/_8$ inch, so in carpenter's measurements, 2.4 hundredths equal about $^5/_{16}$ inch. That means the pipe will fall only $^5/_{16}$ inch in 10 linear feet.

It takes great care to position the pipe so that it *falls* or slopes correctly. It's precision work. If it isn't properly done, the pipeline won't slope evenly. When a pipe is laid level or actually slopes the wrong way, it's called a *backfall*. Any backfall will be obvious to the inspector because water will pond in the low spots. Because backfalling pipe effectively reduces the usable diameter of the pipeline, specifications are often stringent. Many demand a grade (slope) tolerance of within 0.01 foot. It takes an accurate laser set-up (described in Chapter 3) and extremely precise pipe laying to meet this tolerance. Do it once and do it right!

Pipe Materials

Since there are so many considerations and options when it comes to selecting pipe materials, I've dedicated an entire chapter to the subject. See Chapter 11 for a detailed discussion of pipe materials, sizes, joints, fittings and uses.

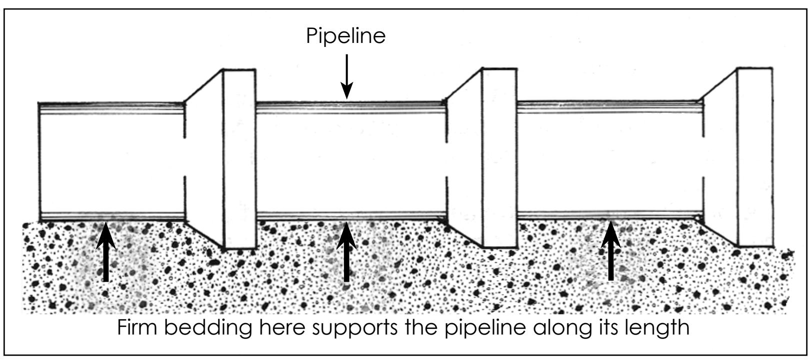


Compacted bedding provides support around pipe
Figure 8-7

The engineer may specify a particular pipe material. But sometimes you just need the pipe to meet a prescribed standard. That means you, the contractor, can select the pipe material for the job. Three important factors to consider when selecting pipe material include: cost, strength and ease of installation.

Pipe Cost

Price will vary with demand and the cost of raw materials. For example, PVC pipe prices tend to go up when petroleum prices increase. And if there's a high demand for a certain type of pipe in your area, you can count on your local supplier raising his prices. Check current prices before you commit yourself to a specific type of pipe. Most pipe suppliers are eager to help you by providing price quotations.



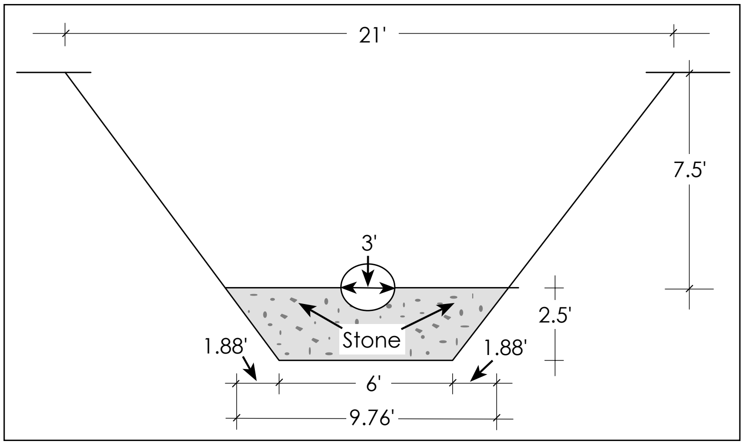
Bedding supports pipe along its length
Figure 8-8

Pipe Strength and Bedding

Most sewer systems use the force of gravity to transport the sewage. A gravity sewer pipe doesn't have the water pressure and vacuums inside the pipe that stress pressure pipe, but it must be strong enough to resist the weight of the earth on top of it. Some pipe, such as PVC, is relatively soft and can flatten out (or squash) if a heavy weight is placed on it. Rigid pipe materials such as concrete and clay resist flattening, but they're more brittle.

Pipe bedding can help strengthen pipe, and make it easier to place the pipe with the appropriate fall. Bedding consists of sand, gravel, crushed concrete or crushed stone. Its purpose is to reinforce the pipe by providing firm support around its walls to resist the flattening effect, and to provide a firm base along the length of the pipeline. See Figures 8-7 and 8-8.

Bedding also allows groundwater to disperse without eroding the surrounding soil. Some designers just require a 6- to 12-inch stone bed beneath the pipe, while others require the stone bed to cover the pipe



V-trench with stone bed to pipe's spring line
Figure 8-9

up to its spring line. The spring line is located at the pipe's widest horizontal dimension. In certain cases, the specs might require stone placement all the way to the top of the pipe. Once the pipe is in place, the trench over that pipe length is backfilled using a loader or dozer.

A properly-bedded line won't collapse under the anticipated load. But if you install the line without sufficient bedding, the stress of the weight of the backfill may twist and bend the line, causing it to leak or even collapse. If the natural ground is soft and likely to move, you may need an additional form of bedding called foundation stabilization.

TRENCH WIDTH AFFECTS pipe strength requirements. The sides of a trench resist downward pressure of the backfill. So the wider the trench (in proportion to the pipe diameter), the greater the load on the pipe. For this reason, some pipe-laying specifications outline maximum acceptable trench width.

Utility Trench Excavation and Bedding Volumes

If you're using small diameter pipe, you can ignore the pipe's volume when calculating bedding volume requirements. Here's what that formula looks like, assuming the trench has vertical walls:

Cubic feet of bedding = total bedding depth (in feet) × trench width (in feet) × trench length (in feet)

Dividing by 27 will convert the volume to bank cubic yards.

V-trench volumes are a little trickier. To calculate utility V-trench excavation volume, multiply the end area by the trench length. Since the end area of a V-trench is shaped like a trapezoid, it equals one-half the sum of the bases (top and bottom lengths), multiplied by the trench height.

For practice, let's calculate the volume of the trench in Figure 8-9. Assuming it's 600 feet long, the sum of the bases (top and bottom) is 27 (21 + 6) feet. Dividing 27 by two, and multiplying by the 10-foot trench height, we get 135 square feet for the end area. Multiplying the end area by the 600-foot trench length yields 81,000 cubic feet. Dividing by 27 gives us 3,000 cubic yards.

The next step is to determine the stone bedding's volume. Had the stone been placed only beneath the pipe, its volume would be the end area of the stone multiplied by the trench length. But in this case the bedding is 2.5 feet deep, covering half of the pipe up to its spring line. When the stone bedding covers a portion of the pipe, you need to account for pipe volume displacement.

Before accounting for the pipe volume displacement, however, calculate the stone bedding volume as if the pipe didn't exist. It forms a trapezoid with 9.76- and 6.0-foot bases, and a 2.5-foot height, so the end area is 19.7 square feet and total volume for the 600-foot trench is 11,820 cubic feet.

Now we need to deduct the pipe displacement volume. Figure 8-10 lists pipe volume displacement figures for round and oval reinforced concrete pipe. In this example, the inside diameter is 36 inches, and the stone bedding covers just half the pipe. The corresponding displacement is 5.28 cubic feet per linear foot of pipe. With 600 feet of pipe, the total displacement is 3,168 cubic feet. Subtracting 3,168 from 11,820 leaves 8,652 cubic feet, or 320 cubic yards of stone bedding.

To calculate trench backfill volume, we need to subtract the stone bedding and pipe volumes from the total trench volume. We already know that the stone bedding volume is 8,652 cubic feet. Using the 36-inch full pipe displacement factor (10.56) from Figure 8-10, total pipe volume comes to 6,336 (10.56 × 600) cubic feet. Adding those two totals and then subtracting from the 81,000 cubic foot trench excavation volume, we get a backfill total of 66,012 cubic feet, or 2,445 cubic yards.

If your bedding supplier sells material by the ton instead of the cubic yard, you'll have to convert loose cubic yards to tons. A ton equals 2,000 pounds. Typically, bedding material weighs about 3,000 pounds per loose cubic yard. So one ton equals 0.67 LCY and 1 LCY equals 1.5 tons. When ordering bedding material, keep in mind that stone, gravel or sand weighs more when it's wet. Since the supplier weighs each truck load, the moisture content of the load becomes very important. All you can do is hope that the bedding material isn't loaded immediately after rainy weather. Keep that in mind when you're bidding a job.

TOTAL SPOIL EQUALS total trench volume minus backfill volume. In this example, the spoil volume comes to 555 (3,000 – 2,445) cubic yards.

Selecting Equipment

Highly productive excavation is expensive. On a large project, your combined crew and equipment costs may run $10,000 per day. So it's important to select the right piece of equipment for each phase of your project.

Round Pipe			
Inside Pipe Diameter (Inches)	**Outside Pipe Diameter (Inches)**	**Full Pipe Cu. Ft. Displacement of Pipe/LF**	**Half Pipe Cu. Ft. Displacement of Pipe/LF**
12	16	1.4	0.7
15	19.5	2.07	1.04
18	23	2.89	1.45
24	30	4.91	2.46
30	37	7.47	3.74
36	44	10.56	5.28
42	51	14.19	7.1
48	58	18.35	9.18
54	65	23.04	11.52
60	72	28.27	14.14
66	79	34.04	17.02
72	86	40.34	20.17

Oval Pipe			
Inside Pipe Diameter (Inches)	**Outside Pipe Diameter (Inches)**	**Full Pipe Cu. Ft. Displacement of Pipe/LF**	**Half Pipe Cu. Ft. Displacement of Pipe/LF**
12x18	17x23	2.13	1.07
14x23	19.5x28.5	3.03	1.52
19x30	25.5x36.5	5.08	2.54
24x38	31.5x45.5	7.82	3.91
29x45	38x54	11.19	5.6
34x53	44x63	15.12	7.56
38x60	49x71	18.98	9.49
46x70	56x80	24.43	12.22
48x76	61x89	29.61	14.81
59x91	74x106	42.78	21.39

Pipe volume displacements
Figure 8-10

Equipment you'll use in sewer system work includes: track excavators, wheeled backhoes, backfill equipment, compaction tools, hand tools, laser and optical levels, pumps, and dump trucks. I'll discuss each of these pieces of equipment briefly in this section. For a detailed look at backhoe operation, refer back to Chapter 5. Methods for estimating equipment production rates are given in Chapter 2.

Track Excavators

Occasionally, you'll use a large wheeled or chain trencher as your primary excavation tool. But your first choice on most jobs will be the large track excavator. It's more versatile and can maneuver around obstructions and crosslines.

To optimize excavator production, the trench depth should be 60 to 70 percent of the maximum reach of the equipment. A machine that can dig down 25 feet will work efficiently in trench depths down to 16 or 17 feet. If the trench goes much deeper than that, the machine will be less efficient.

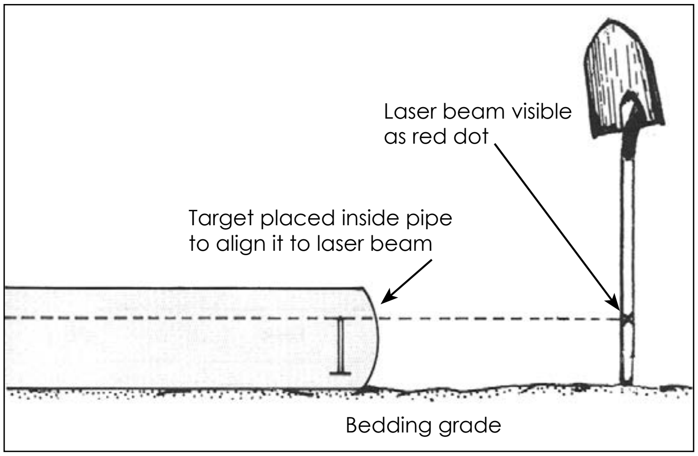
When an excavator is the primary excavating tool, the work pace of the excavator and pipe crew will dictate the work pace for the other equipment on the jobsite. If the scheduled production rate is 50 linear feet per hour and it yields 120 cubic yards of soil, the backfill and compaction equipment will have to keep up with that rate.

Track Backhoes

Most tracked backhoes can be fitted with dipper sticks of varying lengths. In some cases it makes sense to fit a suitable dipper to an existing machine rather than use a different machine. A short dipper stick gives faster cycle times in relatively shallow excavation work. The long dipper stick is better suited to deep trenches. When changing buckets, make sure your crew positions the boom and stick with the holes squarely aligned with the bucket so that the bucket pin will slide through with minimum effort. Keep in mind that equipment that's too large will hamper the work just as much as equipment that's too small.

Backfill Equipment

Select backfill equipment with slightly more capacity than the job is expected to need. This will ensure that backfilling keeps pace with the excavator. There will be some unavoidable delays in excavation, and there will be times when the excavation goes better than expected. When the excavation rate increases unexpectedly, it's nice to have backfill equipment that can meet the faster pace.



Laser used to align pipe and shovel to grade bedding
Figure 8-11

Compaction and Hand Tools

Compaction tools are described in Chapter 6. Hand tools include shovels, a bar for levering the pipe in place, a screwdriver for assembling pipe couplers, a target for the laser, a ladder for access into and out of the trench, a pipe saw for cutting and beveling pipe, and plumbing tools such as a pipe wrench for repair of damaged water services.

Pipe layers tend to be possessive about their shovels, usually preferring a particular size or style. They often put a reference mark on their shovels to help grade out the pipe bedding with a laser, as shown in Figure 8-11.

Laser and Optical Levels

Lasers have revolutionized pipe laying. The laser beam is used to align pipe on both the horizontal and vertical planes. A transit or laser-aligning instrument is used to set the laser in position and align the beam. Your laser should give the pipe layer a continuous reference point that's precisely on line and grade.

Pumps

If your crew is working in groundwater conditions, selecting the right pump is important. Capacity is a key consideration. If you can't control the groundwater, you'll never finish the job. In some cases, you'll even need 24-hour pumping. It's best to select a pump that can handle more water than you're expecting to encounter. Specs usually confirm that groundwater is expected. But they never say how much. Selecting the right pump can mean the difference between adequate water control and a flooded-out project.

Work Trucks

A small one-ton flatbed truck with tool boxes is a good choice because it has more capacity than the half-ton pickup.

Your equipment needs can also depend on the location of the work. If you're working in an open area, the minimum equipment required for continuous sewer pipe laying will be: backhoe, backfill machine (loader or dozer), compaction tools, hand tools, laser and optical levels, and a work truck. If your job is located on a busy street, your equipment requirements may double. You can't interrupt traffic flow through the area, and you'll probably need to backfill the same day you excavate.

Forming a Productive Crew

Teamwork is the key to high productivity in sewer system work. The best materials and the best equipment can't make a profit for you if your crew doesn't work together as a team. Even the best superintendent can't finish the job on schedule with a lazy crew. And the best crew will spin its wheels in frustration without a good superintendent. Every member of the team is equally important.

Selecting skilled, efficient workers is essential. But there's more to teamwork than just hiring competent, reliable individuals. Here are three rules for turning a crew of skilled workers into a highly productive, well-coordinated team.

1. *Provide easy access to materials, tools and equipment.* "If you need it, go and find it" isn't the most productive work method. Make sure your workers have easy access to *all* of the materials, tools and equipment they need. This includes materials that might be required to repair the minor damage that happens occasionally. It's wise to stockpile materials that can be used for repairs. This may seem like an unnecessary expense, but the stockpile will easily pay for itself by preventing costly delays in production.

   When you provide the materials for your crew, include a set of specifications and blueprints that show the layout of the job, including all crosslines. The more your crew knows about the project, the easier it is for them to perform efficiently. A well-informed crew makes fewer errors.

2. *Overlap responsibilities.* Each crew member should have a primary responsibility and several secondary responsibilities. For example, the supervisor, equipment operator and pipe layer should all know the location of the crosslines. Since more than one person has this responsibility, there's less chance for error. This makes it easier for production to continue without the interruption of damaged crosslines.

   When you're assigning responsibilities, make sure each crew member clearly understands the specific tasks he's responsible for. This seems obvious and simple enough — but it's a hitch that causes problems even with experienced crews. A little bit of confusion goes a long way, and it can bring production to an abrupt halt. Be clear and detailed with your crew when you're assigning responsibilities.

3. *Make safety easy.* Pipe laying is dangerous work. Common earth weighs over 100 pounds per cubic foot, so even a small chunk of earth or rock falling only a few feet can cause an injury. The safety of the men working in the trenches depends on the skill and judgment of your equipment operators and the aboveground crew.

   Insist on safety every step of the way. Set the tone by using only safe work practices, proper equipment, material handling, and shoring methods. Insist on hard hats and heavy work boots. It seems like a minor thing. But they've prevented many injuries and saved more than a few lives.

When your crew and equipment cost is running $1,000.00 an hour, a 15-minute delay will cost you $250.00. Even a little mistake can cost you thousands of dollars. An efficient crew doesn't waste time or make mistakes.

Like your equipment requirements, crew requirements will vary with site conditions. In a new subdivision, the minimum crew for continuous pipe laying will include: backhoe operator, backfill equipment operator, pipe layer, topman (pipe layer's helper), laborer/manhole finisher, and a foreman. On a busy street, your crew requirements can double.

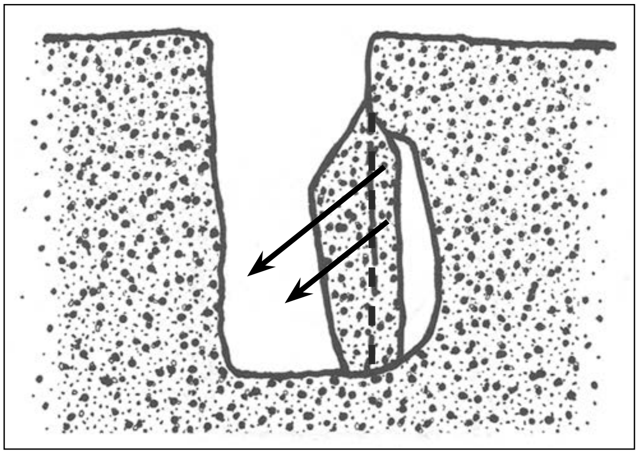
Step-by-Step Installation

Assume you've been awarded a contract and arranged for your materials, equipment and crew. You've already cleared the site. Now what? Let's go step-by-step through a sample sewer system job. We'll begin with the excavation work, selecting a shoring system, then digging and bedding the trenches. Then we'll cut, lay, assemble and align the pipe. We'll install the manholes, test the completed system, and finally, compact the spoil and backfill the trenches.

We're installing a 10-inch sewer pipe in moist loam soil in a residential area. The average depth of the line is 12 feet. There's a 6-inch bedding underneath the pipe and 4 inches of gravel cover on top of the pipe. There are crosslines at each intersection (at every 150 feet along the main line). Left and right service connections are required every 150 feet. Compaction will be native fill compacted to 95 percent of standard Proctor. On top of that, we'll put a 1-foot base and 2 inches of asphalt.

Selecting a Shoring System

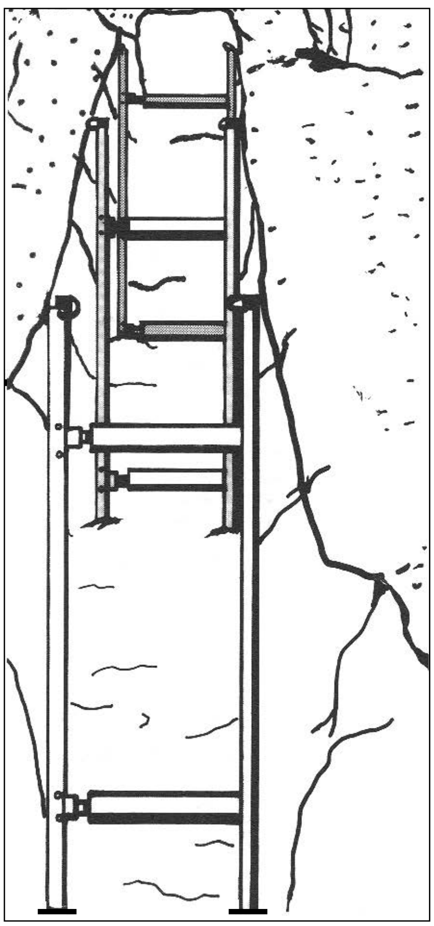
Whatever soil type you're working in, it's your responsibility to use a sound shoring system to prevent cave-ins in your trenches. Contractors who use unsafe or illegal work methods are risking their employees' lives and their own financial health. The best protection against injury



Wet clays and loams "slab off"
Figure 8-12

is safe, sensible work practices. Only about 1 percent of industrial accidents can be blamed on unavoidable circumstances or acts of God. The cause of virtually every accident can be traced to human error. It may be the fault of management, the worker, or both.

Different soil types, depending on the condition of the soil at the time of excavation, behave differently. Sandy soil will tend to collapse straight down. Wet clays and loams tend to "slab off" the side of the lower trench, as shown in Figure 8-12. Firm sand, wet clay and loams should be tight-sheeted using plywood sheets on each side of the shoring jacks, or with the plywood actually attached to the jacks. Reinforce the jacks with stout 3- x 12-inch timbers if necessary.



Shoring jacks
Figure 8-13

Firm, fairly dry clay tends to crack some distance from the trench wall. You can hold dry firm clays and loams using jacks without tight-sheeting.

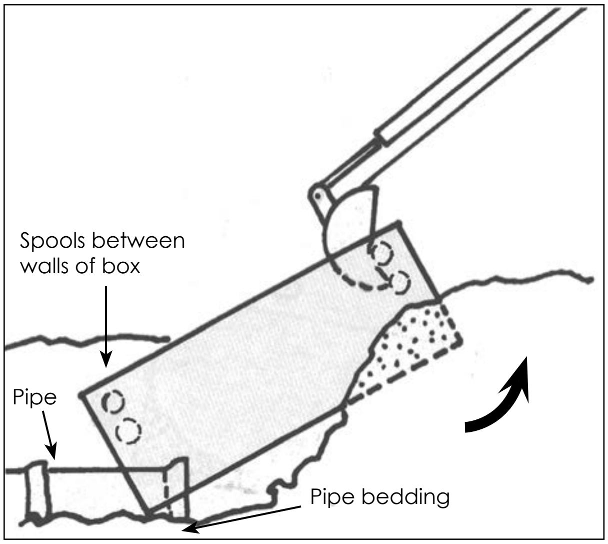
Wet sands and gravels tend to slide into the excavation at about a 45-degree angle. They're not stable enough to allow time to place shoring jacks or sheets, so it's best to use a trench box.

Let's look in detail at the three common shoring methods: the open ditch, shoring jacks and the trench box.

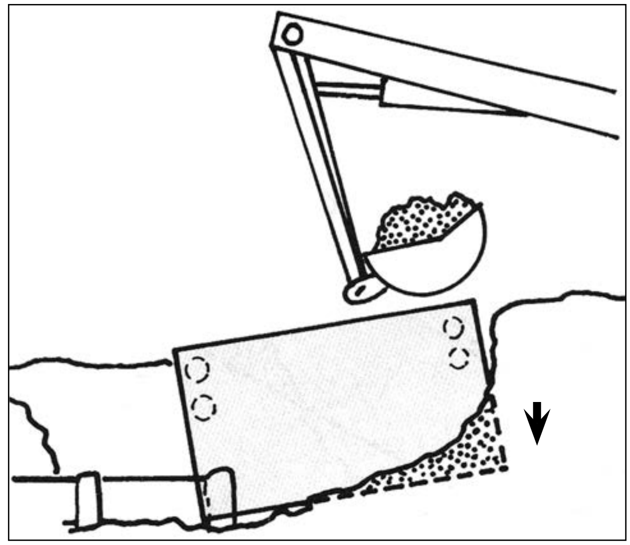
Open Ditch — In shallow excavations where large-diameter pipe requires a wide cut, you may be able to use the open ditch method. The trench walls are sloped back to prevent the tops of the walls from falling in. Use an open ditch in undeveloped areas and *only in reasonably dry, stable soil* where there's little risk of wall collapse.

Shoring Jacks — If the soil is firm clay or loam, shoring jacks are the best choice. See Figure 8-13. They're a quick, efficient shoring system because the excavator can work continuously. Be sure you have enough jacks on hand to keep pace with the excavator. You may even need to use more than one worker to move and set the jacks.

Where the ground is slightly unstable, but stable enough so the trench wall will stand while the jacks are being placed, use plywood sheeting between the jacks and the trench wall. This will increase your labor costs but is



Pulling trench box forward
to next section of trench
Figure 8-14



Excavating between walls of box and shoving
box down into position
Figure 8-15

much cheaper than restoring a cave-in or sending a worker off to the hospital in an ambulance.

> ***WHEN DIGGING TRENCHES*** in damp clays and loams, imported backfill is often specified because the clay and loam are hard to compact. Sand, gravel and crushed rock are the most common imported fill materials — and they're usually expensive because they have to be hauled in.

Trench Boxes — For deep trenches and unstable ground, a trench box is the best shoring system. It's a large mobile box with enough strength to withstand the side pressure of deep excavations.

Sometimes the trench can be dug ahead of the box and the box simply pulled forward into the next section of trench. See Figure 8-14. But when the ground is extremely unstable, first excavate the top few feet and place the trench box in position to begin. Then excavate *between* the walls of the box, as shown in Figure 8-15. As the backhoe excavates material from between the walls of the box, it shoves the box down into position.

A disadvantage of the trench box is that there isn't much room for the pipe layer to work, especially when the pipe layer and the hoe bucket are in the box at the same time. The obvious danger is that a worker can be trapped and crushed by the hoe bucket. For this reason, *the operator must never maneuver the hoe bucket unless he's 100 percent sure of the position of workers in the box.*

As the trench box is pulled ahead in unstable ground, the trench will collapse behind the box. A pipe layer can be trapped by loose material as it flows into the rear of the box. The pipe layer should have enough confidence in the box so that he doesn't run out of the box into an unshored trench. It's definitely *more* hazardous outside the box than inside it, even if the box is temporarily tipped and slammed by falling material.

Trench box walls are at least 6 inches thick. When the box is set below the bottom of trench grade, it creates voids that fill with soil or pipe bedding material when the trench box is moved. This natural filling activity due to side pressure can pull the pipe out of position. So it's important for the grademan to minimize the risk by making sure the box isn't set too far below trench grade.

One variation on the trench box is an open cage framework consisting of steel beams with no top, bottom, sides or ends. It's placed in the top of the trench and then steel or aluminum sheets are driven down each side of the cage as excavation progresses. The strong cage holds the shoring sheets in place. Since the cage and sheets can be handled separately, this system has the advantages of a trench box, but it's lighter weight and offers more flexibility.

Before we make a final shoring selection for our sample project, let's look at some criteria for successful digging and see how the shoring system can affect your digging production rate.

Digging Trenches

To maximize production when you're excavating, it's important that your excavator be able to dig continuously with as few delays as possible. The operator must be able to excavate accurately and avoid crosslines. To choose the best shoring system, you must calculate the trench volume and digging rate correctly. Let's take a closer look at each of these points.

Continuous Digging

The fewer delays you have during excavation, the higher your production rate will be. Of course, efficient production means greater profits. Help your operator avoid production delays. Before trench excavation begins, prepare the jobsite properly and make sure all necessary materials are on hand, including an adequate shoring system.

Staying on Grade

A skilled tracked hoe operator can excavate to a tolerance of 0.1 foot ($^1/_{10}$ foot, or 1.2 inches). That takes precise control. But knowing how to maneuver the equipment isn't enough. The operator must be able to clearly see the work or communicate with the pipe layer or grademan using hand signals to guide him around obstacles.

The pipe layer uses the laser beam as a reference point. When the excavator bucket is close to the desired grade, the laser beam will appear on the bucket. If there are high spots, the beam will appear on the unexcavated dirt. Using the beam as a guide, the pipe layer can direct the operator to a very fine tolerance. The pipe layer's guidance should prevent excavation errors and boost production.

Track hoe operators have a difficult job. It's hard to excavate to grade accurately when the hoe bucket is 15 to 30 feet away from you. A grademan is essential for the track hoe operator. Different operators and grademen use different hand signals to communicate with each other. The exact signals aren't important. What's important is that they communicate effectively.

Avoiding Crosslines

The grademan has to give hand signals to avoid crosslines because the operator often won't be able to see them. A backhoe can break most crosslines with ease. The pipe crew should help the operator avoid damaging crosslines by marking their location well ahead of the excavation equipment.

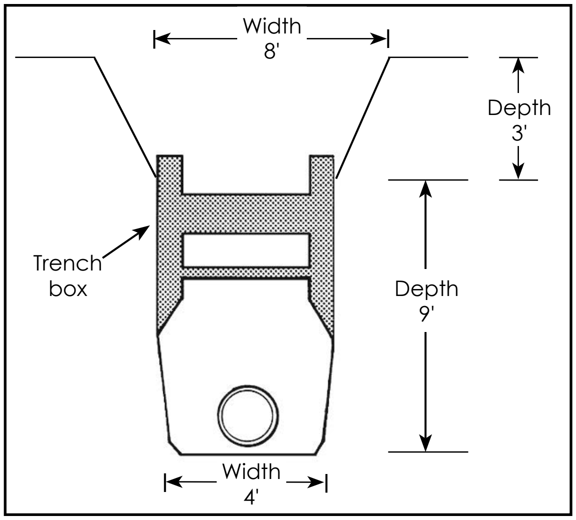
"The grademan has to give hand signals to avoid crosslines because the operator often won't be able to see them."

If the operator knows in advance the exact depth of the crosslines, he can safely excavate above and below that depth. The pipe layer can help by signaling the depth and exact location of the lines when the hoe bucket gets close. The operator should slow the machine so it can be stopped in time if the crosslines aren't exactly where they're supposed to be.

Teamwork is essential. An alert grademan keeps track of crosslines so his operator can concentrate on getting maximum production. If either member of the team isn't doing his share, both will fail. Stress the importance of teamwork with your crew.

Calculating Trench Volume

The size of the pipe and the type of shoring system you use will determine the volume of material you take out of the trench. Even when the pipe diameter is the same, a change in the shoring system makes the trench a different size.



Trench box volume components
Figure 8-16

Recall from Chapter 2, and earlier in this chapter, that vertical wall trench volume equals the trench depth multiplied by trench width and trench length. Dividing that total by 27 will convert the volume to bank cubic yards.

Using the dimensions for our sample project, let's do the trench volume calculations assuming we're using shoring jacks and the trench is 2½ feet wide. Remember, we're going to dig, lay and backfill for 3,000 linear feet of 10-inch sewer pipe. Average depth is 12 feet.

Multiplying 3,000 by 2½ and 12, we get 90,000 cubic feet. Dividing that number by 27 yields 3,333 BCY for the trench volume.

Instead of shoring jacks, suppose we're using a 4-foot-wide x 6-foot-high trench box for our project. It would look something like Figure 8-16. The bottom of the trench is 9 feet deep and 4 feet wide. The top portion is 3 feet deep, and the average width is 8 feet. In this case, the trench volume calculation would be:

$$\frac{(9' \times 4') + (3' \times 8') \times 3{,}000'}{27} = 6{,}667 \text{ BCY}$$

If we were to use an open trench that's 2½ feet wide at the bottom, and slope the walls back at a 1 to 2 slope (1 foot horizontal to 2 feet vertical), the average width is 8.5 feet and the trench volume calculation would be:

$$\frac{8.5' \times 12' \times 3{,}000'}{27} = 11{,}333 \text{ BCY}$$

Notice the dramatic increase in bank cubic yards of volume: 3,333 BCY for shoring jacks, 6,667 BCY for a trench box, and 11,333 BCY for an open trench with sloped sides. And the open trench would entail greater surface restoration. It'll be easier and cheaper to move 3,333 than 11,333 BCY, but don't forget to consider the time required to move and reset the shoring jacks or the trench box. If you use two extra men to move the jacks, the hoe could have virtually uninterrupted trenching.

Calculating Digging Rates and Times

Now that we know the trench volume for each of the three shoring options, we can calculate the actual digging rates and times. We'll use a tracked backhoe for this job. Remember from Chapter 2 how to calculate backhoe production rates. For the purpose of this example, we'll estimate a 40-second cycle time for the shoring and trench box systems using a 2 LCY bucket. That translates to 90 (3,600 sec/hr ÷ 40 sec/cycle) cycles an hour.

Next we need to apply a swell factor to convert the BCY of trench volume to the LCY of bucket capacity. Referring to the conversion table in Chapter 2, 1.28 is the swell factor for moist common earth. That means our 3,333 BCY would swell to 4,266 LCY. Likewise, the 6,667 BCY excavated for the trench box would swell to 8,534 LCY and the 11,333 BCY would swell to 14,506 LCY.

The hoe is fitted with a 2 BCY bucket. Since we're digging in moist common earth (loam), the heaped capacity will be about 110 percent of the hoe's struck capacity — which comes to 2.2 LCY. Multiply 90 cycles per hour by 2.2 LCY to get 198 LCY per hour *before* we adjust for job efficiency and operator ability. Let's use the standard 0.83 factor for efficiency and 0.75 for operator ability. That reduces the production rate to 123 (198 × 0.83 × 0.75) LCY per hour.

To calculate total digging time for the shoring jacks method, divide the swelled trench volume (4,266 BCY) by the production rate (123 LCY/hr). That comes to 34.7 hours. The same calculation for the trench box method yields 69.4 (8,534 ÷ 123) hours.

If we were to choose the open ditch method for this job, the cycle time would be different from the other two methods calculated above. Because there are no space restrictions or delays imposed by the shoring jacks or trench box, assume that the cycle time can be reduced to 20 seconds and the bucket size increased to 3 BCY (3.3 LCY). The machine would produce 180 (3,600 ÷ 20) cycles per hour, or 594 LCY (180 × 3.3) per hour. Adjusting for job efficiency and operator ability, we'd produce 370 LCY per hour. At that pace, the job would require 39.2 (14,506 ÷ 370) hours.

It may seem complex to analyze production rates like this, but how else are you going to make production decisions that maximize your efficiency and your profits? Now you have the data you need to decide whether to use shoring jacks or an open trench with sloped walls for this job.

Bedding the Trenches

Bedding provides firm support for the pipe. This helps protect the pipe from breakage or becoming deformed. The bedding technique you use will depend on whether you're working in an open area or a developed area.

Courtesy of www.shoring.com

Bedding box
Figure 8-17

There are several common methods of placing bedding in trenches in an open area. The first is to use a front loader to dump the bedding material over the edge of the trench. A second option is to use a bedding (rock) box. Figure 8-17 shows a bedding box filled with bedding material that's ready for spreading. A small backhoe (or excavator) is all that's needed to tend a bedding box, which frees up your front loader for other work. The hoe shoves the box, repositioning it along the trench as needed. Just pace your deliveries of bedding material to keep up with the other equipment.

Rock holes offer an alternative to the bedding box method. Rock holes are shallow pits dug at intervals along the line. The pits are filled with bedding material. There's likely to be some waste with this method, but the waste may cost you less than providing the equipment necessary for the other methods. For example, a wheeled loader and operator will cost upward of $600 a day.

Look at how many tasks you've given to your primary excavator. It may not be cost-efficient for him to interrupt continuous excavation to handle the bedding material. But if it's practical to use rock holes, calculate the cubic yards of bedding material needed per linear foot of trench. Generally, the rock holes should be spaced at intervals that will allow full truckloads to be dumped into the holes. If minimal bedding

Courtesy of Woodruff & Sons

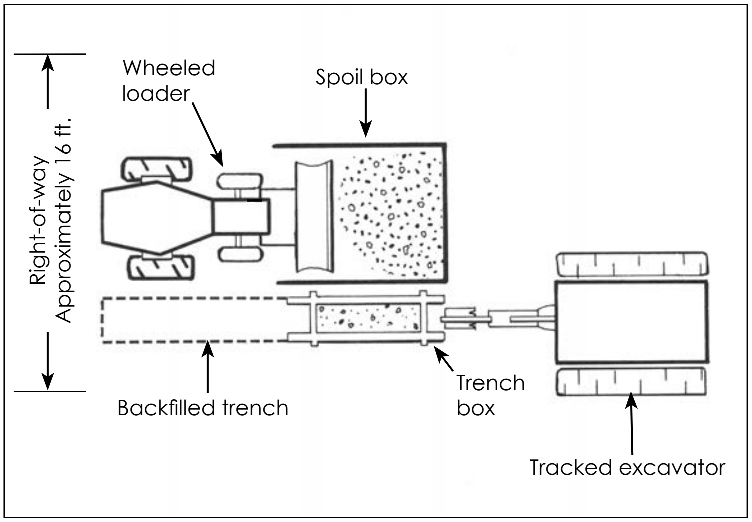
Bedding conveyor
Figure 8-18

is needed and that amount of spacing would be excessive for excavator travel, you can reduce the rock hole size and spacing by half.

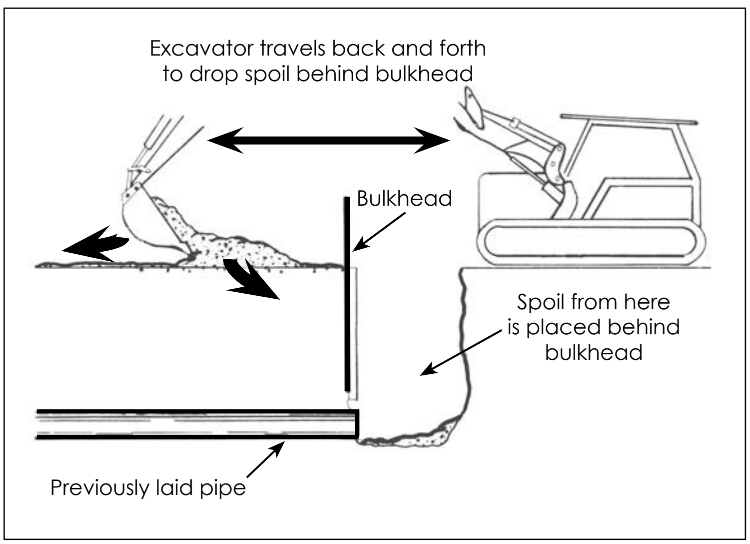
Another trench bedding option is the bedding conveyor. A bedding conveyor mounts underneath the carriage and between the tracks of the excavator. A 3- to 8-cubic-yard hopper, located behind the excavator, stores bedding material and feeds it onto the conveyor. See Figure 8-18. A loader is required to charge the hopper with bedding material. The excavator operator controls the conveyor from inside the cab, so he can place a precise amount of bedding material when and where he needs it. Conveyors are especially useful when the work area doesn't afford a front-end loader enough room to discharge stone from alongside the trench.

Working Within the Right-of-Way

Most subdivision utilities are placed in the street right-of-way. The right-of-way is often narrow. This means your crew doesn't have much room to work. Working in cramped quarters slows production and requires special procedures. It's always tempting to stray beyond the boundaries of the right-of-way. If it's necessary to increase your work area, *get written permission from the owner of the property before you do it.* This will help protect you against costly lawsuits.



Using a spoil box in a narrow right-of-way
Figure 8-19



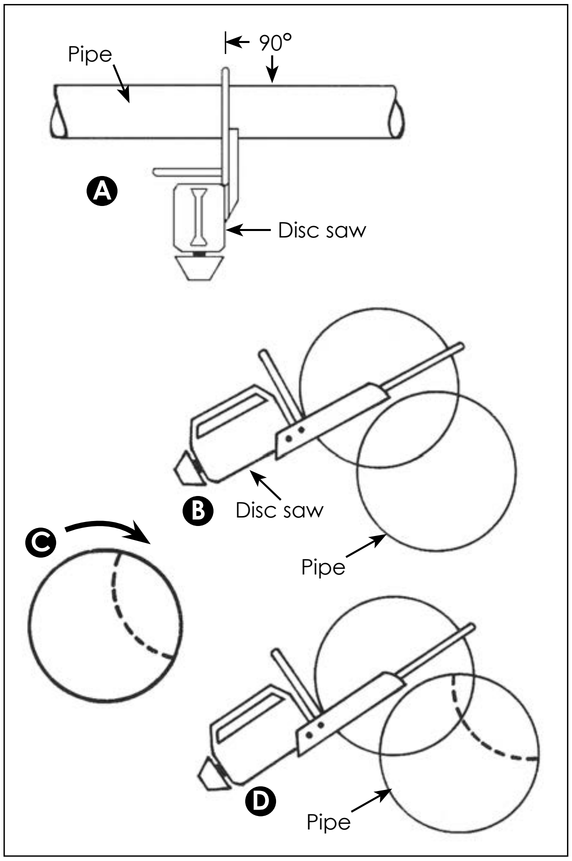
Cut and cover technique
Figure 8-20

If you can't get permission to work beyond the right-of-way and the area available is too small for normal operation, your labor and equipment costs will be higher — perhaps much higher. Be sure to take this into account in your bid.

If you're installing a deep sewer in the two lanes of a street or highway, working room is restricted but adequate. If there isn't enough room to pile the spoil beside the trench, it's most commonly loaded out on trucks. To do this you'll need a right-of-way that's at least 20 to 25 feet wide.

Another option is to use a spoil box, as shown in Figure 8-19. A spoil box holds the spoil within its walls until a loader removes it. Meanwhile, the excavator places new spoil in the box. If you use a spoil box, a bedding box and a trench box with walls extending above the ground in combination, it's possible to install deep pipe in a right-of-way that's only 16 to 18 feet wide.

On rare occasions, you'll be asked to install a line in a 10-foot right-of-way. Here the only option is to *cut and cover.* Cut and cover (also known as *dig and set*) involves placing the spoil from one portion of the trench back over the previously-laid pipe. Figure 8-20 shows how it works. Before entering the narrow right-of-way, all spoil excavated above the first section of pipe is hauled away so there's no backfill over the first section of pipe. Then the spoil from the next section of trench is placed over this pipe. A bulkhead prevents the loose spoil from falling over the end of the pipe. At the last section of pipe, the previously-hauled-off spoil is returned for backfill. This method requires shoring to minimize the trench width, and an excavator with good horizontal reach. If the trench is relatively shallow, your operator might be able to use a wheeled backhoe. But a tracked excavator is usually



Cutting pipe with a disc saw
Figure 8-21

more suitable because it can travel back and forth, making spoil placement easier.

It's easier to negotiate a narrow right-of-way if the soil is clay or loam, making the use of hydraulic shoring jacks practical. A sheet of 1-inch plywood will work well with hydraulic jacks, but a sheet of steel will have a longer life.

Cutting the Pipe

Accurate measuring and cutting are essential in sewer system work. The product of careless measurements and cutting will be leaks. And leaky sewer pipes won't pass the air test. Let's discuss how to cut small- and large-diameter sewer pipe accurately.

For small-diameter pipe, use a disc saw to make a square cut. Don't make the common mistake of rolling the pipe to mark it all the way around before cutting. Here's how to make an accurate cut, using the steps shown in Figure 8-21:

A) Begin by moving the saw into cutting position at a 90-degree angle to the pipe.

B) Holding the saw in this position, make a deep cut into the pipe.

C) Now roll the pipe forward a little bit.

D) Using the first cut as a guide, insert the saw again and make the second cut. For the final cut, roll the pipe forward again and repeat the procedure.

For large pipe, mark the pipe all the way around before cutting. But don't just mark one spot and hold a pencil on the spot and roll the pipe to complete the marking. Make several marks on the pipe by *measuring from the end of the pipe.* Measure each mark separately to make sure they're all equidistant from the end of the pipe. Position the saw at a 90-degree angle to the marks and begin cutting.

The Pipe Layer

Pipe layer wages may not be much better than common labor wages, but pipe laying involves much more skill, experience and responsibility than that of a common laborer. The job involves working with expensive equipment, including lasers, surveying levels, and transits. It requires physical labor, of course, but more often it requires directing the heavy equipment used in deep sewer installation. It also requires an understanding of mathematics, elementary surveying and plan reading.

A deep sewer installation project involves the use of tons of heavy equipment costing hundreds of thousands of dollars to move thousands of cubic yards of earth to install pipe to a tolerance of one or two hundredths of a foot. The pipe layer has primary responsibility for making it all go right.

But that's not all. The pipe layer does all of this in a dangerous environment. Even with the best safety practices, it only takes one small mistake or misjudgment to cause an injury or death. One of the basic rules of industrial safety is to stay out of areas where overhead objects can fall on you. Few workers would deliberately stand under the eaves of a house with framers or roofers working above them. But by the very nature of their work, pipe layers routinely work in trenches 5 to 25 feet deep with other activities going on above them. Besides this obvious risk, the trench itself is a potential death trap. This makes safe shoring absolutely *vital*.

"One of the basic rules of industrial safety is to stay out of areas where overhead objects can fall on you."

In order to get the pipe in the ground safely and profitably, the pipe layers, the topman and equipment operators must work together as a well-coordinated team. There's no room for slips. The work *must* happen as planned. Without the required coordination, it'll be dangerous, it'll be expensive — it'll be a fiasco!

Depending on the excavation rate, the pipe layer may or may not remain in the trench while the hoe digs the next set. If he does, he's at risk from the hoe operator's error. An overfull hoe bucket incorrectly maneuvered can drop hundreds of pounds of earth or rock on him. He's also threatened by error by workers on the surface of the ground. It's this risk that makes the topman a vital part of the team.

The Topman

The topman carries and hands down tools, slings the pipe if it's being machine-handled, checks pipe grade, fuels and maintains pumps, cuts and prepares pipe and fittings, and generally assists both the pipe layer and hoe operator.

Remember, the counterweight of the large tracked hoe swings out and away from the machine's centerline in the opposite direction of the boom and dipper. Because this happens out of sight of the operator, he'll often depend on the topman to let him know whether the counterweight is clearing power poles, traffic signs, mailboxes or other vertical obstructions. So it's the topman who acts as another pair of eyes for the tracked hoe operator.

The topman has a similar duty when pipe bedding is dumped over the edge of the trench. The loader operator probably won't be able to see the pipe layer. The bedding must be dumped accurately or it will displace small-diameter pipe aligned by the pipe layer. So it's the topman who transfers the pipe layer's directions to the loader operator. While the pipe layer, operator and topman each have different jobs, each job is vital.

Laying the Pipe

Pipe can be laid either by hand or by machine. Whether pipe is being laid by machine or by hand, your crew must always handle pipe with care. Most pipe is strong, but any pipe can be damaged by carelessness.

Hand Laying

Most small-diameter pipe is laid by hand. Pipe weighing up to about 180 pounds per length can be laid by hand, if necessary.

Concrete pipe is usually *thrown* into the ditch by the topman. This technique only works when the walls of the trench are nearly vertical. The topman picks up the pipe and swings it (in an upright position) out over the trench. Then he releases it to fall, bell first, onto the pipe bedding. Here's an important rule for all pipe throwers: *Don't throw the pipe until the pipe layer asks for it.* The pipe layer will be preparing the pipe bed and may accidentally walk under a falling pipe.

Never stand pipe up vertically near the edge of a trench. It can fall over into the trench and onto the pipe layer. Long sections of PVC pipe (12 to 20 feet) should be handed down into the trench. And remember that PVC pipe can be fragile at low temperatures and requires extra care.

Machine Laying

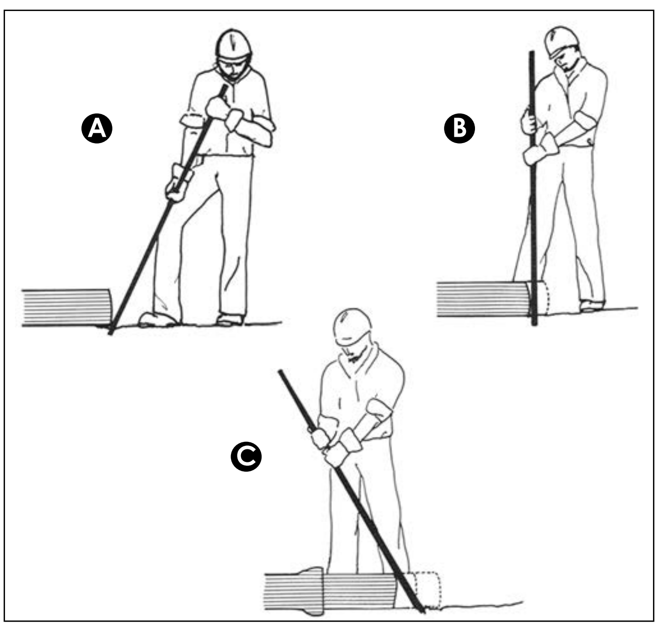
Sometimes the track excavator digging the trench is used to lay the pipe. But this cuts into production time. There are two other machines often used for laying pipe: the wheel backhoe and the crawler pipe layer. A skilled backhoe operator can maneuver his machine very efficiently on a dry, firm spoil pile. And the machine's capacity will allow it to lift and set pipes weighing 1,500 pounds or more. The crawler pipe layer may cost more per hour, but it'll get the job done quicker.

Here's how to calculate pipe laying production rates. Let's say we're using a wheeled backhoe to lay 24-inch by 8-foot concrete sewer pipe 10 feet deep into a 2½-foot-wide trench. Assume it takes 12 minutes to dig a two-pipe (16-foot) set. Remember that a set is a section of trench that can be excavated with the hoe in one position. The time required for a wheeled hoe to dig, bed and lay the set might look like this:

Dig set	12 min.
Bed set	2 min.
Hook, lower and lay pipes	4 min.
Total	18 min.

To calculate how many sets per hour your crew will complete, divide 60 by your per set total (18 minutes). In this case, that's 3.33 sets. With each set being 16 feet, you'll lay 53 feet (16 × 3.33) of pipe per hour.

If the hoe only has to dig and bed (no laying), then it can complete a set in 14 minutes. That's 4.29 sets (60 ÷ 14) per hour. Multiply 4.29 by 16 feet and you get a hoe production rate of 69 feet per hour. This is 16 feet per hour faster than if it had to lay the pipe in addition to digging and bedding it. The savings from the additional 16 feet per hour may be enough to pay for a separate pipe laying machine. Check the cost of each work method before you commit yourself to it.

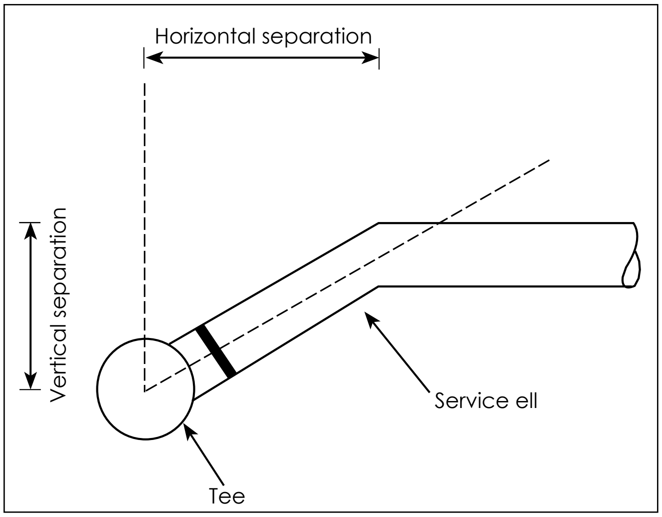


Assembling pipe with a steel bar
Figure 8-22

Assembling the Pipe

The assembly technique you choose will depend on the type and size of pipe being laid. Small-diameter concrete pipe uses roll-over gaskets. It can be shoved together by hand. Small-diameter pipe made of non-PVC material uses slip-type gaskets. A steel bar can be used to shove this type of pipe into position. It gives additional leverage. If the pipe is in the right place, the two sections of pipe can be joined in one smooth motion. See Figure 8-22.

Medium-diameter pipe (10 to 24 inches) requires a different assembly technique. It



Finding the position of the service pipe ell
Figure 8-23

can be suspended from a laying machine and swung into position *(stab joining).* This works well with ductile iron pipe. Or a backhoe can be used to lay it in position and shove it carefully into place.

Joining the Main Line and the Service Lines

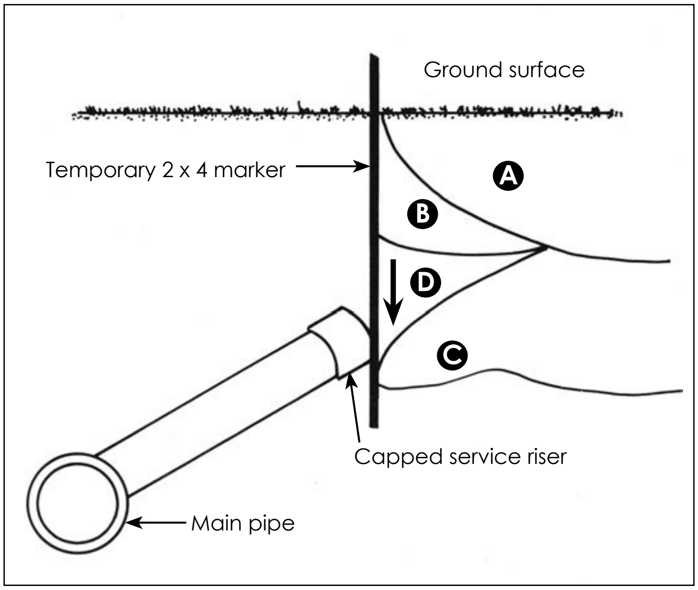
The pipe material will determine whether you install the service lines or the main line first. If the pipe is concrete or clay, the tees are an integral part of the pipe. Location of the tee can vary only by about a foot. The service pipe must be installed after the main line. But if you're using PVC pipe, the placement of the tees is more flexible. This has several advantages:

- The service pipe can be installed before the main line.
- The wheel backhoe installing the service pipe can install it more quickly and easily.
- If the service pipe is installed ahead of the main line, the service pipe trench is dug from the property line back to the main. Service pipe can be laid to grade and in a position that allows easy hookup as the main line passes through.

Having an offset between the service pipe and the main line works fine as long as there's a vertical separation of at least 2 feet between the two lines. See Figure 8-23. When the vertical separation is less than 2 feet, it's hard to get enough "flex" to make a good hookup. In this case, you may want to use the engineer-approved *no-hub coupler* or a *bell-by-bell slip coupler* to join the service pipe.

When your service team is ready to join the service pipe and the main line, the line they're hooking up to should already be well filed and beveled. If it's only been factory-beveled, it needs to be beveled some more. This will make hookup easier. A gasoline or electric abrasive disc (or special beveling tools) can be used to speed beveling on large-diameter pipe. For small-diameter PVC service pipe, a good rasp will do the job. It's always easier and safer to do the beveling above ground and before the pipe is installed.

We've talked about the advantages of installing the service lines first, but there's a disadvantage, too. If the service pipe is installed first, the main line crew has to hook up each service as it comes to it. This can slow production of the expensive main line crew and equipment. It may be



Digging toward a riser
Figure 8-24

more efficient for the main line crew to just install the riser pipe of the service. That's the section of service pipe that rises from the depth of the main pipe up to a level where your crew can install the service pipe to the property line. The service line is usually from 5 to 8 feet deep at the property line.

A smaller, cheaper service crew consisting of a wheeled backhoe, operator and pipe layer can follow behind, extending the services to the property line. It's common practice to dig backwards from the property to the riser pipe. The main line crew marks the end of the riser pipe with a 2 x 4.

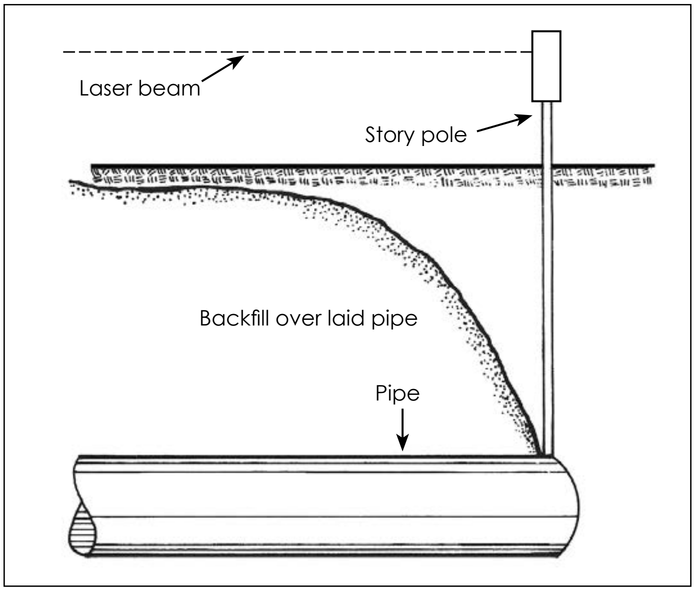
The wheeled backhoe operator has a difficult job: First, the service crosses under curbs and gutters, sidewalks and the other utility main lines. Second, he's digging directly toward the fragile riser pipe. If he damages the riser pipe or pulls it out of the main, it's a disaster.

Figure 8-24 illustrates a safe way to dig toward the riser. The letters represent the digging sequence. Section A is taken out first, then Sections B and C are carefully excavated. And Section D is moved last. The dirt should be shoved down and away from the capped riser. The service pipe layer must closely watch the digging to help avoid damage. In most cases, the wheeled hoe operator can't see into the trench. Hand digging completes the exposure of the capped riser and it's ready for hook up.

As always, teamwork is vital. A good service team can install service pipes at the rate of nearly one per hour. There are some tricks that help production. Rather than excavating completely under sidewalks and crosslines, it may be possible to push a pipe or steel bar underneath the obstruction. Even a 2-inch-diameter hole is enough to get the expander through. An expander can be made out of a length of steel cable attached to a 5- or 6-inch-diameter plug. It's pulled through the smaller hole to expand it enough to get the 4-inch service pipe through. Make plenty of 4-inch couplers available to the service crew so that pipes can be quickly and easily joined.

Aligning the Pipe

Once the pipe is laid and assembled, it must be aligned and brought precisely to grade using a laser beam or an optical level.



Transferring grade with a story pole
Figure 8-25

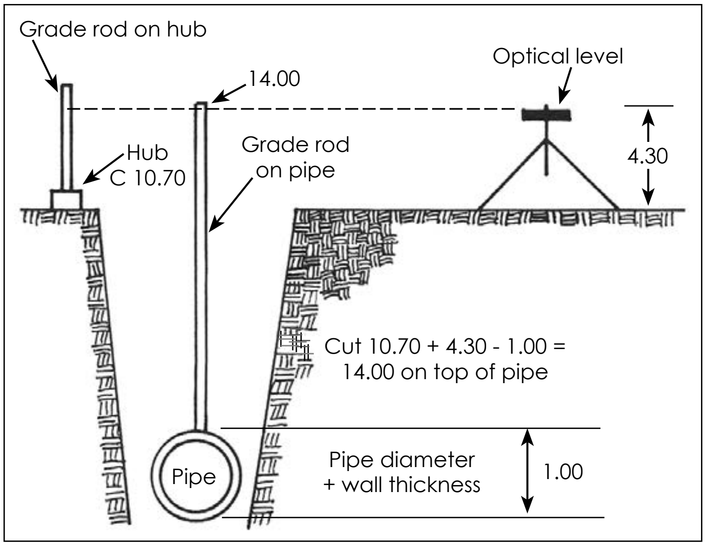
A transit or laser-aligning instrument will set a laser in position and help adjust the beam to line and grade. The laser projects this beam for several hundred feet. The pipe layer uses the beam as a reference point. Wherever the beam of light is intercepted, it shows up as a red dot. The red dot of the laser beam is the reference point that's used to align the pipe on both horizontal and vertical alignment.

But the laser isn't perfect. If you've ever used a high-power telescope, you know that differences in air temperature can distort the line of sight. Differences in air temperatures in a pipeline can deflect the laser beam. Changing temperatures cause the most trouble when you're working in extremely hot or cold weather. Pipe that's been in the ground for several days will have a moderate temperature because it's insulated against the heat and cold. But lengths of pipe that are strung out along a proposed pipeline may be much warmer or cooler.

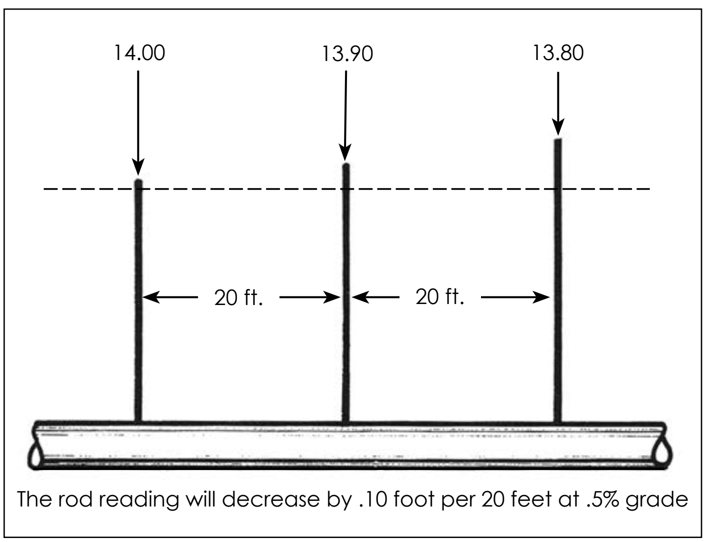
Most laser manufacturers offer an air blower that can be set up adjacent to the laser. The blower moves air through the pipeline. This helps maintain a more even temperature. But the beam may still wander off its true line and grade. Before laying the next joint of pipe, it's wise for the pipe layer to recheck the position of the beam in the pipe he just laid. If the beam is in a different position, it means the beam is wandering. If the beam is moving, he needs to monitor the pipe grade and alignment very closely. He should check the grade every 20 feet and the alignment every 50 feet.

If he's having laser beam problems due to temperature distortions, he can try setting up the laser above ground and using a story pole to transfer grade to the pipe. See Figure 8-25. Let's say he establishes that the laser beam is exactly 10 feet above the top of the pipe. He dials the correct grade into the laser. The rest of the pipe must also be 10 feet below the laser beam. This works well in relatively shallow trenches. In deeper trenches, there's the danger of a false reading if the story pole isn't held perfectly vertical. In general, it's better to correct the problem beam by using blowers, or to *shoot in* each pipe with an optical level.

I covered laser set-up and grade checking in Chapter 3, but let's recap. The engineers provide hubs and a cut figure at intervals of 25, 50 or 100 feet along the pipeline and at each manhole. The pipe layer sets up an optical level, establishes its height above the hub, and then adds



Finding rod reading on top of pipe
Figure 8-26



Checking grade with an optical level
Figure 8-27

it to the cut figure to find the *required rod reading at flow line.* See Figure 8-26. If he sets the grade rod on top of the pipe, he has to deduct the diameter of the pipe plus the thickness of the pipe wall. This gives him the *required rod reading on the top of the pipe.*

Using this information, your pipe layer can calculate the required rod reading on the top of subsequent pipes. If he's laying pipe at 0.5 percent grade, he's raising the pipeline 50 feet per 10,000 feet, 5 feet per 1,000 feet, 0.5 foot per 100 feet, or 0.05 foot per 10 feet. See Figure 8-27.

He can just leave the optical level in the same spot and elevation, deducting 0.05 foot for each 10 linear feet of pipe. When the distance between the optical level and the rod becomes too great, he moves the level ahead, establishes the rod reading from the last pipe, and makes subsequent adjustments from that rod reading.

Be sure your pipe crew understands how to convert the percent grade into *grade difference per joint.* For example, at a 0.40 percent grade, the pipeline rises 0.1 foot per 25 feet. That converts to 0.05 foot per 12.5-foot joint of pipe.

Checking the horizontal alignment is especially important in the first section of pipe. If the pipe is out of alignment, it'll show up near the beginning. And it's easier to correct alignment at the beginning than at the end.

The laser's horizontal alignment is especially critical when your crew is installing small-diameter (6- to 8-inch) pipe. With pipe that small, there are only a few inches for correction before the beam is interrupted by the pipe wall. Laser alignment is less critical when installing large-diameter pipe.

Correcting Alignment Errors

If the pipe is out of horizontal alignment, there are three options:

- Laying to a curve: Some inspectors will allow a slight curve in the pipe. But laying pipe to a curve is difficult because the laser can't be directed around the curve. This means constantly resetting the laser or *shooting in* with an optical level as each pipe is laid.
- Installing an additional manhole: You can change the direction of the line by installing an additional manhole. If the problem was caused by your error, it's not likely you'll get paid for the manhole. But it's not always the contractor's error. The engineer's surveying team may have made an error that caused a misaligned pipe. In that case, you can demand payment for the extra work and for any loss incurred because of it.
- Starting over: You can always begin again. This can be an expensive option. But if the error is caught early enough, it may be less costly to start over than to continue laying to a curve or to install an additional manhole.

In any case, get full approval by the engineer's inspector before you make a decision on how to correct the problem.

Installing Manholes

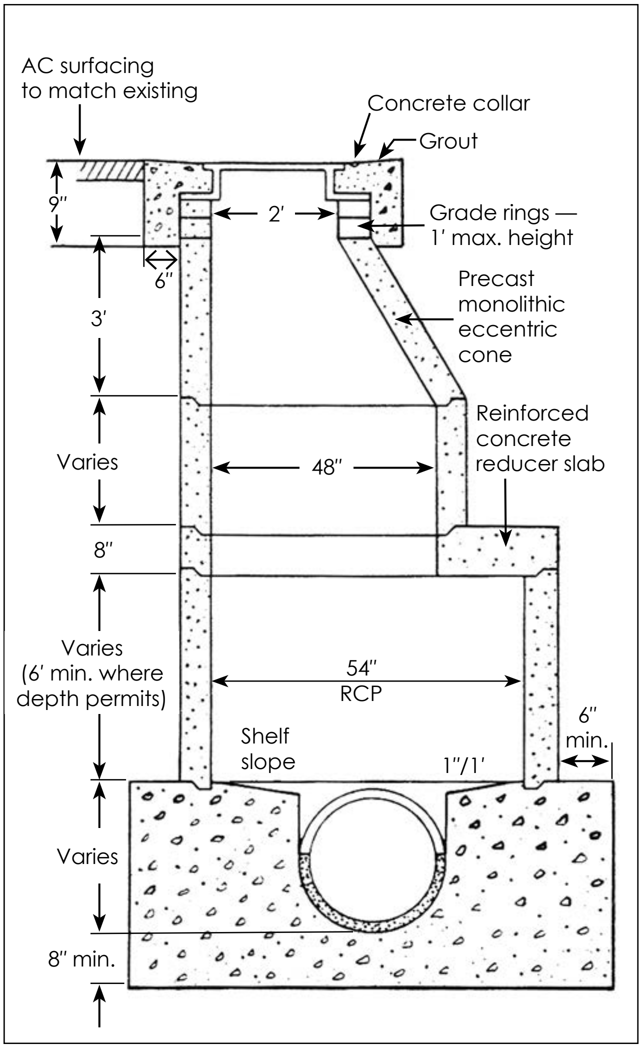
Manholes are used to change the direction of lines and at intersections of lines coming from different directions. Excavating for manholes requires special techniques. Teamwork between the operator and pipe layer is especially important.

When a pipeline goes straight through the manhole, excavation is rather simple. Where the pipeline makes a 90-degree turn, however, the equipment operator should try to do as little excavation as possible to minimize the amount of surface restoration that's needed. The operator will have to rely on the pipe layer's directions to excavate the manhole accurately.

Blockages are rare in a well-designed, properly-installed sewer system. But access is still needed to be able to get into the system easily to inspect, monitor, clean and repair it. All gravity sewer systems require manholes at specified intervals. The most commonly used manhole material is precast concrete. Figure 8-28 shows a section drawing of a typical manhole. A manhole has three main parts: the section, cone and base.

Section — Precast manhole sections are usually 4 or 6 feet in diameter and 1, 2 or 3 feet high.

Cone — This is the top section of the manhole. It's usually 2 or 3 feet high. There are two types of cones, *eccentric* and *concentric*. The eccentric



Typical manhole section
Figure 8-28

cone has a top opening set off to one side of the circular section. The concentric cone has a top opening in the center of the circular section. Use the concentric cone for the shallower manholes. Flat-top manholes are also available for very shallow trenches and special purposes such as lift stations.

Base — This is the bottom section of the manhole. Precast bases are available with or without precast channels. Precast bases must be set to a precise elevation. In shallow manholes and on firm ground, it's easier and more economical to use ready-mix concrete for the base, and to set the precast sections on top of it. Here are three ways to handle this:

- Set a 1-foot precast section up on blocks and pour the base inside of and around it.
- Pour the base, form the channels and place a 1-foot precast section on the base before the concrete hardens. Use this method in shallow work and dry ground.
- In deep, wet trenches, specifications usually demand that a base of drain rock is used as a foundation; and that adequate shoring is used, such as the manhole shield shown in Figure 8-29. Removing the trench box is difficult in deep, wet ground because it has to be lifted straight up. This requires a large backhoe or crane. Another way to shore the deep trench is with interlocking steel sheets driven into the ground.

Controlling Groundwater

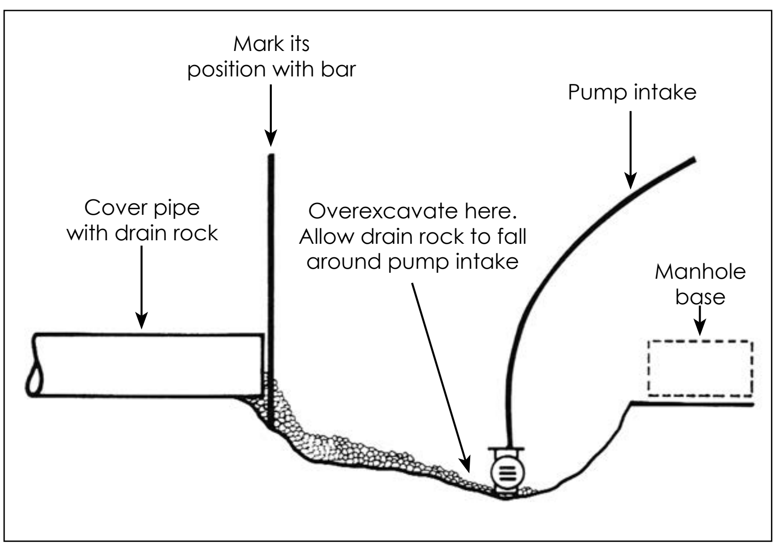
In high groundwater, manhole excavation can be slow and tedious. You'll probably have to excavate a couple of feet below pipe grade to allow enough depth for the manhole base. If high groundwater is a problem, digging that extra foot or two below pipe grade can draw a lot of water, even if water is being controlled at the level of the pipe bed.

Courtesy of www.shoring.com

Manhole shield
Figure 8-29

Groundwater in sand and gravel makes them almost fluid. An inexperienced operator may make the mistake of trying to excavate too quickly. A big hoe can scoop out the spoil very quickly. But any splashing in the hole will cause more subsidence. Excavation becomes a never-ending process as banks undermined by the water collapse into the hole. Figure 8-30 shows a workable technique. Here are some other ideas that will help when digging in groundwater:

1. Try to get a pump below the water table to dry out the excavation.
2. Keep the pump intake clear by surrounding the pump intake in drain rock, or by placing it in a slotted pipe.
3. Drain rock helps stabilize running sands and gravels. Use it.
4. If you don't have shoring wide enough to adequately shore a manhole excavation, open it up. Slope the excavation walls back to a safe angle.



Excavating for a manhole
Figure 8-30

Even with adequate shoring, controlling the groundwater while the concrete sets is often a problem. One solution is to over-excavate by a couple of feet and set a sewer pipe vertically off to the side of the hole. Surround it with drain rock and place a pump suction hose inside the pipe. This will allow control of the water level during pouring.

In extreme conditions, double up on the pumps and the sewer pipe sump — a leaking manhole in high groundwater conditions is expensive to repair. Deep manhole installation can be profitable only if it's done right the first time.

Testing the System

CONSIDER PLACING a couple of layers of vapor barrier over the drain rock foundation before pouring the concrete. This provides a seal so that the water can't rise up through the base of the manhole if your pump fails.

Specifications usually require pipeline testing to make sure there are no leaks into or out of the system. A faulty system may let sewage leak out or groundwater seep in. Look for both. Throughout this chapter I've stressed the importance of teamwork and precision. The two go together. Teamwork is necessary for precision work. Precision is necessary because everything you install will be tested and may have to be guaranteed for at least one year.

No project is complete until it's been tested and inspected. That's a measure of your team's workmanship. Several different tests are used on sewer lines. Any or all of them may be used on the lines you install.

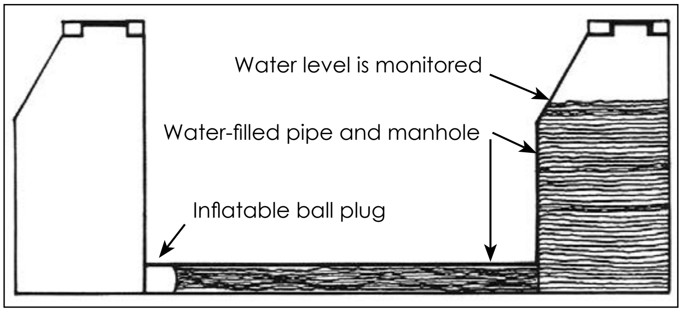
Visual Testing

A common visual test is *lamping* — shining a powerful flashlight through the line. An inspector looks toward the lamp from the opposite end. The inspector can tell if the line is straight and true and on grade, and will see any curves where the line should be straight. Any puddles caused by low spots in the line will also be obvious.

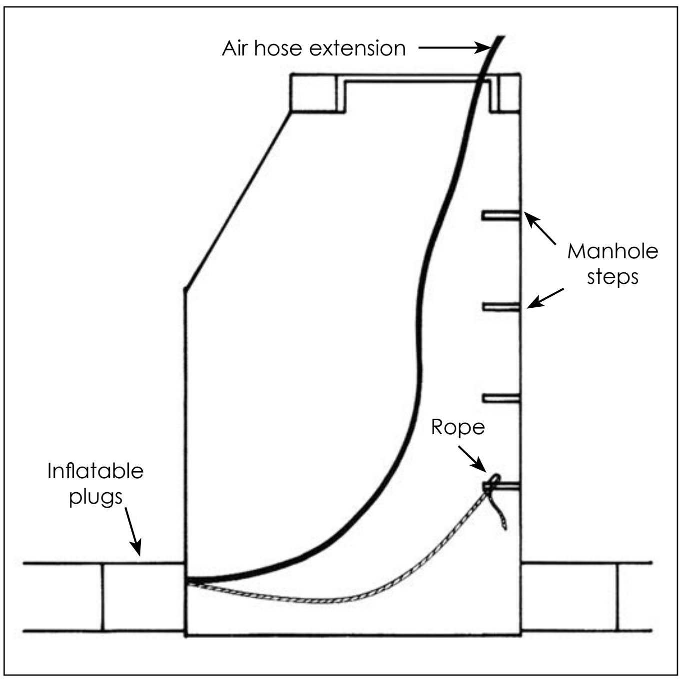
A video camera can also be used to make a visual inspection, especially on curved sections that don't permit direct observation of all pipe between manholes. A camera can examine every inch of the interior of a pipeline. Ponds, puddles, high spots, low spots, joints, infiltrating water, dirt and silt in the pipes will all show up. The inspection can also be recorded: potent evidence if you didn't do something right.

The Mandrel Test

Some pipe materials may flatten or deflect under backfill and compaction. To make sure that this hasn't happened, some inspectors demand a *mandrel test*. This involves pulling a mandrel through the line. The mandrel has a slightly smaller diameter than the pipe and will get stuck if there's been any deflection.



Exfiltration test
Figure 8-31



Extension hose fitted to inflatable plug
Figure 8-32

Water Testing

There are two common water tests: the *infiltration test* to find out if water is entering the pipe, and the *exfiltration test* to see if water is leaking out.

For an infiltration test, the line is sealed off. If water is entering the line, it'll accumulate in downstream manholes. The source of the infiltration can be detected by lamping or video inspection.

For the exfiltration test, portions of the line are isolated and the manholes filled with water. If the water level drops significantly, there's probably a leaky manhole. Figure 8-31 shows how the exfiltration test works. It's easier to place and remove a plug located in a manhole downstream from the manhole being tested.

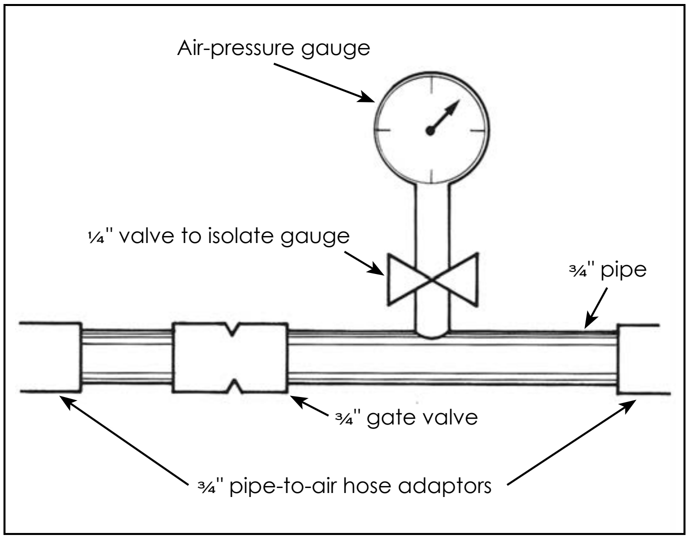
If this isn't possible, you may need to attach an extension hose to the plug so you can drain the flooded manhole you're testing. See Figure 8-32. The air hose extension allows the air plug to be released when the manhole is flooded. The inflatable plugs are tied to the manhole steps to prevent the plugs from being washed down the pipe when the water is released.

Concrete pipe will absorb some water during the test. Don't get excited about the water level dropping during the first 24 hours. It always will. But any fall in the water level after that will probably be due to exfiltration rather than absorption.

Where high groundwater outside the pipe makes infiltration likely, an exfiltration test may not be required.

Air Testing

A pipeline that can hold low-pressure air for a period of time is usually sound. The air test is the most common test applied to newly-completed lines. For an air pressure test, all pipe ends are capped and sealed. Each section can be isolated by inflatable plugs at the manholes. Then air is



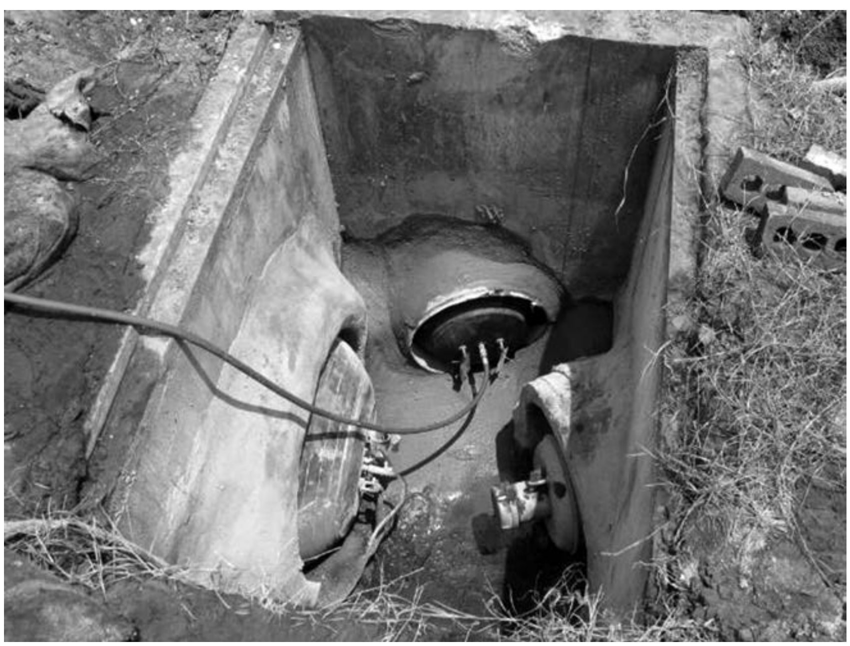
Apparatus to monitor air pressure
Figure 8-33

pumped into the line and the pressure is monitored for a period of time. Exact details for the test should be in the job specifications.

Figure 8-33 shows an air-pressure gauge used to monitor air pressure. It's important to isolate the gauge from the main air line with a small valve, otherwise the high air output from the compressor will damage it.

Inflatable plugs like the one in Figure 8-34 are used for both air and water testing. Air is pumped through the tube in the ball to the pipeline. These large test balls are expensive. As an alternative, you can fabricate larger diameter plugs from wheel centers and inner tubes.

Even though the air test is usually low pressure, from 4 to 10 psi, it can still be dangerous. Always brace large diameter plugs with lumber to prevent air pressure from dislodging them. And use common sense. If



Courtesy of www.shoring.com

Inflatable test plugs
Figure 8-34

you're removing a test ball in a manhole, there isn't much room to get out of the way if it blows from the air pressure. Remember, 10 psi means 10 pounds of pressure *per square inch of surface.*

Cleaning the Lines

When silt and dirt reduce flow capacity, it's necessary to clean the lines. You can use a special flushing ball. It's similar to the test ball but has grooves around the outside which jet water past the outside of the ball. To use it, rapidly flood a manhole so rising water forces the ball and dirt downstream. Then retrieve the ball by reeling in the rope attached to the ball. Pulling the ball back in causes water to jet past the grooves, dislodging silt and dirt accumulated at the bottom of the pipe.

If you need to get a rope through a line, either float a light nylon string downstream or blow a string through with a special parachute-umbrella designed for this purpose. I've also seen an inexpensive battery-powered toy truck do the job: A nylon string was attached to the bumper and the truck was sent down the line. A few minutes later the truck came out at the other end, with the string attached. This works especially well in small diameter pipes, assuming there's not too much debris in the way.

In some cases, you may need to hire a cleaning service with specialized equipment that can flush the lines with high pressure water. This is especially true when dealing with huge storm or culvert pipe, since it isn't practical to plug the pipe.

Backfill, Compaction and Surface Restoration

Backfilling and compaction for your sewer line projects are explained in Chapter 6. Surface restoration can involve landscape restoration, fence removal and paving.

Asphalt surfacing is best left to specialist subcontractors with the equipment and know-how to patch or resurface. The same is true for concrete work. If you have the people and know-how, by all means do it yourself. If not, stick to doing what you do best.

If you have to do much surface restoration, let me recommend an excellent tool that will save hours of hand work with a rake. Have a 4- to 5-foot-wide toothless bucket fit on a wheeled backhoe. A bucket like that will skim spoil off lawns easily. A substitute is a 4-foot-wide by 1-foot-high by 1-inch-thick steel plate bolted or welded to a standard hoe bucket.

[Blank Page]

9

ESTIMATING SURFACE EXCAVATION

Pipeline contractors occasionally need to estimate the cost of grading or leveling land. If you have to bid a job that includes some grading, the formulas used for calculating soil quantities back in Chapter 2 won't be enough. For trench excavation, the quantity of soil to move equals trench length times width times depth. Even if you have to average the depth of the trench, the formula remains the same.

The calculations are a little more complex if you have to compute the volume of soil to be moved when reshaping the land surface, leveling land for a building, or sloping the surface for proper drainage of a road or parking lot. The design engineers will usually show only the existing elevations and the finish elevations. It's up to you to find the quantity of material to be moved. The shape of the surface to be excavated or filled may be irregular, including hills, gullies and depressions. Multiplying the trench length times the width times the depth won't work. That's why this chapter is so important. It will explain the formulas that *do* work when bidding a grading or leveling job.

Calculating quantities for grading and leveling the land surface may be complex, but the work itself can be relatively simple. On a pipeline job you can have a narrow right-of-way, rock, groundwater, and difficult compaction problems. Grading and leveling will be done in relatively open areas, and may only involve the top few feet of soil. And grade tolerances aren't as stringent as they are when laying pipe.

To estimate general excavation, you must be familiar with determining areas and volumes of solids. Most professional earthwork estimators

REMEMBER, A CUBIC YARD of soil is the volume that would fit in a perfect cube 3 feet on each side (27 cubic feet). But a cubic yard doesn't have to be in the shape of a cube. It could also measure 9 feet by 3 feet by 1 foot. Or it could cover 108 square feet at a depth of 3 inches. It's the irregular shapes that make it difficult to calculate volumes.

use a digitizer board and earthwork software to calculate cut and fill volumes, so they don't have to be concerned with calculating areas and volumes by hand. But no computer program is a substitute for good judgment and a "feel" for the mathematics involved in earthwork takeoffs. So let's look at some of the math you'll use.

Calculating Area

Area measures a flat surface: It's two-dimensional (a plane). Calculating area is the first step toward calculating volume, so let's go over the basics. I'll discuss volume calculations in the next section.

A *square* is a simple geometric shape whose base length and height are equal. See Figure 9-1. To calculate its area, we simply multiply its base times its height: for a 5-foot square, 5 feet times 5 feet equals 25 square feet. You find the area of a *rectangle* or *parallelogram* the same way: base times height equals area.

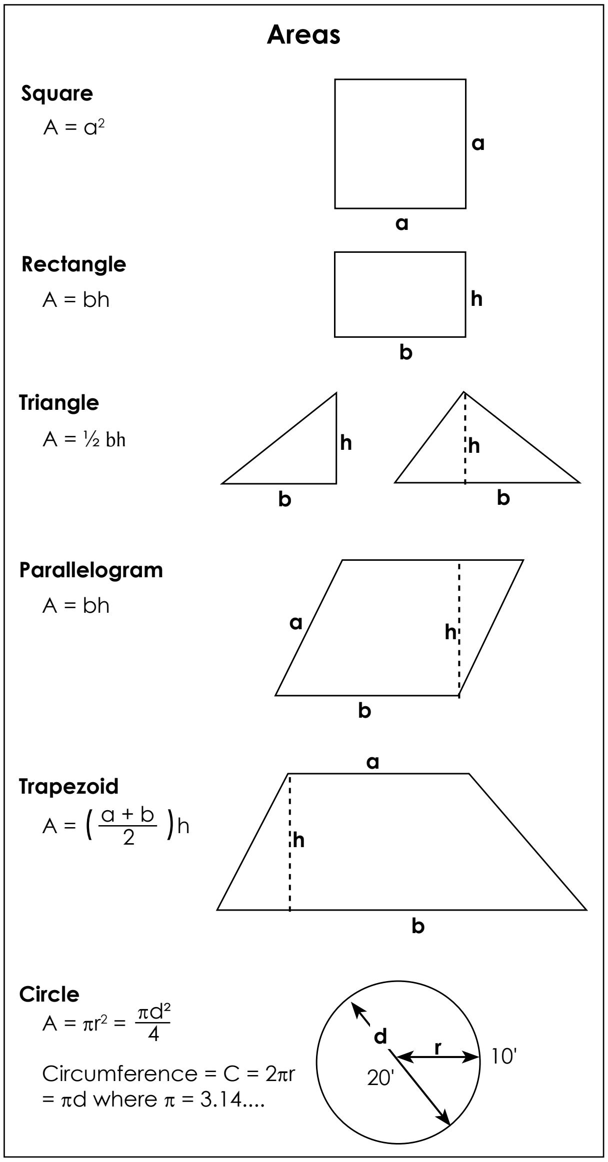
WHEN YOU MULTIPLY a dimension by itself, it's called *squaring* the number. In math symbols, it looks like this: 5^2. Don't be intimidated by math symbols. Mathematicians are efficient and would rather use symbols than words.

The area of a *triangle* is equal to base times the height, divided by two. Rather than memorizing this formula, you can think of a square or rectangle and imagine a diagonal line drawn through it. What you get is two equal-sized triangles. The area of each triangle is equal to one-half the area of the original shape.

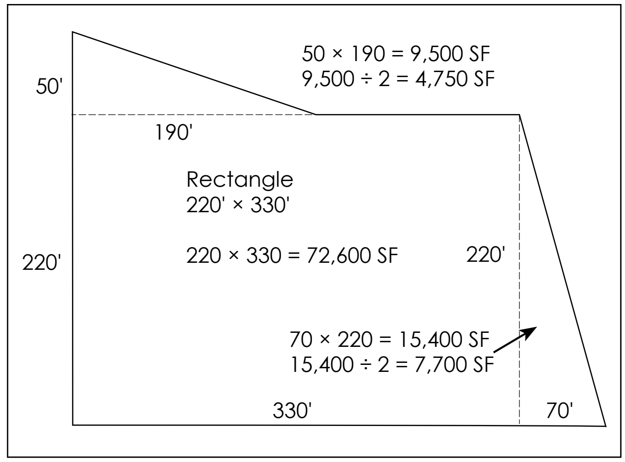
The area of a *trapezoid* is equal to the average lengths of the parallel sides times the height. For example, using the trapezoid in Figure 9-1, you'd need to add lengths a and b and divide that sum by two. Then multiply the result by the height h.

Many site plans have round planters and cul-de-sacs. The formula for finding the area of a *circle* is *pi* times the radius squared. Recall that the radius is simply half of the circle's diameter. You might also recall from high school geometry that pi equals 3.1416, but rounding off to 3.14 is accurate enough for earthwork calculations. So if we have a 48-foot-diameter circle, the radius is 24 feet. The area, then, is 3.14 times 24 squared (24 times 24), which equals 1,809 square feet. You can also use pi to find the circumference of a circle: pi times diameter equals circumference. Again, refer to Figure 9-1.

Here's another formula for finding the area of a circle: square the diameter and multiply that number by 0.7854. For example, if we have a circle with a diameter of 5 feet, the area of the circle will be 5 times 5 times 0.7854, which equals 19.635, or 19.6 square feet.



Areas of various plane figures
Figure 9-1



Finding the area of an irregular shape
Figure 9-2

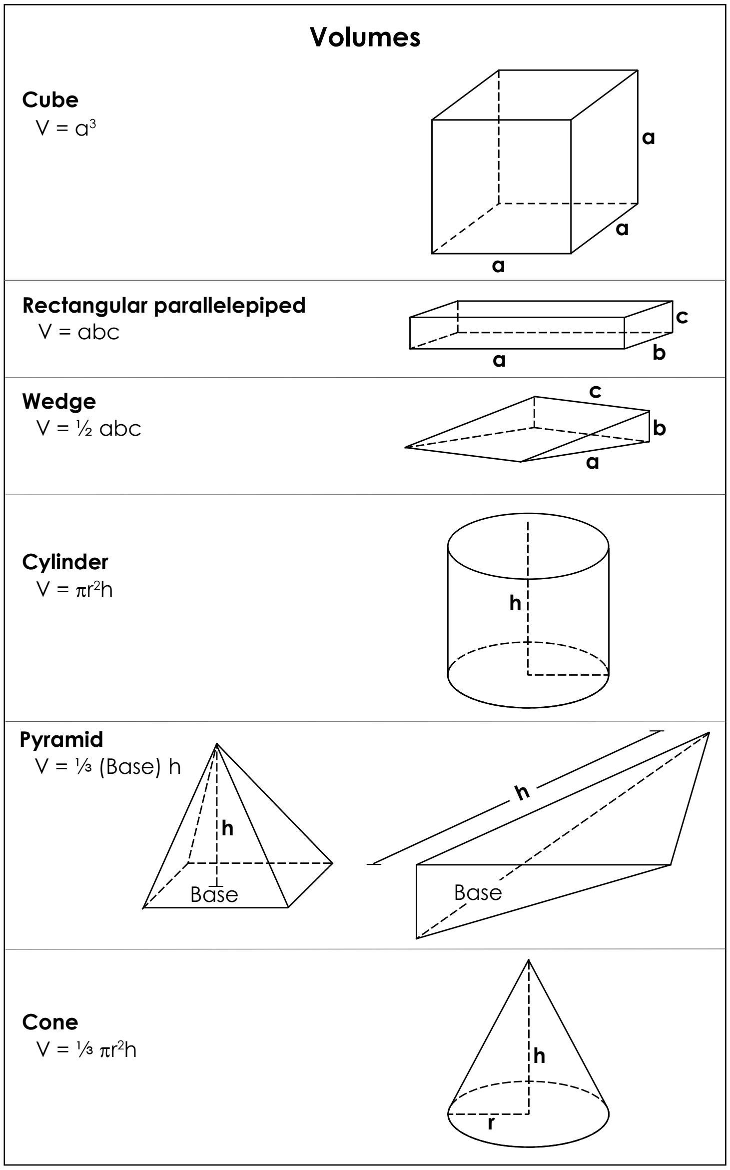
Sometimes you need to find the area of an *irregular shape* like the one in Figure 9-2. It helps to cut the irregular shape into two or more easily-calculated shapes, and then use a combination of formulas. In Figure 9-2, you'd first divide the area into a rectangle and two triangles. Then simply calculate the area of each and add these sums together. In this case, the area is 72,600 SF plus 4,750 SF plus 7,700 SF, or 85,050 SF.

Calculating Volumes of Solids

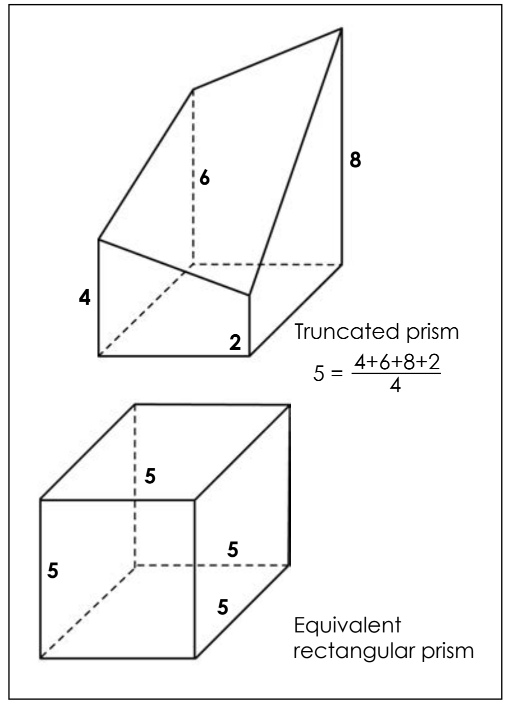
Once you're familiar with calculating areas, you can apply it to volume calculations for solids. A *cube* is a three-dimensional solid whose sides are all equal in length. To calculate a cubic volume: multiply the length times the width times the height. If the 5-foot square we've been talking about becomes a 5-foot cube, its cubic volume is 125 cubic feet (5 feet x 5 feet x 5 feet = 125 cubic feet). In math symbols, that's 5^3.

A *parallelepiped* is shaped like a box (the box may be leaning). The volume of a parallelepiped is equal to the length times the width times the height. See Figure 9-3.

The volume of a *wedge* (a three-dimensional triangle) is equal to half the length times the width times the height.



Volumes of various solids
Figure 9-3

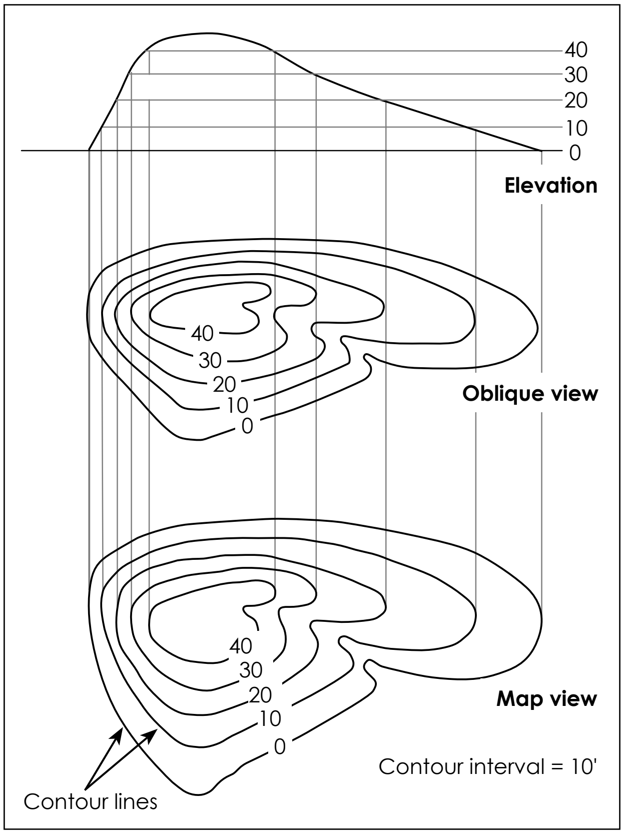


Truncated prism
Figure 9-4

If a circle has depth, it becomes a *cylinder*. It's easy to find the volume if you remember the formula for a circle. Just incorporate its depth (height) into that formula: pi times radius squared times the cylinder's height.

For *cones* and *pyramids*, volume equals ⅓ times the base area times the height of the solid.

When you have a known base area but the height of the shape is irregular, that's a *truncated prism*. This type of solid is the one you'll encounter most often when doing an earthwork takeoff. To find the volume, average the height of the four corners and then multiply it by the area of the base. In Figure 9-4, let's say we have a base of 100 square feet and heights at the four corners of 4, 2, 6 and 8 feet. If you add the four heights together and divide by four, you find an average height of 5 feet. Multiply 100 square feet by the 5-foot height to find the volume — 500 cubic feet. You can divide by 27 to convert cubic feet to cubic yards. In this case, that equals 18.5 cubic yards.



Contour lines and elevations
Figure 9-5

Reading Contour Lines

Before you can estimate cut and fill quantities, you'll need to be familiar with topographic *(contour)* maps and contour lines. A topographic map is a two-dimensional representation of a three-dimensional land form. Contour lines on the map represent the third dimension *(relief)* of the ground surface. See Figure 9-5. A contour line represents points of equal elevation above or below an arbitrary reference *(datum)* plane such as sea level or top-of-slab *(TOS)* elevation. Closely-spaced contour lines indicate a steep slope, while contours spaced far apart indicate a gentle slope. Contour lines rarely cross one another, except at unusual geological features such as overhanging cliffs and natural bridges.

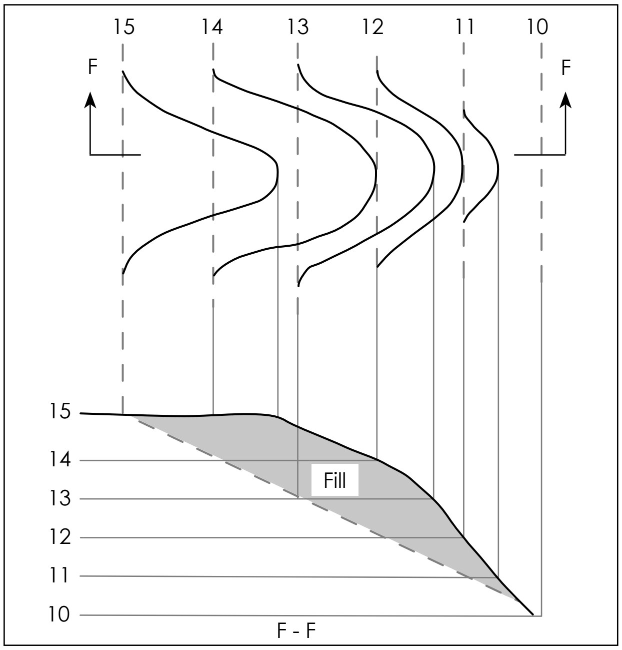
The elevation change represented by two adjacent contour lines is known as the *contour interval (CI)*. The contour interval should remain constant throughout any given contour map. In low-relief areas, the contour interval may be as small as 6 inches; and in areas of great relief, as large as 500 feet.

Existing and Proposed Contours

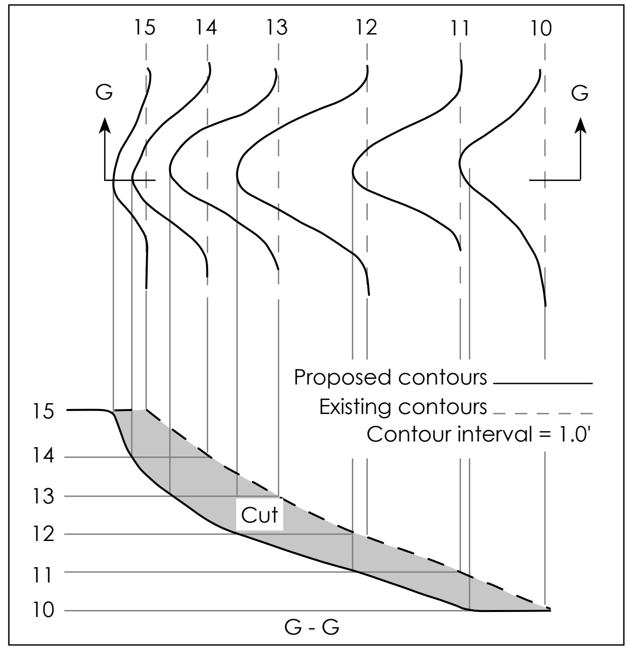
> ***ONE WAY TO GRASP THE CONTOUR*** lines concept is to think of them as rings you can see in the soil around a lake when the water has receded. All points on any continuous ring will be at the same elevation.

The designer draws existing and finish *(proposed)* contour lines on the same site plan, with existing contours normally represented by dashed lines and proposed contours by solid lines. That makes it easy to determine where, and how much, work needs to be done. At the point where a grading change begins, a proposed *(solid)* contour moves away from an existing *(dashed)* contour of equal elevation and returns to the existing contour at a point where the grading change stops. Figure 9-6 shows a cross section, or *profile*, of a proposed contour that moves toward lower existing contours.

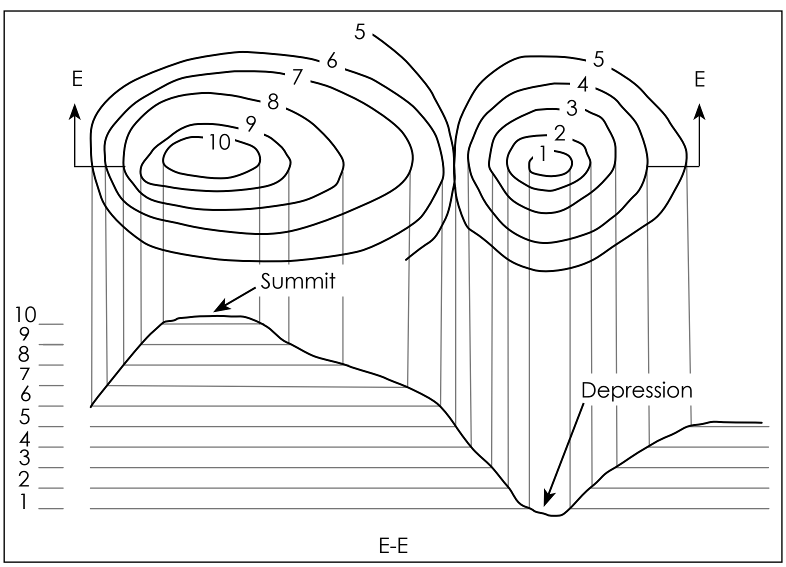
Notice how the proposed 14-foot elevation line extends out and over the existing 12-foot elevation line. That means the existing 12-foot elevation needs to be increased to a 14-foot elevation, indicating the need for filling. By the same token, cutting is required when proposed contour lines move toward higher existing contours, as shown in Figure 9-7.



Proposed contours requiring fill
Figure 9-6



Proposed contours requiring cut
Figure 9-7



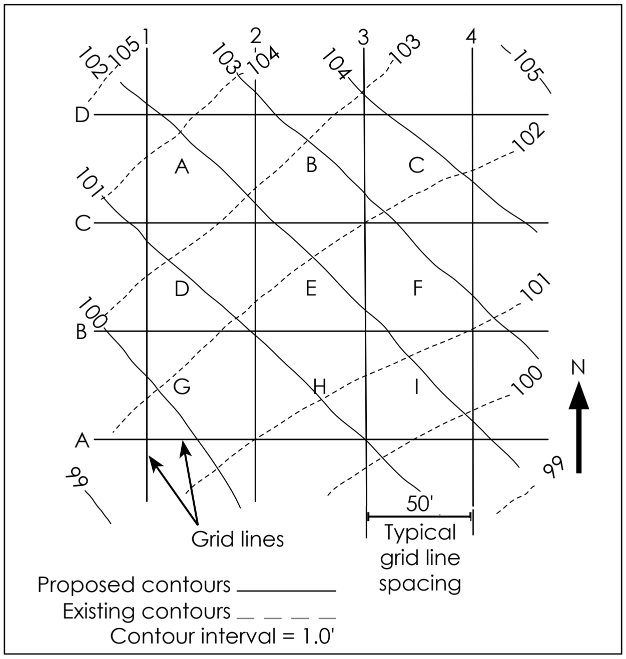
Summits and depressions
Figure 9-8

Convex and Concave Slopes

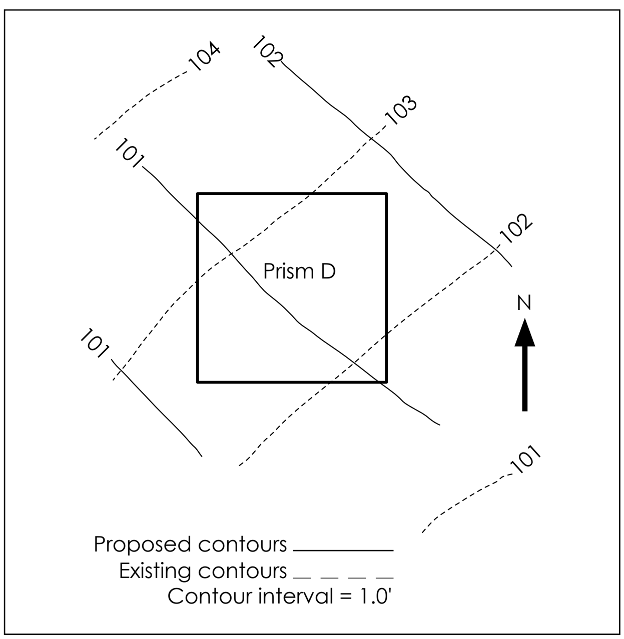
Looking from left to right in Figure 9-6, note the decreasing horizontal space between the proposed contours — especially between the proposed 13-foot and 12-foot elevations. That's an indication that the land surface slope is increasing. The resulting slope is a convex shape that bows outward. Figure 9-7 demonstrates the opposite situation, resulting in a concave slope.

Summits and Depressions

Contour lines that form a closed loop represent either a summit or a depression. The profile in Figure 9-8 shows an example of each. You can distinguish between summits and depressions based on the elevation markings. A summit's elevation mark will be the highest in that region of the contour map, while a depression's will be the lowest.



Site plan transferred to tracing paper
Figure 9-9



Detailed section (prism) of the site plan
Figure 9-10

Estimating Cut and Fill Quantities with the Cross Section Method

In this section, you'll learn how to take off cut and fill quantities by sectioning the site into grid cells and determining the volumes within each cell. You'll also learn how to determine the *zero line* location. Zero lines, also known as *daylight lines,* are imaginary lines that separate cut areas from fill areas. They also show work boundaries — where work terminates at the edges of the site.

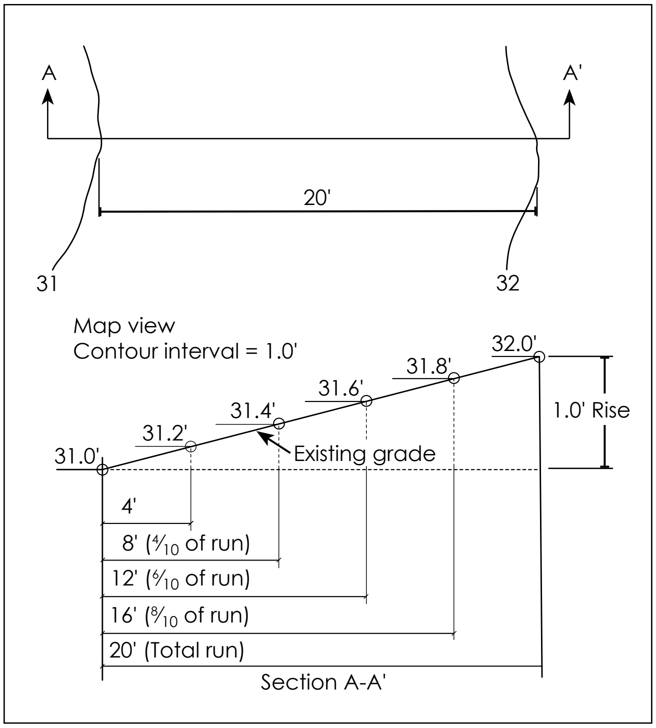
Figure 9-9 illustrates the first step to estimating cut and fill quantities. Tracing graph paper, placed on top of the site plan, allows you to trace the blueprint and incorporate grid lines. The blueprint stays clean, while the tracing paper becomes a record of how the takeoff was generated.

The appropriate grid line spacing depends upon the site's topography (land surface shape) and the required level of precision.

Be sure to grid-off structure areas such as building slabs and paved areas separately from grid cells in the "green" (grassy) areas where there aren't any structures. Proposed elevations in structure areas must be lowered to subgrade in order to get accurate cut and fill quantities. I'll discuss that in more detail later in this chapter.

The *Cross Section Method* is the first cut and fill estimating technique that we'll cover in this section. In a nutshell, it involves cutting the site plan into smaller three-dimensional shapes and calculating the volume of each individual shape. Each shape that represents a cut or fill volume is known as a *prism* or *grid cell*. See Figure 9-10.

For simplicity's sake while performing these calculations, assume that the slope between two existing (or proposed) contour



Contour lines at 31 and 32 feet
Figure 9-11

lines is constant. That means the elevation of any point between contour lines is proportional to the relative distances of the point from the contour lines. If that sounds a little complicated, don't worry. The plan view and cross section shown in Figure 9-11 should help clear things up.

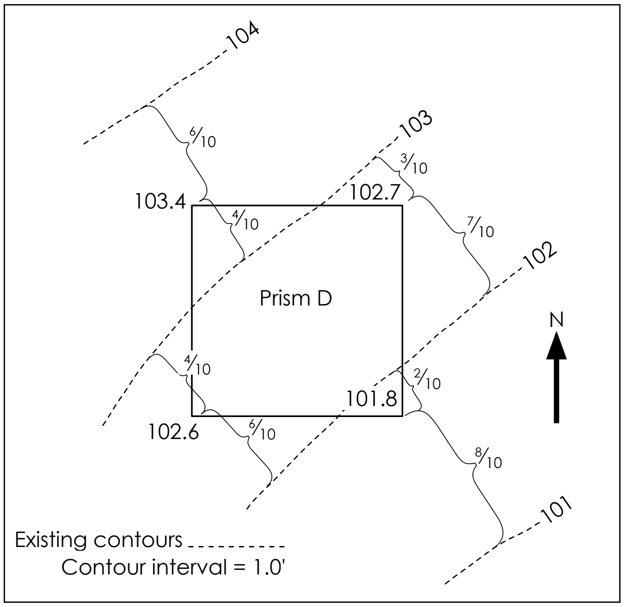
Cross section A-A' reveals a series of five right triangles. The triangles' bases, shown with dashes, represent horizontal distances between contour lines. Each triangle's elevation is directly proportional to the length of its base. For example, the 31.2-foot elevation is two-tenths of the horizontal distance between contour lines 31.0' and 32.0'. Two-tenths of 20 feet is 4 feet of run. Similarly, the 31.8-foot elevation has 16 feet of run. This math works the same way going the other direction, too. You can determine a point's elevation based on its relative horizontal distance between points. The point that's (horizontally) eight-tenths of the way from contour line 31.0' to contour line 32.0' has a 31.8-foot elevation (0.8 times the 1-foot contour interval). Relative distances of a point between contour lines are usually determined by "eyeballing," or with a scale. Another option is the Subcontour Method, which I'll discuss later in this chapter.

If you put the technique I've just described into practice, you find that Prism D (Figure 9-10) has *existing* corner elevations as shown in Figure 9-12. Doing the same for Prism D's *proposed* contours, you get something resembling Figure 9-13. Note the elevations of the top right corner of Prism D in both figures. The existing elevation is 102.7 feet, and the proposed elevation is 101.8 feet. That indicates a 0.9-foot cut depth.

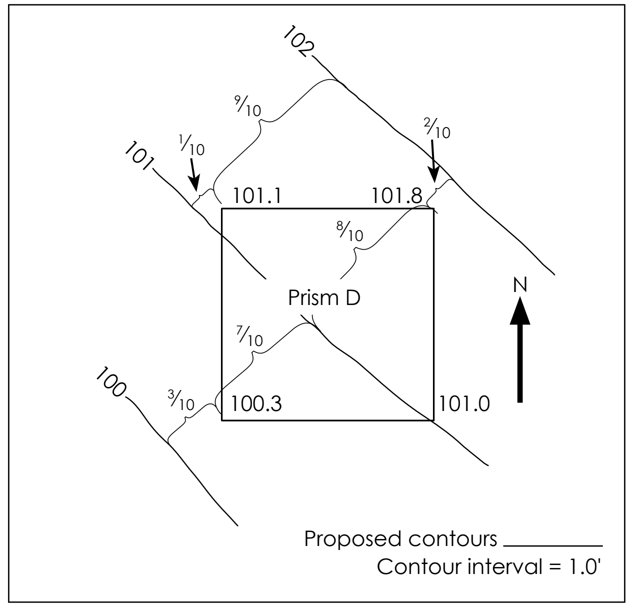
Sometimes it helps to think of a prism in "before" and "after" terms. However, it's not always practical or necessary to re-draw the site plan as two separate drawings. Figure 9-14 shows the entire site plan, with existing and proposed elevations labeled at each grid corner.

Proposed elevations are less than existing elevations in Prisms A, D, and G. Those areas require cutting. Prisms C, F and I call for filling because proposed elevations are greater than existing elevations.

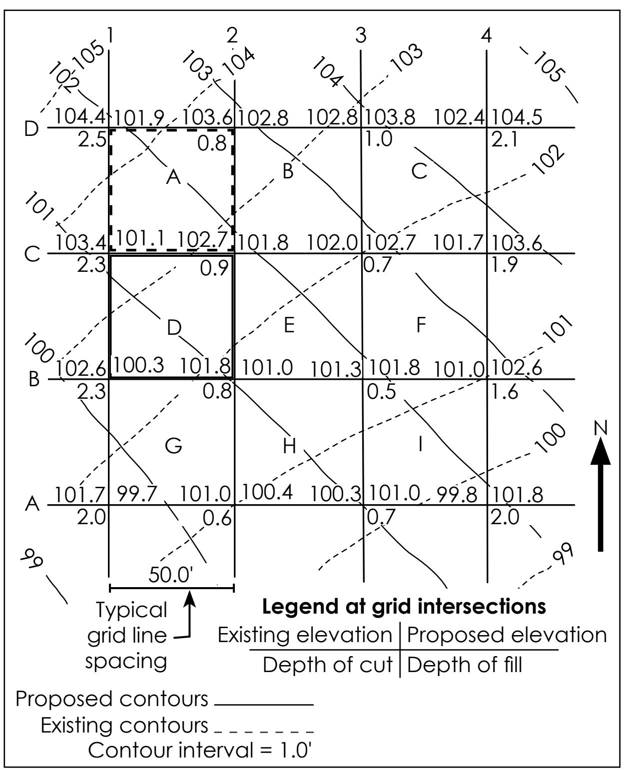
Prisms B, E, and H have areas requiring both cut and fill. Therefore, within those prisms, there exists a line where neither cut nor fill is required. This theoretical line separating cut areas from fill areas is the zero line. It's the heavy dashed line in Figure 9-15. Later in this chapter, I'll discuss the zero line in more detail.



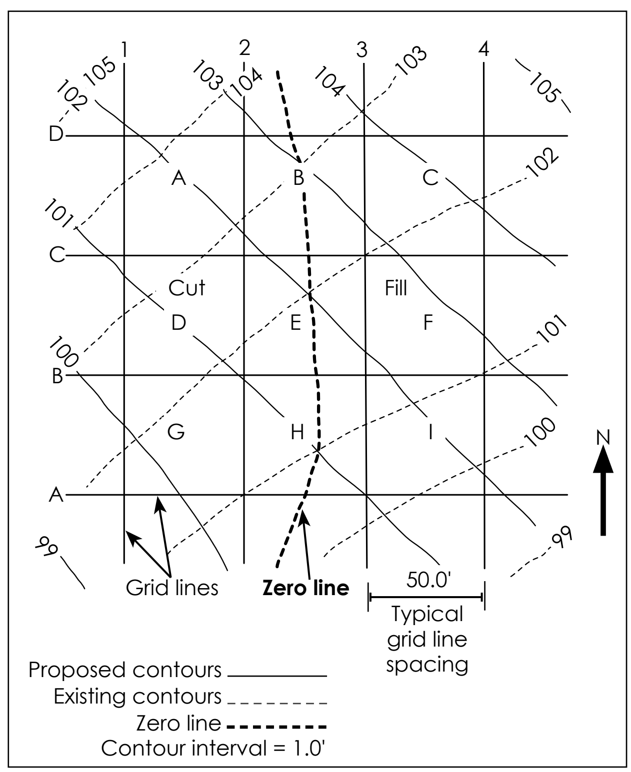
Prism D's existing contours
Figure 9-12



Prism D's proposed contours
Figure 9-13



Site plan with cut and fill requirements
Figure 9-14



Site plan with zero line
Figure 9-15

Now that we've determined cut and fill depth at the grid corners, we can estimate the soil volume to be cut or filled within each prism. First, average the cut and fill depths of the prism's four corners. For Prism D, that means adding 2.3, 0.9, 0.8 and 2.3, and then dividing that total (6.3) by four. The average comes to 1.58 feet. Multiplying the cut depth average by the prism area will give you the prism's volume. The prism's area is 2,500 square feet (50 times 50), so its volume comes to 3,950 cubic feet. To convert that number to cubic yards, divide it by 27, which is simply the number of cubic feet in a cubic yard. In this case, that comes out to at just over 146 cubic yards.

To help get a better sense of how the Cross Section Method works, look back at Figure 9-4. We've taken an awkwardly-shaped prism and converted it mathematically to a rectangular prism of the same volume. Most cut and fill estimating software works on the same principle, except the grid cells are very small. Depending on the size and scale of the digitized drawing, the grid cells could be as small as one square foot.

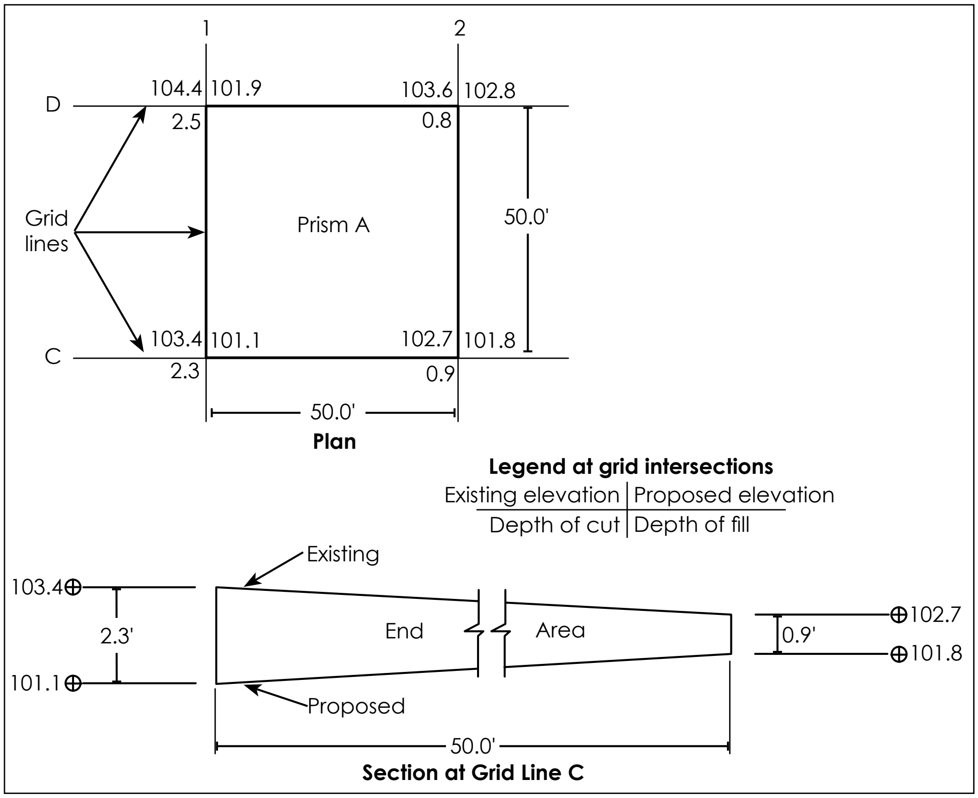
A prism can be any two-dimensional shape when you're estimating cut and fill quantities. But the Cross Section Method only works with rectangular or square prisms. Squares make the math easy, but site conditions such as buildings, parking lots, planters and sidewalks often make it necessary to use triangular or circular grid shapes. Next, I'll show you a way to handle those.

The Average End Area Method

Another good way to calculate cut and fill volumes is known as the *Average End Area Method*. With this method, you take the average area of two parallel cross sections and multiply it by the distance between them.

We can use Prism A from Figure 9-14 to put the Average End Area Method to the test. Grid Lines C and D frame Prism A. The cross section at Grid Line C is diagrammed in Figure 9-16.

The existing and proposed land surface dimensions at Grid Line C form a trapezoid. To calculate the area of a trapezoid, multiply the average length of the two parallel sides by the distance between them. In this case, the two parallel sides are 2.3 feet and 0.9 feet. That averages out to 1.6 feet (2.3 plus 0.9, divided by two). The distance between the two parallel sides is 50 feet, so the area of the trapezoid is 80 square feet. Using the same technique, you'll find that the area of the trapezoid at Grid Line D is 82.5 feet. The average area of the two parallel, adjacent trapezoids is 81.25 square feet. To calculate total cut volume, multiply 81.25 by the distance between the cross sections, which is 50 feet in this case. That comes to 4,063 cubic feet, which is roughly 151 cubic yards.



Prism A top view and cross section at Grid Line C
Figure 9-16

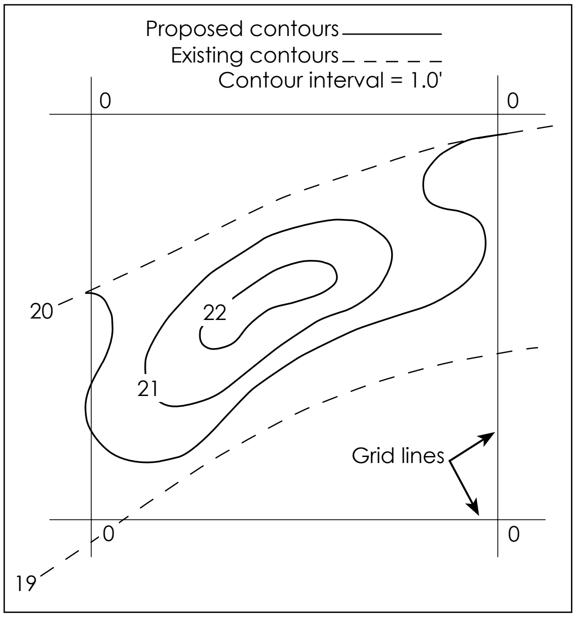
Irregular Regions

The grid square shown in Figure 9-17 indicates that no work is required within the prism. However, the proposed contours imply that the area will require fill. In this situation, the need for fill is overlooked due to the prism's size and shape. Important contour information is "hidden" within prism corners. This is what I refer to as an *irregular* region.

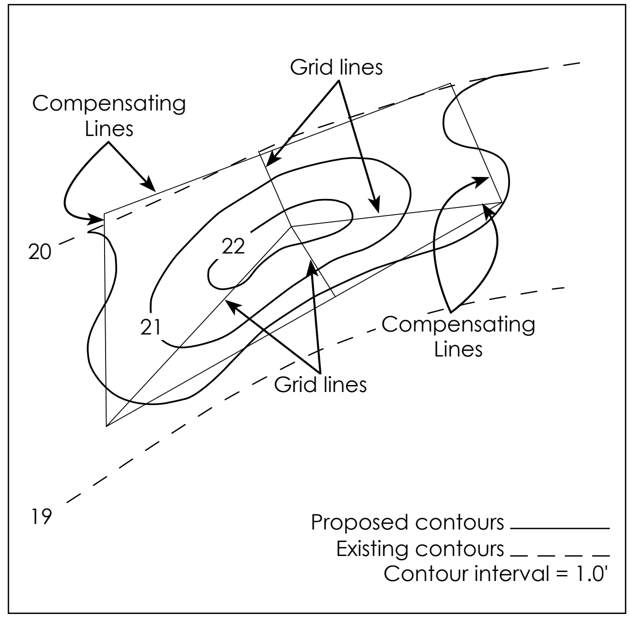
In an irregular region, you need to establish a grid system that captures corner depth information at all points where there is:

- a change in direction of land slope
- a radical change in direction of contour lines
- no activity (zero line)

Figure 9-18 demonstrates one way to grid the region. *Compensating lines* convert an area bounded by curved lines into an equivalent area bounded by straight lines. That allows you to perform cut and fill calculations using the Average End Area Method.



Irregular region
Figure 9-17

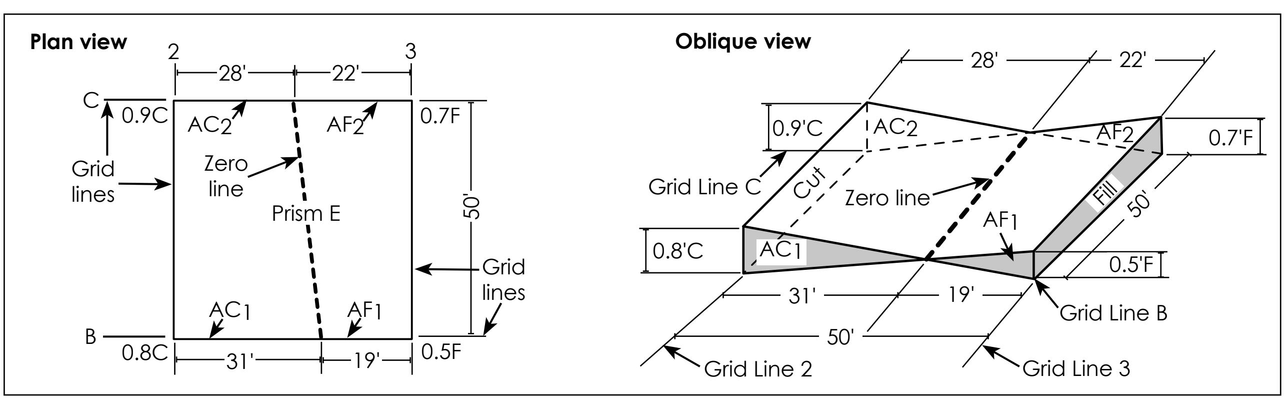


Dividing the irregular region into workable parts
Figure 9-18

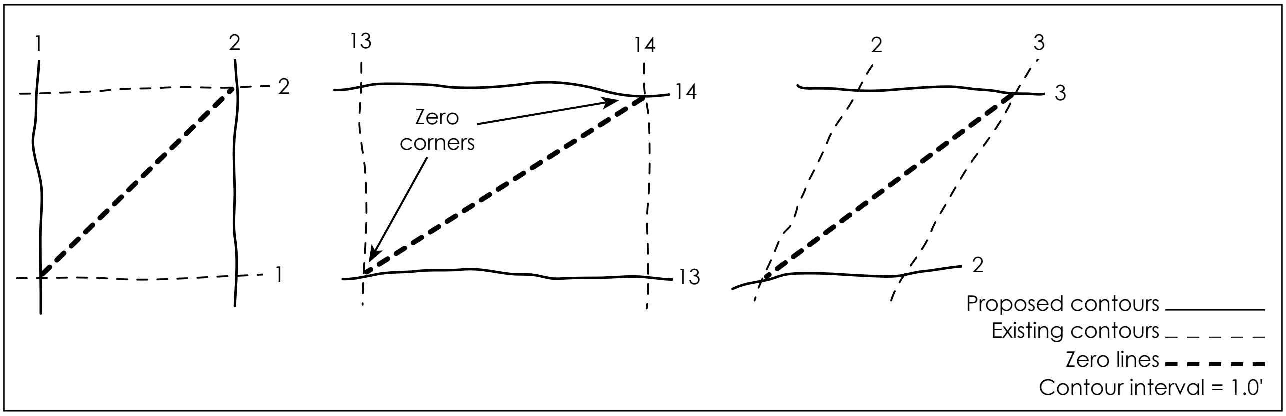
The Zero (Daylight) Line

> ***TO CALCULATE CUT***
> and fill volumes in prisms requiring both cut and fill, use the Average End Area Method.

Some areas, such as Prisms B, E, and H in Figure 9-14, require both cut *and* fill. In this situation, we need to think of the prisms as two distinct sections — one is cut and one is filled. The zero line divides each prism and represents the transition from cut section to fill section. I'll show you an example of how this works. Let's say Prism E has a zero line, as shown in Figure 9-19.



Detailed views of Prism E
Figure 9-19



Zero corners
Figure 9-20

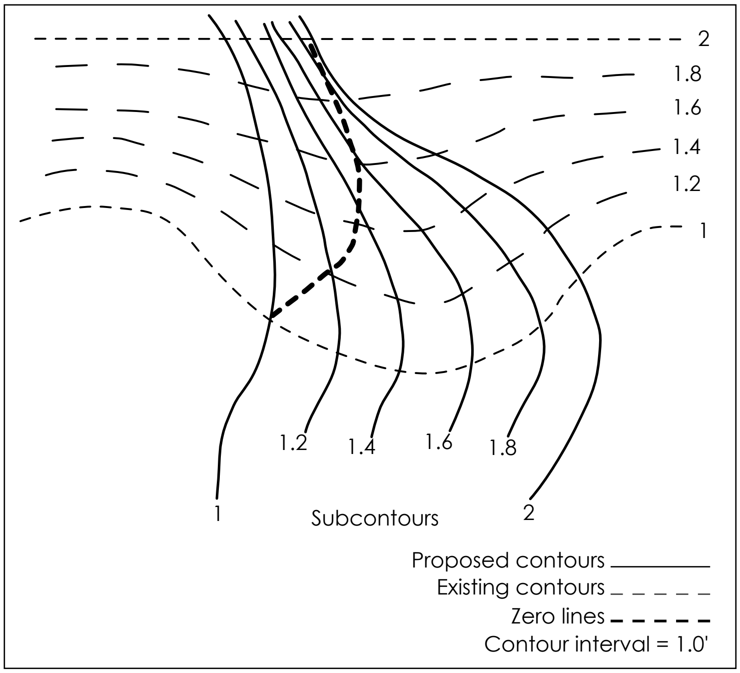
The area between Grid Line 2 and the zero line requires cutting. Using the Average End Area Method, I'll start by finding the area of Triangle AC1. The area of a triangle equals its base times its height, divided by two. For Triangle AC1, that comes to 12.4 square feet (0.8 x 31, divided by 2). Doing the same for Triangle AC2, we get 12.6 square feet. So the average end area is 12.5, and if we multiply that by 50, we get 625 cubic feet for the total cut volume. To get total fill volume, we'll need to do the same calculations with Triangles AF1 and AF2. When all is said and done, the total is 311 cubic feet. So Prism E as a whole will require a net soil export.

Subcontours Help Define the Zero Line

The interaction between existing and proposed contour lines of equal elevation determines the zero line's path. If existing and proposed contour lines (of equal elevation) intersect to form a rectangular- or parallelogram-shaped region (as shown back in Figure 9-14), the zero line will be a diagonal through the region. If the zero line intersects a contour (or subcontour) line, then there will also be an opposing contour (or subcontour) line of equal elevation located at the point of intersection.

One way to determine zero line location is to "eyeball" it by connecting points where existing and proposed contour lines of equal elevation intersect. These areas of intersection are known as *zero corners*. See Figure 9-20.

In regions with irregular contour line shapes, you can use *subcontour lines* to determine the zero line's path. Subcontour lines are just additional contour lines plotted with smaller intervals than the originals. The subcontour lines in Figure 9-21 have a 0.2-foot contour interval, and they reveal enough information to draw the zero line.



Using subcontour lines to determine the zero line
Figure 9-21

Topsoil

The zero line will shift to a new position if the depths of topsoil stripped *(TS)* and topsoil replaced *(TR)* differ. Figure 9-22 illustrates the shift.

As a rule, if more topsoil is stripped than replaced, the zero line shifts to a higher existing elevation. In cases where more topsoil is replaced than stripped, the zero line shifts to a lower existing elevation.

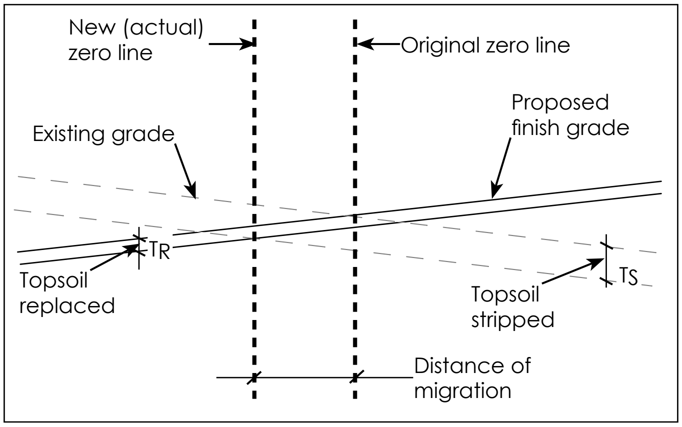
Topsoil is usually stripped and stockpiled at the beginning of the site-clearing operation. Avoid all of the heavily-traveled traffic routes and natural drainage paths when choosing a stockpile location. Use silt fences in appropriate locations to retain sediment. On large sites, stockpile the topsoil in several small piles throughout the site. That makes it easier and more economical when respreading the soil.

The site designer's specs usually require topsoil stripping at structure areas only. But it may be faster or more cost-effective to strip the entire site. A 4- to 6-inch stripping depth is most common, but that depth will vary depending on the site.

Topsoil Respreading

You shouldn't spread topsoil while it or the subgrade is frozen or muddy. Replace at least 4 inches of topsoil if the site plans don't specify a depth. Ideally, you want "mellow" soil in place to encourage vegetation growth. Once topsoil is spread, correct surface irregularities to prevent water from collecting in any pockets. Compact the topsoil enough to ensure good contact with the underlying material, but not so much that it will increase runoff and inhibit seed germination.

FOR TOPSOIL-STRIPPING PURPOSES, *structure areas* are where buildings, sidewalks and paving are to be constructed. By convention, a structure area is considered to be 5 feet beyond any building, and 1 foot beyond any curb, drive, or sidewalk.



Zero line, adjusted for difference between topsoil stripped and topsoil replaced
Figure 9-22

Topsoil Volumes

For estimating purposes, separate topsoil stripping and replacement volumes from other soil quantities, because:

- Topsoil that's stockpiled for future replacement on the site is a physically separate entity.
- Equipment used to strip and replace topsoil might not be the same equipment used to perform other site cut and fill operations.
- You may not need all of it. Excess topsoil can be sold to other contractors or saved for use on other projects.
- Topsoil must be conducive to the growth of vegetation, so it's installed in a relatively loose state compared to sub-topsoil material.

> ***EXCESS TOPSOIL*** makes good filler material for coastal regions and pond slopes. On a site requiring dirt import, this allows you to overexcavate a pond to get good fill dirt, and replace it with excess topsoil that would otherwise be hauled off the site.

Calculating stripped topsoil volumes is pretty straightforward: Multiply the cut depth by the area of the stripped region. Keep in mind that topsoil isn't replaced in areas where structures will stand. You'll need to account for that when calculating how much topsoil to replace, and how much will be left over.

Net Cut and Fill Volumes

A site plan's existing and proposed contour line elevations don't account for topsoil alterations. That's not a problem if the depth of the replaced topsoil matches what's stripped. But if the depths don't match, the site plan's contour elevations won't be accurate. This is true in any area involving topsoil removal and eventual replacement.

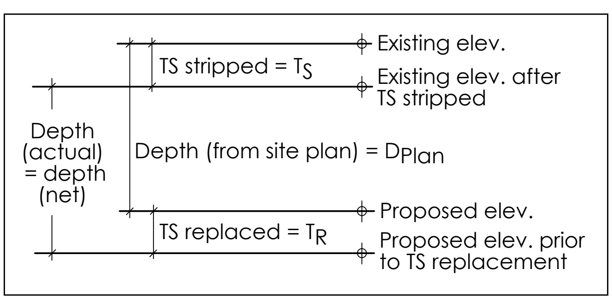
To allow for net topsoil changes, we have two options:

1. Adjust the values assigned to the existing and proposed contour lines on the site plan before drawing grid lines, or

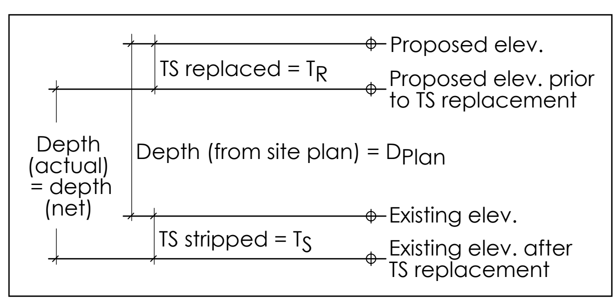
2. Mathematically adjust for the topsoil and work with the site plan, as is. As you might have already guessed, I recommend using math to make the adjustments. In areas requiring cut, here's how to calculate the actual amount of cut needed. Determine the distance between existing and proposed elevations, taken directly from the site plan. Subtract the stripped topsoil thickness. Finally, add the replaced topsoil thickness. This calculation is perfectly logical. If you strip more topsoil than you replace, you won't need to cut as much as the site plan indicates. On the other hand, if you replace more than you strip, you'll need to cut more than the site plan indicates. See Figure 9-23.

In areas requiring fill, you can calculate the net fill depth in nearly the same manner. You still begin with the distance between existing and proposed elevations, taken from the site plan. But now you'll *add* the stripped topsoil thickness and then *subtract* the replaced topsoil thickness. Figure 9-24 illustrates the situation.

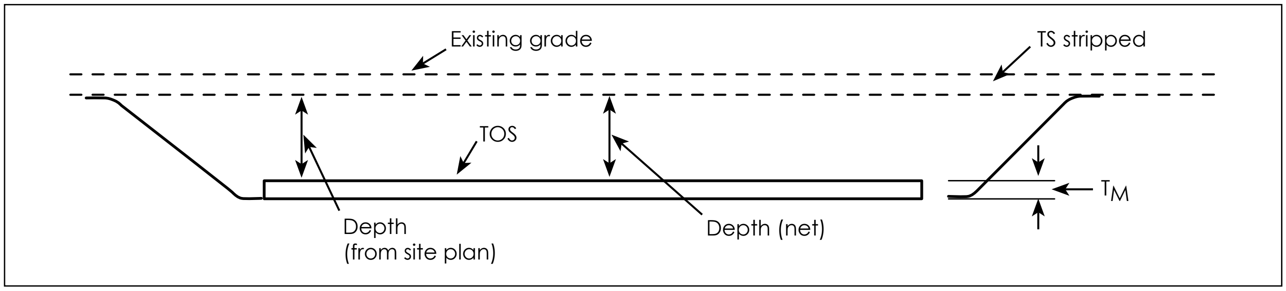
You can also use this math technique to calculate the depth of cut (or fill) within an entire prism. Let's say you have a prism requiring 2.5-, 0.8-, 0.9- and 2.3-foot cuts in its respective grid corners. The cut depth averages 1.63 feet. But what if the plans call for stripping 6 inches of topsoil, and only replacing 4 inches of it? As before, start with the average plan cut (1.63 feet), then subtract the stripped depth (0.5 feet) and add the replaced depth (0.34 feet). The average *net* cut is 1.47 feet. To calculate the net cut volume, simply multiply the average net cut by the area of the prism.



Calculating the net cut requirement
Figure 9-23



Calculating the net fill requirement
Figure 9-24



Net cut requirement, factoring in the slab
Figure 9-25

Cut and Fill Volumes Under Slabs and Paving

Some designers provide the elevations at the top-of-pad *(TOP).* Other times you may be given proposed elevations based on the top-of-slab *(TOS)* or some other finished surface. Areas that are intended to have a finished surface won't get their topsoil back, but you still need to factor in the finish material thickness.

In areas requiring cut, the existing elevations are greater than the top-of-finished-surface elevations. Any topsoil that's stripped will reduce the net cut requirement. At the same time, the finished surface thickness increases the net cut requirement. See Figure 9-25.

To calculate the net cut requirement, we'll use math techniques similar to what we've already covered in this chapter. Start with the distance between the existing elevation and the finished surface elevation. Then add the thickness of the paving or slab material. Finally, subtract the stripped topsoil depth. For areas requiring fill, the calculation is the same, except you'll *subtract* the slab thickness, and *add* the stripped topsoil depth.

For these calculations, the finish material thickness should include any material that's considered an integral part of the slab or paving. For instance, slab thickness includes any leveling sand or granular fill beneath the slab. Paving thickness includes concrete and any base and sub-base material.

Some projects require you to overexcavate 5 feet or more beneath and beyond the building footprint, and then fill the void with stone or other select fill. In that case, you'll first have to build the pad up to grade. Then excavate the void and fill it with acceptable material.

Earthwork Estimating Accuracy

Earthwork estimating methods might alarm a mathematical purist, but we have to be practical. To find the exact elevation at each corner would take too long, and it wouldn't help much because we're assuming the grid cell depth is the average depth of the four corners. Technically, elevation information within the grid cell isn't accounted for unless we grid off this site into very small areas, and we don't have time to do that. But if you use enough grid cells, the errors will tend to cancel each other out, leaving you with very nearly the correct volume to be moved. Most excavation estimators agree that you're more likely to have a serious error because of a mistake in calculations than in the assumptions about elevation between contour lines.

Keep in mind that site plans are inherently inaccurate because contour lines are usually interpolated from spot elevations shot in the field by surveyors. Some engineers use old surveys instead of drawing contours based on the current condition of the site. It's best if you can visit the site and shoot a few spot elevations of your own before you do a takeoff.

When you're calculating earthwork quantities, reliability is more important than extreme accuracy. Since it's probably impossible to predict the precise swell or shrinkage of the earth to within 5 percent, much less the time required to complete the project, there's no point in getting excited about absolute precision in your soil volume data. Instead, concentrate on recording corner elevations in a form that's easy to check and worry about bigger errors that can put you out of business.

As you calculate the volume in each grid cell, you'll begin to see a pattern evolve. There'll likely be areas of cut and areas of fill. Use colored pencils to illustrate this: Shade all cut areas one color and all fill areas another color. Now you can clearly see how the earth has to be moved.

Minimize errors by writing the volume quantity in each grid cell. When you've followed this same procedure for each grid cell, gather the cut and fill sums and calculate a total for each category (cut and fill). Convert both quantities to loose cubic yards, and then subtract one total from the other. If the total cut volume is greater than the fill volume, the site will require export. If the fill volume is greater than the cut volume, the site will require import. Then the all-important questions: *How to do it, how long will it take, and how much will it cost?*

If you've color-coded the grading plan, it will help you see the haul distances and pattern of excavation and fill. The average distances from the cut areas to the fill areas will help you determine the most suitable equipment to use. For a short haul, you'll probably use dozers. For a longer haul, use self-loading scrapers. Long-distance hauling requires loaders and trucks. You can use a grader for very slight cuts and fills. If there's a basement or new pond on the site, you'll probably have to plan on using an excavator.

Minimize the Risks

Nothing is certain in the earth mover's world. You have to worry about complexity of the takeoff, swell and shrinkage factors, the weather, water requirements and possibly drying requirements. You'll also have to consider the equipment selection, crew selection, control and motivation. All of these variables affect the dollar cost per unit, and it's up to you to minimize and rationalize the risks. Any successful excavating contractor takes risks on a daily basis. But don't be a foolhardy gambler. Try to:

1. Identify the risk
2. Predict the likelihood of an unwanted outcome
3. Place a dollar amount on it

I'll use the rest of this chapter to discuss some major risk items and their potential costs.

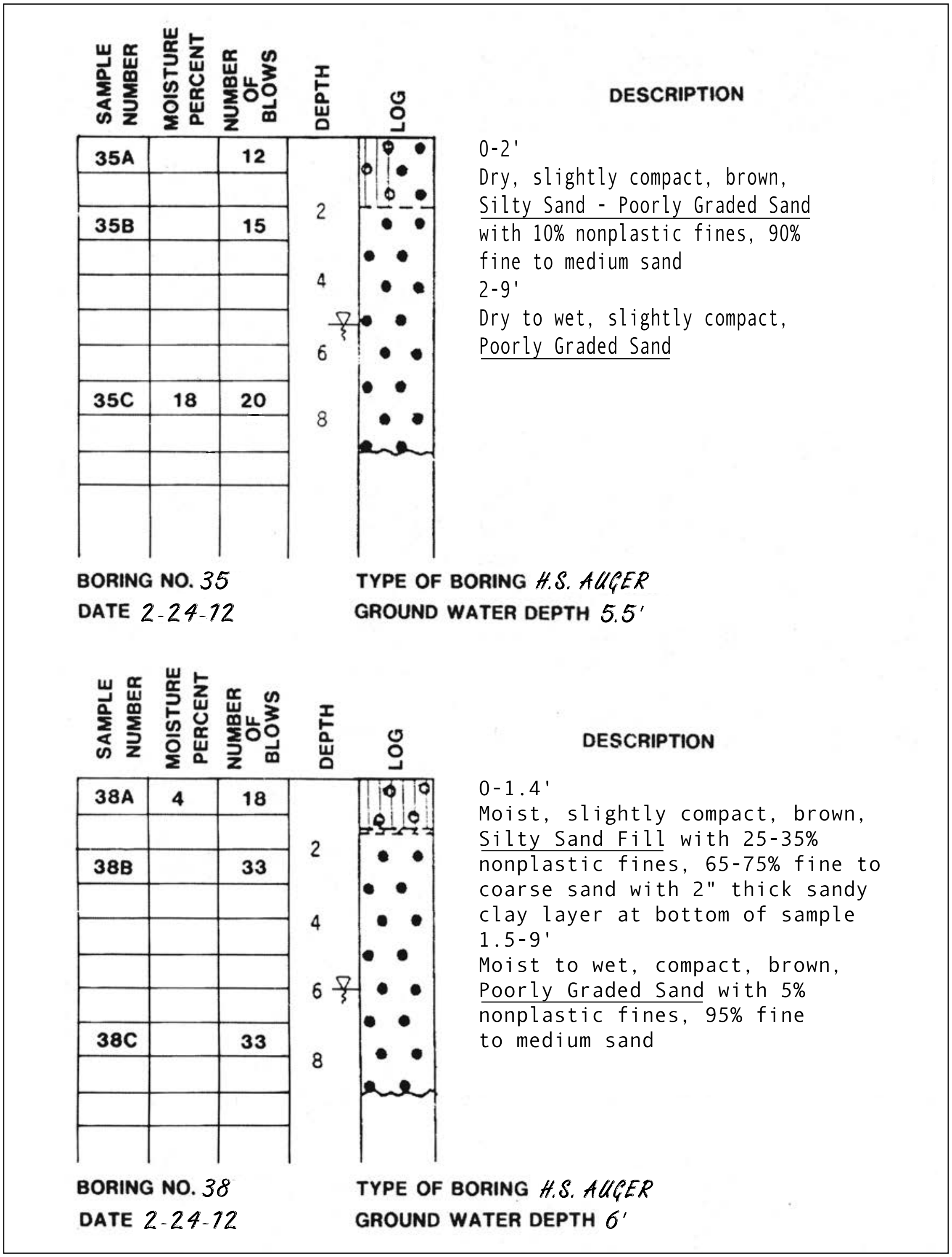
Subsurface Conditions

On some jobs, you'll get a set of boring logs in the bid package. Figure 9-26 shows typical boring log entries. You'll also get a site plan indicating the locations where the borings were taken. If you're dealing with a project that has a basement or deep pond, and you're not given boring logs, you're stepping into the unknown and maybe a nasty surprise. And even if you have soil boring logs, the sample holes are usually few and far between, so useful information may be missing.

In some cases, it may be practical to do your own subsurface exploration. Take a backhoe to the site and dig your own holes. The site investigation required depends on what your contract says. For example, you're protected if there's a "Differing Site Conditions" clause in the contract (paraphrased below):

(a) Contractor shall promptly, and before conditions are disturbed, give a written notice to Owner of —

(1) Subsurface or latent physical conditions at or near the jobsite which differ materially from those indicated in the contract documents, and



Typical boring log entries
Figure 9-26

(2) Unknown physical conditions at or near the jobsite, of an unusual nature, which differ materially from those ordinarily encountered and generally recognized as normal in work of the character called for in the contract documents.

(b) Owner shall investigate the site conditions promptly after receiving notice. If the conditions do materially so differ and cause an increase or decrease in the cost to Contractor or the time required for performing any part of the work, whether or not changed as a result of the conditions, an equitable adjustment shall be made under this clause and the contract modified in writing accordingly.

Nearly all federal contracts and most state public works contracts include a Differing Site Conditions clause. It appears in Federal Acquisition Regulation §52.236-2 and is considered a benefit to both contractor and owner. The contractor can bid the job based on what's known and expected, rather than on the worst possible contingency. If site conditions differ from what was expected, the contractor will get paid for work actually done. The owner gets more competitive bids with smaller contingency allowances.

If the contract doesn't allow classification of soils for pay purposes (an *unclassified soils* contract), you may not be able to collect for unforeseen excavation expenses due to boulders, granite or groundwater. Under those conditions, you have two choices: take a backhoe out to the site and satisfy yourself on the conditions expected; or get an amendment to the contract that allows extra pay for extra work. The program *Construction Contract Writer* (at the site www.craftsman-book.com/) makes it easy to draft contracts that protect an excavation contractor.

The Weather and Soil Conditions

Even if you have subsurface conditions and soil volumes figured out, weather-related variables can affect the project. Dry, dusty earth will require wetting, and therefore you need to add water truck rental to your costs. Conversely, a downpour turns everything into a muddy mess, and can reduce production rates to a crawl or shut the project down temporarily. You're usually better off waiting until the site dries out. That's why most excavation contractors are wary of signing a contract that requires completion by a certain date.

Before bidding that "must-do" job, add a contingency allowance to cover possible problems. This will also provide a cushion for equipment rental costs, since you have to pay the rent even when the equipment sits idle waiting for the site to dry.

[Blank Page]

10

Dealing with Rock & Groundwater

Rock

Geology is a science dealing with the earth's history through the study of rocks. It's a complex and fascinating subject worthy of study by anyone who makes a living moving earth. In this book, we don't have the space to cover the entire subject in depth, but there are some broad concepts that help us understand what rock is, where we're likely to find it, and how to deal with it. Practically all soils originally derived from the weathering of various types of rock.

Types of Rock

Rock rippability mainly depends on the type of rock you're dealing with, so you should have a basic understanding of the three fundamental types: igneous, sedimentary and metamorphic. When molten material cools and hardens, it forms *igneous* rock. In contrast, *sedimentary* rock is formed from compacted layers of material deposits. *Metamorphic* rock is igneous or sedimentary rock that's been altered by heat and pressure. Let's discuss each rock type in detail.

Igneous Rock

When magma (the hot material that lies beneath the earth's crust) cools, it forms igneous rock. Because of the way it's formed, igneous rock is homogeneous (consistent throughout) and has few planes of weakness. That makes it difficult to rip.

There are two types of igneous rock: *extrusive* and *intrusive*. Extrusive igneous rock is molten rock that cools at the earth's surface (lava). In contrast, intrusive (plutonic) rock forms and cools deep within the earth and is eventually exposed by erosion and/or movement of the earth's surface. Igneous rock that's relatively young in geological time may be found in an unweathered, unaltered state. This is sometimes called lava rock, and it's extremely difficult to work with.

Igneous rock is classified according to composition and texture. *Composition* is defined by the mineral constituents in the rock, and *texture* is defined by the size of the mineral grains. As a rule, the faster an igneous rock cools, the finer the grain will be. Thus, extrusive rocks are *fine-grained,* and intrusive rocks are *coarse-grained.* Coarse-grained igneous rock such as granite is easier to rip than fine-grained rock such as basalt. Some igneous rock can't be ripped unless it's weakened by weathering. The most stubborn igneous rock doesn't even respond to light blasting. It requires a high powder factor to blast it effectively. (The powder factor is the ratio of explosive to the rock needed to fragment it.) Here's a breakdown of igneous rock types, and where you're likely to encounter them:

Granite is a coarse-grained plutonic rock composed primarily of orthoclase feldspar, quartz, and small amounts of dark minerals such as hornblende, magnetite, biotite and muscovite. Granite is the most common coarse-grained igneous rock in the world, and can be gray, white, pink or yellow-brown.

Rhyolite is the fine-grained equivalent of granite. It's light gray or pink in color, and found abundantly in the Yellowstone National Park area and in parts of Arizona and Pennsylvania.

Gabbro is a coarse-grained igneous rock composed primarily of feldspar, hornblende and other dark minerals. Except for its darker color, gabbro has properties similar to granite. It's found predominantly in the Adirondack Mountains of New York.

Basalt is the volcanic equivalent of gabbro. It's dark and contains gas bubbles. Basalt is the most abundant volcanic rock, and is found throughout the northwestern United States. Slightly coarser sheets of partially-weathered and altered basalt are known as "trap rock."

Diorite is a coarse-grained igneous rock that's intermediate in composition between granite and basalt. It has a salt-and-pepper appearance and is found predominantly in Vermont and New York.

Pumice is a light-colored volcanic equivalent of granite. It contains gas bubbles and is very lightweight. Scoria is similar to pumice in texture, but basaltic in composition. Like pumice, scoria resembles a sponge.

Obsidian is a dark, glassy volcanic rock that's similar to granite or rhyolite in chemical composition. It's normally found in the western United States and Virginia. Dull, weathered and partially-altered obsidian is known as *pitchstone.*

Sedimentary Rock

Sedimentary rock is the most abundant type of exposed rock on the Earth's surface. Most sedimentary rock is the product of the disintegration and decomposition of other rocks (igneous, sedimentary, or metamorphic), deposited in layers by the action of water, ice and wind.

Sedimentary rock *textures* can be classified into two groups: clastic and non-clastic. *Clastic* (fragmental) sedimentary rock is made up of fragments of other rocks. Examples of clastic sediments are gravel, sand and silt.

Non-clastic (chemical) sedimentary rock contains calcium and magnesium, and it's formed by material precipitated from solution in water, and by evaporation. Chemical sedimentary rock often contains shell fragments of marine animals. Examples of chemical sediments are limestone, dolomite, gypsum and salt (halite).

Most sediments are moved from a source area and deposited in a sedimentary or *depositional* basin. As the sediments enter the basin, the largest clastic particles are the first to precipitate out of the water. The non-clastic particles are the last to settle and are therefore deposited farthest from the source area. Over time, loose sediments are consolidated into solid rock, primarily through compaction and cementation. Because of the way sediments are deposited, sedimentary rock is formed in horizontal layers of various thicknesses. These layers are called beds, or *strata.*

Conglomerate and Breccia have grain sizes greater than 2 mm and are deposited closest to the source area. A *conglomerate* is composed of rounded water-worn fragments, and a *breccia* is composed of broken, angular fragments. Both types of deposits are primarily made from quartz cemented by a mass of finer material.

Sandstone is mainly cemented quartz sand with grain sizes ranging from $1/16$ to 1 mm. Depending on the grain size, sandstone is classified as fine-, medium-, or coarse-grained. Sandstone may be white, gray, yellowish, or dark red.

Siltstone has a grain size ranging from $1/256$ to $1/16$ mm. Siltstone feels gritty like sandstone, but the individual grains are too small to be seen with the naked eye.

Shale is composed principally of clay particles, and has a grain size smaller than $1/256$ mm — the finest fraction of the clastic sediments. Shale is thinly bedded and fractures into thin chips. It feels smooth and the grains are too small to be seen. Shale and slate are often indistinguishable. To determine which is which, breathe on the rock and smell it. If it smells like mud, it's shale; if not, it's slate.

Non-Clastic sedimentary rocks are limestone, dolomite, gypsum, salt and chert. They're chemically precipitated out of water and deposited farthest from the source area. Limestone often contains fossilized shell animals.

Caliche is a sedimentary rock with a unique method of deposition. During rainy seasons in an arid or semi-arid climate, rainwater sinks into the earth and raises the level of the water table. During dry seasons, the level of the water table is lowered as groundwater rises to the surface through capillary action to replace water that has evaporated. As the water rises, it brings with it substances in solution derived from underlying material. As this rising water evaporates at the surface, a material referred to as caliche is deposited. Although caliche can be made of many compounds, calcium carbonate is the most abundant constituent. Most caliches are excellent for use as paving base material.

Metamorphic Rock

If an igneous or sedimentary rock is formed, and later buried at great depth where it's exposed to tremendous heat and pressure, the rock will change (metamorphose) physically and/or chemically. Rock altered in this way is called metamorphic rock. Examples of metamorphism include shale altering to slate, limestone to marble, sandstone to quartzite, granite to gneiss, and bituminous coal to anthracite coal. Massive metamorphic rock such as gneiss, marble and quartzite are not rippable unless they're fractured. In general, metamorphic rock rippability lies somewhere between sedimentary and igneous rock.

Hot magma intrusions can also produce metamorphism in a process called contact metamorphism. In addition to the metamorphism of the parent rock near the magma intrusion, the cooling gases deposit minerals (sometimes precious) within voids and fissures in the surrounding rock.

Metamorphic rock is classified according to texture, grain alignment and mineral composition. During metamorphism, flat minerals are often reoriented to a parallel alignment, referred to as a *foliated* texture. This parallel structure allows foliated metamorphic rock to split easily in the direction of the foliation. In other cases, pore spaces are diminished, and the texture is referred to as *non-foliated.* Non-foliated metamorphic rock doesn't split easily.

All exposed rock is subject to weathering action that, over time, breaks it down into fine particles — creating the many and varied soil types. Mountains are eroded and washed into the plains, creating clays and silts, often many feet deep. If you live and work solely in such valleys and plains, you're not likely to encounter rock. On the other hand, if you venture into hilly or mountainous areas, you'll have to learn quickly how to deal with rock.

Ripping and Rock Work

Large dozers can rip rock that's nearly solid, but the standard utility dozer is too small to be effective in real rock work. Still, a small dozer fitted with rippers can loosen hard soils and relatively soft sedimentary or decomposed rock.

There's an art to breaking out rock. Most rock formations and soils were originally laid in horizontal beds. Movement in the Earth's crust upset these flat layers and jumbled them in every direction — even edgewise and at angles other than horizontal. If you can't penetrate hard ground from one direction, try approaching it from a different angle. The rock may be less resistant when hit from a different direction.

Larger dozers can exert a force of 20 to 30 tons on a ripper tip. That's enough to rip and fragment most rock. Ripper penetration depends on the angle of the ripper. A tip angle of 60 degrees allows good initial penetration. Try 45 degrees to exert good lifting or prying force. To pry out boulders, use an angle of 35 degrees while raising the shanks.

Larger machines designed for heavy-duty ripping are usually fitted with adjustable rippers. Smaller dozers are fitted with fixed shank rippers useful for loosening hard earth prior to blade work. There are two very important points to remember when using rippers. First, always be prepared to back off. If you hit an immovable object, press the clutch immediately to avoid damage. And second, never turn the dozer while the rippers are in the ground.

Rippable and Unrippable Rock

For our purposes, we can subdivide rock into two categories: *rippable* and *unrippable*. A rippable rock is one that can be excavated by mechanical means, without the use of explosives. An unrippable rock can't be moved by conventional earth-moving equipment. It requires blasting.

Generally, sedimentary rock and some metamorphic rock respond to ripping better than igneous rock, because they tend to be layered. Good candidates include caliche, soft sedimentary rock such as chalk, some sandstone, and any rock that's fractured or fragmented. You can move rippable rock with special-purpose rock buckets (Figure 10-1) or sometimes with special sharp-pointed rock teeth fitted to a conventional hoe or loader bucket.

Courtesy of Dymax Construction Equipment

Rock bucket
Figure 10-1

Obviously, production rates in rock are much slower than in easy-digging clays. In some instances, it makes economic sense to exchange the hoe for a trenching machine. Both wheeled and ladder-type trenchers work well in soft- to medium-hard rock and give a good production rate. See Figure 10-2.

Prior to bidding a project, you need to determine whether the rock is rippable, or whether it requires drilling and blasting. One of the best indicators of rippability is *seismic velocity:* the speed at which sound waves travel through the rock. Field studies have shown that seismic velocity is inversely proportional to the rocks' rippability. In other words, rock that transmits sound waves at low velocities is more rippable than rock that transmits sound waves at high velocities. Sound velocity can range from 1,000 feet per second (fps) in loose soil to 20,000 fps in hard, solid rock.

Some dozer manufacturers publish seismic velocity charts that can be compared with field seismic information and used as a guide for determining rippability. Seismic velocity charts are unique to a given tractor and ripper, and the actual rippability for a particular job still depends on other variables such as the extent of stratification (layering), fractures, planes of weakness, softening due to weathering, rock brittleness and grain size.

Tooth penetration is usually the key to ripping success, regardless of seismic velocity. Rippability suffers if there are no bedding joints

Wheel trencher
Figure 10-2

or fractures. This is especially true in homogeneous materials such as mudstone, claystone and fine-grained caliche, or tightly cemented conglomerates and glacial till.

Tractor-Mounted Rippers

The three basic tractor-mounted ripper types include radial-lift, fixed parallelogram (or parallel-lift), and adjustable parallelogram. Any of these rippers can be attached to a tractor without interfering with the tractor's dozing ability.

Radial-lift rippers swing the shanks up and down in an arc motion, changing the tooth angle at various depths of ripper penetration. This is especially useful when working in close proximity to existing structures such as walls or footings, and for ripping soils containing boulders.

Fixed parallelogram rippers raise and lower the shanks through a vertical plane, maintaining a constant tooth angle at any depth of penetration, which keeps the tooth at its optimum cutting angle and reduces tip wear.

Adjustable parallelogram rippers are the most versatile ripper variety because the tooth angle is adjustable, even while the tractor is moving. See Figure 10-3. This type of ripper is also available with a single, hydraulically-controlled shank called an impact ripper, which is useful when dealing with tough rock.

Adjustable parallelogram ripper
Figure 10-3

Most rippers are available in a single- or multiple-shank configuration. The appropriate shank arrangement depends on tractor power, penetration depth, the material's resistance to being ripped, and the required degree of breakage. The breakage requirement depends on the loading equipment that's being used. For example, scrapers require smaller fragments than mass excavators, front-end loaders or dozers. Ripping with just the two outer teeth increases penetration and requires less power, but it also creates larger rock sizes than those created when using all three teeth. Ripped rock that's still too large can be blasted, rolled over with the ripper tractor or crushed with a crane-mounted drop ball until it's a manageable size.

"Teeth that slide into the same groove during subsequent passes without ripping usually indicate dull, worn teeth that should be replaced or reversed."

Ripper teeth *(tips)* come in three lengths. Short tips are useful for high-impact jobs when tip breakage is a concern, and when ripping with tandem tractors, since the additional tractor pushing power exerts tremendous stress on the ripper teeth. Medium-sized tips are used

Courtesy of Terry Newman

Rock saw
Figure 10-4

for ripping moderate-impact materials where abrasion isn't excessive, while long tips are best suited for loose materials where breakage isn't a concern. Some ripper teeth are reversible, which extends their service life.

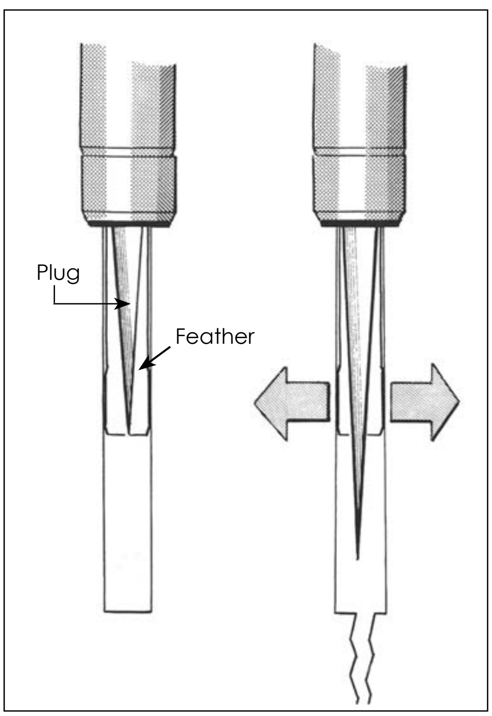
Sometimes using a single shank with tooth penetration that matches rock stratum *(layer)* thickness will maximize productivity. But it's usually more productive to use multiple shanks. In any case, it's a good idea to rip as deeply as possible, because shallow penetration will cause tooth wear that's disproportionate to the ripper production. Teeth that slide into the same groove during subsequent passes without ripping usually indicate dull, worn teeth that should be replaced or reversed.

Other Rock Machines

Rippers aren't the only equipment option when it comes to removing rock. Rock saws, like the one in Figure 10-4, are used for trenching through rock. A wheel-mounted chain cuts a 12-inch wide trench up to 3 feet deep. Depending on the rock density, it can cut about 17 feet of trench per hour. For a wider trench, rock saws can make two parallel cuts, and the portion between them can be broken out using pneumatic hammers.

Courtesy of Don Bundock

Road miner
Figure 10-5



Plug and feather rock splitter
Figure 10-6

Figure 10-5 shows a road miner *(rotomill)* that's typically used to mill asphalt, concrete and rock. The drum teeth are interchangeable to suit the type of material being milled. Rock saws and road miners are powerful pieces of equipment, so no one but the operator should be in the vicinity during excavation.

Specialized Equipment for Splitting Rock

A plug and feather rock splitter is useful for splitting isolated rock humps and large boulders. This tool works in all types of rock and it's faster and more powerful than paving breakers. The splitter is safe when working in a small space like a trench and can be used in urban areas where blasting isn't allowed.

Figure 10-6 shows how a plug and feather splitter works. First, a hole is drilled in the rock. Then the plug and feather is driven into the drill hole. As the plug is hydraulically driven between the wedges, the expansion cracks the rock. Hydraulic impact hammers *(rock breakers)* perform a similar function, as the nickname implies. See Figure 10-7.

Tractor loader backhoe equipped with hydraulic hammer
Figure 10-7

Bidding Strategies for Rock Work

When you bid work in an unfamiliar area, there's always the risk of finding rock. Let's go back to geology for a minute. Mountainous areas continue being eroded by water and ice. The ravines and valleys in the mountains become rivers, carrying sediment down toward the oceans. The sediment spreads out over the flood plain of the flat areas.

Generally, hilly or mountainous areas will have more rock, while the flood plains are relatively rock-free. When you travel to look at prospective contracts, take note of the geography and geology that surround you. A flat-bottomed valley usually indicates a flood plain composed of sediment. In this case, groundwater might be your main concern. On the other hand, a town situated on a hillside may be sitting a few feet above bedrock. In this case, ask yourself a few questions: Do the houses have basements? Is field rock (outcropping) evident? Consider talking with locals who might have knowledge about the area's soil.

Usually, if rock is known to exist, a bid item will be set aside especially for payment for rock excavation. This is a fair way of dealing with the problem. But sometimes engineers don't go to the trouble and expense of exploratory drilling or digging test holes. In these cases, you're dealing with an unknown.

This is when the Differing Site Conditions clause, which we discussed in Chapter 9, comes in. You, as a savvy underground utility contractor, should always look for this clause in a contract. No matter how much due diligence you put in before making a bid that includes rock work, sometimes you'll get a nasty surprise. This clause gives the contractor the ability to bid jobs based on what he knows and expects, rather than on the worst possible scenario. If site conditions differ from what was in the bid, the contractor will get paid for work actually done; and the owner gets more competitive bids with smaller contingency allowances. This clause, in Federal Acquisition Regulation § 52.236-2, is a benefit to both contractor and owner — which is why almost all federal contracts and most state public works contracts include it.

What happens if a particular contract doesn't allow classification of soils for pay purposes (an "unclassified soils" contract)? What happens is you may not be able to collect for additional excavation expenses, whether they're due to boulders, granite or groundwater. What are your options? Before putting in your bid, take a backhoe out to the site and check the conditions yourself; or get an amendment to the contract that allows extra pay for extra work. The program *Construction Contract Writer* (at the site www.craftsman-book.com/) makes it easy to draft contracts that protect an excavation contractor.

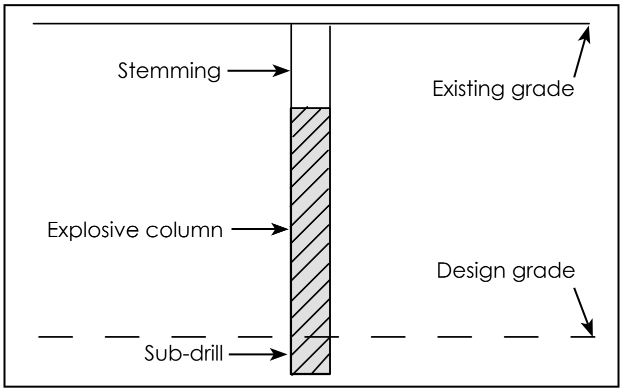
If exploratory drilling along a proposed trench line reveals the likelihood of 500 bank cubic yards of rock, you can bid the job on those terms. If it's known that rock exists but no quantity has been established, you may bid based on an estimated quantity of rock. This is a difficult bid, because in some instances you can shoot, remove and haul off hundreds of cubic yards of rock for a relatively low cost. Conversely, 200 bank cubic yards can cost you thousands of dollars to blast and remove.

Using Explosives

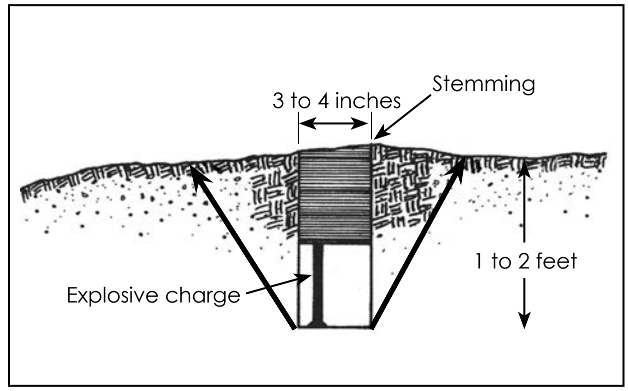
Rock blasting is a technical and dangerous discipline, so I'm not going to explain how to be a do-it-yourself blaster. Hire an experienced powderman. A good powderman will make it look easy. A bad one will be a hazard and cost you a fortune in delay time. My goal in this section is to help you recognize the difference.

Ammonium nitrate is the main ingredient in most commercial explosives. One reason why ammonium nitrate fuel oil (ANFO) is so popular is that it's relatively inexpensive. ANFO, although not water resistant, is packed in water-resistant bundles for use in damp locations.

As shown in Figure 10-8, boreholes for blasting are normally *subdrilled* to a few feet below design grade, to ensure that the rock is broken at that specific grade. The borehole is filled with an explosive up to predetermined depth, leaving a portion at the top empty. The portion containing explosive is called the *explosive column,* and the remaining space is called *stemming*. Stemming is the rock cuttings or sand packed



Borehole
Figure 10-8



The danger of a large diameter, shallow hole
Figure 10-9

on top of the explosive to reduce the risk of the shot blowing vertically out of the drill hole

As you might expect, the denser the explosive, the more rock it will blast. Explosive material density specifications, provided by the manufacturer, equate the weight of one cubic foot of explosive to one cubic foot of distilled water.

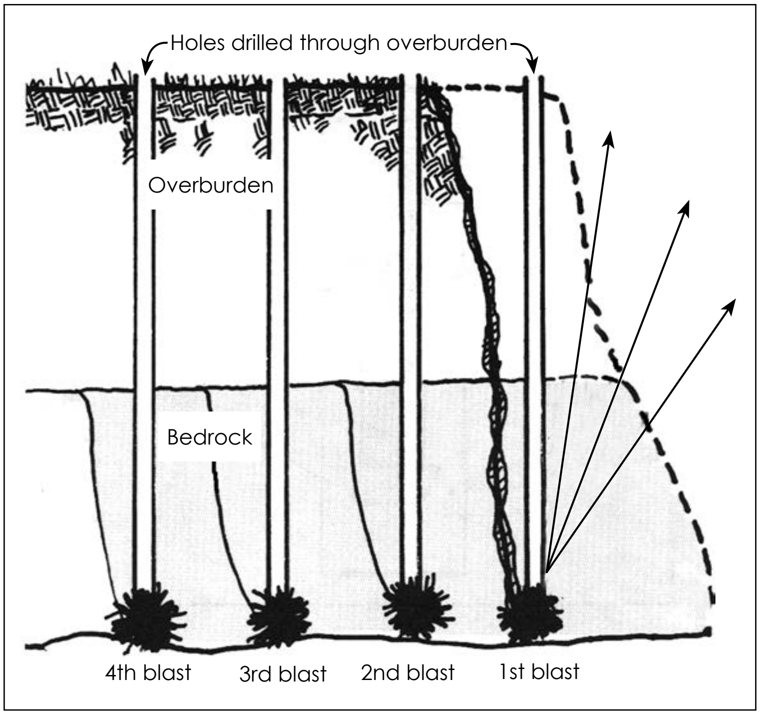
Where explosives are the only practical way to excavate rock, there are two approaches you can use. First, you can deal with each rock mass as you come to it. This is usually the more expensive method because of the inherent unpredictability of when and how much rock you'll encounter. A better way is to use an *airtrack* ahead of the trenching for exploratory drilling. An airtrack is a track-propelled, mechanical drilling rig that's capable of drilling dozens of feet into bedrock. Then you can shoot the rock ahead of the laying crew. This method has the added advantage of using the *overburden* (soil on top of the rock) to hold down the shot.

HERE'S WHAT YOU NEED to understand about blasting, in a nutshell: The effect of a charge depends on the amount of explosive, the power of the explosive and the resistance it encounters.

But here's a word of caution: Even if you have an airtrack available, don't use it to shoot shallow (less than 2 feet deep) rock humps. The airtrack drills a 3- to 4-inch-diameter hole, which is too wide for a shallow hole. That adds to the risk of the shot going upward, as you can see from Figure 10-9. The shallow, large-diameter hole will tend to lift the rock vertically, making it less effective than a small-diameter drill hole with tightly-packed stemming.

Single Charge Blasting

There are two common blasting techniques: single charge and sequential firing. Single charge is the simplest form of blasting. The powderman drills a hole in the rock, places an explosive charge in the hole and sets it off. The shock wave of the explosion travels in the direction of least resistance — up, sideways or, in rare cases, down.

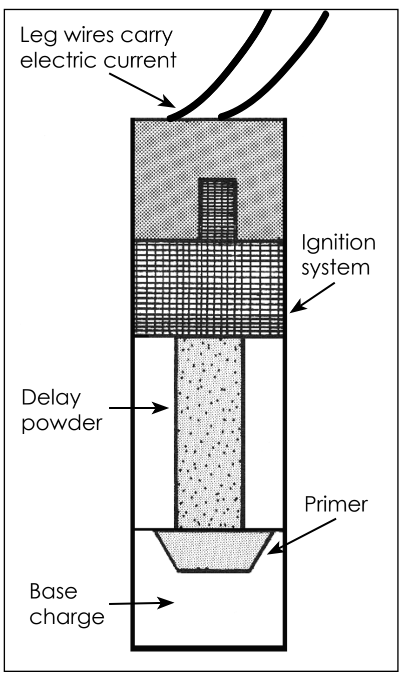


Sequential firing
Figure 10-10

If the charge is set in bedrock, the direction of least resistance will be up. If the single charge is set in a small boulder, it should blow the boulder apart.

Sequential Firing

Sequential firing is the most commonly used and efficient method of breaking rock for underground utility line work. The powderman sets up a series of explosive charges in the bedrock, and the charges are detonated in sequence. The charge that explodes first creates an open face and a line of least resistance for the charge that comes next. This controls the force and direction of the explosions. See Figure 10-10. The powderman will usually use electric blasting caps or a detonating cord to provide an initial high-intensity explosion that sets off the main charge.



Blasting cap
Figure 10-11

For the charges to fire in sequence, there has to be a delay after the explosion of each charge. Either electric blasting caps or a detonating cord can provide this delay. With detonation cord, delay is a function of the cord burning rate. Electric blasting caps can have a built-in time delay. The caps are connected to an electric source in series. An electric charge is transmitted simultaneously to all caps, but they explode in sequence according to the time delay in each cap. Figure 10-11 shows an electric blasting cap.

The best way to control the explosion is to use the medium surrounding the charge. An uncovered rock face will produce a lot of flying rock that's thrown out and away from the source of the blast. If your powderman uses the same amount of explosive but sets the charges before the rock is exposed, little or no rock may be thrown out of the excavation. Here's why.

Remember that the effect of the explosion is determined by the force of the blast and the resistance against that force. If the explosion is set off above ground, there's only air to resist the force of the blast. But if the explosion is set off below ground, the surrounding earth resists the force of the blast and absorbs the fast-moving rock. The resistance against the blast is greater than the force of the blast itself. A good powderman knows this and he'll use it to your advantage. He can detonate a below-ground blast large enough to break up the bedrock while using the overburden to contain and control the blast.

Below-ground blasting can be done two ways. The first way is to drill through the overburden down into the bedrock and set the charges with the overburden still in place. The second is to remove the overburden, set the charges and then cover up the charges with spoil. A blasting mat is used for extra protection.

> *"Remember that the effect of the explosion is determined by the force of the blast and the resistance against that force."*

Be careful when covering a charge with spoil. The charges are linked together by tiny wires. The powderman will use a galvanometer to check these wires to ensure the circuit isn't damaged during backfilling. If any wires are broken, he can't ignite the charge, so the circuit will have to be repaired before detonation. Tracing wires through loose dirt set on top of live, primed charges is dangerous work.

A good blast will break up the rock without damaging existing utility lines or structures. A bad blast may cause damage and leave rock that can't be excavated and must be reshot. If the blaster doesn't drill the holes deep enough or doesn't use enough powder, the shot may leave a hump of solid rock near or above pipe grade. If there's a weak point in the bedrock below the explosion, the shot may even go down instead of up. If you have to dig out or re-drill and reshoot a hump, there'll be about a two-hour delay for your laying crew.

Obviously, blasting rock is a lot more complex than just moving dirt around. And rock work probably isn't finished when the blasting is done. The specifications usually demand that you haul the rock off the site after you've broken it up. Then you have to haul in fill to replace the rock. Be sure to allow for these additional costs in your bid.

Sonic Velocity

Sonic velocity, the speed at which a given rock transmits acoustical shock waves, is a major factor in determining which type of explosive to use. The denser the rock, the faster it transmits shock waves. One way to estimate sonic velocity in the field is to strike the rock with a one-pound hammer. If the rock craters and spalls from the blow, the sonic velocity is probably in the 8,000 to 10,000 feet per second (fps) range. If the hammer leaves a smooth dent, the velocity is from 10,000 to 13,000 fps. If the hammer chips the rock, leaving jagged edges, the velocity is from 13,000 to 15,000 fps. And if the hammer rebounds without damaging the rock, the velocity is from 15,000 to 18,000 fps.

Seismic investigation is a more precise method with which to determine sonic velocity. It involves a sound sensor (geophone) that times how long it takes a sound wave to travel between equally-spaced impact stations.

Velocity of Detonation

Velocity of detonation *(VOD)* is the speed at which an explosive changes from a solid to a gas. If the VOD is slower than the speed at which the rock transmits shock waves (sonic velocity), the rock breakage along the explosive column won't be uniform. Conversely, if the VOD is close to the sonic velocity, breakage will be more uniform along the entire explosive column. Most explosives have a VOD ranging from 10,000 to 18,000 fps. VOD increases as the diameter of the explosive increases. VOD also increases or decreases slightly as ambient temperature increases or decreases, respectively. Solid explosives exhibit less sensitivity to temperature than do liquid explosives.

Working in Groundwater

Surface water from rain and irrigation seeps down into the soil, forming underground pools. The level of underground water is known as the *water table*. Because of varying soil conditions, seasonal rainfall and topography, the water table doesn't exist at a constant depth below ground. In some cases, a shallow impermeable soil layer may result in a water table at or near surface level.

Groundwater causes several problems for the utility contractor. It creates unstable soil that's dangerous to work in and impossible to use as backfill. It can flood your trenches, washing out all the work you've done, so you can't finish the project.

High groundwater should be detailed in the specifications. You should know about it before bidding the job. This is one area of site preparation where you may want to be *overprepared*. It's important that you know how to handle saturated soil and flooded trenches, so I'll discuss each situation in more detail.

Saturated Soil

When silt and clay are saturated with water, they're impossible to compact. On jobs where compaction is important, you'll probably have to haul silt and clay spoil off the site and import replacement fill. The saturated soil won't be suitable for fill as long as it's wet, but on large jobs, there may be time for the soil to dry out.

In pastures and other areas where compaction isn't a problem, you can use sloppy soil as backfill. The fill will slowly assume the same characteristics as the surrounding soil.

When granular soils, such as sand and gravel, are saturated, they drain quickly and will be reasonably stable even when damp. Some dampness may even aid compaction of this type of soil.

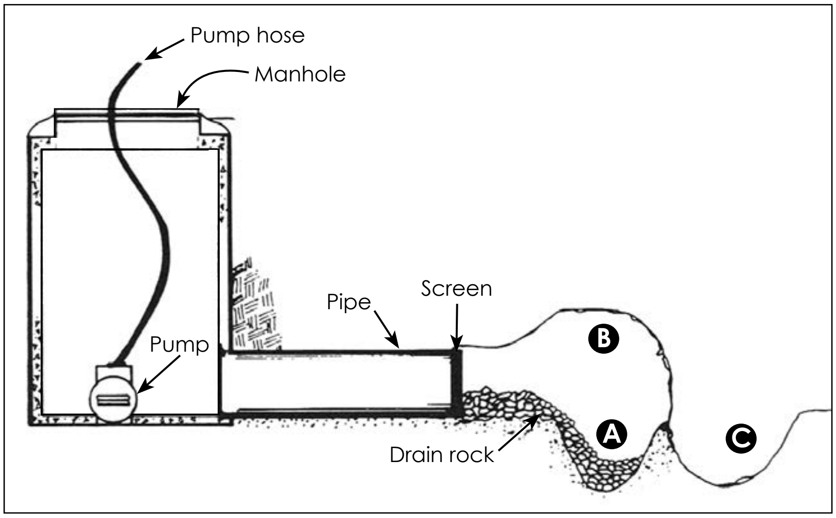
Seeping Water and Flooded Trenches

Special techniques are required when underground utilities must be installed below the water table. Water seeping into an excavation acts as a lubricant, allowing large slabs of dirt to slip out of place, causing dangerous cave-ins. When water seeps into granular soils, the soil begins to run or flow. This is known as *flowing sand* and it's extremely dangerous. The drier top layer is quickly undermined by the layer moving underneath it, and collapse is likely. Use shoring to protect your crew and your work in areas where there's seeping water. Drain rock that's at least 2 inches in diameter will provide a firm foundation for your pipelines.

In some cases, with a shallow trench, you can dig, lay and backfill at a rate that outpaces the water infiltration. But with deeper trenches in a high water table, you're facing a more complex problem. Go far enough into the water table and it may cause the water to *boil up* into the bottom of the excavation.

Have you ever tried to force an inflated object underwater? If so, you know how powerful water pressure can be. Water surrounding the trench exerts pressure on the water in the bottom of the excavation. So in a trench 10 feet below the water table, the water enters the trench under pressure. It isn't seeping; it's rushing into the trench. The upthrust may be strong enough to *blow up* the trench bottom, so you don't have a stable foundation for pipe laying. This bubbling, boiling-up action can make it virtually impossible to excavate. When a bucket full of soil is removed, it's replaced almost immediately by waterborne soil.

I've had the misfortune of having to work in flooded trenches, both as a pipe layer and equipment operator. So I know it *is* possible to get



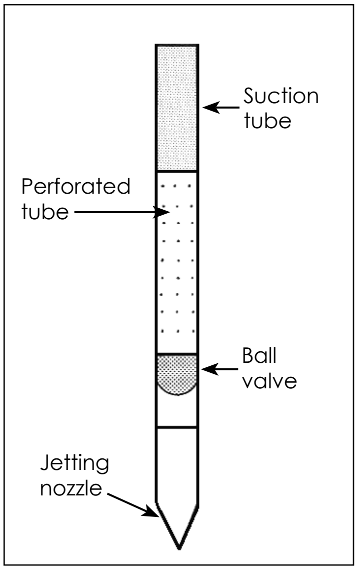
Sequence of excavation in high groundwater
Figure 10-12

pipe in the ground under these conditions. The first and most important lesson is that there's no such thing as too much pumping capacity. If your pump won't handle the water, you can't dig the trench.

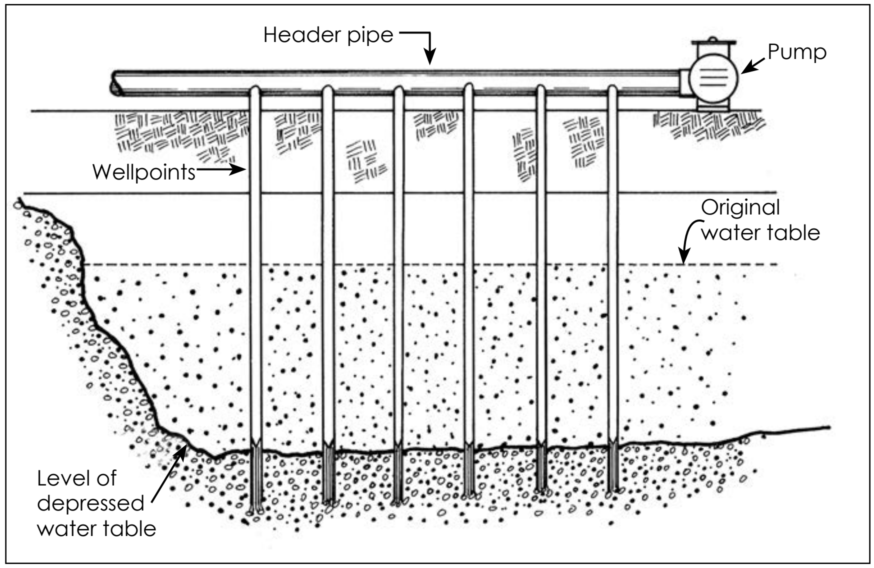
Large diesel-powered trash pumps are the best choice. Semi-permanent electric-powered submersibles can be effective too. The ideal spot for a semi-permanent electric pump is in the manhole downstream. Plug the outfall line and simply let the pump clear the water flowing down the pipe. Given enough pump capacity at this point, we only have to deal with the water below pipe grade. But if you're laying in a permeable soil like sand and gravel several feet below the water table, that water below pipe grade can amount to thousands of gallons per minute. Always use caution when using electric pumps. A severed power cord or pump malfunction in standing water could get someone electrocuted.

If possible, use newly-laid pipe to channel groundwater to the manhole. A weld mesh screen on the end of the last pipe will prevent drain rock from entering the pipe, but the water will be muddy and full of silt. It can block pump intake hoses, so the water may need to be filtered through a baffle tank or sump before it's discharged to the pump.

Once your crew has the pump set up, they can dewater the trench and excavate ahead of the pipe. Figure 10-12 illustrates the work sequence from A to C. The idea is to excavate the trench in short, deep sections. For each section, rock is piled behind the area that's about to be excavated. That way, the rock will slide into the excavation as the sloppy earth is removed. The sequence is repeated until there's sufficient room to lay a pipe section.



A wellpoint
Figure 10-13



A wellpoint system depressing the water table
Figure 10-14

IT'S A GOOD IDEA to cover laid pipe with a clean, compacted fill. That'll help prevent groundwater from following the pipeline to the area where you're laying new pipe.

Keep in mind that production will be slow if you need to lay pipe using this technique. You'll also use large quantities of rock.

Sludge deposits might accumulate as you run groundwater out through laid pipe. In small-diameter pipe, manual or mechanical flushing is used to clean out the sludge. In large-diameter pipe, a worker may need to get inside the line to clean it. That's dangerous work. If a pump fails somewhere up the line, a heavy flow of water may flood the line, putting the worker in extreme danger. Make sure you have enough dependable equipment to handle any emergency.

Wellpoint Dewatering

If you have a lot of pipe to install in bad groundwater conditions, consider dewatering ahead of pipe laying. Wellpoints, placed around the excavation site, are a potent dewatering solution. A wellpoint is a perforated tube that brings water to the surface via a suction tube (riser pipe). See Figure 10-13. Each wellpoint in the system connects to a header pipe, through which the water is pumped away. Figure 10-14 illustrates a complete wellpoint system working to depress the water table.

Wells are usually limited to a 20-foot suction lift. Well spacing varies from 3- to 12-foot centers, depending on soil porosity. A 1.5- or 2-inch self-jetting wellpoint will normally pump 10 and 25 gallons per minute, respectively. High-capacity 2-inch wells produce roughly 35 gallons per minute.

Dewatering with a mud pump
Figure 10-15

If wellpointing is needed, solicit bids from subcontractors. When pipe is laid and the trench is refilled, the wellpoint contractor removes his wellpoints. Obviously, this can be an expensive procedure. But at least it's a cost you can identify ahead of time.

Wellpoint systems work well in coarse-grained soils. They're not as effective in clay and they simply won't penetrate soil with large boulders. If wellpoints aren't an option, or you require greater production than wellpoints offer, you'll need suction wells. Suction wells use larger diameter pipe and the well excavation process is more complex.

Other dewatering methods include soil cement, chemically freezing the soil, and bentonite pressure injection. During the winter in cold climates, if the bottom of the excavation is above the frost line, it may not be necessary to dewater because the water will be frozen into the soil.

The best way to dewater an open excavation such as a pond or open trench is to drop a 3- to 4-inch flexible hose into the water at the lowest point and pump it dry using a centrifugal *mud pump*. See Figure 10-15.

During any dewatering operation, it's important to control where the pumped water is going. Improper disposal may have unintended consequences such as flooding areas beyond the site. It's also important to anticipate any adverse effects, such as disruption of the water table.

Courtesy of Florida Excavations, Inc.

Sheet piling with walers
Figure 10-16

Sheet Piling

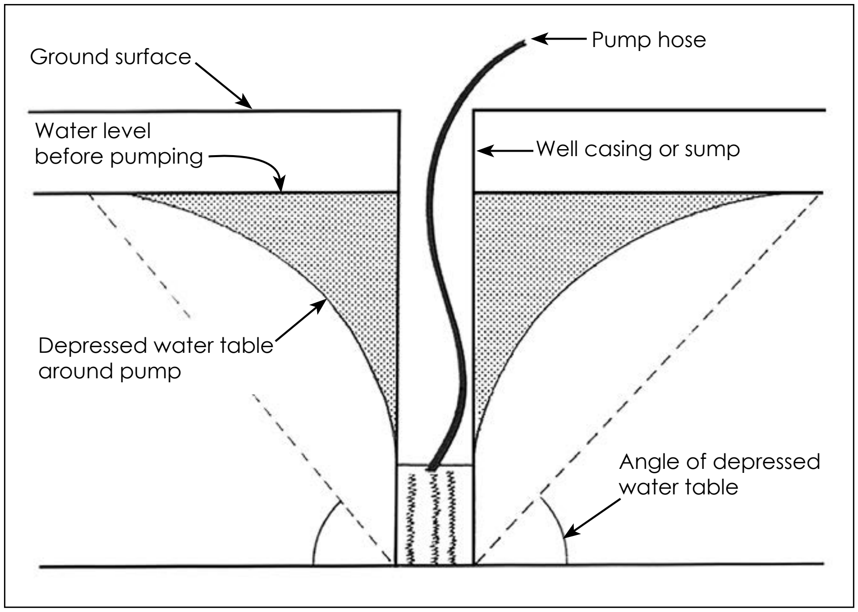
Sheet piling consists of interlocking panels that form a rigid soil or water barrier. Due to the nature of the work, sheet piling installation should be subbed out to an expert. But once installed, it can help minimize dewatering requirements and create a safer working environment. Other advantages of sheet piling include:

- displacement of soils (rather than removal), so adjacent structures are unaffected due to soil movement
- excellent stability, even in earthquake zones
- reusability
- topography and groundwater have little effect on the installation
- readily adjustable length, and especially useful when space is limited

Sheet piling is driven into the ground with impact or vibratory hammers — making sheet piling noisy to install, and impractical for use in stiff clay or soils containing boulders. Sheet piling systems can be free-standing *(cantilevered),* or reinforced with I-beams, cross beams or hydraulic rams *(walers)*. Figure 10-16 shows a sheet pile system with walers near the top of the wall.

"Steel panels are heavy, so trucking costs are high."

Sheet pile panels for pipe excavation work are usually black or galvanized steel, although vinyl, wood, plastic and fiberglass styles are available too. The panels are Z-shaped, so when multiple members are connected, they form a corrugation — which adds strength. The panels are available in lengths ranging from 15 to 70 feet, with 40-foot panels being the most common. They come in 12-, 10-, 8- and 7-gauge thicknesses. Steel panels are heavy, so trucking costs are high. Ten 40-foot panels may be enough to exceed a truck's weight limit.



Cone of depression
Figure 10-17

Cone of Depression

Groundwater and its behavior is a branch of engineering called hydrology, which is complex and beyond the scope of this book. But one hydrology concept you need to understand is *cone of depression,* which is illustrated in Figure 10-17. The cone's angle of depression depends on soil permeability, the quantity of water drawn from the bottom of the cone, and the speed with which it's drawn. Fast pumping creates a steep angle, while slower, sustained pumping flattens the angle. You're unlikely to achieve an angle of depression of greater than 60 degrees over a short time period. That means you need to space the sumps close together, or at least 6 to 10 feet below pipe grade, to adequately dewater a trench line. The greater the depth of your dewatering sumps, the greater the area that can be dewatered — *if* you have sufficient pump capacity and discharge facilities.

Production Rates in High Groundwater

Anytime you're working in high groundwater, expect lower production rates. Pump failures can slow the work. Your earthmoving equipment bucket loads won't exceed the bucket's struck capacity, and practical capacity of your trucks will be reduced. Be sure to factor that into your bid.

11

Pipe Materials

Since there are so many varieties of pipe available for fluid and gas transport, I've dedicated this entire chapter to the subject. Here, I'll discuss a broad range of pipe materials, their sizes and styles, recommended uses and the fittings and gaskets that connect them.

Pipe ends have one of four styles: plain end *(PE)*; beveled end *(BE)* for welding; threaded and supplied with one coupling per length *(T & C),* or bell and spigot. Steel pipe can be cut to any length and sold threaded both ends *(TBE)* or threaded on one end only *(TOE).* Copper and PVC are manufactured only as PE. Reinforced concrete pipe has bell and spigot ends that are pushed together and sealed with a rubber O-ring gasket.

DWV and Pressure Pipe

Drain, waste and vent *(DWV)* pipe carries wastewater away from homes and buildings to a sewer line or septic tank. Since the water isn't under pressure, DWV pipe can have thinner walls than pressure pipe, and joints don't need to be sealed as tightly. However, DWV pipe materials need to be able to withstand chemicals that might be poured down a drain.

Generally, 3-inch soil pipe is best for carrying solids from toilets, while 1½- or 2-inch pipe is appropriate for wastewater from sinks, laundries, showers and tubs.

> ***MOST RESIDENTIAL DWV SOIL PIPE*** used to be 4 inches in diameter. But low-flow toilets reduced average water levels in the pipe, resulting in clogs. 3-inch-diameter DWV pipe is now the common choice for residential projects.

Pressure pipe — often made from copper — is responsible for delivering clean, potable water. As the name implies, pressure pipe must be strong enough to resist continuous pressure without leaking or bursting.

Pipe Size

The pipe sizing classification system was originally based on a pipe's inside diameter *(ID)*. But variations in wall thickness meant the outside diameter could vary for two pipes of the same size. That made pipe connecting an uncertain and frustrating task, so outside diameter *(OD)* eventually became the accepted standard for pipe size classification.

Pipe Strength

Pipe is available in a number of different thicknesses or *schedules*. The American Society for Testing Materials *(ASTM)* establishes standards by which they're graded.

The three primary strength designations for pipe include standard wall *(Std.),* extra strong wall *(XS)* and double extra strong wall *(XXS)*. The latter two designations are sometimes referred to as extra heavy wall *(XH)* and double extra heavy wall *(XXH),* respectively.

For steel pipe up to 12 inches in diameter, wall thicknesses are assigned schedule numbers. They range from schedule 10 *(S.10)* which is light wall, to schedule 160 *(S.160)* which is double extra heavy wall. However, wrought iron pipe is classified by the more common designations Std., XS, and XXS, not by schedule numbers.

Many polyethylene pipe manufacturers use the Standard Dimension Ratio *(SDR)* method for rating pressure piping. The SDR is the ratio of pipe outside diameter to the wall thickness (diameter divided by wall thickness). For example, an SDR 11 means the outside diameter of the pipe is 11 times the thickness of the wall. So, relatively speaking, thin-wall pipe has a high SDR rating and a thick-wall pipe has a low SDR rating.

Copper Tubing

Copper is the most commonly used material for residential water supply lines because it's lightweight, easy to work with and resists corrosion. Copper comes in two forms: *hard (tempered)* or *soft (annealed)*. Hard tubing is rigid, and usually sold in lengths of 10 or 20 feet. Soft copper tubing comes in flexible coils.

Type M copper pipe is thin-walled. It's used primarily behind walls inside homes to distribute water from the service line and water heater to the fixtures. Main lines are typically run with ¾-inch Type M copper, with ½-inch Type M distributing water to individual fixtures.

Type L copper pipe is thicker than Type M and is used for indoor and outdoor water services. It's especially useful outside wherever the pipe will be exposed. Hard Type L tubing is sold in 20-foot lengths and soft Type L tubing is sold in 100-foot rolls.

Type K is the thickest variety of copper tubing, and it's mainly used for underground lines. Type K soft copper tubing is sold in 60- or 100-foot rolls, except for 2-inch tubing, which is sold in 40-foot rolls.

Copper Connections and Fittings

Soldering is the most commonly used method for connecting copper pipe. Typically, fittings that are soldered to the tube have threaded ends, but the tube itself does not. Soldering forms a stronger union than compression fittings. One disadvantage of soldering, however, is that it isn't reversible. Once soldered, the connected pipes can only be separated by cutting them.

Small-diameter copper tubing is connected with compression fittings. First, a compression nut is placed around the tubing and over a small ring. The nut is then screwed to a fitting, compressing the ring onto the tube and thereby sealing the joint. Since no solder is used, the joint may be disconnected with a wrench without cutting the tubing.

Galvanized Pipe

Galvanized pipe is steel pipe covered with a protective zinc coating. Unfortunately, minerals in water react with the galvanizing material, forming a scale, which eventually clogs the pipe. Except perhaps for repair work, galvanized pipe isn't a good candidate for water supply lines. Galvanized pipe (T & C) is sold in 21-foot lengths, while TOE galvanized pipe comes in 10½-foot lengths.

Galvanized pipe fittings are usually *malleable* (soft) cast iron. They're screwed onto the threaded pipe after applying a small amount of pipe joint compound or joint tape to the threads. Larger-diameter pipe is welded rather than threaded.

Black Pipe

Black pipe gets its name from the black oxide scale that's formed when steel pipe is forged. The factory also coats the pipe with protective oil to prevent rust and corrosion.

Black pipe is used for hot water circulation in boiler systems, and for indoor and outdoor residential gas distribution. It shouldn't be used for potable water or for DWV lines.

Black pipe is sold in standard 21-foot lengths with threads at both ends. Black malleable (soft) cast iron fittings screw onto the threaded pipe, and require pipe joint compound or plumber's tape for sealant. Larger-diameter pipe is welded rather than threaded.

Cast Iron Pipe

Cast iron pipe, also known as *soil pipe,* was frequently used in gas, sewage, drainage and commercial building soil stack applications. Despite its durability, cast iron pipe fell out of favor in recent decades with ductile iron being a popular substitute.

Cast iron pipe is joined by rubber sleeve-type couplings and band clamps. It can be connected to other drainage pipe materials by using transition fittings (special couplers that adapt from one pipe type to another.)

Ductile Iron Pipe

Ductile iron pipe is expensive and too heavy to lay by hand, but it's very strong. Ductile iron is often used for water, sewage lines and fire protection systems. It may be specified in areas where settlement is likely or where it's vital to prevent sewage leaks that can pollute the surroundings — such as near a municipal well or public water source.

Ductile iron pipe is available in 3- to 36-inch diameters and 20-foot lengths. A sewer system may use another pipe material for most of the system, with ductile iron specified only for sensitive portions. Where this is the case, you'll need to add in the cost of transition fittings.

Plastic Pipe

Plastic pipe is widely used for DWV pipe in residential construction. The smooth inner surface means fewer clogs. When it's used underground, plastic pipe is impervious to chemicals that would corrode cast iron and copper. Plastic pipe is available in flexible, semi-rigid and rigid forms. Plastic water supply lines normally range from ¼ to 1 inch in diameter.

Flexible pipe is commonly used for underground water piping because it's easy and economical to install. But keep in mind that some building codes prohibit the use of plastic pipe for water supply lines in residential construction.

There are several classes of plastic pipe and fittings:

- Acrylonitrile butadene styrene *(ABS)*
- Chlorinated polyvinyl chloride *(CPVC)*
- Polybutylene *(PB)*
- Polyethylene
- Polyvinyl chloride *(PVC)*
- Polypropylene

Most of these are flexible. Metal pipe ruptures when freezing water expands, but flexible plastic pipe doesn't. It needs only be buried deep enough below the surface to protect the pipe from damage. Any plastic pipe used to carry drinking water should have the National Sanitation Foundation seal.

Except for polyethylene, plastic pipe is solvent-welded or glued. Adapters are available for connecting plastic pipe to existing metal plumbing.

Acrylonitrile Butadene Styrene (ABS)

ABS is semi-rigid pipe with pressure ratings ranging from 80 to 160 psi. It's suitable for sewer pipe and has good chemical resistance and excellent impact strength. However, ABS isn't widely used in residential construction because it offers few advantages over PVC. ABS pipe is available in 1¼-, 1½-, 2-, 3-, 4- and 6-inch diameters and 10- or 20-foot lengths.

Chlorinated Polyvinyl Chloride (CPVC)

CPVC is used in hot and cold water supply systems when metal pipe isn't suitable — but check your local plumbing codes to see if it's permitted. CPVC has excellent chemical- and fire-resistance characteristics and is non-toxic and crush resistant. In water distribution systems, it has a 400 psi pressure rating at room temperature and 100 psi at 180 degrees F. This makes CPVC pipe a good choice for fire sprinkler applications.

CPVC connections require special solvent cement. The pipe is available in diameters ranging from ¼ through 12 inches. Smaller-diameter pipe is sold in 100- or 150-foot coils.

Polybutylene (PB)

Polybutylene pipe is the only flexible plastic tubing suitable for use with hot and cold water in pressure systems, but check your local building code to see if it's permitted. PB has excellent chemical resistance to acids and alkalis, but not fuel oil, gasoline or kerosene. It can be joined with heat fusion, flare or compression fittings, but it's not solvent weldable.

Polyethylene

Polyethylene is used in low-pressure water systems (such as golf course sprinklers), underground conduits and gas-pipe reliners. It's also used in industrial and chemical laboratory drainage systems and underground gas piping. Polyethylene has pressure ratings between 80 and 160 psi, and functions in temperatures ranging from 65 to 120 degrees F in low-pressure systems and to 200 degrees F in non-pressure systems.

"Although polyethylene is an inert material, it's susceptible to attack from oxidizing acids, oils, alcohols, UV rays and detergents while under stress."

Polyethylene is joined with nylon or brass fittings, and stainless steel clamps and clamp screws. Couplings aren't required unless the pipe is cut. Polyethylene pipe is available in diameters up to 6 inches or more, and in 100- to 1,000-foot coils.

Corrugated, perforated polyethylene is available for use as drainage pipe around residential foundations. It's usually 4 inches in diameter and is available in 10- or 20-foot lengths.

Over time, polyethylene experiences *creep* and *stress relaxation (deflection)*. Although polyethylene is an inert material, it's susceptible to attack from oxidizing acids, oils, alcohols, UV rays and detergents while under stress. And because polyethylene pipe has thin walls, slight scratches or wear from handling can lead to premature failures.

Polyvinyl Chloride (PVC)

PVC pipe is the most widely used plastic pipe in residential DWV applications due to its crush and chemical resistance, impact strength and ease of installation.

PVC's pressure rating decreases with an increase in temperature. Published pressure ratings are based on an operating temperature of 73 degrees F, and it's functional up to 140 degrees F in pressure systems or 180 degrees F in DWV applications. PVC won't rust, pit or degrade when exposed to moisture and is extremely resistant to a broad range of corrosive agents, including acids, bases, salts and oxidants. But don't use PVC for compressed air or gas systems.

PVC is flexible and forgiving during warm weather installation, but it loses its flexibility during cold weather. Some small-diameter (3 inches or less) PVC is fragile, so engineers often specify full-cover bedding if the soil is rocky.

PVC is available with pressure ratings up to 315 psi. For pressure lines, PVC should be used for cold water only. High-pressure PVC pipe larger than 8 inches in diameter is heavy and requires machine handling.

Schedule 40 and 80 PVC are often used in pressure supply and drainage systems to carry water for golf course sprinklers, agricultural irrigation, underground gas distribution systems, industrial and chemical piping, corrosive fume ducting and crude oil transportation.

PVC comes in 10- or 20-foot lengths that are joined with solvent cement. Since there are so many PVC varieties to choose from, I'll discuss some of them in more detail below.

- *Schedule 40* is dual-use pipe. Even though it's rated for pressure, Schedule 40 is most often used for drainage where a more durable pipe is preferred. *Schedule 80,* with its thicker walls and higher psi rating, may be specified for a variety of applications. These pipes come in diameters ranging from $^1/_8$ through 24 inches.
- *ASTM D2241* is SDR pipe and it's available in diameters ranging from $^1/_8$ through 36 inches.
- *ASTM C900* pipe is used for water mains and is available in diameters ranging from 4 through 36 inches.
- *ASTM C909* PVC pipe is molecularly oriented through a heat and expansion process during its manufacture. This gives it higher tensile and impact strength. C909 is available in diameters ranging from 4 through 24 inches.
- *Foamcore* PVC has a solid outer layer, a lightweight cellular core intermediate layer, and a solid inner layer. Foamcore pipe is suitable for drainage only, and comes in diameters ranging from 2 through 18 inches.
- *ASTM D3034* is thin-walled pipe that's rated for drainage or conduit only. It's sold with or without perforations and is available in diameters ranging from 4 through 15 inches.
- *Folded* PVC is used for relining existing underground pipes and is available in diameters ranging from 4 through 15 inches.

Although there's no universal standard, PVC manufacturers generally follow a common color scheme for their pipe:

- White for DWV or pressure systems
- White, blue, and dark gray for cold water piping
- Green for sewer service
- Dark gray for industrial pressure applications

PVC and resin compound pipe usually comes in 20-foot lengths, which is too long for deep trench work. It's hard to dig and prepare a 20-foot digging set. That's when 12½-foot pipe lengths come in handy, especially if you're using a 16- or 20-foot trench box.

PVC and resin compound pipe is easy to cut and bevel. This allows precise positioning of tees and wyes, which can speed up production if the service pipes are laid prior to the main line.

"Some cities outlaw PVC pipe in buildings because it gives off noxious fumes when it burns."

You'll use slip gaskets with this type of pipe, which I'll discuss later in the chapter. Be sure your cutting and beveling are accurate or your gaskets will be out of place and your installation will be faulty.

PVC pipe and fittings are joined together with solvent cement or compression couplers, while large-diameter pipes are connected with gaskets. One disadvantage of the glue joint is that the surfaces to be joined must be perfectly dry. That's not easy if you're working in wet laying conditions. Be sure to cut pipe ends square and bevel the cut end with a chamfering tool. When you've seated the pipe in the connection, give it a quarter turn.

Some cities outlaw PVC pipe in buildings because it gives off noxious fumes when it burns. This may limit its use to belowground applications in some cases.

Polypropylene Pipe

Polypropylene pipe has excellent chemical resistance, including salt water and sulfur-bearing compounds. It's also lightweight and has good tensile strength. Polypropylene is flexible, resistant to most ordinary household chemicals and it's stronger than polyethylene, with a higher functioning temperature (up to 180 degrees F).

Corrugated culvert pipe
Figure 11-1

Polypropylene is available in diameters ranging from ½ through 63 inches. It's manufactured in rolls and in straight pieces up to 40 feet long. It can be used for water or sewer lines and for natural gas distribution.

Corrugated Polyethylene Culvert Pipe

Corrugated polyethylene pipe has a smooth interior surface to allow drainage. It comes in 20-foot lengths and a variety of diameters ranging from 4 through 48 inches. See Figure 11-1.

Corrugated polyethylene is a flexible structure that can withstand severe pressures without compression or fracture. It's strong, lightweight, easy to handle and more economical than steel pipe. Available external band clamps can ensure a tight joint and connection points.

Cross-Linked Polyethylene Pipe

Cross-linked polyethylene pipe *(PEX)* is a modified medium- or high-density polyethylene pipe. It's available in diameters from ¼ through 2 inches.

Because of its 200-degree F working range, common PEX applications include hot water distribution systems such as radiators and underfloor radiant heat piping, in addition to sewer and cold-water distribution.

Reinforced concrete pipe
Figure 11-2

Concrete Pipe

Stormwater pipe carries rainwater, groundwater, or similar flows to a safe discharge point. In contrast, sewer pipe carries liquid and water-carried wastes from homes, commercial facilities, industrial plants and institutions to a treatment plant. What the systems have in common is that each system must be watertight, hydraulically efficient, abrasion-resistant, and meet the strength requirements of any depth of fill and live load. Concrete pipe, which has an impressive record of strength and durability, fits the bill. See Figure 11-2. It's the most economical and reliable pipe material available.

Concrete pipe usually comes in 8-foot lengths. The short sections make it easier to work with around existing municipal services. Concrete pipe joints are sealed with O-ring rubber gaskets or butyl mastic compound. For installations with *internal* or *external head* conditions, joints may be sealed with a rubber gasket. Internal head is the pressure created by water pressure inside the pipe trying to leak into the soil. External head is created by water pressure outside the pipe, trying to leak into the pipe.

TO PREVENT SAND from entering through pipe joints, wrap the joints with filter fabric. Otherwise, the pipe will need to be cleaned out periodically.

Concrete pipe is available in non-reinforced and reinforced *(RCP)* styles. The reinforcing is either wire or reinforcing steel, placed in three layers around the pipe. Some concrete pipe is lined with a PVC coating.

ASTM C76 reinforced concrete pipe is available in 12- to 144-inch diameter sections and is available with bell-and-spigot or tongue-and-groove ends. These joints are adequate for most storm sewer installations.

ASTM C655 concrete pipe is similar to ASTM C76, except that it's designed for a specific *D-Load*. D-Load is a measure of a concrete pipe's strength. It's expressed in pounds per linear foot, divided by the inside pipe diameter expressed in feet. The D-Load of a pipe is dependent on the wall thickness, reinforcing steel and the strength of concrete used in its manufacture.

Here are five of the commonly-specified RCP classes, and their associated D-Load ratings:

- *Class I,* 800 lb/ft/ft D-Load
- *Class II,* 1,000 lb/ft/ft D-Load
- *Class III,* 1,350 lb/ft/ft D-Load
- *Class IV,* 2,000 lb/ft/ft D-Load
- *Class V,* 3,000 lb/ft/ft D-Load

Classes III through V are usually specified for construction projects. Class III pipe is used under normal loads. Class IV is specified under airport runways and highways with heavy traffic. Class V is normally used under railroad tracks.

Elliptical Reinforced Concrete Pipe

Elliptical (oval-shaped) pipe is used in restricted areas where equivalent capacity round pipe won't fit. If there's limited vertical clearance it can be installed horizontally. Where there's limited horizontal clearance it's installed vertically. A vertical ellipse also increases the water flow capabilities of the pipe.

> "Elliptical (oval-shaped) *pipe is used in restricted areas where equivalent capacity round pipe won't fit."*

Elliptical pipe is normally sold in circular diameter equivalents of 18 through 144 inches. It's available with tongue-and-groove joints that can be sealed with either class C mortar or mastic compound.

Fiber-Reinforced Concrete Pipe

Fiber-reinforced concrete pipe, such as HardiePipe™, is relatively new but gaining acceptance as an RCP alternative. A special fiber eliminates the need for reinforcing steel, while reducing weight and eliminating rust concerns. This style of pipe is available in 12-, 15-, 18-, 24- and 36-inch diameters. It's easy to cut with a diamond blade power saw or an abrasive disc. Standard lengths are 16 feet, but shorter lengths are available. They're joined with rubber gaskets.

Other Pipe Materials

Vitrified Clay Pipe

Clay pipe is manufactured in nominal diameters ranging from 8 through 42 inches and in 4-, 6- and 8-foot lengths. Like concrete, clay has a high load-bearing capacity. Clay pipe is lighter than concrete. It also has fixed tees and wyes. Joints used to be made with tarred rope and mortar joints. Now there are modern gaskets you can use with clay pipe that take less time to install.

Fiberglass Pipe

Fiberglass pipe is often used for handling extremely corrosive materials such as acids. Fiberglass has the advantage of being both lightweight and strong. However, the downside is that cutting, joining and repairing are all more difficult than with some of the more common pipe materials.

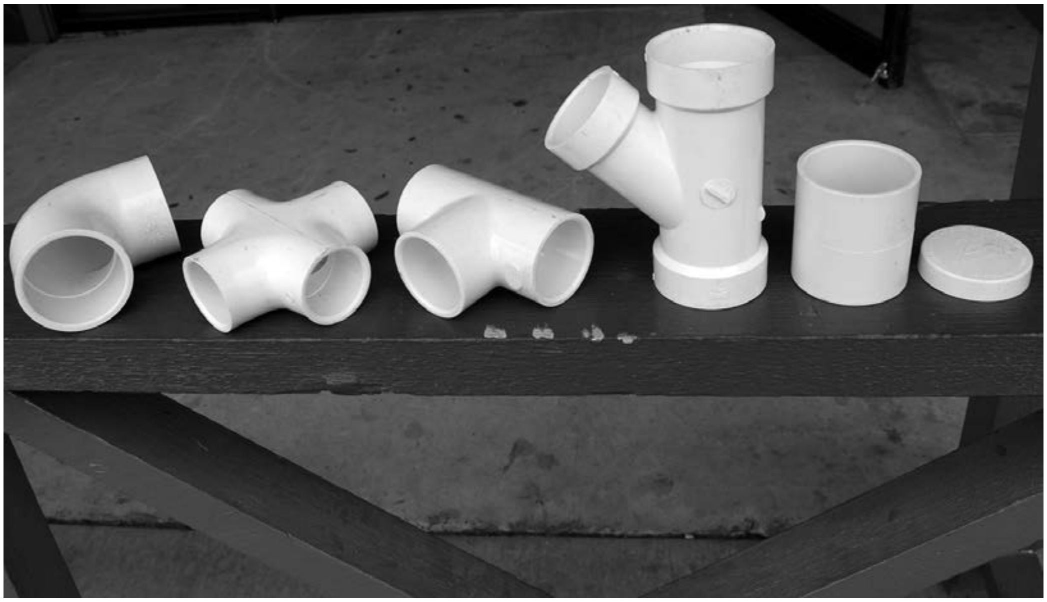
Wooden Water Pipe

At one time, *wood pipe* was used for water mains, especially in the New England states. Some wood pipe was made the same way wood barrels are made today. In other cases, it's a hollowed-out log. I doubt if you'll be laying any wood pipe, but if you work in an older city, you may be called on to replace some.

Size or Material Change and Directional Fittings

Use pipe fittings to change pipe size, type or direction of flow. Common PVC pipe fittings are shown in Figure 11-3. From left to right in the figure, we have an ell, cross, tee, wye, coupling and cap.

Some fittings for large water pipe require a *thrust block,* which is a mass of concrete placed to resist the thrust of water that's inevitable when water changes direction. It's a good idea to wrap the fittings with plastic sheeting such as Visqueen before the concrete is poured. If the fittings require future reworking, the wrapping makes it easier to



Common PVC fittings
Figure 11-3

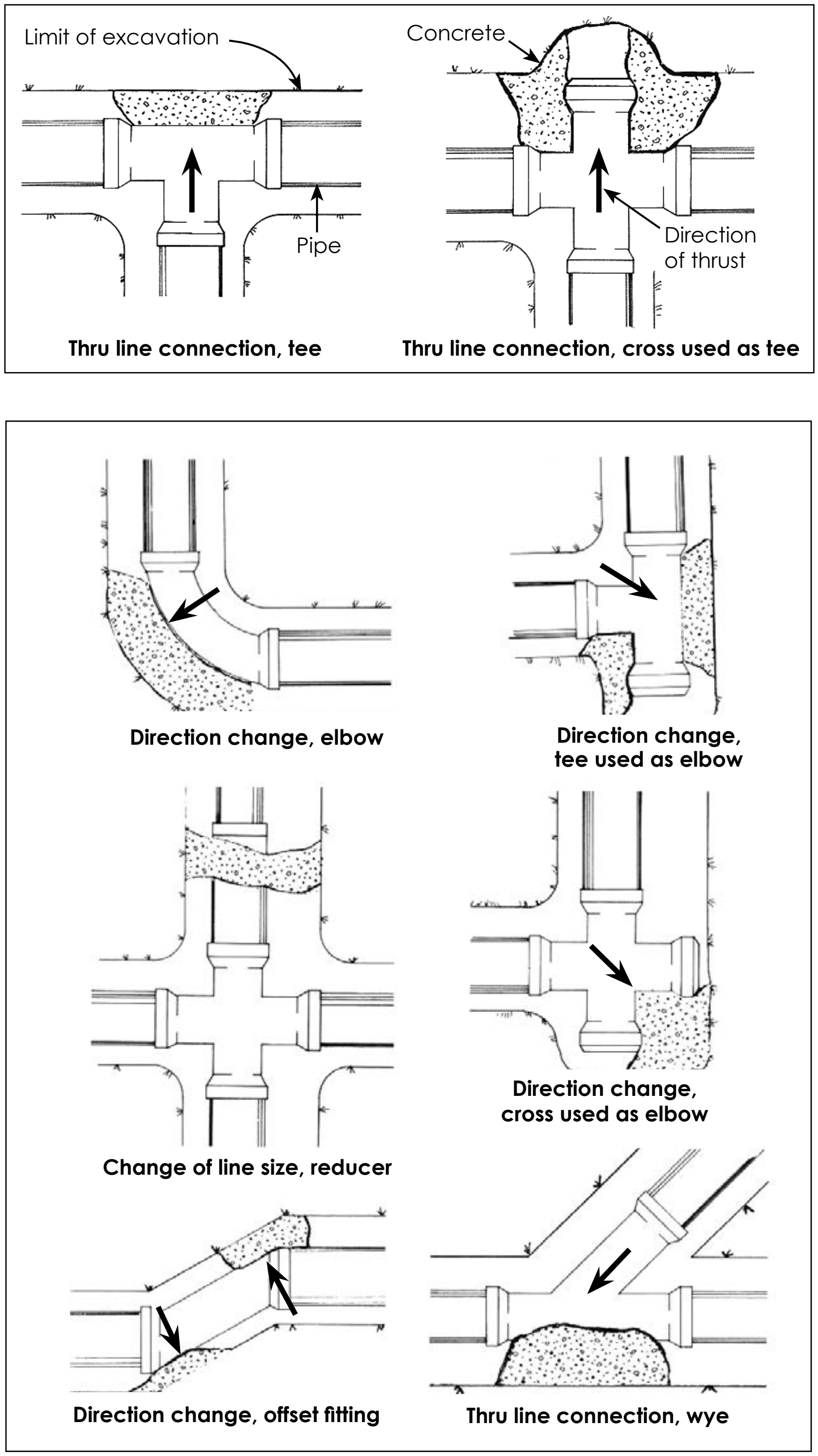
bust out the concrete without damaging the pipe or the fitting. Figure 11-4 illustrates some common thrust block configurations. Refer back to Chapter 7 for more discussion about thrust blocks.

Ell is the common term for elbows or bends. 45- and 22½-degree ells are the most commonly used. Sometimes ells are described by the fraction of a 360-degree circle they contain. For example, since ¼ of a circle is 90 degrees, a 90-degree ell is called a ¼. Likewise, a 45-degree ell is called a $^1/_8$ and a 22½-degree ell is called a $^1/_{16}$.

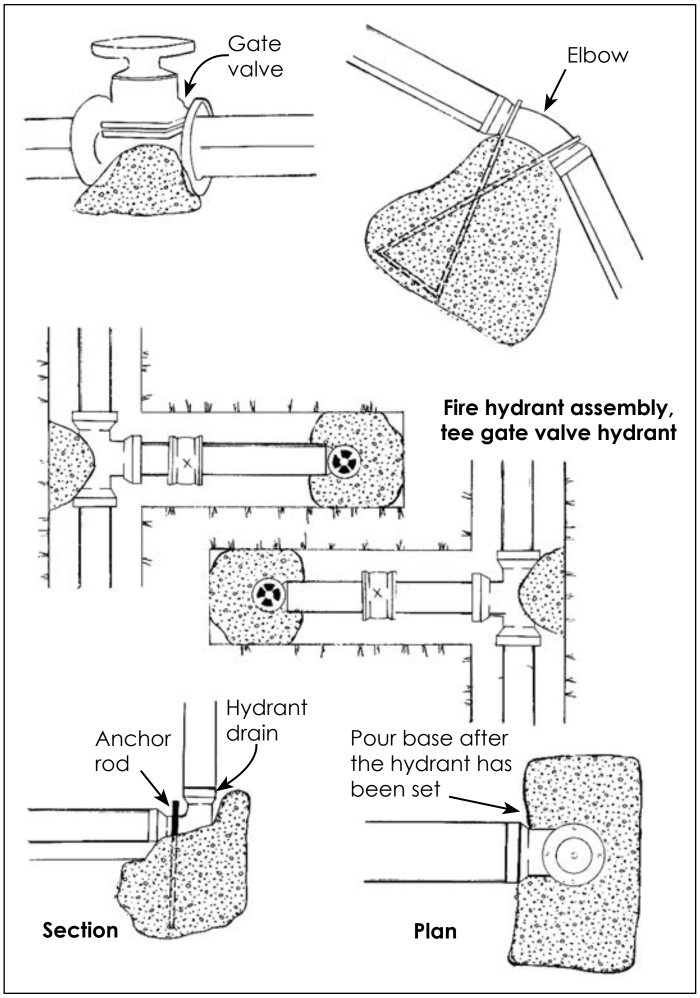
As the name implies, a *tee* is a T-shaped fitting that connects pipes of unequal sizes, or changes the direction of the pipe run. Use tees to connect the main line to the service lines. As the main line will always equal or exceed the diameter of service lines, a 6- by 4-inch tee would be used for a 6-inch main line with a 4-inch branch line. The smaller measurement is always the size of the branch line.

Wyes are Y-shaped fittings that allow the service pipe to enter the main line at a 45-degree angle. You can set wyes vertically and use them with a 45-degree ell. This provides an upright riser commonly used for the cleanout at the end of a line. It also allows easy access for tools when it's necessary to clean the line.

A *cleanout assembly* consists of a wye, a 45-degree ell and a capped (or plugged) length of pipe rising up to the surface of the ground. In the event of a blockage in the line, the cleanout allows easy access to the line. Cleanouts are usually used where the service line changes direction on private property.



Line fittings and thrust blocks
Figure 11-4



Line fittings and thrust blocks (Cont.)
Figure 11-4

To avoid water infiltration, all blank and unused connections are plugged or capped. You can use fittings, either of the same material as the pipe or mechanical plugs.

Remember that you'll be testing the system once it's complete. So be sure your plugs and caps are all firmly in place. In fact, it's good practice to place a 2 x 4 service marker against a cap or plug so it can help hold the cap in place during air testing. See Figure 11-5.

Gaskets

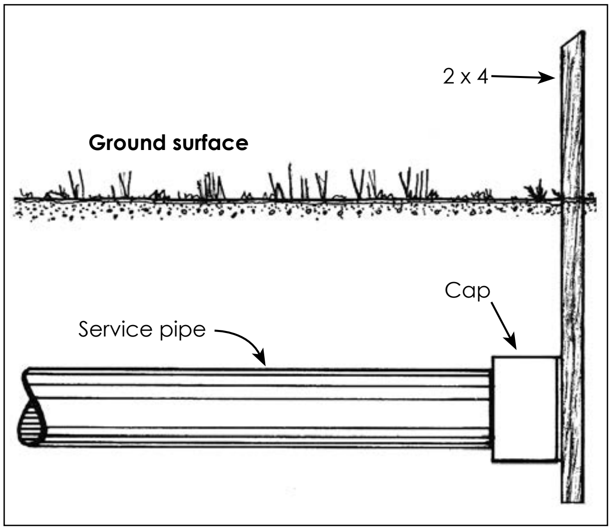
Gaskets provide the seal between the bell and spigot of individual pipe sections. All types of pipe require gaskets, except pipe fitted with glue-joints. Rubber compounds are the most common gasket material. Under compression, the rubber is displaced, filling any voids or irregularities between the surfaces of the bell and spigot.

When joining PVC pipe with gasket connections, be aware that some gaskets are designed to be used in a specific direction. It's possible to insert the gasket into the bell backward. If you assemble the pipe with the gasket in backward, you may *fishmouth* the gasket, pushing it out of the gasket seat during assembly. With some loose gasket systems, it's important not to lubricate the bell. If lubricant gets behind and underneath the gasket, it too can cause the gasket to fishmouth.

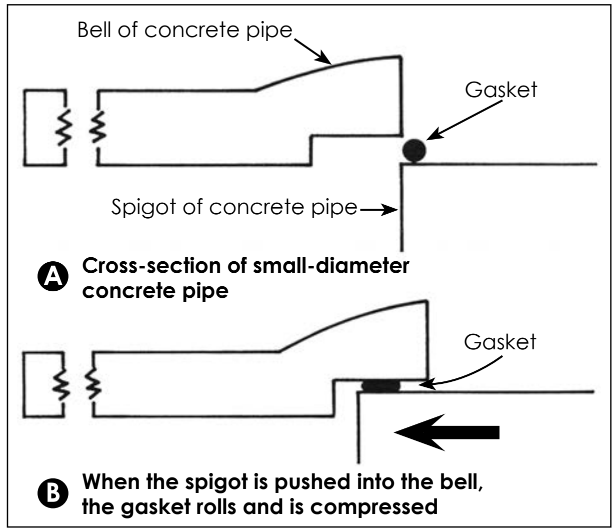
Different types of pipe require different types of gaskets. Be sure you use the correct gasket for the pipe you're installing. Every seal in the line depends on it. For example, gaskets used for pressure pipe rely on internal pressure to force the gasket against the spigot and bell. These gaskets don't work well at low pressures.

There are four main types of gaskets: *roll-over gaskets, fixed O-rings, compression gaskets* and *slip-type gaskets.*

WHEN YOU JOIN PIPES
of different material — such as joining an existing clay sewer service to a new PVC service pipe — you'll need a special fitting such as flexible rubber bands that slip over the spigots and are held in place by adjustable clamps.



2 x 4 service marker placed against cap
Figure 11-5



Roll-over gasket in small-diameter pipe
Figure 11-6

Roll-Over Gaskets

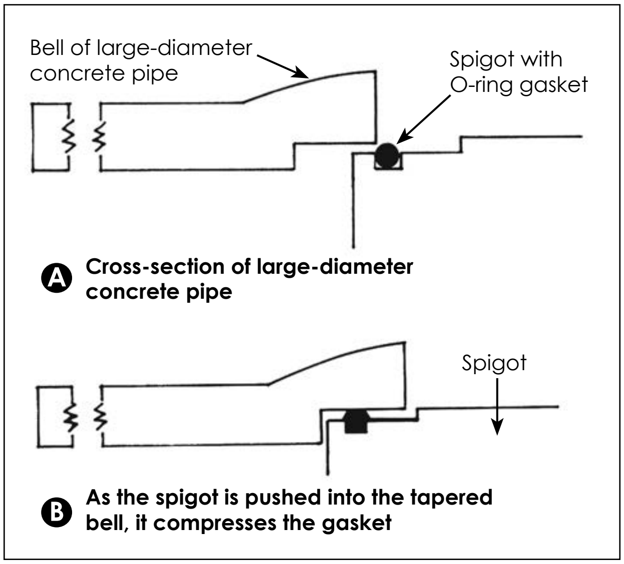
Roll-over gaskets are commonly used for concrete sewer pipe up to 10 inches in diameter. They're soft and usually D- or teardrop-shaped. Rolling the gasket into position compresses it. See Figure 11-6.

For a roll-over gasket to work properly, the bell and spigot must be perfectly aligned, and free from dirt, grease or anything that will cause the gasket to slip or not roll over like it's supposed to.

To install the roll-over gasket, set the gasket on the outermost edge of the spigot. Holding the pipe firmly, use your hand and knee to sharply push the spigot into the bell. Always check the gasket by feel. If the gasket is in the wrong place, you'll be able to feel that it's not seated smoothly inside the bell.

"Faulty pipe will result in a faulty seal and a joint that leaks."

Pay attention to the quality of the finish on the bell and spigot. The gasket will take care of tiny irregularities. But chips or bubble spots in the concrete may result in a bad seal. If a pipe has finish defects, either send it back or repair it with grout. Faulty pipe will result in a faulty seal and a joint that leaks. Also, keep in mind that if the inspector finds sand in the pipe, he'll suspect a leak and that will lead to close scrutiny of the entire system.



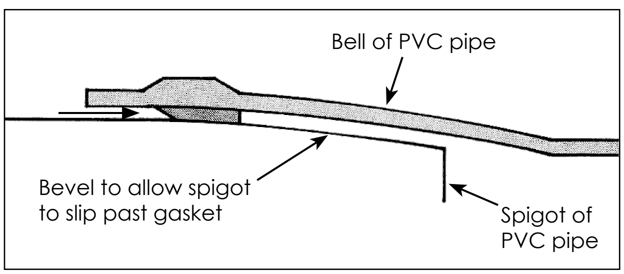
O-ring gasket in large-diameter concrete pipe
Figure 11-7

O-Ring Gaskets

O-ring gaskets are used for large-diameter concrete pipe. A groove or indentation in the spigot holds this gasket in place. See Figure 11-7. Use a lubricant to help slide the gasket into the bell. Commonly called *pipe slick* or *soap,* pipe lubricant is specially formulated so that it won't harm the rubber compound. In a pinch, you can use household vegetable shortening, which has similar properties. But don't use equipment lubricating grease in place of pipe lubricant. Grease will attack the gasket and eventually erode it.

Compression Gaskets

Compression gaskets are mechanically compressed, and commonly used in flanges, mechanical joints, water service fittings and pressure sewer lines.



Slip gasket used with PVC pipe
Figure 11-8

Slip Gaskets

Figure 11-8 shows a slip gasket on a PVC pipe joint. Be sure you insert loose gaskets in the proper direction. Some gaskets are marked, while others are hard to figure out; so read the manufacturer's directions carefully. The directions will also tell you how to care for the gaskets. Many rubber gaskets deteriorate in sunlight or exposure to the elements, and need special handling.

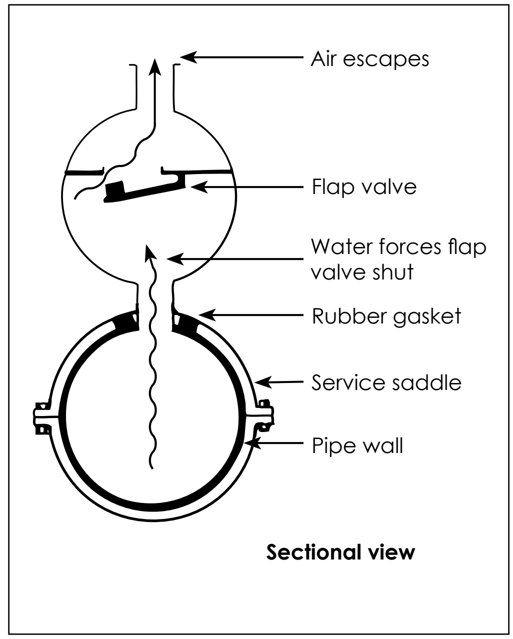
Water Control Fittings

There are three important *control* fittings that you'll use to regulate the flow of water in the main:

- *Gate valves (G V)* open or shut off the flow of water through the main line. A typical gate valve is shown in Figure 11-9.
- *Fire hydrants* deliver a large volume water in an emergency.

Courtesy of Ferguson Waterworks, Sarasota

Typical gate valve
Figure 11-9



Air relief valve
Figure 11-10

- *Air relief valves* allow air to escape from the main line when there's no other escape. An air bubble in a pipeline reduces the pipe's carrying capacity and contributes to water hammer. Avoid air bubbles in your line by installing it with constant, gradual slopes. Bubbles develop when air is trapped at a high point that isn't a point of use. If a high point in the line is unavoidable, be sure to install an air relief valve so that the air has a means of escape. A typical air relief valve is shown in Figure 11-10.

Joints

Three types of joints are used for main pipelines and fittings: *slip joints, mechanical joints* and *flanged joints*. Slip joints, also known as *push joints,* are the easiest to install. They're used for almost all main line pipe connections. Slip joints are specified by Ring-Tite® or other brand name. Figure 11-11 shows a typical slip joint. It has one major disadvantage: thrust may cause the joint to come apart. As long as pipe is laid in a straight line, this isn't a problem. But any change of direction will need reinforcement. Joints can be reinforced by blocking, river-crossing joints or by using specially-cast fittings that allow the assembly to be tied together with bolts or threaded stock.

Courtesy of Ferguson Waterworks, Sarasota

Push joint fittings
Figure 11-11

Courtesy of Ferguson Waterworks, Sarasota

Flanged joint fittings
Figure 11-12

A m*echanical joint (MJ)* is a compression coupling; it seals by mechanically forcing a wedge-shaped gasket against the outside diameter of the pipe and the inside edge of the fitting. This is done either by using bolts to pull in a follower or, in the case of small-diameter service fittings, by the force of the nut being threaded onto the fitting. Mechanical joints are less likely to come apart than slip joints, but they still require blocking.

A *flanged joint* (abbreviated *Flg*) is completely rigid after assembly. See Figure 11-12. You'll use flanged joints for aboveground pipe work, such as pump houses, or where a line must hold pressure immediately after assembly. Flanged fittings are sometimes used for valves, tees and crosses. Assemble the flanges above ground whenever possible. It takes time and room to clean both flanges, fit a gasket between them and tighten the numerous nuts and bolts.

Fittings

There are six common types of service line fittings: threaded, compression, glue, flanged, adaptor and control. Some fittings come with a different fitting type on each end. For example, if you see the notation *MJ x Flg. G. V.,* it's referring to a gate valve with a mechanical fitting on one end and a flanged fitting on the other.

Threaded Fittings

Threaded fittings are often used for galvanized iron and PVC pipe. Pipe can be threaded on site, using a pipe vice and die. Pipe purchased in standard lengths will arrive already threaded. Short lengths of threaded pipe are called *nipples*. The spigot end of threaded pipe is always referred to as the *male* end. The coupler or nut thread is the *female* end.

All threaded connections require a sealing tape or paste compound. But don't use thread-sealing paste *(pipe dope)* on plastic threads. You can use Teflon tape for both plastic and steel threads. Be sure to wrap the tape in a clockwise direction, so it doesn't unravel as the thread is tightened.

Compression Fittings

Compression fittings consist of a *compression nut* and a *gasket* or *ring* (sometimes called a *ferrule* or *olive*). The nut screws on to press the gasket into place, forming a seal. This type of joint can be used on all types of pipe, but be sure to reinforce soft polyethylene pipe with steel inserts so you don't damage it during installation. To get a good seal, the pipe should be free of defects and debris.

Glue Fittings

Glue fittings are used to connect plastic pipe. They're simple to assemble. Just be sure that the mating surfaces are dry when you apply the glue. The PVC will take the glue better if you use a primer to soften the PVC first. It's good practice to twist the pipe as you push the ends together. This spreads the adhesive evenly.

Flanged Fittings

Flanged fittings are used to hook up water meters so the meter can be lifted directly out of its setting. Meters with quick-detach flanged couplers measure water usage, either in gallons or cubic feet.

If you install a meter backwards, it will either work in reverse or it won't work at all. This causes confused meter readers and temporarily-happy water consumers. Make sure you install the meter the right way.

Adapter Fittings

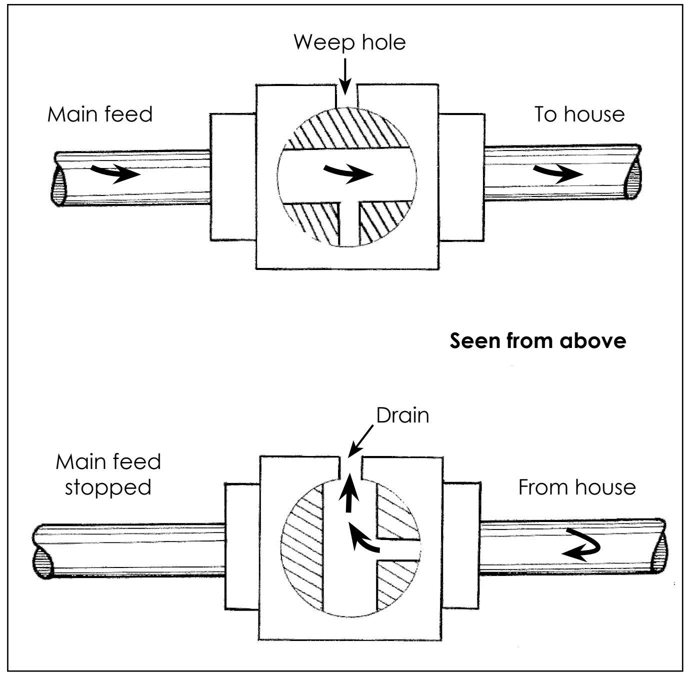
Adapter fittings allow you to switch from one type of fitting to another when you're trying to join two mismatched or otherwise incompatible pieces.

Control Fittings

Control fittings are needed to interrupt flow, reduce water pressure, and to shut off the water to a service line when required. Three important control fittings are the *corporation stop,* the *stop and drain,* and the *curb stop.*

Courtesy of Ferguson Waterworks, Sarasota

Typical corp stops
Figure 11-13



How a stop and drain works
Figure 11-14

Corporation Stop

The primary control is the corporation stop, or *corp*. See Figure 11-13. This fitting is either threaded directly into the main pipe or threaded into a *service saddle* which is strapped to the main pipe.

The corp operates on a different principle than a gate valve. The corp uses a tapped, drilled shaft enclosed in a tight-fitting body. Turning the shaft 90 degrees closes the hole and prevents water from passing through. Corps are made from bronze or gunmetal. These materials can be damaged by the unprotected jaws of a pipe wrench, so be careful during installation. There's a nut and washer at the bottom end of the tapered shaft that tighten the shaft into place. Old corps on service lines may have loose nuts. Tightening these nuts can help stop a leak. It's also a good practice to check the tension of the nuts on new corporation stops.

Stop and Drain

As the name implies, a stop and drain interrupts the water supply and lets the water drain back from the pipe beyond the fittings. In cold weather, this lets you drain the pipes so they won't freeze. Be sure to install these fittings according to the direction arrows marked on the outside of the fitting. See Figure 11-14.

Courtesy of Ferguson Waterworks, Sarasota

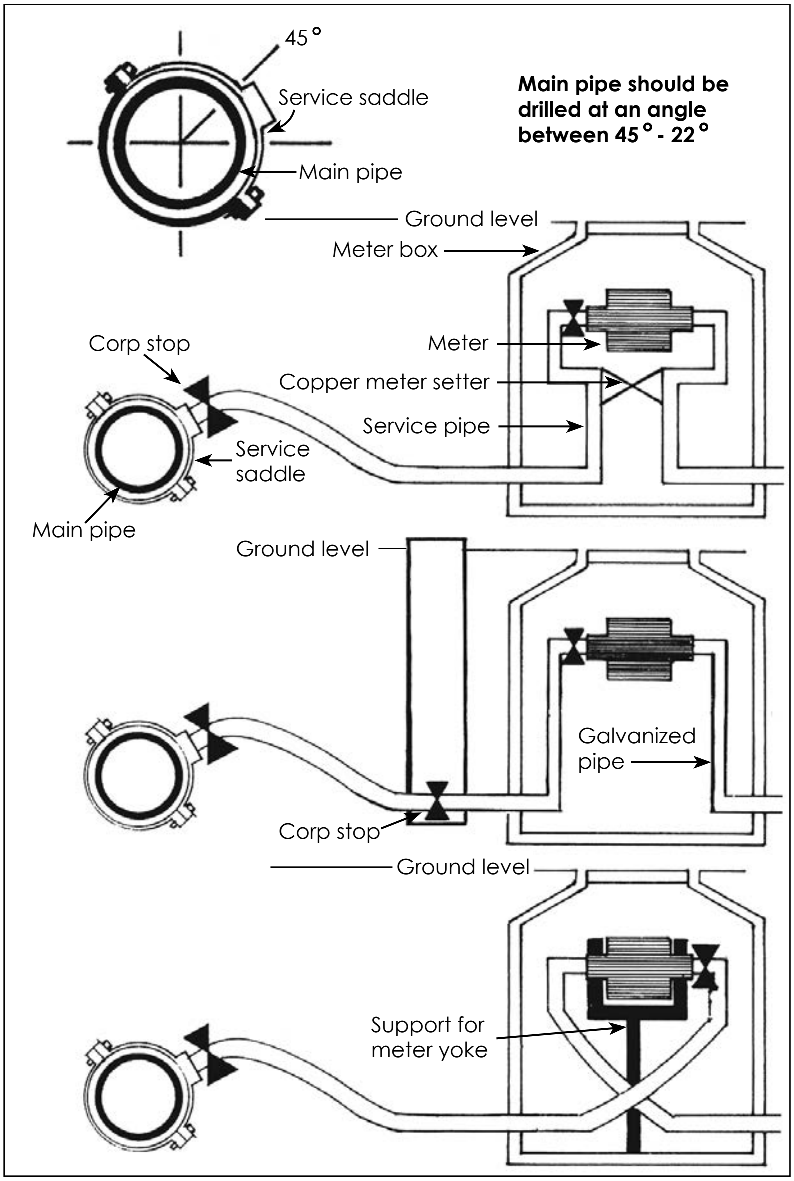
Meter setter with valve
Figure 11-15

Curb Stop

A curb stop is an in-line valve that works on the same principle as the corp stop. Some service line specs demand both a curb stop and a valve in the meter box. The valve in the meter box is usually part of the meter setter, as shown in Figure 11-15. If there's a valve already provided on the meter setter, the specs will usually call for a corp stop instead of a curb stop. Typical water service line plans using corp and curb stops are shown in Figure 11-16.

Repair Clamps

Pipe repair clamps are used to fix accidental damage or to correct problems created by sloppy installation. When using repair clamps on existing pipe, be sure the pipe is clean and free from scale. All clamps are equipped with high-tensile bolts and require adequate torque to ensure a watertight seal. And remember to torque the bolts down alternately. If you overtighten on one or both sides of a coupler, you'll end up with broken bolts and a clamp that's out of alignment.



Typical water service plans
Figure 11-16

Three commonly-used repair clamps are the *compression coupler,* the *bandage-type coupler* and the *split-ring bell repair clamp.* Before we discuss the function of each type of clamp, take a look at Figure 11-17. It shows pipe outside diameters. You'll need this information to select the right gasket and repair clamp.

Figure 11-17 also shows that the spigot OD is less than the overall OD of the full-size pipe. So joints made to the overall OD require compression gaskets that are larger than the spigot dimensions. Rough-cast middle sections of full-size pipe won't fit the bell or collar of the pipe. So compression couplers must be used.

> ***NOTE THE REFERENCE*** to MOA in Figure 11-17. MOA stands for *milled overall.* You'll use MOA pipe for the short sections required in fitting assemblies. MOA pipe isn't the same as MEE pipe. MEE means *milled each end.* MEE pipe is full-size pipe that has the middle section left in its rough-cast condition.

When a section of pipeline is damaged, you can cut out the damaged piece and clamp a replacement length into place with compression couplers. Figure 11-18 shows a typical compression coupler.

If the pipe has a break along its length, you can repair it using the wraparound, bandage-type coupler. You can also use a saddle clamp to repair a corp that has been torn out. See Figure 11-19.

To repair a fishmouthed gasket, use the split-ring bell repair clamp shown in Figure 11-20. It's less expensive than cutting out a section of pipe and adding two straight couplers. Careful installation will prevent fishmouthed gaskets.

Size (inches) inside diameter	Cast and ductile iron (O.D.)	Spigot or MOA* Class 150 (O.D.)	Spigot or MOA* Class 200 (O.D.)	Pipe Class 150 (O.D.)	Pipe Class 200 (O.D.)	PVC (O.D.)
4	4.80	4.81	4.81	5.27	5.57	4.500
6	6.90	6.91	6.91	7.37	7.56	6.625
8	9.05	9.11	9.11	8.57	9.74	8.625
10	11.10	11.66	11.66	12.12	12.12	10.750
12	13.20	13.92	13.92	14.38	14.38	12.750
14	15.30	16.22	16.22	16.73	16.88	--
16	17.40	18.46	18.46	18.97	19.19	--

*MOA = milled overall

Comparative pipe outside diameter
Figure 11-17

Courtesy of Ferguson Waterworks, Sarasota

Compression coupler
Figure 11-18

Courtesy of Ferguson Waterworks, Sarasota

Saddle-type repair clamp
Figure 11-19

Courtesy of Ferguson Waterworks, Sarasota

Split-ring bell repair clamps
Figure 11-20

All of the materials you use in your water system work require careful inventory and storage. Treat these materials with the respect they deserve. Have some organized system of storage that prevents damage and loss until the material is needed for use. Many of the parts are small and easy to misplace. Missing parts can cause delay and inconvenience, and inflate labor costs. Make sure your crew has easy access to the materials they need.

Index

Abbreviations, surveyor 110-111
Acrylonitrile butadiene
  styrene (ABS) pipe 301
Adapter flange systems................... 197-198
Adapter fittings 316
Addendum... 37
Administrative costs 20
AGL Corporation 127
Air blower, pipeline 243
Air relief valves 314
Air testing.. 249-250
Airtrack drilling rig................................ 287
Alignment, pipe 242-245
American Institute of Architects 48
Angle dozing 82
Angle of repose 171
Area, calculating 254-255
Asphalt removal 138
Associated General Contractors
  of America... 36
ASTM pipe standards 298
Auger boring 177
Average end area method 262-263
Avoiding errors, estimating 34

Backfall.. 120
  sewer pipe 219
Backfill volume, trench 222
Backhoe
  components 142
  controls.. 142-143
  crosslines, work around 151-153, 158
  crew hand signals 164
  front bucket, using 160-162
  hard digging.. 154
  hydraulics 143
  leverage....................................... 144-145
  moving across trench 157
  operating... 141
  operator ability 147-148
  production rates 146-147
  regulating response time 144
  set, excavating 146
  sewer system work 155
  size selection 150
  track excavator 163
  track vs. wheeled 166
  tree removal.. 131
  vibratory compactor 192
  vibratory plate 188
  water system work 156
  wheeled 149
Backhoe loader 70
Bandage-type coupler 319
Bank cubic yards (BCY)....................... 60-61
Barber chair 134
Basalt... 276
Base, manhole 246
Bedding
  box 234
  calculating cubic yards......................... 40
  calculating volume 221
  conveyor 235
  sewer pipe 221
  sewer trench 233-235
Bell and spigot pipe 297
  gaskets 311-312
Benching 172
Benchmark 111
  elevation... 115
Beveled end pipe 297
Bid abstract
  design engineer 9
  sample 11
  unit prices 10
Bid bonds 45
Bid openings 41
Bid tabulations 10
  archived 10
Bidding, rock work 285
Bids
  adding contingency.............................. 27
  calculating markup 25-26
  direct cost sheets 34
  front end loading 36-37
  including overhead 23-24
  markup factor 29-30
  material supplier 19
  reviewing 41-42
  sample 37-41
  subcontractor 19
  unbalancing 36-37
Biomat 215
Black pipe 299
Blank connections 311
Blasting, rock 280, 282
  detonation velocity 290
  estimating sonic velocity 289-290
  explosives, using................................ 286
  sequential firing 288
  single charge blasting 287
Blue tops 88
Bonding
  cost 45
  financial documentation 53
  for specific jobs..................................... 55
  improve bonding capacity 56-58
  job costs... 20
  line of credit 44
  prequalifying for............................. 52-54
  risk factors 55-56
Bonds
  bid 45
  maintenance 47
  municipal 9
  payment 47
  performance 46-47
Boring, hole 176-177
Boring logs....................................... 271-272
Borrow 61
Breccia 277
Broad form, indemnification..................... 52
Brush, clearing 129-130
Bucket fill factors 66
Bulldozer 77
  angle dozing 82
  clearing brush..................................... 130
  cut techniques...................................... 79
  cycle time 84-85
  downgrade dozing................................ 80
  fine grading.. 80
  production rate 86-87
  safety 82
  sidecasting 82
  slot dozing 81
  steep slopes, working 83
  U-blades 81
  uphill dozing 81

Calculating
  area 254-255
  average depths 63-64
  cut and fill volumes 254, 267-269
  equipment operating cost............... 14-15
  soil quantities 63
  trench excavation quantities 60
  trench volume 63
Caliche 278
Capacity
  earthmoving equipment 65
  water pipe 207
Caps 311
Cast iron pipe 300
Centerline, establishing......................... 123
Centrifugal mud pump 294
Chain loading, scrapers 94
Changed conditions.................................. 51
Changes, contract 51
Chlorinated polyvinyl
  chloride (CPVC) pipe......................... 301
Circle, area of 254-255
Clamps, pipe repair......................... 318-319
Clastic sedimentary rock 277
Clay pipe... 308
Cleaning pipe lines 251
Cleanout assembly, pipe 309
Clearing site 129
Coffins... 172
Compacted cubic yards (CCY) 61
Compaction
  equipment 192-193
  methods....................................... 186-191
  saturated soils 291
  soil 181
  soil density tests 182-185
Compensating lines................................ 263
Competitive bidding
  contract awards 6
  ground rules.. 36
Compression
  coupler... 319-320
  gaskets 313
  pipe fittings 316
Compression, soil 188
Concave slopes 258
Concrete pipe.. 306
  elliptical reinforced 307
  fiber-reinforced 307
  reinforced (RCP) 306-307
Concrete slab removal 138
Cone of depression 296

Cone, manhole.. 245
Cone, volume of....................................... 256
Conglomerate rock 277
Construction Contract Writer 48
  differing site conditions clause 273
  excavation contracts........................... 286
Contingency... 27
Contour interval...................................... 257
Contour maps, reading 257-258
Contract,
  differing site conditions clause 271
Contracting
  excavation 5
  pipeline 5
  utility line 5
Contractor, underground utility 8
Contractors' burden 17-18
Contracts
  American Institute of Architects......... 48
  avoiding pitfalls..................................... 47
  bidding 6
  changes in 51
  Construction Contract Writer 48
  delays and damages 50
  indemnity provisions.......................51-52
Control fittings 316
  water pipe 204-205
Conversion factors, soil volume...........61-62
Convex slopes 258
Copper tubing..................................298-299
Corporation stops........................... 204, 317
Corrected cyclers per hour...................74-75
Cost keeping systems..........................42-43
Costs
  administrative 20
  bonds 45
  controlling...42-43
  escalation 27
  job..20-21
  knowing... 13
  labor 16
  labor burden 17-18
  markup factor 29-30
  office 22-23
  owned equipment 15
  tools and equipment.............................. 14
Couplers...319-320
  sewer pipe 241
Craftsman Book Company 39, 48
Crawler pipe layer 239-240
Crew
  backhoe operator 147-148
  equipment options 96-98
  hand signals... 164
  job schedules 98-103
  pipe layer 202
  productivity 59
  sewer pipe 226, 237-238
  staying on grade 230-231
  superintendent 201
  topman 238
  water pipe installation........................ 200
Cross section method,
  estimating C&F 259-262
Cross-linked polyethylene (PEX) pipe ... 305
Crosslines, sewer line trenching 231
Crosslines, excavation 151-153
  trackhoe 170
  wheeled backhoe.................................. 158
Cube, volume of...............................255-256
Culvert pipe.. 305
Curb stop 318
Cut and cover 236
Cut methods, tree............................132-133
Cut sheet 113
Cut, surveyor calculation........................ 111
Cuts and fills
  calculating net volumes 267-268
  calculations 254
  estimating quantities 259-265
  under slabs/paving 269
Cutting, water pipe 207-208
Cycle time
  bulldozer 84
  equipment 64-65
  scraper 92
  track backhoe 168
  track excavator 73
  track loader 76-77
  wheeled backhoe.................................... 65
  wheeled loader 75
Cycles per hour
  corrected 74-75
  equipment 64
Cylinder, volume of................................ 256

Daily operating costs, equipment....... 14-15
Daylight line............................259, 264-265
  depths of topsoil...........................266-267
Debt subordination, bonding 56
Deep hole test 216
Deflection, testing for............................. 248
Degree of slope 118
Demolition, existing structures............. 138
Density tests, soil 182-185
Depreciation, equipment 15
Depressions, contour............................... 258
Design and build contracts 9
Design engineer 9
Design, water system.............................. 196
Detonation velocity 290
Dewatering
  cone of depression............................... 296
  mud pump... 294
  pumping trenches........................291-292
  wellpoint system..........................293-294
Differing Site Conditions
  contract clause 271
  federal contract requirement............. 286
Digging cycle, backhoe 142-143
Diorite 276
Direct cost sheets 32-33
  road slide correction job 39
Direct costs
  know for estimating 13
  markup factor 29-30
  spreadsheet..30-33
Direct overhead 20-21
Directional
  boring 176
  drilling 177
Disk harrow 130
Ditching 89
Dozer...77-87
  angle dozing 82
  clearing brush...................................... 130
  cut techniques.. 79
  cycle time 84-85
  downgrade dozing.................................. 80
  fine grading.. 80
  production rate 86-87
  safety 82
  sidecasting 82
  slot dozing.. 81
  steep slopes, working 83
  U-blades 81
  uphill dozing 81
Draftsman plan symbols.................106-108
Drain rock, using 247
Drain, waste, vent (DWV) pipe 297
Drainfields
  drain pipe.. 216
  percolation tests 216
  protecting.. 218
  sand mound system............................ 217
  Wisconsin system 217
Drilling
  horizontal.. 177
  rock.. 280
Drilling machine 209
Drywell 217
Ductile iron pipe..................................... 300
Dutchman cut..................................134-135

Earthmoving equipment
  bulldozers..77-87
  capacity 65
  mobilization costs 60
  motor graders 87-90
  scrapers...90-94
  track excavator 73
  wheeled backhoe loader 70
  wheeled loader 75
Earthwork estimating
  average end area method...........262-263
  cross section method 259-262
  degree of accuracy 270
  math calculations 253-256
  minimizing risks..........................271-273
  site conditions...................................... 271
  weather variables 273
Earthwork quantities
  estimating 60
  trench 63-64
Effective blade length 89
Electronic blasting caps 288
Elevating scrapers 91
Elevation 111
Elevations, reading 257-258
Ells 309
Employer costs, estimating 17-18
Engineer
  measurements 112
  planning pipe grades.......................... 120
  septic system 216
  survey...112-113
  working with.. 12
Engineer's estimate 9
Equipment...
  airtrack 287
  backhoe operations......................141-154
  bulldozers..77-87
  compaction 192-193
  crew hand signals................................ 164
  cycles per hour 64
  daily operating costs 14-15
  job schedules 98-103
  motor graders 87-90
  operator ability factor 68-69
  operators 7
  pricing 10
  production estimate 64
  productivity 59
  rent or lease 14
  repair costs 15
  right choices for work.......................95-98
  rippers.. 281
  road miner 284
  rock saws 283
  rock splitting/breaking....................... 284
  safe operations.............................163-164
  scrapers...90-94
  sewer pipe laying................................. 224
  survey...114-115
  track excavator 73
  track loader.......................................75-77
  water pipe installation........................ 199
  wheeled backhoe loader 70
  wheeled loader 75
Equipment operators 7
Escalation 27
Estimate, sample 32-33
Estimating
  avoiding errors 34
  check your work...............................35-36
  contingency 27
  costs.. 13
  guides 10-11
  labor burden 17-18

labor costs 16
markup 24-26
material costs 18-19
overhead costs 23-24
profit 28-30
records, using own 12
spreadsheet 30-33
taxes and insurance 18
Estimating quantities
cubic yards of bedding 40
excavation 253-256
filter fabric 40
rock work 285-286
trench excavation 60
Excavation
around crosslines 151-153, 158
avoiding crosslines 231
backhoe production rate 146-147
below water table 291
cut and cover method 236
dewatering systems 291-295
estimating quantities 60, 253-256
explosives, using 286-289
hard digging 154
inside trench boxes 229
manhole 246-247
right-of-ways 235-236
rock work 279-290
rock work bid strategy 285
sewer pipe trenching 224
sewer system work 155
sheet piling, using 295
shoring systems 171-175
soil compaction 181
spoil box, using 236
V-trench volume 221
water service tie-ins 206-207
water system work 156
Excavation contracting 5
Excavator, bedding conveyor 235
Exfiltration water test 249
Existing utilities, locating 137
Expenses, overhead 22
Exploratory drilling 286
Explosives, rock work 286
detonation velocity 290
estimating sonic velocity 289-290
sequential firing 288
single charge blasting 287
Export quantities 61
Extrusive igneous rock 276
EZflow pipe 216

Factor
markup 29-30
soil volume conversion 61-62
Fall, pipe 219
Fiber-reinforced concrete pipe 307
Fiberglass pipe 308
F.I.C.A. 17
Field testing, soil density 185-186
compacting 189
Fill factors
bucket 66
loader bucket 75
Fill, surveyor calculation 111
Filter fabric, estimating 40
Finish grading 88
Fire hydrants 313
Firebreaks 129
Fishmouthed gasket repair 319
Fittings, pipe
caps 311
copper 299
corporation stop 317
curb stop 318
ells 309
joints 315-316
plugs 311
PVC 304
reducers 310
repair clamps 318-319
stop and drain 317
tees 309
thrust blocks 310-311
valves 311, 313-314
water control 313
wrapping 308
wyes 309
Fixed time, scraper 92
Flanged fittings 316
Flanged joints 315
Flowing sand 291
Foreman, utility line 7
Front end loading 36-37
F.U.T.A. 17

Gabbro 276
Galvanized pipe 299
Gaskets 311
compression 313
O-ring 313
repairs 319
roll-over 312
slip 313
Gate valves 311
water control 313
Geology 275
Global positioning system (GPS) 117
Glue pipe fittings 316
Government contracts 6
GPS surveying 117
Grade 118
checking, optical level 120, 244
sewer system work 155-156
slope, sewer systems 219
Grade rod 115
Graders 87
ditching 89
effective blade length 89
finishing 88
production rates 89-90
ripping 89
sidecasting 89
trimming 88
Granite 276
Grass, clearing 129
Gravity pipe systems 218
Grid layout, water 195
Grid system, estimating C&F 259-262
Groundwater
cone of depression 296
controlling 246-247
prepare for problems 290
pumping 291-292
saturated soil 291
wellpoint system 293-294

Hand signals, crew 164
Heaped capacity 65
scraper 92
Heavy equipment
operators 7
production rates 39
Hoe dipper, using 131
Hoe-mounted vibratory compactor 193
Hole-Hog 159
Hourly operating cost, equipment 15
Hourly production rate
correction factors 72
equipment 64
trench estimating 71
Hubs 88, 113
Humboldt undercut 133
Hydraulic impact hammer 284
Hydraulics, backhoe 143
Hydrology engineering 296

Igneous rock 275
Impact rammer 190
Import quantities 61
Imported fill 189
Indemnity provisions, contract 51-52
Indirect costs, knowing 13
Indirect overhead 22-23
Infiltration water test 249
Information stake 113
Inspections, pipeline 248
Instruments, survey 114-115
Insurance costs 17
Intermediate form, indemnification 52
Intrusive igneous rock 276
Irregular shape, area of 255

Jib crane 200
Job costs 13
Job overhead 20-21
calculating 24
Job plans 105
Job schedules 98-103
Jobsite, preparing 129
Joints, pipe
fittings 315-316
flanged 315
mechanical 315
slip 314

Labor burden, estimating 17-18
Labor costs
estimating 16
pricing 10
Lamping 248
Laser 121
pipe alignment 122
pipe placement 124
setup using transit 125-126
sewer pipe alignment 242-245
Lava 276
Level, optical 114-115
Leverage, backhoe 144-145
Liability insurance 17
Lien period 49
Lift stations 218
Lifts, soil layers 191
Limited form, indemnification 52
Line fittings 310-311
Line of credit, bonding 44
Load factors 66
soil 67
Load time, scraper 92
Loader 199
determining bucket capacity 74
wheeled backhoe 70
Logs, cutting 136-137
Loose cubic yards (LCY) 61

Maintenance bonds 47
Mandrel test 248
Manholes
controlling groundwater 246-247
installing 245-247
precast components 245-246
trench shields 246-247
Manhours
estimating guides 60
pricing 10
Manufacturer specs, equipment 65-66
Margin, calculating 24-25
Markup 13
calculating 24-25
factor 29-30
vary with job 25
Material layout, pipe/accessories 139-140
Materials
estimating costs 18-19
pricing 10
supplier bids 19
takeoff 18-19

Measurements, engineer's 112
Mechanical joints 315
Meetings, pre-construction 42
Metamorphic rock 278
Meter setter with valve 318
Micro tunneling 178
Military contracts 6
Milled each end (MEE) 319
Milled overall (MOA) 319
Mobilization, equipment 60
Modified Proctor Test 61
Moisture density tests 61
Moldboard, grader 88
Motor graders 87
  ditching 89
  effective blade length 89
  finishing 88
  production rates 89-90
  ripping 89
  sidecasting 89
  trimming 88
Mud pump 294
Mueller Company 204, 209
Municipal bonds 9
Municipal projects, publicly funded 8-9
Municipal sewer systems 218

National Earthwork & Heavy Equipment Estimator 39, 60
Negligence 52
No dig construction 176
Non-clastic sedimentary rock 277-278
Nuclear density gauge 185-186

O-ring gaskets 313
Obsidian 277
Office overhead 22
  calculating 24
Offset fittings 310
Offsets, calculating 202-203
Open-bowl scrapers 91
Open ditch shoring 228
Opening, bid 41
Operating costs, equipment 14-15
Operator
  backhoe 147-148
  hand signals 164
  production rate factors 68-69
  trackhoe 163-164
Optical level 114-115
  aligning sewer pipe 242-245
  checking grade 120
  using 116
Optimum hourly production rate 66
  bulldozer 87
Optimum moisture content, soil 182
Overhead
  calculating 23-24
  direct 20-21
  including in bid 23-24
  indirect costs 22-23
  job 20-21
  knowing costs 13
  office 22
Owned equipment operating costs 15

Paddle-wheel scrapers 91
Parallelepiped, volume of 255-256
Parallelogram, area of 254-255
Payload, scraper 91
Payment bonds 47
Payment schedule, contract 48
Percolation tests 216
Performance bonds 46-47
Pipe
  ASTM standards 298
  calculating capacity 207
  carrying capacity 219
  cutting water filled 207
  diameter, sewer systems 219
  displacement volume 222-223
  ends 297
  outside diameters 320
  restraints 197-198
  schedules 298
  size 298
  Standard Dimension Ratio 298
  strength 298
  weights 200
Pipe bursting 179
Pipe fittings
  caps 311
  copper 299
  corporation stop 317
  curb stop 318
  ells 309
  joints 315-316
  plugs 311
  PVC 304
  reducers 310
  repair clamps 318-319
  stop and drain 317
  tees 309
  thrust blocks 310-311
  valves 311, 313-314
  water control 313
  wrapping 308
  wyes 309
Pipe joints
  fittings 315-316
  flanged 315
  mechanical 315
  slip 314
Pipe layer 7, 202
  aligning sewer pipe 244
  sewer pipe 237-238
Pipe laying
  aligning the pipe 242-245
  aligning with string line 127
  assembling the pipe 240
  backhoe production rate 233
  bedding 220
  bedding requirements 221-222
  bedding the trench 233-235
  below water table 291
  by hand 239
  calculating offsets 202-203
  calculating pipe capacity 207
  cleaning the lines 251
  crew, sewer pipe 226
  cutting the pipe 237
  dewatering trenches 291-292
  direct tap 204
  directional boring 176-178
  establishing the centerline 123
  grades 118, 120
  installing manholes 245-247
  installing service lines 203-205
  jacking 178
  joining main to service 241
  joining new and old 206-207
  lasers 121-127
  laying out materials 139-140
  machine laying 239-240
  micro tunneling 178
  pipe materials 297-308
  pipeline connections 310-311
  placement using laser 124
  positioning hubs 126
  production rates 240
  saddle tap 204-205
  sewer system work 155
  sheet piling 295
  shoring systems 171-175
  sliplining 178
  slope, sewer systems 219
  spring line 221
  staying on grade 230-231
  surface restoration 251
  testing the system 248-250
  track excavator 74
  water system work 156
Pipe materials
  ABS plastic pipe 301
  black pipe 299
  cast iron pipe 300
  concrete pipe 306-307
  copper tubing 298-299
  corrugated polyethylene 305
  CPVC plastic pipe 301
  drain, waste, vent (DWV) 297
  ductile iron pipe 300
  fiberglass pipe 308
  galvanized pipe 299
  PB plastic pipe 301-302
  PEX pipe 305
  plastic pipe 300
  polyethylene plastic pipe 302
  polypropylene pipe 304
  pressure pipe 298
  PVC plastic pipe 302
  sewer systems 219-220
  vitrified clay pipe 308
  wooden water pipe 308
Pipeline contracting 5
  backhoe operations 141
  compaction methods 186-191
  explosives, using 286-289
  following plans 110
  installing septic systems 211
  installing sewer systems 218
  installing water systems 195
  material layout 137-138
  pipe laying 121-127
  rock work 279-290
  sewer system work 155
  shoring systems 171-175
  site clearing 129-137
  subcontractor bids 19
  supplier bids 19
  trenchless construction 176
  water system work 156
  working in groundwater 290-296
Plain end pipe 297
Plan reading 105-109
Plan view 105
Plans
  reading 105
  symbols 106-108
  two scale 109
  utility site 109
Plastic pipe 300-305
Plug & feather rock splitter 284
Plugs 311
Plutonic rock 276
Polybutylene (PB) pipe 301
Polyethylene pipe 302
  corrugated culvert pipe 305
Polypropylene pipe 304
Polyvinyl chloride (PVC) pipe 302
  fittings 304
  gaskets 304
  manufacturers' colors 304
  types and uses 303
Precast concrete manhole 245
Pre-construction meeting 42
Prequalification, bonding 52-54
Pressure pipe 298
Prints 105
Private developer contracts 6
Proctor tests 183-184, 189
Production rate, equipment
  backhoe 146-147
  backhoe, sewer line 233
  bulldozer 86-87
  graders 89
  hoe-mount vibratory compactor 193

scraper 94-95
sheepsfoot roller 192-193
track loader 76
wheeled backhoe 71
Production rates
crew and equipment 59
equipment 64
groundwater, working in 296
heavy equipment 39
job efficiency factor 68-69
operator ability factor 68-69
optimum hourly 66
pipe laying 240
rock work 280
Profile 257
Profile view 105
Profit 27-30
Profit margin 24-25
Progress payments 48
Project
crew & equipment options 96-98
keeping cost records 12
plans 105
publicly funded 8-9
survey 113
Psi 196
Publicly-funded projects 8-9
bid advertisements 9
Puddling 186-187
Pumice 276
Pumping, groundwater 291-292
Pumps, groundwater 247
Pusher, foreman 7
Pushers 93-94
PVC pipe, restraints 198
Pyramid, volume of 256

Quotes, material supplier 19

Rake blade 130
Rammer, impact 190
Reading
contour lines 257-258
plans 105-109
Rectangle, area of 254-255
Reducers 310
Reference stake 113
Reinforced concrete pipe (RCP) 306
D-Load ratings 307
Repair clamps 318-319
Retention 48
Rhyolite 276
Right-of-way, permissions 235-236
Rippable rock 279
seismic velocity charts 280
Ripping 89
Risk factors, bonding 55-56
Road graders 87
Road miner 284
Rock
bid strategies 285
breakers 284
composition of 276
explosives, using 286
igneous 275
metamorphic 278
ripping 279-284
saws 283
splitters 284
strata 277
study of 275
Roll-over gaskets 312
Roller, compaction 188
Rotomill 284
Run factor, calculating 202-203

Saddle tap, water service 204-205
Saddle, water line 159
Saddle-type repair clamp 319-320
Safety
dozer 82
equipment operations 163-164
trench box 229
Salvage rights, timber 130
Sample bid 37-41
Sand mound system 217
Sandstone 277
Satellite GPS 117
Saturated soil 291
Scale, plan 109
Scrapers 90
chain loading 94
cycle time 92
load time 92
maneuver and dump time 93
payload 91
production rates 94-95
pusher 93
self-loading 91
spot and delay time 94
straddle loading 92
struck capacity 91
Sediment control 138
Sedimentary rock 277
Seepage pit 217
Seismic velocity 280
Self-loading scrapers 91
Septic engineer 216
Septic systems 211
avoiding overload 215-216
components 212
contamination 214-215
drainfield 216-218
failure 214
percolation tests 216
seepage pit 217-218
water table, separation 217
Septic tanks 212
contamination 214-215
maintenance 214
two-compartment system 213
Service lines, installing 203-205
Set, backhoe 146
Sewer pipe
DWV 297
joining main to service 241
placing in trench 239-240
Sewer project, sample bid abstract 11
Sewer systems 155, 211
aligning the pipe 242-245
assembling the pipe 240
backhoe production rate 233
bedding the trench 233-235
calculating trench volume 221
cleaning the lines 251
crew 226
cutting the pipe 237
equipment needed 224-225
installation 227
installing manholes 245-247
municipal 218
pipe bed requirements 221-222
pipe diameter 219
pipe materials 219-220
rate of flow 219
shoring 227-230
slope 219
testing 248-250
Shale 277
Sheepsfoot roller 192
Sheet piling 295
Shoring jacks 172, 228
Shoring systems 171-175
open ditch, sloped walls 228
sewer pipe laying 227-230
shoring jacks 228
trench boxes 229-230
Shuttle loading, scrapers 94
Side cut 134
Sidecasting
dozer 82
graders 89
Signals, operator 164
Silt fencing 138
Siltstone 277
Site conditions, checking 271
Site elevations 111-112
Site preparation 129
clearing brush 129-130
material layout 137
tree removal 131-137
Slip gaskets 313
Slip joint 314
Sliplining 178
Slope 118
steep, dozing 83
ways of measuring 119
Slot dozing 81
Social Security tax 17
Soil
bearing loads 197
compacting in lifts 191
compaction 181
compaction methods 186-191
difficult to compact 189
maximum dry density 184
optimum moisture content 182
permeability 216
Proctor density tests 183-184
rolling 188
structure 182
swell percentage 66
testing costs 191-192
vibrating 188
weights and load factors 67
Soil density tests 182-184
Soil pipe 297-298
Soil volume conversion factors 61-62
Soil volume, measuring 60-61
Sonic velocity 289
Split-ring bell repair clamp 319-320
Spoil 61
piles, dozing 81
Spoil box 236
Spot time 84-85
Spring line 221
Square, area of 254-255
Stakes, reference 113
Standard Dimension Ratio 298
Standard Proctor Test 61
Station number 111
Steel pipe 299
Steel sheets 172
Steep slopes, dozing 83
Stepping 172
Stone bedding, pipe 221
Stop and drain fitting 317
Stops 317-318
Stormwater systems 211
pipe 306
Straddle loading, scraper 92
Strata 277
String line setup 127
Struck capacity 65
scraper 91
Subcontractors, collecting bids from 19
Subsurface conditions 271
Summits 258
Superintendent
utility line 7
water pipe installation 201
Supervisor, utility line 7
Supplier, material quotes 19
Surveying 110-127
instruments 114-115
using GPS 117
Swell percentage, soil 66
Symbols, plan 106-108

Tabulations, bid ... 10
Takeoff
  material supplier quotes ... 18-19
  math calculations ... 254-256
Tamping-foot vibratory roller ... 188
Tanks, septic ... 212-214
Tap, water service lines ... 159, 204
Taxes, employer ... 17-18
Tees ... 309
Testing
  cost, soil density ... 191-192
  sewer pipeline ... 248-250
  soil density ... 182-185
  water pipe ... 208-210
Threaded pipe ... 297
  fittings ... 315
Thrust blocks ... 197, 208
  pipe connections ... 310-311
Thrust, water pressure ... 196-197
Tie-in, water service ... 206-207
Timber salvage rights ... 130
Top-of-slab elevation ... 112
Topman ... 238
Topographic maps ... 257
Topsoil
  stripping and replacing ... 266
  volumes ... 267-268
Track backhoe ... 163
  controls ... 167
  counterbalance ... 166
  cycle times ... 168
  digging technique ... 168-169
  operator, staying on grade ... 230-231
  sewer pipe laying ... 224
  when to use ... 165
  working around crosslines ... 170
  working in mud ... 174
Track excavator ... 163
  production rate ... 73
  sewer pipe trenching ... 224
Track loader ... 75
  cycle times ... 76-77
  production rate ... 76
Trackhoe ... 163
Tractor-mounted rippers ... 281
  ripper teeth ... 281-282
Trailer scrapers ... 90-91
Transit ... 115
  aligning laser setup ... 125-126
  aligning sewer pipe ... 243-245
  pipe alignment ... 122-123
Trapezoid, area of ... 254-255
Trash pumps ... 292
Travel factor, calculating ... 202-203
Travel time, scraper ... 92, 94-95
Tree removal
  cutting logs ... 136-137
  Dutchman cut ... 134-135
  Humboldt undercut ... 133
  side cut ... 134
  single cut ... 132
  site clearing ... 130
  using backhoe ... 131
  using chain saw ... 132
Trench boxes ... 172-175, 229-230
Trench shields, manhole ... 246-247
Trenching
  around crosslines ... 151-153, 158
  backhoe production rate ... 146-147, 233
  calculating material volume ... 71
  calculating soil volume ... 63-64
  calculating trench volume ... 221, 232
  continuous digging ... 230
  crosslines, avoiding ... 231
  estimating excavation ... 60
  hard digging ... 154
  holding grade ... 148
  machine ... 199
  moving hoe over trench ... 157
  sewer system work ... 155
  shoring systems ... 171-175
  water pipe ... 199
  water system work ... 156
  wheeled backhoe ... 199
Trenchless construction ... 176
Triangle, area of ... 254-255
Trimming ... 88
Truncated prism, volume of ... 256
Tunneling, pipe ... 178

U-blades ... 81
Unbalancing bids ... 36-37
Underground utilities, locating ... 137
Underground utility contracting
  available work ... 6
  backhoe operations ... 141
  bonding, importance of ... 8
  compaction methods ... 186-191
  equipment costs ... 14
  estimating variables ... 11
  explosives, using ... 286-289
  following plans ... 110
  installing septic systems ... 211
  installing sewer systems ... 218
  installing water systems ... 195
  material layout ... 137-138
  pipe laying ... 121-127
  profit expectations ... 29
  publicly-funded projects ... 8
  risks and rewards ... 8
  rock work ... 279-290
  sewer system work ... 155
  shoring systems ... 171-175
  site clearing ... 129-137
  subcontractor bids ... 19
  supplier bids ... 19
  trenchless construction ... 176
  water system work ... 156
  working in groundwater ... 290-296
Unemployment insurance ... 17
Unit prices
  bid abstract ... 10
  comparative ... 10
Unrippable rock ... 279
Uphill dozing ... 81
Utility line
  engineering design ... 9
  pricing work ... 10
Utility line contracting ... 5
  available work ... 6
  backhoe operations ... 141
  compaction methods ... 186-191
  explosives, using ... 286-289
  following plans ... 110
  groundwater, working in ... 290-296
  material layout ... 137-138
  pipe laying ... 121-127
  profit expectations ... 29
  rock work ... 279-290
  septic systems, installing ... 211
  sewer system work ... 155
  sewer systems, installing ... 218
  shoring systems ... 171-175
  site clearing ... 129-137
  subcontractor bids ... 19
  supplier bids ... 19
  trenchless construction ... 176
  water system work ... 156
  water systems, installing ... 195
Utility line team ... 7
Utility lines, locate existing ... 137
Utility site plans ... 109

V-trench ... 221
Valves, pipe ... 311
Velocity of detonation ... 290
Vibrating plate
  backhoe ... 188
  compactor ... 190
Visual inspections, pipe ... 248
Vitrified clay pipe ... 308
Volume, calculating ... 255-256
  soil quantities ... 60-62
Volume per cycle ... 65

Warranties ... 47
  materials and equipment ... 49
Wastewater pipe ... 297
Water control fittings ... 313
Water hammer ... 196
Water pipe
  restraints ... 197-198
  weights ... 200
Water pressure, measuring ... 196
Water service lines
  cutting, water filled ... 207
  installing ... 203-205
  pressure testing ... 208-210
  repairing live service ... 201
  tie-ins ... 206-207
Water service plans ... 318-319
Water systems ... 156
  crew superintendent ... 201
  installation depth ... 198
  installation equipment ... 199
  grid layout ... 195
  installing ... 195
  joining lateral to main ... 159
  joining new and old ... 206-207
  repairing damaged lines ... 201
Water table ... 290
  cone of depression ... 296
  excavating below ... 291
Water testing ... 249
Weather variables ... 273
Wedge, volume of ... 255-256
Weights, soil ... 67
Wellpoint dewatering ... 293-294
Wheeled backhoe
  front bucket, using ... 160-162
  laying pipe ... 239-240
  operating ... 149-163
  selecting right hoe size ... 150
  sewer system work ... 155
  transmissions ... 149
  water pipe installation ... 199
  water system work ... 156
Wheeled backhoe loader ... 70
  production rate ... 71
Wheeled loader, cycle times ... 75
Widow-maker ... 134
Windrows ... 80
Wisconsin system ... 217
Wooden water pipe ... 308
Worker's compensation insurance ... 17
Worksheet, estimating ... 32-33
Wrapping fittings ... 308
Wyes ... 309

Zero line ... 259, 264-265
  depths of topsoil ... 266-267

Practical References for Builders

Excavation & Grading Handbook Revised

The foreman's, superintendent's and operator's guide to highway, subdivision and pipeline jobs: how to read plans and survey stake markings, set grade, excavate, compact, pave and lay pipe on nearly any job. Includes hundreds of informative, on-the-job photos and diagrams that even experienced pros will find invaluable. This new edition has been completely revised to be current with state-of-the-art equipment usage and the most efficient excavating and grading techniques. You'll learn how to read topo maps, use a laser level, set crows feet, cut drainage channels, lay or remove asphaltic concrete, and use GPS and sonar for absolute precision. For those in training, each chapter has a set of self-test questions, and a Study Center CD-ROM included has all 250 questions in a simple interactive format to make learning easy and fun. **512 pages, 8½ x 11, $42.00**

Estimating Excavation

How to calculate the amount of dirt you'll have to move and the cost of owning and operating the machines you'll do it with. Detailed, step-by-step instructions on how to assign bid prices to each part of the job, including labor and equipment costs. Also, the best ways to set up an organized and logical estimating system, take off from contour maps, estimate quantities in irregular areas, and figure your overhead. **448 pages, 8½ x 11, $39.50**

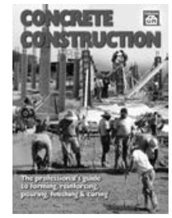
Construction Contract Writer CD-ROM

If you have a computer running *Windows*™, this unique software lets you draft, in minutes, a contract that precisely fits your needs and the particular job requirements, and meets both your state and federal requirements. You just answer a series of questions — like an interview — to construct a legal contract for each project you take on. Anticipate where disputes could arise and settle them in the contract before they happen. Include the warranty protection you intend, and the attachments your state requires. You'll write iron-clad contracts that fit your jobs like a glove and hold up in court should something go wrong. An internet connection is required to activate the program and download FREE updates for the first 12 months. **$115.00**

CD Estimator

If your computer has *Windows*™ and a CD-ROM drive, CD Estimator puts at your fingertips over 150,000 construction costs for new construction, remodeling, renovation & insurance repair, home improvement, framing & finish carpentry, electrical, concrete & masonry, painting, earthwork and heavy equipment, and plumbing & HVAC. Quarterly cost updates are available at no charge on the Internet. You'll also have the *National Estimator* program — a stand-alone estimating program for *Windows*™ that *Remodeling* magazine called a "computer wiz," and Job Cost Wizard, a program that lets you export your estimates to *QuickBooks Pro* for actual job costing. A 60-minute interactive video teaches you how to use this CD-ROM to estimate construction costs. And to top it off, to help you create professional-looking estimates, the disk includes over 40 construction estimating and bidding forms in a format that's perfect for nearly any *Windows*™ word processing or spreadsheet program. **CD Estimator is $108.50**

Concrete Construction



Just when you think you know all there is about concrete, many new innovations create faster, more efficient ways to do the work. This comprehensive concrete manual has both the tried-and-tested methods and materials, and more recent innovations. It covers everything you need to know about concrete, along with Styrofoam forming systems, fiber reinforcing adjuncts, and some architectural innovations, like architectural foam elements, that can help you offer more in the jobs you bid on. Every chapter provides detailed, step-by-step instructions for each task, with hundreds of photographs and drawings that show exactly how the work is done. To keep your jobs organized, there are checklists for each stage of the concrete work, from planning, to finishing and protecting your pours. Whether you're doing residential or commercial work, this manual has the instructions, illustrations, charts, estimating data, rules of thumb and examples every contractor can apply on their concrete jobs. **288 pages, 8½ x 11, $28.75**

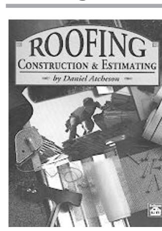
Builder's Guide to Accounting Revised

Step-by-step, easy-to-follow guidelines for setting up and maintaining records for your building business. This practical guide to all accounting methods shows how to meet state and federal accounting requirements, explains the new depreciation rules, and describes how the Tax Reform Act can affect the way you keep records. Full of charts, diagrams, simple directions and examples to help you keep track of where your money is going. Recommended reading for many state contractor's exams. Each chapter ends with a set of test questions, and a CD-ROM included FREE has all the questions in interactive self-test software. Use the Study Mode to make studying for the exam much easier, and Exam Mode to practice your skills. **360 pages, 8½ x 11, $35.50**

Building Code Compliance for Contractors & Inspectors

Have you ever failed a construction inspection? Have you ever dealt with an inspector who has his own interpretation of the Code and forces you to comply with it? This new book explains what it takes to pass inspections under the 2009 *International Residential Code*. It includes a Code checklist — with explanations and the Code section number — for every trade, covering some of the most common reasons why inspectors reject residential work. The author uses his 30 years' experience as a building code official to provide you with little-known information on what code officials look for during inspections. **232 pages, 8½ x 11, $32.50**

Roofing Construction & Estimating



Installation, repair and estimating for nearly every type of roof covering available today in residential and commercial structures: asphalt shingles, roll roofing, wood shingles and shakes, clay tile, slate, metal, built-up, and elastomeric. Covers sheathing and underlayment techniques, as well as secrets for installing leakproof valleys. Many estimating tips help you minimize waste, as well as insure a profit on every job. Troubleshooting techniques help you identify the true source of most leaks. Over 300 large, clear illustrations help you find the answer to just about all your roofing questions. **432 pages, 8½ x 11, $38.00**

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 271 CARLSBAD, CA

POSTAGE WILL BE PAID BY ADDRESSEE

Craftsman Book Company
6058 Corte del Cedro
P.O. Box 6500
Carlsbad, CA 92018-9974

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 271 CARLSBAD, CA

POSTAGE WILL BE PAID BY ADDRESSEE

Craftsman Book Company
6058 Corte del Cedro
P.O. Box 6500
Carlsbad, CA 92018-9974

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 271 CARLSBAD, CA

POSTAGE WILL BE PAID BY ADDRESSEE

Craftsman Book Company
6058 Corte del Cedro
P.O. Box 6500
Carlsbad, CA 92018-9974