Fundamentals of Soil Compaction






Soil Compaction for Confined Areas

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Chapter 1 - Introduction

Soil Compaction — A Long Accepted Practice

Soil Compaction has been practiced by man for thousands of years.

The first attempts at earthen dams and irrigation ditches demonstrated the value of compaction by adding strength and some measure of protection against moisture damage. Early tamped earth buildings depended on thorough compaction for stability.

However, it was not until road building became a highly developed art, during the period of the Roman Empire, that the importance of Soil Compaction was fully appreciated. Roman roads, which are still in use, were built with careful attention to subsoil conditions and with thorough compaction of gravel and clay base.

Figure 1: Roman Road

The Roman road builders knew that their cut stone road surfaces were only as good as the foundation on which they rested.

Some years ago, most compaction was done only on large construction sites, such as roads and airports. Very large, heavy machinery was used.

Only in the last few decades has the importance of confined area compaction been recognized.

With the introduction of self contained portable rammers and vibratory plates, confined area compaction became practical.

Now Soil Compaction is commonly specified for building foundations, trench backfills, curbs and gutters, bridge supports, slab work, driveways, sidewalks, cemeteries and other confined area work.

Properly done, Soil Compaction adds many years to the useful life of any structure by increasing foundation strength and greatly improving overall stability. Dynamic compaction equipment such as vibratory rammers, plates, or rollers form an integral part of a construction site setup. What are these machines really needed for? What really happens down there - in the soil? Which piece of equipment is best used when? How can the compaction progress of the soil be monitored? All these questions - and quite a few more - have been answered in detail in this handbook.

Chapter 2 - What is Soil?

Soil is any natural material found on the surface of the earth except for embedded rock, organic plant and animal material.

Soil may be divided into four major groups according to particle size. As shown on Figure 2, the major groups are:

Group	Particle Size	
	Min	Max
Clay	0	0.00024" (.006mm)
Silt	0.00024" (.006mm)	0.003" (.076mm)
Sand	0.003" (.076mm)	0.08" (2.03mm)
Gravel	0.08" (2.03mm)	3" (76.2mm)

Soil Classification

The American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) classify soil as **granular** or **cohesive** on the basis of a sieve analysis of the soil.

Granular Soil consists mainly of sands and gravels. **Cohesive Soil** consists mainly of silts and clays.

In granular soil, the particles are held in position due to the frictional force that exists at the contact surfaces. In the dry state, granular soil particles can be easily separated and identified. In a moist state, a granular material, such as sand, may be formed to desired shapes but will crumble easily as soon as it is disturbed.

In cohesive soil, the molecular attraction between soil particles is the force which holds the soil in place. As these particles are very small in size, high in number, and densely arranged, the cohesive force within the soil is very high. Cohesive soils are very hard in the dry state. When moist, they are plastic and can be molded or rolled to almost any shape.

How to Test For The Correct Amount of Moisture

The moisture content of a soil, either granular or cohesive, is a critical factor in the workability of that soil.

Moisture acts as a lubricant between soil particles. Too little moisture will not allow soil particles to move into a dense arrangement. Too much moisture will saturate a soil taking up space which would normally be filled by soil particles.

A simple method of testing whether the soil contains the right amount of moisture for compaction, is to take a handful of the soil to be compacted and squeeze it into the size and shape of a tennis ball (Figure 3a) and drop it on the ground from about 1 foot (Figure 3b). Uniform gravel or mostly sandy soils do not react well to this test.

	Granular Materials (35% or less passing the 0.075 mm sieve)							**Silt-Clay Materials (>35% passing the 0.075 mm sieve)**			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, % passing											
2.00 mm (No. 10)	50 max										
0.425 (No. 40)	30 max	50 max	51 min								
0.075 (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid Limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments, gravel and sand		fine sand	silty or clayey gravel and sand				silty soils		clayey soils	
General rating as a subgrade	excellent to good							fair to poor			

Figure 2: AASHTO Group Classification

At Optimum Soil Moisture — The ball breaks apart into a small number of fairly uniform fragments.


Figure 3a & b: Soil Testing

If Too Dry — The soil does not form into a ball at all, and moisture must be added to the soil.

If Too Moist — The soil does not break apart (unless the soil is very sandy), and soil should be allowed to dry if possible.

Figure 4: Dry Clay

Figure 5: Wet Clay

Grain Size Distribution

Since a soil may contain different particle sizes, it is useful to know the amount of each size present in the soil. To do this, a sample of the soil that is to be utilized on the construction site and is to be compacted is extracted at the job site and then subject to analysis in a soil laboratory. The sample of soil is dried and crumbled to separate the particles and then run through a series of standard sieves of different sizes. The amount of soil retained on each sieve is noted and calculated as a percentage of the total sample weight. The percentages obtained are plotted against sieve sizes to give a **Grain Distribution Curve** for the soil under investigation.

Figure 6: Sieve

Figure 7: Sieve Test

Figures 6 & 7 courtesy of Humboldt Mfg. Co.

The shape of curve gives an indication of the **gradation** of the soil. A “well graded” soil is defined as a soil which contains a broad range of grain sizes. A well graded soil is distinguished by A curve with a fairly uniform incline.

A “poorly graded” or “uniform” soil is a soil that contains limited range of grain sizes. A steep curve is characteristic of this soil as shown in Curve B.

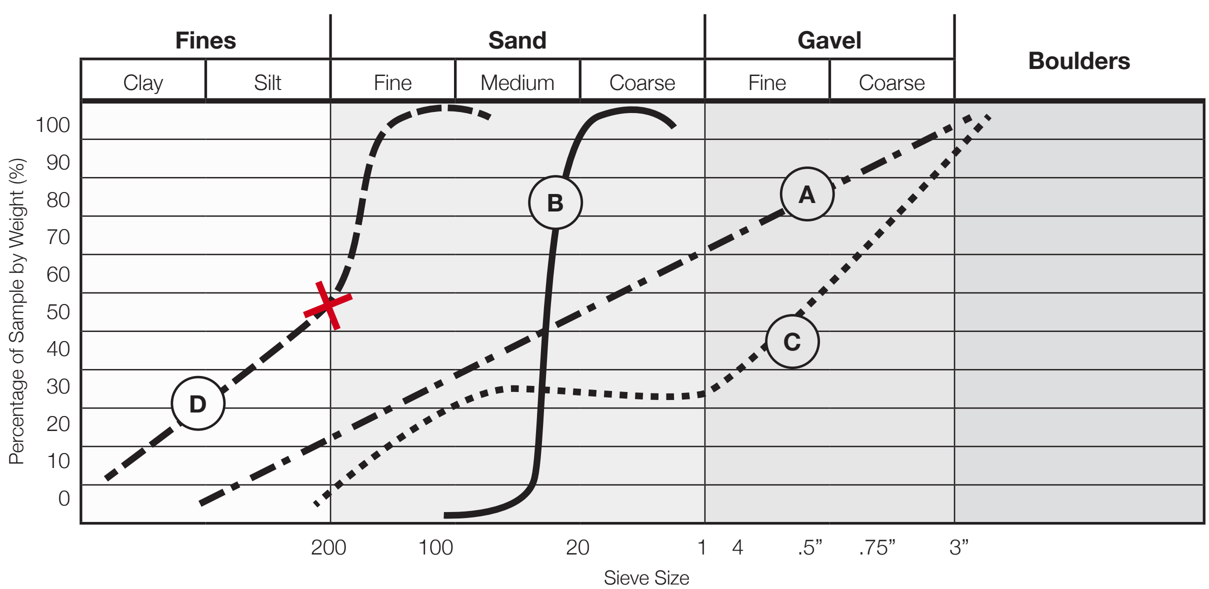


Figure 8: Grain Distribution Curve

A soil that is missing certain particle sizes will have a curve with a horizontal portion as indicated in Curve C. Such soil is termed as “gap graded”.

Point X on Curve D shows that 48% by weight of that soil is finer than #200 sieve, meaning a very cohesive soil.

A well graded soil compacts to higher density than a poorly graded soil, and, therefore, has a higher load bearing capacity. This is because the finer grains can be vibrated or compacted into the cavities between the larger particles. If the fine grains were not present, those cavities would stay unfilled, resulting in air voids and lower load bearing capacity of the soil.

Response to Moisture

The response of soil to moisture is important, since the soil has to carry the load year round, rain or shine. Rain, for example, may transform soil into a plastic state or even into a liquid form. In these forms, the soil has little or no load bearing capacity.

Soil Classification Systems

Various soil classification systems exist to indicate the quality of soil as construction material. These classification systems take into consideration particle sizes, grain size distribution, and the effect of moisture on the soil. One of the soil classification systems is the Unified Soil Classification System (USC). A summary of USC is indicated in below chart. The meaning of the System Code Letters are also indicated in Figure 9 to make the Chart simple and easy to understand.

Unified Soil Classification

COARSE-GRAINED SOILS
(more than 50% of materials is larger than No. 200 sieve size)

	Group Symbol	Brief Description	Suitable as Construction Material
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	Clean Gravels (Less than 5% fines)		
	GW	Well-graded gravels, graveled-sand mixtures, little or no fines	Excellent
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines	Excellent to Good
	Gravels with fines (More than 12% fines)		
	GM	Silty gravels, gravel-sand-silt mixtures	Good
	GC	Clayey gravels, gravel-sand-clay mixtures	Good
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	Clean Sands (less than 5% fines)		
	SW	Well-graded sands, gravelly sands, littlw or no fines	Excellent
	SP	Poorly graded sands, gravelly sands, little or no fines	Good
	Sands with fines (More than 12% fines)		
	SM	Silty sands, sand-silt mixtures	Fair
	SC	Clayey sands, sand-clay mixtures	Good

FINE-GRAINED SOILS
(50% or more of material is smaller than No. 200 sieve size)

	Group Symbol	Brief Description	Suitable as Construction Material
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity	Fair
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Good to Fair
	OL	Organic silts and organic silty clays of low plasticity	Fair
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, miscaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor
	CH	Inorganic clays of high plasticity, fat clays	Poor
	OH	Organic clays of medium to high plasticity, organic silts	Poor
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils	Not Suitable

Figure 9: Soil Classification

Chapter 3 - Soil Compaction

What is Soil Compaction?

Soil Compaction is the technique of applying energy to the loose soil, which consists mainly of solids and a certain percentage of voids - which can be filled either with air or with water - is to reposition the soil particles in such a way as to obtain a maximum reduction of the voids.

Soil Compaction is therefore the process of consolidating the soil, while reducing or minimizing voids, by applying mechanical force to the soil with compaction equipment. By compacting the soil, its density is increased while simultaneously improving a number of its properties.

Why is Soil Compaction Necessary?

Nearly all man made structures are ultimately supported by soil of one type or another. During the construction of a structure, the soil is often disturbed from its natural position by excavating, grading or trenching. Whenever this occurs, air infiltrates the soil mass and the soil increases in volume. Before this soil can support a structure over it or along side it, these voids must be removed in order to be a solid mass of high strength soil.

Residential construction as well as commercial construction can benefit from Soil Compaction.

Soil Compaction provides the following benefits:

Increases Load Bearing Capacity: Air voids in the soil cause weakness and inability to carry heavy loads. When soil particles are mechanically compacted the soil particles are squeezed together thus reducing voids resulting in higher density. Higher loads can be carried by the soil, as a better force distribution – a larger number of particle contact points and an increased shear strength.

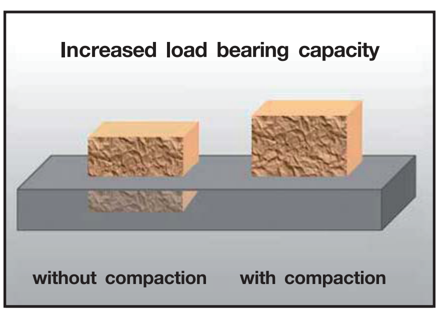


Figure 10: Load Bearing Capacity

Prevent Soil Settlement: If a structure is built on uncompacted or on unevenly compacted soil, settlement of soil occurs due to the static load placed on the soil causing the structure to deform. If the settlement is more pronounced at one side or corner, cracks or complete failure can result.

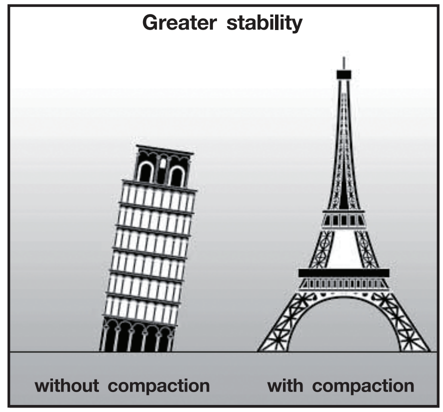


Figure 11: Stability

Reduces Water Seepage: Compacted soil reduces water penetration. Water flow and drainage can then be brought under control.

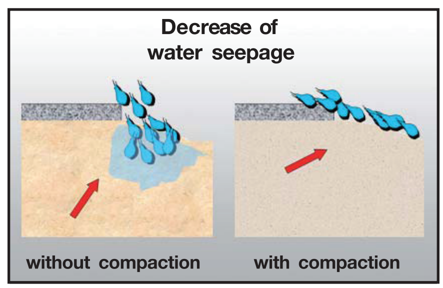


Figure 12: Water Seepage

Reduces Swelling and Contraction of Soil: If air voids are present, water may penetrate the soil to fill the air voids. The result will be a swelling action of the soil during the wet period and a contraction action during the dry season.

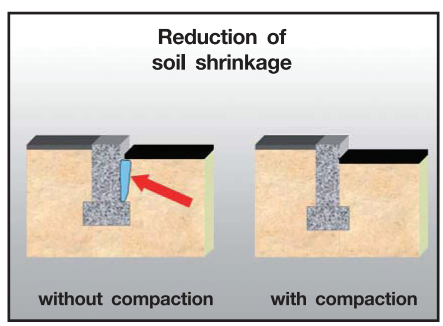


Figure 13: Soil Shrinkage

Prevents Frost Damage: Water expands and increases its volume upon freezing. This action often causes pavement heaving and cracking of walls and floor slabs. Compaction reduces these water pockets in the soil.

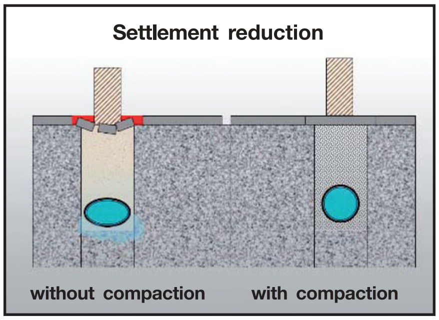


Figure 14: Settlement Reduction

In summary, compaction should be used every time the soil is disturbed. Effective compaction means densely packed soil without any voids.

Methods to Compact Soil

Three major methods are used to compact soil.
1) Static Force - Compaction is achieved using a heavy machine whose weight squeezes soil particles together without the presence of vibratory motion. **EXAMPLE:** A static roller (Figure 15).

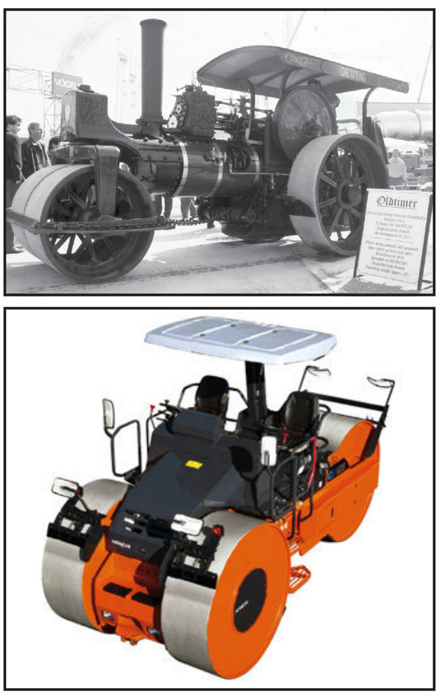


Figure 15a & b: Static Roller

NOTE: Static rollers have largely been replaced with vibratory.

2) Impact Force - Compaction comes from a ramming shoe alternately striking and leaving the ground at a high speed, literally "kneading" the ground to increase its density. **EXAMPLE**: A Rammer or sheepsfoot roller (Figure 16 and 17).

Figure 16: Rammer

Figure 17: Sheepsfoot Roller

3) Vibration - Compaction is achieved by applying a high frequency vibration to the soil. **EXAMPLE**: A vibratory plate or smooth drum roller (Figure 18 and 19).

Figure 18: Vibratory Plate

Figure 19: Smooth Drum Roller

Choosing the Correct Method

Granular soils are best compacted by **vibration**. This is because the vibration action reduces the frictional forces at the contact surfaces, thus allowing the particles to fall freely under their own weight. At the same time, as soil particles are set in vibration, they become momentarily separated from each other, allowing them to turn and twist until they can assume a position that limits their movements. This settling action and repositioning of particles is compaction. All the air voids that were previously present in the soil mass are now replaced by solidly packed soil.

Cohesive soils are best compacted by **impact force**. Cohesive soils do not settle under vibration, due to natural binding forces between the tiny soil particles. These soils tend to lump, forming continuous laminations with air pockets in between.

Figure 20: Settlement Reduction

Clay particles present a problem because of their extremely light weight which causes the clay to become very fluid when excess moisture is present. Also, clay particles have a flat, pancake shape appearance which prevents them from dropping into voids under vibration. Therefore, cohesive soils, such as silt and clay, are effectively compacted using **impact force** which produces a shearing effect that squeezes the air pockets and excess water to the surface and moves the particles closer together.

Combinations of impact force and vibration are also used. For example, large vibratory plates and vibratory rollers combine static weight with vibration to achieve compaction.

Chapter 4 - Soil Testing

Compacted Soil is measured in terms of **density** in pounds per cubic foot (lbs/ft^3).

EXAMPLE: Loose soil may weigh 100 lbs/ft^3. After compaction, the same soil may have a density of 120 lbs/ft^3. This means that by compaction, the density of the soil is increased by 20 lbs/ft^3.

Laboratory Testing

To determine the density value of a soil from a given job site, a sample of the soil is taken to a soil test lab and a **Proctor Test** is performed.

The purpose of a Proctor Test is two fold. The Proctor Test (1) measures and expresses the density attainable for any given soil as a standard; and (2) determines the effect of moisture on soil density.

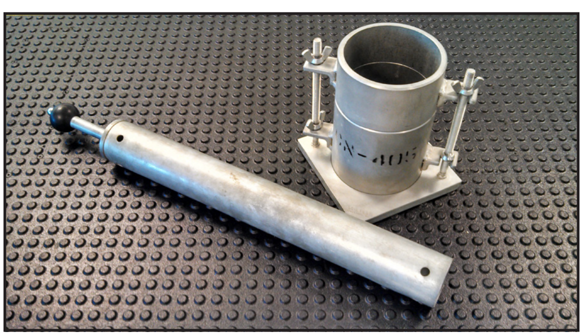


Figure 21: Cylinder Mold & Drop Hammer

In this test, a sample of soil is compacted in a standard container 4” dia. x 4.59” high which has 1/30 ft^3 capacity. The container is filled in 3 layers. Each soil layer is compacted using a 5.5 lb weight which is lifted through a distance of 12” and dropped 25 times evenly over each soil layer, yielding a soil sample which has received a total of 12,375 ft-lb of energy per ft^3, determined as follows:

1 ft x 5.5 lb x 25 drops x 3 layers x 30 = 12,375 ft-lb/ft^3

After striking off the surface of the container, the soil sample is weighed immediately after the test (wet weight) and then weighed again after drying the soil in an oven (dry weight). The difference between the wet and dry weights represents the weight of water that was contained in the soil. The density of the dry soil can now be expressed in terms of lb. per cubic foot. The amount of water or moisture may also be expressed **as a percentage** of the dry weight.

Specifications	**Standard Proctor**	**Modified Proctor**
Weight of the Hammer	5.5 lb	10 lb
Distance of Drop	12”	18”
Number of Soil Layers	3	5
Number of Drops on Each Layer	25	25
Volume of Test Container	1/30 ft^3	1/30 ft^3
Energy Imparted to Soil	12,375 ft-lb/ft^3	56,250 ft-lb/ft^3

The procedure is repeated, adding different amounts of water to the soil with each repetition and the soil weights as well as the percentages of moisture are recorded as described previously.

EXAMPLE: For a given 1/30 ft^3 soil sample:
Wet Weight = 4.6 lb
Dry Weight = 4.0 lb
Weight of Water Lost = .6 lb

We then calculate:
Soil Dry Density = 4.0 lb / 1/30 ft^3 = 120 lb/ft^3
% Moisture = .6 lb / 4.0 lb x 100 = 15%

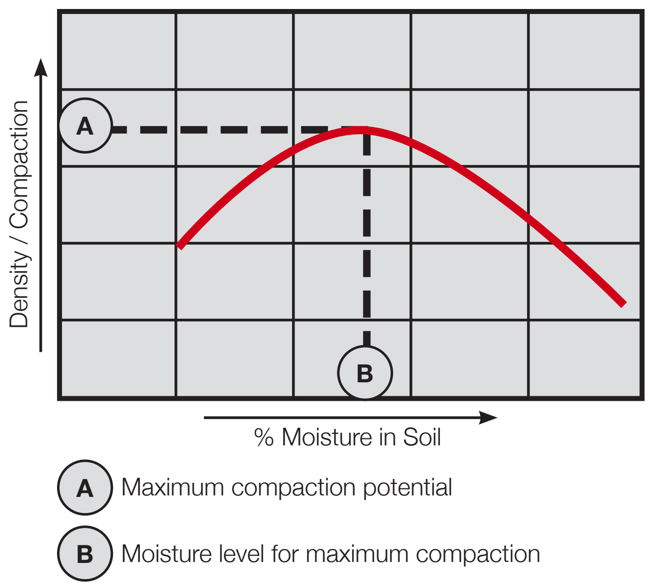


Figure 22: Moisture Density Curve

The curve is referred to as the **Moisture Density Curve** or **Control Curve** (Figure 22).

Conclusions

1. At a certain moisture, the soil reaches a maximum density when a specific amount of compaction energy is applied.

2. The maximum density reached under these conditions is called **100% Proctor Density**.

3. The moisture value at which maximum density is reached is called **Optimum Moisture**.

4. When compacting soil at above or below optimum moisture, and using the same compacting effort, the density of the soil is less than when compacted at optimum moisture.

5. The 100% Proctor value thus obtained in a laboratory test is used as a basis for comparing the degree of compaction of the same type of soil on the job site.

EXAMPLE: For the soil under investigation, 100% Proctor represents a density of 120 lbs/ft^3 Assuming the same soil is compacted to a dry density of 115 lbs/ft^3. The degree of compaction for the soil is then expressed as:

115/120 x 100 = 96%

In other words, the soil is being compacted to 96% Proctor.

The above lab test for soil density was developed by R.R. Proctor, a Field Engineer for the City of Los Angeles, California, back in the early 1930s. It is now universally accepted throughout the construction industry and is known as the **Standard Proctor Test**.

The trend to construct heavy structures, such as Nuclear Power Plants and jet runways, has increased the demand for tougher compaction specifications. For those structures, a **Modified Proctor Test** was developed. The principles and procedures for both tests are very similar.

Each soil behaves differently with respect to maximum density and optimum moisture. Therefore, each type of soil will have its own unique control curve.

The Proctor Test is usually conducted in the laboratory, not on job sites.

It is quite possible that a soil may be compacted to more than 100% Proctor, for example, to 104%. This is because the 100% Proctor value is obtained by using a specific amount of energy during compaction. If more energy is put into the soil, higher densities are to be expected.

The Standard Proctor Test has been adopted as AASHTO, Standard T 99 and ASTM, Standard D 698. Modified Proctor has been adopted as AASHTO, Standard T 180 and ASTM, Standard D 1557, respectively.

On establishing the Proctor curve for the soil and determining its 100% density, the architect/engineer is now in a position to specify the percent Proctor to which the soil must be compacted. Actual compaction then takes place in the field.

Field Testing Methods

There are several methods for compaction testing sand cone, or balloon, paste and water replacement methods however: The nuclear density test is the most popular and the method of focus for this booklet.

The Nuclear Method

There are many methods of measuring density, however the Nuclear Density/Moisture Meter operates on the principle that dense soil absorbs more radiation than loose soil. The Nuclear Meter is placed directly on the soil to be tested and is turned on. Gamma rays from a radioactive source penetrate the soil, and, depending on the number of air voids present, a number of the rays reflect back to the surface. These reflected rays are registered on a counter; and the counter reading visually registers the soil density in lb/ft^3.

This density is compared to the maximum density from a Proctor Test and the relative Proctor Density is obtained as before.

The Nuclear Method is popular because it is accurate and fast — test results are obtained in 3 minutes — and the soil is not disturbed. Newer Nuclear Meters incorporate “quick indicator modes” for instantly checking the density after each pass the equipment makes. In addition, the Nuclear Meter method allows to quickly establish optimum compactor usage by eliminating over compaction, equipment wear and abuse, and wasted operator time. The initial cost of a Nuclear Meter can be upward of several thousand dollars; however, the time saving per test is considerable when compared to other methods. In the United States all portable nuclear gauge operators are required by the NRC (Nuclear regulatory commission) to receive formal radiation training.

Figure 23: Nuclear Test

Chapter 5 - Equipment Types and Selection

How does one choose the right compactor for the job? The answer is not always straightforward or simple, because a number of factors must be considered, mainly, soil type, physical conditions of the job site and compaction and specifications to be met.

The above factors must be evaluated with two purposes in mind. First, to determine which machines are able to do the job, and secondly, to recommend the one which will do the job most economically.

Let’s discuss each factor separately.

Soil Types

As stated earlier, soil may be granular or cohesive in nature.

Granular Soils

For **granular** soils, compaction by vibration is most effective and economical. Vibration decreases friction between soil particles allowing them to rearrange themselves downward into a tightly packed configuration, eliminating all air voids. The effect of vibration penetrates deep into the soil, meaning that large layers of soil may be compacted, which contributes to the economy of the compaction process.

Vibratory Plates are the machines commonly specified for use on granular soils because they are dependable, relatively inexpensive and very productive.

Vibratory rollers are used where even higher production rates are necessary.

The various granular soils have different **Natural Resonant Frequencies**, defined as that frequency which causes the greatest soil particle motion.

The **smaller** the soil particle, the **higher** the natural frequency; the **larger** the particle, the **lower** the natural frequency.

That is why lightweight vibratory plates, of approximately 200 lb, with a high frequency of 5,800-6,000 vibrations per minute and low amplitude, are the best compactors for fine and medium sands. Other vibratory compactors with lower frequencies and a higher amplitude are necessary for coarse sands, gravels, and mixes containing more cohesive particles.

Loose granular material, slightly moist

Hand-packed granular material

Drop from knee height

Granular material evenly distributed after drop test

Figure 24: Granular Sequence

For optimum compaction, a plate with a frequency approximately equal to the natural frequency of the soil particle mix being compacted should be used.

A Word About Pea Gravel

One common misconception about pea gravel, a granular soil, is that it is not compactable and, therefore, does not require compaction.

Pea gravel is compactable because the stones are not all perfectly round, making them subject to settling if compaction is not performed.

Whether the soil settles 1/2” or 4” does not matter, as there is no support for the structure above it either way. So, be sure that pea gravel is always compacted.

Slurry Mixes also tend to settle in the same manner, and these mixes should NOT be specified without compaction.

Figure 25: Pea Gravel

Cohesive Soils

For **cohesive soils**, impact type machines must be used. The impact force produces a shearing effect in the soil, which binds the pancake shaped particles together, squeezing air pockets out to the surface.

Figure 26: Trench Roller

The high shoe lift of the ramming machine is very desirable in order to provide high impact energy and to make the forward advance possible. A high rammer speed, in the range of 500–700 impacts per minute, also creates a vibratory action that is desirable with granular as well as with cohesive soils. Vibratory trench rollers with special cleated drums also perform well on cohesive soils because of their shearing action.

As general rule:

For **granular soils**, the first choice should be a vibratory plate or Smooth Drum vibratory roller. Your second choice could be a Rammer for narrow trench applications.

For **cohesive soils**, a Rammer or vibratory trench roller should be used.

Physical Conditions of the Job Site

In a trench or next to a foundation wall, the space available often determines the machine model.

A 6” wide utility trench necessitates using a Rammer with a shoe size not exceeding 6” wide.

A 24” wide trench with granular fill may be compacted using a Rammer or vibratory plate, with the vibratory plate being the faster machine. If there is no room at the end of the trench to turn a unidirectional plate around, then a reversible vibratory plate should be used. For very long trenches, a vibratory trench roller would be the most productive choice. Wacker Neuson trench rollers have variable widths between 24”-32” by simply changing the drums, or by adding or removing a drum extension. We will discuss this in more detail in the section of this book dedicated to roller applications.

On the other hand, when compacting the granular base for a large warehouse or driveway, only a large gasoline or diesel vibratory plate or vibratory roller will provide the area capacity needed to do the job in a reasonable time.

Specifications to be Met

Many compaction specifications are still written as the “method” type which specify the type of machine to use, the soil depth or lift, and the number of passes. Machine selection in this case, is dictated by the specifications. For instance, it is completely unrealistic to specify a vibratory plate with 8000 lb of centrifugal force to run over lifts of 4”, and specify a minimum of 20 passes.

These types of specs not only waste many man hours, but drastically increase the maintenance cost of compactors and, most of all, do not achieve compaction.

Most specifications, however, are the “end result” type, allowing the use of any equipment which will achieve the specified Proctor Density.

Soil is compacted in layers which are called “lifts”, and most manufacturers rate their equipment as to the maximum lift each machine can compact under ideal conditions. This is only a guideline!!!

In the case of “end result” specs, recommend a machine according to the soil type and job physical dimensions, and be sure it has a lift rating greater than the depth of soil layer to be compacted.

However, for modern compaction machines, the lift to be compacted should not be less than **1/3 the maximum rated lift**. If thin layers must be specified, a lighter machine must be used to achieve proper compaction.

During any compaction process, it is very important that the soil be at or as close to **optimum moisture** as possible as this will insure achieving the density required and expending the least amount of energy and making the minimum number of passes of the equipment.

Performing compaction on soil that is so dry that the compaction effort raises a cloud of dust is a waste of time and money. Such dry soil will not accept compaction energy, and even many passes will not compact the soil to an acceptable density.

All WACKER NEUSON Compaction Equipment is designed and rated to provide 95% or better Standard Proctor Density with three to four passes, when the soil moisture is near optimum.

Soil Should not be Overcompacted

As soon as the specified density is reached, compaction should be stopped. If the machine is continued to be run over a compacted area, soil particles will start to move sideways, under the effect of continued compactor pressure; thus breaking up a stable soil which results in a decrease in density.

If possible, soil testing should be started immediately after the first and each pass thereafter, continuous monitoring will help determine the number of passes for the soil type and moisture condition, and eliminate the possibility of damaging the machine due excessive passes on fully compacted soil.

Summary

When recommending equipment for a compaction job, the soil types have to be taken into consideration.

Soil Types

Cohesive Soils	Use a Rammer or cleated Vibratory Trench Roller
Granular Soils	Use a Vibratory Plate or Smooth-drum Vibratory Roller, Rammers can also be used
Mixed Soils	Use any Rammer or Trench Roller, also some vibratory plates with a higher amplitude

Physical Dimensions and Restrictions of the Site

Match the size of the machine to the job.

WACKER NEUSON offers optional narrow shoes for rammers and special narrow plates when compacting in extremely narrow areas.

Reversible vibratory plates are available for use in trenches and open areas where turning is impossible or inconvenient.

Specifications

Density Requirements, Site Size, Optimum Moisture, and Number of Passes — Match the equipment to these special requirements.

Figure 27: WACKER NEUSON rammer with a 12” extension and 4” shoe for narrow trench compaction

Chapter 6 - Rammers

Rammers produce an **impact force** which is necessary for the compaction of **cohesive soils**.

WACKER NEUSON rammers are classified as **vibratory impact rammers.** That is due to their high number of blows per minute, ranging from 450 to 800. At this high impact rate, vibration is induced in the soil. Because of their vibratory action, coupled with impact, vibratory impact rammers can also be used on **granular and mixed soils**.

An efficient rammer should provide:

- **High Impact Power** (ramming shoe must come off the ground 2”–3”)
- **Good Balance** (easy to guide and good shock isolation to reduce operator fatigue)
- **Durability** (to withstand the high stresses created in the rammer)
- **Easy Maintenance**

Certain points should be considered when purchasing or comparing rammers.

Features to Look for When Choosing a Rammer:

1. Central lifting point
2. Guide handle
3. Air cleaner system
4. Integrated fuel filter
5. Integraed oil filter
6. Drive engine
7. Encapsulated ramming system
8. Bellows
9. Ramming shoe
10. Wear-resistant steel plate

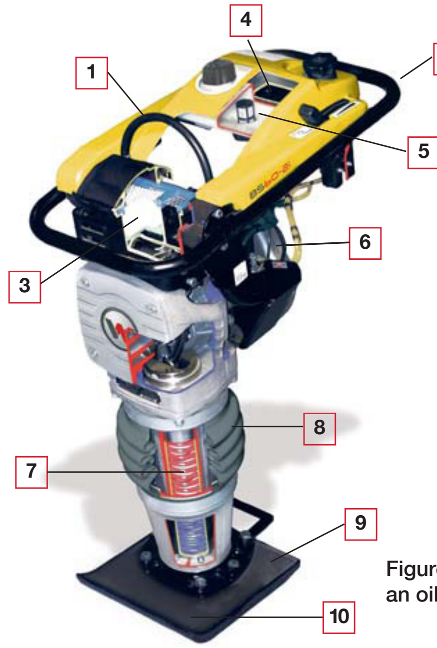


Figure 28: Cut-away model of an oil-injected vibratory rammer

Two Cycle Engine

Lubrication of the moving parts is provided by oil injected with the fuel.

Centrifugal Clutch

A centrifugal clutch allows easy engine starting with the ramming system disengaged, and also allows the engine to idle during short work stoppages.

Power Transmission Gears

The power which is developed by the engine must be transferred to the ramming system to produce 450 to 800 impact blows per minute. This is the function of the power transmission gears.

In all WACKER NEUSON rammers, hardened gears machined from forgings do the job.

Ramming System

Also called spring system. It has two functions. One is to store the energy developed by the engine and then release it to the shoe during the downward stroke. The second is to work as an elastic buffer between the oscillating ramming shoe motion and the circular rotation of the upper mechanical components, that is the gears, clutch and engine.

WACKER NEUSON spring systems are comprised of two sets of springs, with a piston in between. Each set of springs consists of two separate coil springs placed inside each other. Therefore, the total number of springs in any WACKER NEUSON rammer is four springs. Lesser number of springs, or no springs at all, reduce the efficiency and impact power.

Oil Bath Lubrication

High quality rammers incorporate a sealed oil bath lubrication system. The oil is splashed throughout the machine, providing reliable and continuous lubrication for all internal parts. A periodic oil change is all the attention that an oil lubricated machine needs. Daily or weekly greasing is eliminated. Grease lubrication is only used in rammers which were designed decades ago.

High Impact Force

A high impact machine is desirable so that deeper soil lifts may be compacted. High impact force is possible only with a well designed spring system and a long shoe stroke.

A short shoe stroke reduces the impact force and prevents machine advance on slopes and unleveled soil.

Rammers come in a variety of sizes and can be equipped with 2 cycle, 2 cycle oil injected, 4 cycle and diesel engines. WACKER NEUSONS WM 80 engine has almost 50% less moving parts and are designed for percussion applications.

Application criteria for Vibratory rammers

Each and every corner and most confined areas can be perfectly reached with vibratory rammers. Backfills around foundations and close to walls can be easily compacted.

The ease with which a rammer can be guided ensures exact operation and with careful handling damages to insulations or membranes of buildings are avoided.

The main application of vibratory rammers in **road construction** lies in the area of **drainage pipe systems, drainage collectors, culverts and curbing**. Pipe bedding and areas around services, e.g. drainage dewatering pipes require thorough but also very careful compaction, so as to avoid later pipe damages or settlements caused by traffic loads.

Another especially critical area is around **surface water collectors** as these are vulnerable to **later settlements**. The rammer easily negotiates the most difficult confined areas.

The thorough compaction of **foot paths and bicycle tracks** gains greater importance daily. A constant and lasting surface compaction is as much of a framework for settlement-free substructures as the compaction of **edge support areas** of foot paths, cycle tracks and curbstones.

It is often the case that neither vibratory plates nor rollers can reach the boundary areas. The obvious thing to do is to use vibratory rammers in such cases. Thanks to the specific compacting action of rammers it becomes possible to choose either higher lifts or to reduce the number of passes necessary to reach the required percentage of compaction. And both choices will undoubtedly benefit the contractor.

Services, such as **cable ducts,** are almost always located in the area of foot paths or sidewalks. After repair jobs or after placing of new services, the usually narrow trench must be backfilled and the fill material compacted. Preference should be given to vibratory rammers for this type of application.

A roads asphalt layers must be repaired as quickly as possible in the event of damage caused by **frost heaving, repairs of services, and damage to road surfaces** (caused by for example settlement incidents).

Many times the damage covers only a few square feet. Transporting heavy equipment, e.g. a vibratory handheld roller, to the road repair area is uneconomical. Additionally, the use of heavy equipment is not always possible, as manhole covers, gully holes, streetcar tracks, and such things are often found to be in the way.

In applications as these the just mentioned **vibratory rammers** offer themselves as most **rational and economical tools**. They are usually to be found on the job site in any case, as they will have been used previously for other necessary soil compaction applications.

Chapter 7 - Vibratory Plates

Vibratory plates apply high frequency, low amplitude vibrations to the ground, and are used mainly for compacting granular soils such as sand and gravel; mixes of granular and cohesive soil; and asphalt mixes, both hot and cold.

Figure 29a & b: Single Direction Vibratory Plates

Small vibratory plates are usually powered by small gasoline or diesel engines up to about 10 HP.

A vibratory plate consists essentially of two masses, upper and lower. The upper mass includes the engine, centrifugal clutch and engine console. The lower mass, includes the base plate with the vibration producing exciter unit rigidly bolted onto it, or integrally cast into the base plate.

Vibratory plates are generally **high production** machines, in terms of volume of soil compacted (yds^3/hour), because of their fast forward speed, deep effective lifts and large plate contact areas.

Rubber shock mounts isolate the upper mass from the vibrating lower mass. The power transmission from the engine to the exciter is achieved using V belts. The guiding handle can be mounted on the upper or lower mass and is usually rubber shock-mounted to reduce operator fatigue.

Important Design Factors For Vibratory Plates

The total static weight, the exciter design, the exciter frequency, and the positioning of engine/exciter all play an important part in the efficiency and performance of the vibratory plate.

Static Weight

The static weight of a small vibratory plate (150-300 lb weight class) is usually negligible compared to the centrifugal force that is generated in the exciter. Here, the vibratory force is the dominant force which acts on soil particles during the compaction process. For larger vibratory plates (above 300 lb), the vibration action, as well as the static weight have a combined effect on soil particles. The total effect is to vibrate and squeeze soil particles together to achieve compaction.

Figure 30: Plate Compacting Flagstone

Exciter Design

The exciter unit of any vibratory plate can be thought of as the “heart” of the machine.

Exciter units operate on the principle of turning an unbalanced “eccentric” weight at high speed to produce centrifugal force. This centrifugal force causes the machine to vibrate, move forward and compact the soil.

The fact that centrifugal force produced varies with the square power of the exciter speed is of practical importance in the operation of a vibratory plate for two reasons.

If the engine is over speeded just a little bit, centrifugal force increases a lot; which will overload the exciter bearings.

If the engine runs under speed just a little bit, centrifugal force will be much too low, causing poor performance, slow forward speed and low compaction effort.

Therefore, it is extremely important that any vibratory plate engine be set to the manufacturer’s recommended speed with a tachometer and that the operator runs the unit at the designed speed!

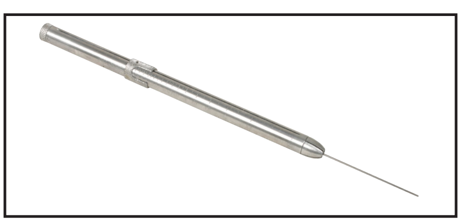


Figure 31: Vibrotach
Figure 31 courtesy of Humboldt Mfg. Co.

Exciter units are lubricated with automatic transmission fluid (ATF) or oil. On an ATF or oil lubricated exciter, it is important that the exact amount and type of ATF or oil specified be contained in the unit. Too little ATF or oil will cause the bearings to burn up; too much oil will allow the exciter weights to churn the ATF or oil, causing foaming, overheating and poor performance.

Exciter Frequency

Each soil particle size responds differently to the various exciter frequencies. Laws of physics state that a small mass responds favorably to rapid vibration and that a larger mass responds favorably to slower vibration. Therefore, an attempt should be made to match the frequency of the exciter to the dominant particle size of a soil mix.

As the exciter frequency approaches the resonant frequency of particles, sympathetic vibration occurs and soil particles vibrate with maximum amplitudes.

Engine/Exciter Layout

The relative position of the exciter mounting to the engine is also an important design factor.

A centrally mounted exciter is one placed in the direct center of the base plate, directly under the engine. This provides uniform amplitude at the front and rear of the plate.

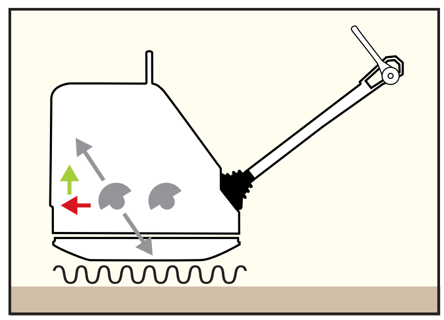


Figure 32: Reversible vibratory plate with centrally mounted exciter

A front mounted exciter is placed at the front of the base plate, and the engine is mounted in the rear. The amplitude at the front of the base plate is larger than that at the back. The result is faster forward speed and the ability to compact soil with a certain amount of cohesive material content. This design also allows for lower overall center of gravity which contributes to the stability of the machine.

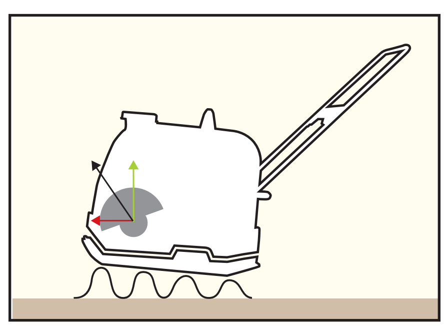


Figure 33: Single direction – forward traveling – vibratory plate

Figure 34: Remote Control Reversible Plate Model DPU 130 Compacting Granular Base

Reversibility

Some larger vibratory plates are unique due to the fact that they are reversible. The exciter system of a reversible vibratory plate has two eccentric weights that revolve in opposite directions.

These eccentric weights are arranged in a way that will move the plate in the opposite direction every time the relative position of one eccentric is changed 180° with respect to the other. This is done by a special spring and cam changing device that insures 180° change in relative position with each shift without changing the direction of rotation of the two eccentric weights.

The change of direction of travel of a reversing plate occurs instantaneously at full shaft speed, without having to bring the plate to a neutral position or stop. Modern designers use hydraulic power to change the eccentrics in infinite increments from full forward to full reverse.

This design allows a vibratory plate to do spot compaction, i.e., no forward/reverse motion but the full centrifugal force of all eccentrics is used for compaction only. No energy is wasted to propel the machine.

The latest vibratory plate design features 2 pairs of reversible eccentrics in the exciter housing. These plates are fully steerable at the touch of a finger. And for additional operator safety some of these steerable plates are remote controlled. The operator stands on top of a trench and the unit works in the trench. This safety feature may save costly trench shoring in many places.

Diesel Power

Diesel powered vibratory plates offer several advantages over similar gasoline models. One is diesel, a common fuel on jobsites used to power loaders, trucks, and many types of light equipment which eliminates the need for multiple fuels. Secondly, maintenance costs are also lower because diesels have no spark plugs, carburetor, or electrical ignition components to service. Third, one can expect longer engine life due to the sturdier construction of diesels.

A diesel powered plate has higher initial cost, although its lifetime cost per hour of operation is lower than that of a gasoline engine.

Excavators can also be fitted with boom mounted vibratory plates. These are not as efficient because the operator has to continually switch between bucket and plate.

Figure 35: Boom Mounted Compactor

Application criteria for vibratory plates

Vibratory plates are often used in trench compaction, due to the fact that they are relatively narrow and quite simple to handle. Cohesive soils are difficult or almost impossible to compact as the plate loses its travel speed to the point of a complete stand-still (vacuum between base plate and soil) and then starts digging itself in. On the other hand, vibratory plates achieve optimum results on dry, loose back-filled soils.

TAKE NOTE: The variety of vibratory plates on the market is abundant. Centrifugal forces vary anywhere from between approx. 1,800 lbs up to over 36,000 lbs The smaller machines, are applied to light compaction jobs. Some examples of these applications are peripheral areas, cable trenches, sand bed compaction, sub-grade surfaces or asphalt patchwork.

The heavy vibratory plates weighing over 700 lbs offer high compaction performance. Not only can these machines be used for major surface compaction jobs, they are also in many cases extremely efficient in trench compaction with the advent of remotely controlled (cable or infrared) vibratory plates.

Smaller plates with a dead weight of approximately 100 to 400 lbs find their main application in service trenches, areas inaccessible for heavy equipment, confined areas, base course for interlocking paving stones, footpaths, and the like.

The handling ease, complete lateral clearance, and reduced measurements provide for compaction on small surfaces, in confined areas and corners, around manhole covers and gully holes, and also along curbs or curbstones and footpath edges.

Under no circumstance should compaction jobs be carried out on lifts of more than 15” of loose material or on soils with a particle size greater than 3”.

Vibrating of interlocking paving stones

The best set paving stone is only as good as its sub-base and this is depends on the quality of the compaction. The compaction work ultimately determines the carrying capacity of the pavement. Even if the sand fill has been compacted before the laying of the interlocking paving stones (incorrect procedure), load settlements and resultant unevenness may occur. This type of occurrence can almost be completely eliminated if the interlocking paving stone is vibrated with vibratory equipment. The individual paving stones are nestled compactly into the sand layer through vibration, some sand even climbs up between the joints, thereby creating an improved lock between one paving stone and the next.

Basically only vibratory plates with higher exciter frequencies should be used for this type of application. From approximately 65 Hz (approx. 4,000 rpm’s) upwards the base plate has the right frequency for the paving stones. Rough, uncontrolled and erratic blows, such as would be the case with low- frequency vibratory plates with values in the range of approx. 40 - 50 Hz, do not take place. The surface of the paving stone is often extremely hard and is therefore in danger of breaking due to the blow impact force - and changing a broken paving stone can be extremely laborious.

Chapter 8 - Rollers

In general, rollers may be classified as static, vibratory, or sheepsfoot.

Static rollers rely on their intrinsic weight to achieve compaction. Their use for soil compaction is steadily diminishing with the introduction of vibratory rollers because the static roller must have high intrinsic weight in order to handle even moderate soil lifts. The heavy static weight means higher component costs and increased size which make handling and transportation difficult.

Static rollers, however, are still used for asphalt rolling as they provide the desirable smooth surface.

Vibratory rollers have exciter weights in one or more drums and provide vibration action (dynamic force) in addition to the static weight. Vibratory rollers produce superior compaction, particularly on granular soil because the vibratory impulses break up the frictional force between soil particles, thus allowing deeper layers of soil to vibrate and settle. The vibratory action permits the use of larger lifts and provides quick and effective particle rearrangement i.e., compaction.

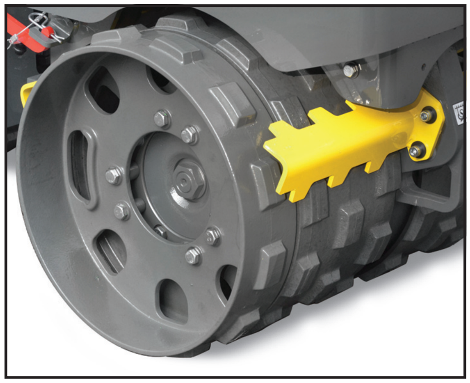
Sheepsfoot rollers, static or Vibratory, (See Figure 36) have drums with many protruding studs, each similar in shape to a sheep’s foot, that provide a kneading action on the soil. The total force becomes concentrated on the small protruding sheeps foot.

Figure 36: RT 82

These machines can effectively compact cohesive soils as they break hard soil lumps and homogenize the soil into a dense layer. Sheeps foot rollers are sometimes used for drying areas saturated with water because they create multiple indentations in the soil, increasing the exposed surface area, thus speed up drying.

Trench Roller with Split-drums

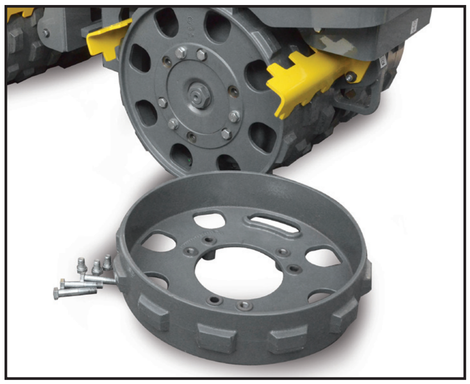
RTSC2 trench roller with split-drums in its 32" configuration



The outer drum is attached for a 32" width

Removing the drum extension bolts

Using the integrated handles to remove the outer drum



The outer drum is now removed

RTSC2 trench roller in its 22" configuration

Figure 37: Trench Roller with Split-drums

Other Compacting Rollers

There are other specialized rollers, such as the segmented pad and sanitary landfill type compactors and pneumatic tired rollers; however, these are outside the scope of this booklet.

Roller Application

For confined area soil compaction, the double drum vibratory rollers dominate the roller field.

When selecting a walk behind double drum vibratory roller for confined area soil compaction, the following specifications and parameters should be considered.

- Drum width for suitability to the application.
- Static weight for ease of handling and transport.
- Centrifugal force output for deep soil compaction.
- Dynamic linear force which is the centrifugal vibratory force per inch of the drum width.

Figure 38: RD 12

$$\text{Dynamic Linear Force} = \frac{\text{Centrifugal Force}}{\text{Number of Drums x Drum width}}$$

For the WACKER NEUSON roller RD12, the **Dynamic Linear Force** is calculated by taking the centrifugal force and dividing by the width of the drum. In this example, the RD12 is front drum vibration only, so the calculation is based on one drum. Rollers that have dual-drum vibration will need to divide the centrifugal force by the number of drums to find the total dynamic linear force.

$$\frac{3400 \text{ lb}}{35.4 \text{ in}} = 96 \text{ lb/in}$$

- Static Linear Force which is the static force per inch of the drum width.

For the WACKER NEUSON Roller, Model RD12, **Static Linear Force** is:

In this case take the static weight over each drum and divide by drum width. Assume 40%/60% (front/rear) weight distribution.

$$\frac{1029 \text{ lb}}{35.4 \text{ in}} = 29 \text{ lb/in front drum}$$

$$\frac{1462 \text{ lb}}{35.4 \text{ in}} = 41.2 \text{ lb/in rear drum}$$

Using WACKER NEUSON roller, Model RD12, as an example, the dynamic linear force is shown to be 2.3 times the static linear force. For this reason, a small vibratory roller can achieve higher compaction results than a static roller twice its size.

Application criteria for rollers

Other considerations in the selection of a roller compactor are adequate engine horsepower for reserve power in handling tough applications and grades; the sealing of all moving components from dust and moisture and the availability of a water sprinkling system for blacktop application (water is used to lubricate and clean the drum surfaces). Also keep in mind; the frequency of maintenance, accessibility of components for service and maintenance, and the ready availability of parts and service.

The advantages of using vibratory rollers are: they are used for larger area compaction where width and speed are beneficial, they are used on inclines where vibratory plates do not have enough gradability, in trenches and around footings where the roller can propel itself without requiring lifting equipment to place it as well as on rough and uneven ground where the positive drive makes for easier travel.

Figure 39: RD 16

Smooth drum rollers of WACKER NEUSON are commonly used on parking lots for subase compaction and asphalt compaction.

Trench rollers are used in trenches and confined areas especially where the material is rich in cohesive soil.

The designs of roller compactors are many and varied. Often the application dictates the design used. It is good to remember that it is not always the largest design that produces the most work.

There are no national standards for asphalt placement. However there are guidelines for good practice.

- Never place asphalt when temperatures are below 40 degrees.
- Always use some type of compactor (usually a smooth drum roller is used) for subase compaction
- Once the subase is compacted, the asphalt is layed down and compacted with a smooth drum roller. If the area is too confined a vibratory plate can be used
- The initial pass provides the greatest amount of compaction.

Chapter 9 - Machine Application Summary

The following charts will help you select the proper compaction machinery based on the application, the area and depth to be compacted, and the material to be compacted. Local conditions such as grain distribution for the material, and moisture may affect the compactability of the soil, therefore these charts are only to be used as a guide.

Dynamic compaction equipment: Typical applications

MAIN APPLICATION AREAS	TYPE OF EQUIPMENT					
	Vibratory rammers	Vibratory plates	Single drum vibratory rollers	Double drum vibratory rollers	Universal rollers (sheepsfoot)	Articulated vibratory rollers
Soil Compaction						
Narrow services or cable trenches	Δ	•	-	-	-	-
Trenches	Δ	Δ	•	-	Δ	-
foundation jobs	Δ	Δ	•	Δ	Δ	-
Backfill around structures	Δ	Δ	•	Δ	Δ	-
Landscaping and gardening	Δ	Δ	Δ	Δ	•	Δ
Foot and bicycle paths	•	Δ	Δ	Δ	-	Δ
Garden and courtyard drives	•	Δ	Δ	Δ	-	Δ
Sports and games facility	-	Δ	•	Δ	-	Δ
Parking lots and industrial areas	-	•	-	Δ	-	Δ
Road construction	•	•	-	Δ	•	Δ
Railway construction	•	Δ	-	Δ	•	-
Hydraulic engineering, refuse dumps	•	•	-	•	Δ	-
Asphalt compaction						
Small patch applications	•	Δ	Δ	Δ	-	Δ
Foot and bicycle paths	•	Δ	Δ	Δ	-	Δ
Garden and courtyard drives	•	Δ	Δ	Δ	-	Δ
Parking lots and industrial areas	-	•	•	Δ	-	Δ
Road construction	•	•	•	•	-	Δ
Other types of compaction applications						
Natural or concrete paving stones	•	Δ	-	-	-	-
Roller compacted concrete	•	Δ	•	Δ	•	Δ
Stabilized sand	•	Δ	-	-	-	-

Δ well suited • relatively suited - Not suited

Dynamic compaction equipment: Layer depths and number of passes in relation to type of equipment and type of soil

AREAS AND TYPE OF COMPACTION EQUIPMENT		TYPE OF SOILS								
		I. Granular soils (non-cohesive to cohesive)			II. Mixed soils (slightly cohesive to cohesive)			III. Fine-graines soils (cohesive)		
	Operating weight lbs.	Suit-ability	Lifts inch	# of passes	Suit-ability	Lifts inch	# of passes	Suit-ability	Lifts inch	# of passes
Light compaction equipment (mainly for services areas in trenches)										
Vibratory rammers (light)	up to 55	•	up to 6”	2-4	•	up to 6”	2-4	•	up to 4”	2-4
Vibratory rammers (medium)	55-132	•	8” - 16”	2-4	•	6” - 12”	3-4	•	4” - 12”	2-4
Vibratory plates (light)	up to 200	•	up to 8”	3-5	•	up to 6”	4-6	-	-	-
Vibratory plates (medium)	220-661	•	8” - 12”	3-5	•	6” - 10”	4-6	-	-	-
Vibratory rollers (light)	up to 1320	•	8” - 12”	4-6	•	6” - 10”	5-6	-	-	-
Medium heavy and heavy compaction equipment (above the services areas in trenches)										
Vibratory rammers (medium)	55-132	•	8” - 16”	2-4	•	6” - 12”	2-4	•	4” - 12”	2-4
Vibratory rammers (heavy)	132-440	•	16” - 20”	2-4	•	8” - 16”	2-4	•	8” - 12”	2-4
Vibratory plates (medium)	661-1653	•	12” - 20”	3-5	•	8” - 16”	3-5	-	-	-
Vibratory plates (heavy)	more than 1653	•	16” - 28”	3-5	•	12” - 20”	3-5	-	-	-
Vibratory rollers	1320-17,036	•	8” - 20”	4-6	•	8” - 16”	5-6	-	-	-

• well or relatively suited - Not suited

The recommended layer depths (lifts) shown may vary according to the type of soil and its properties such as, amongst others, the partical-size distribution curve and water content.

Compactor Selection Guide

SOIL
(COHESIVE/CLAY AND MIXED)

SAND/GRAVEL

ASPHALT

CONFINED AREA

SOIL – RAMMERS

For excavations 4” – 24” wide, or adjacent to structures

SAND/GRAVEL – SINGLE DIRECTION PLATES

For smaller areas and shallow lifts less than 12”

ASPHALT – SINGLE DIRECTION PLATES

For asphalt, patches and edging along curbs, light poles, etc.

LARGER AREA

SOIL – SHEEPSFOOT ROLLER

For excavations 24” wide, or adjacent to structures

SAND/GRAVEL – REVERSIBLE PLATES

For areas with lifts deeper than 12”

SAND/GRAVEL – SMOOTH DRUM ROLLERS

For parking lots, sidewalks, etc.

ASPHALT – RIDE-ON ROLLERS

Compaction of asphalt, gravel sub base, driveways and more.

Chapter 10 - Equipment Maintenance and Safe Operation

Prior to using any compaction equipment, an operator must read the safe operation, and maintenance sections of the manual provided with the machine. The operator should familiarize themselves with the caution and warning symbols on the machine and be familiar with proper starting, handling, and stopping of the machine. Poor maintenance is the main cause of premature construction equipment failure. Because soil compaction equipment operates exclusively under conditions of heavy dust and vibration, proper machine maintenance is vital for long life.

The following maintenance and safety tips are examples which apply to different types of compaction equipment.

NOTE: Each machine comes with its own manual. Figure 40 and 41 are samples from manuals. Refer to your booklet for proper maintenance and guidelines.

In the event that the original operators manual is lost or damaged, you may download or print a copy at no charge from WACKER NEUSON's website.

www.wackerneuson.com

Periodic Maintenance Schedule - SAMPLE

This table lists basic machine maintenance. Tasks designated with a ✓ may be performed by the operator. Tasks designated with ■ require special trainin and equipment.

	Daily before starting	After first 5 hours	Every week or 25 hours	Every 3 months or 300 hours	Every year
Check and replace air filters as needed.	✓				
Check ramming systems oil level in sightglass.	✓				
Check fuel line and fittings for cracks or leaks. Replace as needed.	■				
Tighten ramming shoe hardware.		■	■		
Inspect the machine.		✓	✓		
Clean enginecooling fins.			✓		
Clean and check spark plug gap.			■		
Change ramming system oil*				■	
Inspect central lifting cable for wear, damage, or abuse.				✓	
Replace spark plugs.					■
Inspect and clean fuel filter.					✓

**Change ramming system oil after first 50 hours of operation.*
***Note**: If engine performance is poor, check, and replace air filter elements as needed.*

Figure 40: Maintenance Schedule

Safety Guidelines for
Operating the Machines - SAMPLE

Operator Training	Application area
Before operating the machine: ■ Read and understand the operating instructions in all manuals delivered with the machine ■ Familiarize yourself with the location and proper use of all controls and safety devices. ■ Contact WACKER NEUSON for additional training if necessary When operating with machine ■ Do not allow improperly trained people to operate the machine. People operating the machine must be familiar with the potential risks and hazards associated with it	Be aware of the application area ■ Keep unauthorized personnel, children and pets away from the machine ■ Remain aware of changing positions and the movement of other equipment and personnel in the application area/jobsite ■ Do not operate the machine in areas that contain flammable objects, fuels or products that produce flammable vapors
Operator qualifications	**Safety devices, controls and attachments**
Only trained personnel are permitted to start, operate and shut down the machine. They also meet the following qualifications: ■ Have received instruction on how to properly use the machine ■ Are familiar with required safety devices The machine must not be accessed for operated by: ■ Children ■ People impaired by alcohol or drugs	Only operate the machine when: ■ All safety devices and guards are in place and in working order ■ All controls operate correctly ■ The machine is set up correctly according to the instructions in the Operator's Manual ■ The machine is clean ■ The machine's labels are legible To ensure safe operation of the machine: ■ Do not operate the machine if any safety device or guards are missing or inoperative ■ Do not modify or defeat the safety devices ■ Only use accessories or attachments that are approved by WACKER NEUSON

Figure 41: Safety Guidelines

Chapter 11 - Compaction Costs

As cost is a major factor in any construction project, the cost of compaction must be taken into consideration.

The examples below are an indicator of how the cost of compaction can be calculated and how machine performance greatly affects these costs. Because machine prices are subject to change, the example is a comparison between two vibratory plates.

The price information is hypothetical but the performance figures and formula are **actual** and may be used by job estimators to forecast costs of compaction.

Let us assume that we want to compact the granular backfill around the outside foundation walls of a high rise building. The building is rectangular, 400 x 300 ft. The width of trench around the building is 10 ft. The depth of trench is 10 ft (See Figure 42).

Volume of soil to be compacted
= 2 [(300 x 10 x 10) + (420 x 10 x 10)]
= 2 x (30,000 + 42,000)
= 2 x 72,000
= 144,000 ft^3
or
= 144,000 ft^3/27
= 5,333 yd^3

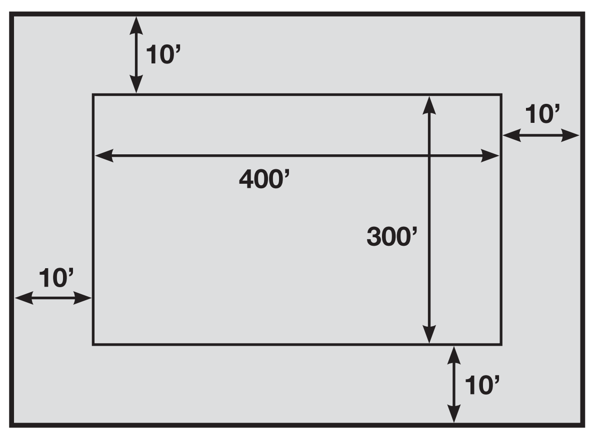


Figure 42: Jobsite Layout

By using the maximum effective lift for each machine, 95-100% Proctor Density is expected to be reached after 3 passes provided that moisture is close to optimum.

To determine the total cost of owning and operating the two vibratory plates for this job, assume that:

*These costs will vary.

1. Machines have a life expectancy of 3000 hours. (4 hrs per day, 250 working days per year, 3 years).
2. Depreciation is determined by pro rating the price of the machine over a 3,000 hour life.
3. Maintenance cost is 80% of the depreciation cost.
4. Fuel cost is $3.50 per gallon.*
5. Labor cost is $20.00 per hour.*

Vibratory Plate Machine Comparison

	Machine A	**Machine B**
Using the above assumptions, the depreciation cost is:	$\frac{\$1,300}{3,000\text{ hr}}$ = $0.43 per hr	$\frac{\$1,800}{3,000\text{ hr}}$ = $0.60 per hr
The maintenance cost is:	$0.43 x 80% = $0.34 per hr	$0.60 x 80% = $0.48 per hr
Fuel costs are:	$\frac{1.6\text{ quarts per hr}}{4\text{ quarts per gallon}}$ x $3.50 = $1.40 per hr	$\frac{1.7\text{ quarts per hr}}{4\text{ quarts per gallon}}$ x $3.50 = $1.49 per hr
Total for machine depreciation, maintenance and fuel is:	$0.43 per hr $0.34 per hr + $1.40 per hr Total: $2.17 per hr	$0.60 per hr $0.48 per hr + $1.49 per hr Total: $2.57 per hr
Production Rate per hour:	200 yd^3/h	366 yd^3/h
Production Rate per 3 passes:	$\frac{200}{3}$ = 66.7 yd^3/h	$\frac{366}{3}$ = 122 yd^3/h
Time needed for compacting 5333 yd^3:	$\frac{5,333}{66.7}$ = 80 hrs	$\frac{5,333}{122}$ = 43.7 hrs
The Total Cost:	($20 + $3.50) x 80 hrs = $1,880	($20.00 + $3.50) x 43.7 hrs = $1,026

NOTE:

(1) The hourly cost of depreciation, maintenance and fuel for Machine "B" is 18% greater than that of Machine "A" ($2.57 vs. $2.17).

(2) Machine "B" required a little more than half the time needed by Machine "A" to finish the job (43.7 hrs vs. 80 hrs).

The above should not lead us to believe that Machine "B" is costly to own and operate. Its high rate of production offsets the higher cost of initial investment.

Since labor constitutes the major expense of any Confined Area Compaction operation, it is, therefore, always advisable to recommend the most productive machine, rather than the least expensive one.

The smaller machine costs less in terms of ownership but more in labor. As one combines both equipment and labor costs, the total cost to finish the job is $1,880 for the small machine as compared to $1,026 for the larger machine. That is to say, the smaller machine, "A", costs almost twice as much to finish this job as the larger machine, "B". This final cost is what determines the profit or loss of the compaction process.

In general, for each compaction situation, one should look at the cost of equipment, as well as the cost of labor involved, and then try to strike a balance between equipment and labor costs.

Conclusion

This booklet has reviewed soil types, soil compaction tests, and the factors that influence the selection of compaction equipment. Also, the general principles and applications of rammers, vibratory plates, and rollers were covered.

With this information, one should now have a better understanding of soil compaction and the equipment connected with it and should also be in a position to be able to recommend the right equipment for the job.

If additional confined area compaction application assistance is needed, please consult with the WACKER NEUSON Sales Engineering Department for expert technical advice; it is free and your inquiries are always welcome.

Glossary

AASHTO – American Association of State Highway and Transportation.

AASHTO T99 - American Association of State Highway and Transportation Officials Standard for the Standard Proctor Test.

AASHTO T-180 - American Association of State Highway and Transportation Officials Standard for the Modified Proctor Test.

Aggregate – (Coarse or Fine) Crushed Rock,sand or gravel which has been graded and may e used for back fill material.

Air Gap reading - The nuclear density meter test procedure which allows for cancelation of error in reading due to the chemical composition of the soil tested.

Amplitude - The distance an oscillating body moves from its neutral axis to the outer limit of travel in one direction.

ASTM – American Society for testing and Materials.

ASTM D 698 – American Society for Testing and Materials Standard for the Standard Proctor test.

ASTM D 1557 – American Society for Testing and Materials Standard for the Modified Proctor test.

Backfill - Materials used to refill a cut or other excavation.

Backscatter – Amethod of Nuclear soil testing in which the radiation source is placed In contact with the sil surface and density readings taken from the reflected radiation. The principle being that dense materials absorb more radiation than materials not so dense.

Bank – mass of soil which rises the normal earth level. Generally any soil which is to be dug from its natural position.

Bank run gravel – A natural mixture of cobbles, gravel, sands and fines.

Bank Yards – The measurement of soil or rock taken before digging or disturbing from its original position.

Base – The coarse or layer of materials in a road section on which the actual pavement is placed. This layer may consist of many different types of materials ranging from selected soils to crushed stone or gravel.

Birm – An artificial ridge of earth. This term is generally applied to the side/slopes of roads.

Borrow pit – An excavation in which material is taken.

Capillary action – The cohesive, adhesive or tensive force which causes water that is contained within soil channels to rise or depress on the normal horizontal.

Centrifugal force – Thee pulling force of a eccentric weight when put in rotary motion which may be changed by varying the rotational speed, and /or mass of the eccentric, and/or center of gravity (shape) of the eccentric weight.

Clay – A cohesive soil composed of particles that are less than 0.006 mm in diameter.

Clean – Free of foreign material. When used in reference to sand or gravel means lack of binder.

Cohesion – The quality of some soil particles to attract stick to like particles.

Cohesive material – A soil having properties of cohesion.

Compacted yards – The cubic measurement of backfill after it has been placed and compacted.

Compressibility – The property of a soil to remain in a compressed state after compaction.

Contact reading – A reading by a Nuclear Density Meter when the bottom of the Meter is in full contact with the compacted.

Core – A cylindrical sample of an underground formation, cut and raised by arotary hollow drill bit.

Crown – The center of an elevation of a road surface used to encourage drainage.

Datum – Any level surface used as a plane of reference to measure elevations.

Density – The ratio of the weight of substance to its volume.

Double amplitude – The distance an oscillating body moves from its neutral axis to the outer limit of its travel in opposite attractions.

Dynamic linear force – The force in lb/in. seen by the soil as produced by a vibratory roller. Calculated by dividing the centrifugal force by the width of the compacting surface(s).

Eccentric – A mass of weight off balanced to produce centrifugal force (lb) and being part of the exciter unit which produces vibration.

Elasticity – Properties that cause soil to rebound after compaction.

Embankment – A fill whose top is higher than the adjoining natural surface.

End result specifications – Compaction specifications which allow results instead of method specifications to be the determining factor in the selection of equipment.

Exciter – The component of a vibratory compactor which creates centrifugal force by means of a power driven eccentric weight.

Fines – The smallest soil particles in a graded soil mixture.

Foot or shoe – The bottom part of a vibratory impact rammer contacting the soil.

Frequency – The rate at which a vibrating compactor operates, usually expressed in VPM – vibrations per minute.

Grade – Usually defined as the surface elevation of the ground at points where it meets a structure.

Grain distribution curve – A soil analysis graph showing the percentage of particle size variations by weight.

Granular material – A type of soil whose particles are coarser than cohesive material and do not stick to each other.

Gravel – Courese grained soil of sizes ranging from 0.08” (2.03 mm) to 3” (76.2mm).

Gumbo – A term applied to clays which are distinguished in the plastic state by a soapy or waxy appearance and by great toughness.

Impervious – Resistance to movement of water.

In-Situ – The natural undisturbed soil in place.

Internal friction – The soil partical resistance to movement within the soils mass. For sand the internal friction is dependent on the gradation, density and shape of the grain and is relatively independent of the moisture content. For clay internal friction will vary with the moisture content.

Lift – A layer of fill as spread or as compacted. A measurement of material depth. The amplitude of a rammers shoe. The rated effective soil depth a compactor can achieve.

Liquid limit – The water content at which the soil changes from a plastic to a liquid state.

Loam – A soft, easily worked soil which contains sand, silt, clay and decayed vegetation.

Muck – Mud rich in humus or decayed vegetation.

Mud – Generally any soil containing enough water to make it soft and plastic.

Optimum moisture content – That percent of moisture at which the density of a soil can be obtained through compaction.

Pass – A working trip or passage of an excavating, grading or compaction machine.

Peat – A soft light swamp soil consisting mostly of decayed vegetation.

Plasticity index – The numerical difference between a soils liquid limit and its plastic limit.

Plastic limit – The lowest water content at which a soil remains in a plastic state.

Proctor standard – A test method developed by R.R. Proctor for determining the density – moisture relationship in soils. It is almost universally used to determine the maximum density of any soil in order that specifications may be properly prepared for field construction requirements.

Proctor modified – A moisture- density test of more rigid specifications than Standard Proctor. The basic difference is the use of heavier weight dropped from a greater distance in laboratory determinations.

Quicksand – Find sand or silt that is prevented from stabilizing by a continuous upward movement of underground water.

Silt – A soil composed of particles between 0.00024” (0.006 mm) and 0.003” (0.076 mm) in diameter.

Soil - The loose surface material of the earth’s crust.

Stabilize – To make soil firm and prevent it from moving.

Static linear force – The force in lb/in seen by the soil as produced by a nonvibratory roller. Calculated by dividing the dead weight of the compactor by the width of the compacting surface(s).

Subbase – The layer of selected material placed to furnish strength to the base of the road. In areas where construction goes through marshy, swampy, unstable land, it is often necessary to excavate the natural material in the roadway and replace it with more stable materials. The material used to replace the unstable natural soils is generally called subbase material, and when compacted, is known as the subbase.

Subgrade – The surface produced by grading native earth, or inexpensive materials which serve as base for a more expensive paving.

VPM – Vibrations per minute, derived by the rate of revolutions the exciter makes each minute.