Original instructions

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DMHOPACENG.922

Compaction Guide

For Ho-Pac Plate Compactors

RAMMER HITS HARDER

FOREWARD

1. THIS GUIDE

This guide contains background information about soil, soil compaction, and basic soil compaction equipment. It also contains general information about the operation of machine-mounted vibratory compactors and drivers, as well as performance data for our compactor models derived from field tests.

For safety precautions, technical information including specifications, service and maintenance information, storage recommendations, warranty information, and product policies applying to individual compactor models, see the Operator's manual for your specific model.

Note: The compaction measuring methods described in this guide are specific to North American practices and thus examples only. You should follow the approved or recommended local or country-specific methods for measuring compaction in your area.

2. DEFINITIONS

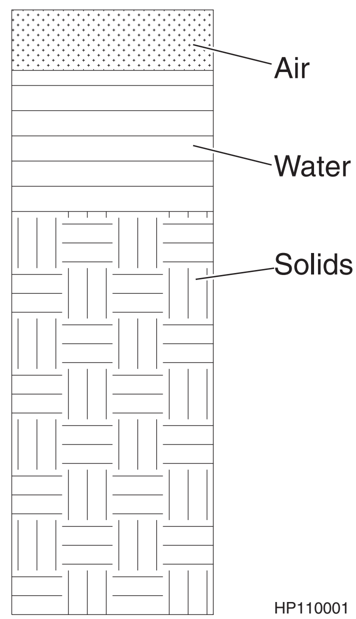
Term	Definition
AASHTO	American Association of State Highway Transportation Officials
Amplitude	Total vertical distance from the neutral position that the vibrating drum or plate is displaced
ASTM	American Society for Testing and Materials
Backfill	Material used to refill an excavation
Bank yards	Measure of soil volume in its original position before digging
Binder	Fines that fill voids in soil or hold gravel together when dry
Centrifugal force	Unbalanced force generated by an eccentric weight rotating at a given speed
Clay	Soil composed of microscopic platelets of rock
Cohesion	A property that causes soil particles to stick together and resist compaction
Compacted yards	A measure of soils or rock after it is placed and compacted in a fill
Compactability	Property of soil that allows it to deform under load
Density	The ratio of the weight of a quantity of soil to its volume, expressed as lb/ft^3, for example.
Elasticity	A property of soil that allows it to compress or deform when a force is applied, but return to its almost original configuration when the force is removed
Expansive Soil	A soil that swells when wetted and shrinks when dried
Fines	Minute clay or silt particles in soil
Frequency	Rotational speed of the eccentric shaft of a vibratory compactor, expressed as vibrations per minute
Granular material	Soil with sandy or gritty particles that are coarser than cohesive (clay) soil particles and do not tend to cohere to each other
Gravel	Loose, rounded fragments of rock varying from 2 to 76 mm (0.08 to 3.0 inches)
Gumbo	Soil material in a plastic sticky state, with a soapy or waxy appearance
Humus	Organic portion of soil formed by decaying plant or animal matter
Lift	A layer or soil or other material before or after compaction
Liquid limit	The water content at which soil passes from a plastic to a liquid state
Loam	A soft, easily worked soil consisting of clay, silt, sand and decayed vegetable material

Term	Definition
Operating weight	Weight of the compacting device, including all fluids and attachments (same as Working weight)
Optimum moisture content	The amount of moisture in a soil required to achieve the greatest dry density of that soil through compaction. Expressed as a percent
Pass	A single series of applications of the compacting device across the surface to be compacted
Permeability	The ability of water to freely pass through soil
Plasticity	The ability of soil (such as clay) to retain its shape when rolled into a fine strand
Proctor test	A standardized laboratory test method for determining the maximum density of soil that is used to establish field compaction specifications, commonly expressed as "% Proctor."
Proctor test, modified	A variation of the Proctor laboratory test for high-shear strength soils
Pumping	A "spongy" condition in compacted soil where excess moisture prevents soil particles from settling firmly together, although the soil may be at or near its maximum density
Sand	A loose granular material composed of mineral particles smaller than gravel, but larger than silt
Shear resistance	The resistance of soil particles to sliding against one another when compacting force is applied, resulting from interference (friction) and cohesion
Silt	Soil composed of particles between 0.005 and 0.050 mm in diameter
Soil	Loose material in the upper layer of the earth's crust composed variously of mineral, vegetable and animal particles
Working weight	See Operating weight

COMPACTION GUIDE

1. SOIL

1.1 SOIL TYPES



Idealized soil diagram

Many soils are a mixture of organic, granular and cohesive soils. Loam is a common example of this. Spaces between the particles may be occupied by air or moisture. The particles vary in size, shape, and composition. Soils are commonly classified by grain sizes, measured by passing the soil through a series of screens or sieves with different mesh sizes. Soils fall into three general categories: organic, granular, and clay or cohesive.

1. Organic soils (peat) contain large concentrations of vegetable and animal material (humus) in various stages of decomposition. Organic soils are not suitable for compaction and the support of rigid construction. Therefore, organic soils are outside the scope of this guide.
2. Granular soils are typically comprised of sand and gravel particles, with 20% or more granular content. The particles range in sieve size from 0.08 mm (0.003 in, sand) to 25.4 mm (1.0 in, medium gravel). Relatively large spaces between the "lumpy" grains allow water to readily drain through the soil.
3. Clay or cohesive soils contain particles of typically very small, flat "platelets," ranging in sieve size from 0.001 to 0.05 mm (0.00004 to 0.002 in), with less than 20% granular content. The platelets pack tightly together, held by molecular attraction, making clay soils very dense. Drainage through clay is poor.

1.2 RECOGNIZING SOIL TYPES

Granular soils may be distinguished from clay or cohesive soils by visual examination and feel.

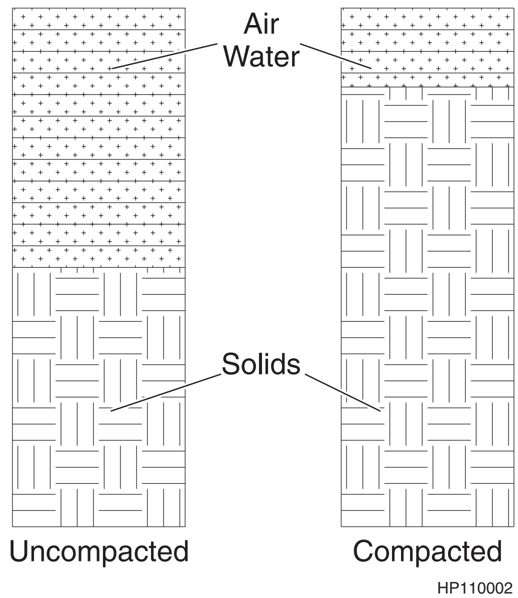
Granular soils have visible grains of sand and gravel. They feel gritty when rubbed between the fingers. They readily mix with water. The particles settle (or the water drains out) when mixing stops. When wet, there is little or no plasticity (the soil will not retain its shape when molded). When dry, there is little or no cohesive strength (the soil crumbles easily).

Clay soils have no particles that are visible to the naked eye. They feel smooth and slippery when rubbed between the fingers. They will not readily mix with water. When wet, the surface is slick and greasy and can readily be molded. If clay is rolled into a slender 'rod' shape, it will retain that shape when the rod is held by one end. When dry, clay soils have high strength, crumble with difficulty, and are slow to saturate with water.

2. COMPACTION

2.1 THE NEED OF COMPACTION

Compaction is the process of mechanically increasing the density or unit weight (kg/m^3 or lb/ft^3) of soil by packing the soil particles closer together to force out air.



Idealized uncompacted and compacted soil comparison

When soil is disturbed by excavation, soil particles become separated by air pockets. The volume of the soil increases, thereby greatly reducing its density. While all disturbed soils will settle (become more dense) with time, mechanical compaction reduces the time for this to occur.

Soil must be as dense as possible to maximize its load carrying capability, provide stability, and minimize subsequent settling that can result in cracking or displacement of, for example, supported structures, paved surfaces, or pipelines. Compaction also reduces subsequent water seepage, swelling, and contraction.

2.2 ACHIEVING COMPACTION

Compaction is achieved through the application of mechanical force to layers or "lifts" of the disturbed soil. This force overcomes friction between the soil particles and causes the particles to move closer together. Compaction falls into two major categories: static and dynamic.

STATIC COMPACTION

Static compaction is simply the application of extreme force to the disturbed material, causing it to compress until it is capable of supporting the applied force. Static forces include kneading and compression, and are typically applied by non-vibratory (sheepsfoot and smooth) rollers. Static compaction is typically limited to the soil and material near the surface and is most effective for thin layers of non-granular materials and asphalt.

DYNAMIC COMPACTION

Dynamic compaction achieves the desired result by introducing waves of motion in the soil that set the soil particles in motion. This causes the soil particles to reorient and fill vacant spaces, thus making the soil denser. Dynamic forces include impact and vibration, and are applied by a variety of hand-guided and machine-mounted devices that generate stress waves that are transferred to the soil.

Impact compaction equipment (also known as rammers and tampers) generates a lower-frequency, longer-stroke (compared to vibratory) motion. This motion is used to break soil "clumps" into smaller pieces and push the pieces closer together. Impact compaction is more effective for soils with less than 50% granular content, such as clay soils.

Vibration compaction equipment generates a higher frequency, smaller stroke motion. This motion, or stress wave, is transferred to the soil by direct contact. The stress wave causes the soil particles to move and vibrate, with effectively liquefies the soil and allows the soil particles to fill voids between them. The result is a denser, more compact soil. Vibration compaction is most effective for soils with 50% or more granular content.

2.3 SOIL/SUBSTRATE TYPE AND COMPACTION

Soil properties that affect the ability of soil to be compacted and also suggest the best compaction force for the job include shear resistance, elasticity, cohesion, permeability, and volume change (swelling or shrinkage).

SHEAR RESISTANCE

Shear resistance is the resistance of soil particles to movement under applied compaction force resulting from friction between the particles. The greater the friction force and the greater the contact area between particles, the more difficult it is to compact the soil. This explains why clay soils are more difficult to compact than granular soils.

ELASTICITY

Elasticity is the property of a soil mass that causes it to return to its original form after deformation (that is, after a load is applied and removed). 'Spongy' organic soils have a high degree of elasticity, which makes them unsatisfactory as a base for surfaces such as roads that experience cyclical loads. Cyclical loads can lead to flexing and cracking of the paved surface if poorly supported.

COHESION

Cohesion is the property of soil particles that causes them to stick to one another. It is stronger in clay soils than in granular soils.

PERMEABILITY

Permeability is a characteristic of soil that allows water to flow through it as a result of gravity. Permeability has a major effect on a soil's gumbo. See “Moisture content and compaction” on page 14.

VOLUME CHANGE

Volume change as a result of changes in moisture content is a critical consideration when soils are used as subgrades for roads. Volume change is generally not a great concern in relation to compaction, except for clay soils where compaction does have a marked influence. With clay soils, the greater the density, the greater the potential volume change as a result of swelling. Swelling also has a negative effect on load bearing capacity.

PARTICLES IN THE SOIL

Another characteristic of soil that affects its compactability is the presence or absence of "binder" materials. Binder materials refer to small particles, or "fines", that fill voids between larger particles and hold gravel together when dry. A soil that consists of a wide range of particle sizes, with the smaller particles filling the voids, forms a dense mass that compacts well.

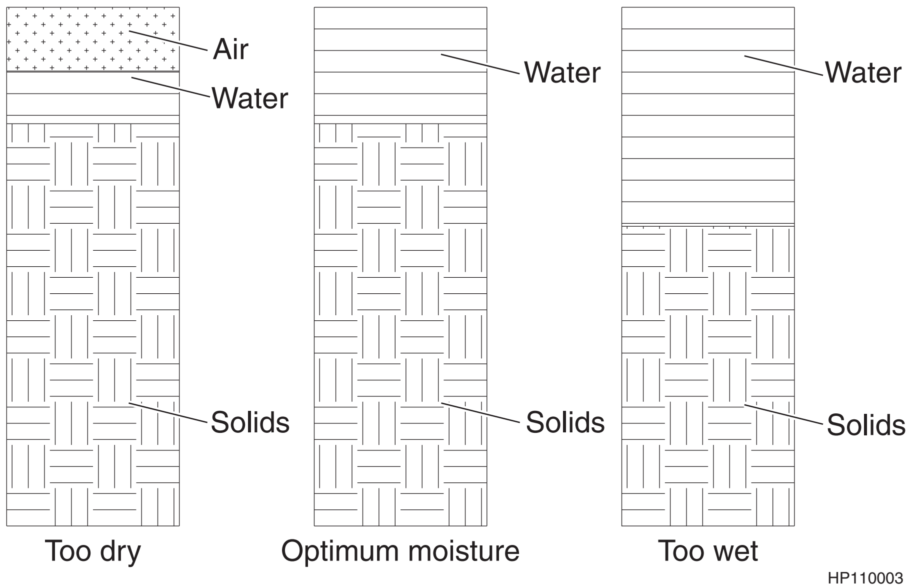
See the table for typical soil behavioral characteristics.

TYPICAL SOIL BEHAVIORAL CHARACTERISTICS

Soil	Permeability	Foundation support	Pavement sub-grade	Expansive	Compaction difficulty
Gravel	Very high	Excellent	Excellent	No	Very easy
Sand	Medium	Good	Good	No	Easy
Silt	Medium low	Poor	Poor	Some	Some
Clay	Very low	Moderate	Poor	Common	Very difficult
Organic	Low	Very poor	Very poor	Some	Very difficult

2.4 MOISTURE CONTENT AND COMPACTION

Moisture content is the amount of water in a soil, expressed as a percent of the total weight of the soil. Achieving and maintaining the optimum moisture content is very important for proper compaction. Optimum moisture content is defined as the percentage of moisture that results in the highest density (fewest air voids) of the compacted material after the water is removed.



Idealized soil moisture comparison

Without water, soil particles will not stick together. Water also acts as a lubricant, allowing the particles to slide together and fill air voids during compaction.

While every soil responds differently, soils with a moisture content near the optimum are more effectively compacted and result in greater compaction densities.

However, if too much water is added, soil density decreases (soil becomes spongy). This is because the water displaces soil particles, expanding the volume of the soil and transforming it into a plastic state with little or no load bearing ability. This is also called pumping. See “Field density measurement relative to a standard” on page 15.

Moisture content has less effect on the compactability of heavy clays than on slightly plastic, clayey sands and silty sands. However, if heavy clay is compacted more than 2% above the optimum moisture contact, it becomes too fluid and difficult to work. Poorly graded soils (with an uneven concentration of particle sizes) are also relatively unaffected by changes in moisture.

On the other hand, granular soils with better grading and higher densities react sharply to slight changes in moisture, resulting in sizable changes in dry density.

2.5 MEASURING COMPACTION

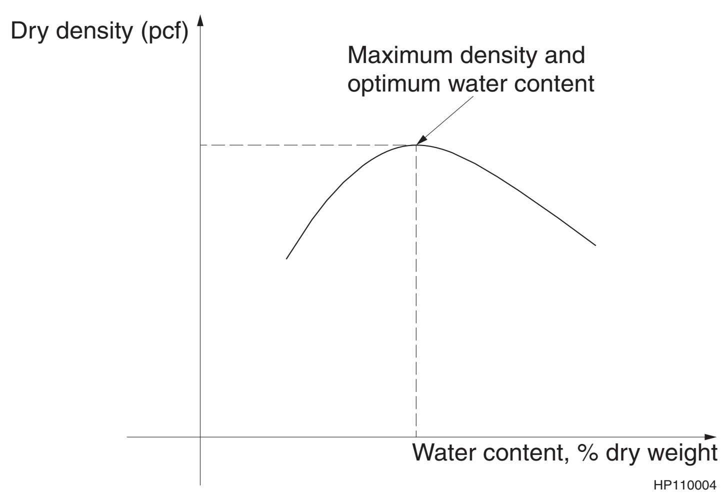
FIELD DENSITY MEASUREMENT RELATIVE TO A STANDARD

Field compaction (density) measurements are based on comparisons with the results of standardized laboratory tests. The Proctor test, a standardized laboratory test widely used in the USA, was developed in the 1930's. The original Proctor test was eventually modified to make it more suitable for evaluating soils capable of supporting heavier loads. These tests led to AASHTO (American Association of State Highway and Transportation Officials), ASTM (American Society for Testing and Materials), and other tests that are widely used to determine the optimum soil density and moisture content for a soil sample.

In the standardized laboratory tests, soil taken from the job site is divided into portions. Each portion is mixed with a different amount of water to produce a range of samples, each with a different moisture content.

Each sample is then placed in a graduated cylindrical container (with a known volume). A specified weight or hammer is dropped on successive layers of the soil from a specified height, for a predetermined number of blows. The compacted volume is recorded and the compacted material is weighed to establish a "wet" density.

The material is then oven dried and reweighed to determine what the water content was at the time of compaction and a "dry" density is determined. The dry density for each sample is plotted against the moisture content at which it was attained. A curve is then drawn through the points to determine the moisture content at which the greatest compacted density will be obtained. This density is referred to as "100% of Proctor". See the illustration.



Maximum density and optimum moisture diagram

Once this laboratory value is established, the field compaction objectives can be specified as a percentage of Proctor. For example, a compaction specification of "95% of modified Proctor" means that the field compacted soil density should be 95% of the value established by the modified Proctor laboratory test.

Percent of Proctor = Field Density Measurement / Max Laboratory Density Measurement

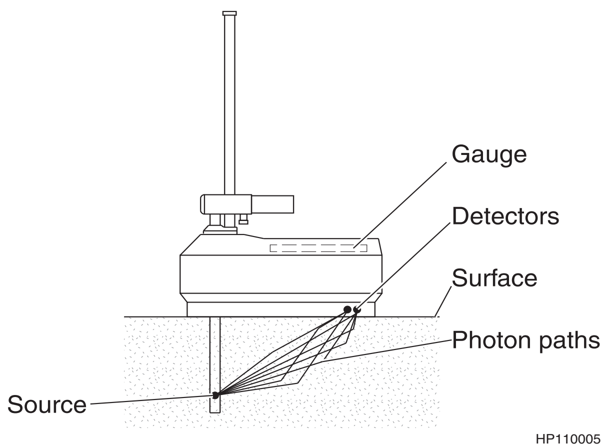
The density of a compacted sample taken from the field site is measured and compared to the laboratory reading to see if the specification has been met. See “Description of field measurement methods” on page 16.

DESCRIPTION OF FIELD MEASUREMENT METHODS

There are several traditional soil density field tests, including the Sand Cone Test, the Balloon Test, and the Shelby Tube test. However, most soil density field tests done today are performed with a nuclear density gauge. This device quickly and accurately determines soil density and moisture content. See the illustration for an operational diagram of a nuclear density gauge.

In traditional field tests, a sample of the compacted material is removed and the volume of the cavity created by the sample is measured.

The sample material is weighed and its wet, compacted density is calculated. It is then dried and again weighed to determine the dry density. The original moisture content and dry density are then located on the Proctor curve to determine if the material has been compacted to the percentage of Proctor specified.



Nuclear density gauge operational diagram

In the nuclear density gauge test, the Proctor density and optimum moisture content are programmed into the nuclear density gauge. A detector probe is inserted into the soil to the desired depth. Gamma rays are emitted from the probe. Some gamma rays are absorbed by the soil and water in the compacted material. The denser the soil and the greater the water content, the more rays that are absorbed.

Those rays not absorbed by the compacted material are sensed by a detector/counter in the nuclear density gauge. The denser the soil, the lower the count. The nuclear gauge provides readouts of radiation counts, wet and dry densities, moisture content and (by comparison with the programmed Proctor values) percent of Proctor.

3. COMPACTION EQUIPMENT

3.1 RAMMERS, PLATES, ROLLERS

Compaction equipment falls into four general categories: rammers and tampers, vibratory plates, vibratory rollers, and static rollers.

The forces produced by each are as follows:

- Rammers produce impact forces.
- Vibratory plates produce vibratory forces.
- Vibratory rollers produce vibratory and static forces.
- Static rollers produce static and kneading forces.

3.2 HAND-GUIDED, MACHINE/BOOM-MOUNTED, SELF-PROPELLED

Rammers and tampers are hand-guided and use a large piston set and springs to create a high impact force at relatively few blows (500-750) per minute (compared to vibratory compactors).

Vibratory plates may be hand-guided or machine-mounted on vehicles with hydraulic booms. Reversible vibratory plates, combining two counter-rotating eccentric weights, are also available. Motor-driven eccentric weights develop a lower impact force per blow than comparably sized rammers and tampers, but deliver many more blows (2000-6000) per minute.

Rollers may be hand-guided walk-behind models, towed behind rubber-tired or track-mounted tractors or self-propelled. Static rollers rely on weight for compaction, while vibratory rollers develop compaction forces through a rotating eccentric weight arrangement mounted inside the roller drum.

3.3 DETERMINING DYNAMIC COMPACTION FORCE

The compacting force generated by dynamic compactors (rammers and tampers, vibratory plates and rollers) is a function of the amplitude of the motion and the frequency at which the moving surface changes directions.

With rammers and tampers, the amplitude is one-half the height that the machine jumps. With vibrating devices, the amplitude is the maximum movement of the vibrating body in one direction from its at-rest or neutral position. The apparent amplitude, or the height the machine lifts itself off the ground between blows, increases as the material becomes more dense and compacted.

With rammers and tampers, the frequency is the number of times the machine jumps per minute. With vibrating devices, the frequency is the rotational speed of the eccentric shaft.

When combined with the mass of the device, these two factors result in an "impulse force" or "centrifugal force," indicating the compaction force of the device. Impulse force is specified in pounds or newtons.

The working or operating weight of hand-guided and self-propelled equipment and the down-force applied to boom-mounted vibratory compactors provide a pre-load force to properly transmit the energy into the soil.

3.4 COMPACTION METHODS AND SOIL/SUBSTRATE TYPES

Certain methods of compaction are best suited to specific soil conditions and situations. The compactor operator must be aware of the type of soil being compacted and be prepared to adjust the compaction technique to achieve the desired results.

In cases where the soil is a mixture of types (granular, clay), select the best method for the type of material that represents the largest percentage of the material to be compacted. In some situations, testing may be needed to determine the best technique.

GRANULAR SOILS

Where particles move freely against one another, such as sand and gravel, vibration will cause the particles to move and settle. Vibratory compacting is well suited for granular soils. The particles respond to different vibration frequencies. As the size of the particles increases, heavier equipment with lower frequencies and higher compaction forces (amplitudes) should be used.

CLAY AND OTHER COHESIVE SOILS

Where the soil particles stick together, a high impact force is required to rearrange the particles and force the air out. Compactors that generate squeezing and kneading forces, such as rammers, tampers, and rollers, are well suited for cohesive soils. When using vibratory compactors, reduce lift heights to achieve the best results.

SAND AND CLAY MIXTURE

Compaction equipment is less effective in semi-cohesive soils that require increased compaction force, when compared to granular soils. As with clays and other cohesive soils, when using vibratory equipment, reduce lift heights and increase the amount of compaction time to achieve desired results.

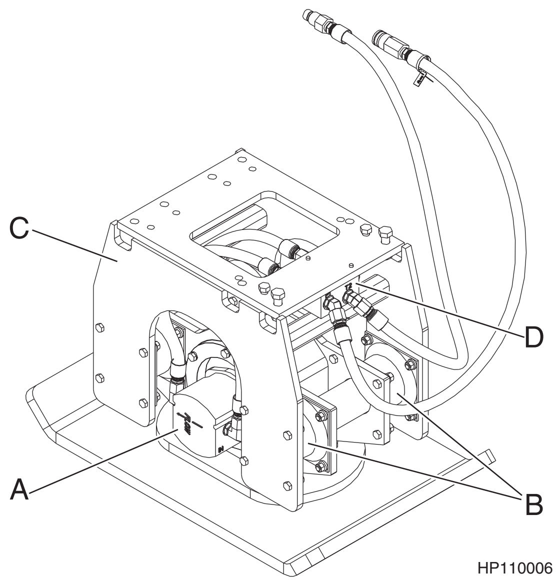
CONFINED VERSUS UNCONFINED AREAS

In confined areas, all types of compactors are generally effective with granular soils. In unconfined areas, compactors tend to push the soil aside rather than compacting it. However, vibratory compactors that settle the soil tend to be more effective than rammers and tampers. Confinement, or lack of it, has less effect on the compactability of clay soils.

4. HO-PAC PLATE COMPACTORS

4.1 TYPE OF MACHINE-MOUNTED COMPACTORS

Our compactors are hydraulically powered vibratory plate compactors and drivers. See the illustration. They are designed for carrier mounting on mobile equipment with hydraulic booms, such as track-mounted backhoes and excavators, mini-excavators, rubber-tired backhoes, and trenchers with backhoe attachments. They may also be used for driving posts and pilings. See “Other operations with compacting equipment” on page 30.



Compactor major sub-assemblies

Vibratory plate compactor consists of four major sub-assemblies:

A. The **dynamic assembly** includes a hydraulic motor, bearings, eccentric mass, housing frame, and base plate.

B. The **suspension system** is composed of four rubber spring mounts that suspend and isolate the dynamic assembly from the mounting frame.

C. The **mounting frame** is a steel-plate fabrication that supports the dynamic assembly and provides attachment points for connecting the compactor to the boom of the carrier.

D. The **hydraulic control valve** is a multi-function, hydraulic control valve that regulates hydraulic flow and helps protect the compactor from excessive hydraulic pressures and flows.

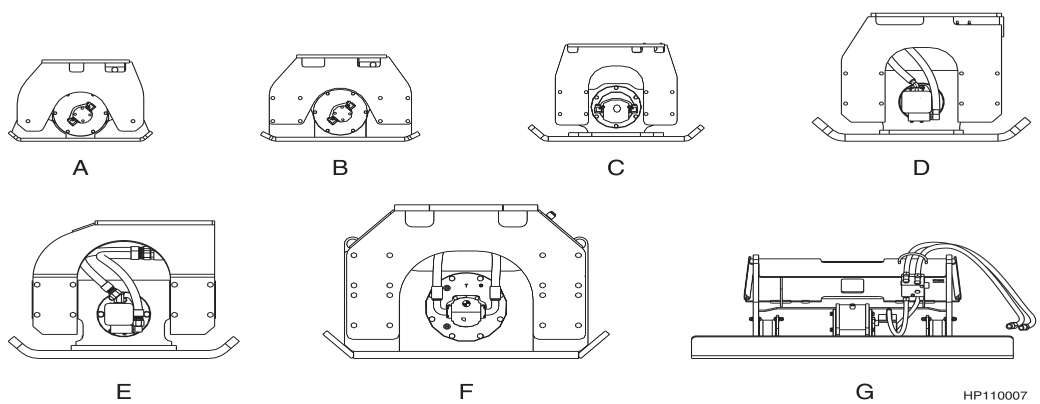
4.2 HOW COMPACTION EQUIPMENT WORKS

The eccentric mass is supported on bearings within the dynamic assembly. It is rotated by the hydraulic motor, which is powered by the carrier hydraulic system. The rotating eccentric mass creates impulse forces that are transferred through the base plate into the soil being compacted. The soil near the base plate begins to vibrate and rearrange, making the soil particles come closer together. This eliminates voids between the particles and forces out air that was trapped in the voids. The down-force applied through the boom of the carrier provides a pre-load force to effectively transfer the vibrating energy into the soil and to follow the material as it compacts. The actual compaction effect of the down-force is minimal.

4.3 RANGE OF AVAILABLE COMPACTION EQUIPMENT

Our hydraulic vibratory compactors are available in different configurations and sizes to accomplish a variety of compaction operations and facilitate attachment to various carriers, including mini-excavators, backhoes, and rubber-tired and track excavators. Complete specifications are available in operator's manuals and other documents that accompany each model.

Improvements to compaction equipment are continuously under development. Contact your local dealer for information about the latest compaction equipment offerings.



Compaction equipment

ID	Model	Recommended carrier size
A	400B	Carriers 1 600 to 5 400 kg (3 000 to 12 000 lbs)
B	700B	Carriers 3 600 to 9 000 kg (8 000 to 20 000 lbs)
C	1000C	Carriers, 4 000 to 14 000 kg (9 000 to 30 000 lbs)
D	1600	Carriers, 8 600 to 20 500 kg (19 000 to 45 000 lbs)
E	2300	Carriers 16 000 to 54 000 kg (35 000 to 120 000 lbs)
F	4000	Carriers 35 000 to 70 000 kg (77 000 to 1500 000 lbs)
G	1000CS	Carriers minimum 1 800 kg (4 000 lbs)

5. COMPACTION TECHNIQUES

5.1 MOUNTING COMPACTION EQUIPMENT

Vibratory compactors can be attached to a wide range of backhoe, mini-excavator, and excavator models. A variety of mounting frame configurations and hardware kits are available to connect the compactors to carrier arms. Custom mounting kits can be built to accommodate many quick-coupler systems.

The carrier hydraulic system is used for hydraulic oil flow and pressure and must be adequate to provide maximum compactor performance while maintaining carrier function. Hydraulic installation kits are designed to match compactors to specific carriers. Depending upon the installation, kits may include a priority valve or a control valve to operate the carrier auxiliary valve.

See the applicable Operator's manuals for complete mounting information and safety precautions.

5.2 PREPARING AN AREA FOR COMPACTION

Proper pre-conditioning of the soil is extremely important to achieve optimum results.

If compaction is being done to specification, first conduct a Proctor or other standardized test to determine the maximum density and optimum moisture content. See “Measuring compaction” on page 15. Just prior to compaction, determine the moisture content of the backfill material.

If the moisture content is too high relative to the optimum, as determined by the Proctor test, spread the material out and allow it to dry, or blend it uniformly with other dry material. If it is too low relative to the optimum, add water. Typically, plus or minus 2% is acceptable, but this range depends on the governing compaction specification.

$V_{water} = 0.0012 \times D_{target} \times V_{soil} \times (W_{target} - W_{actual})$

V_{water} = Volume of water in gallons

D_{target} = Target soil density in pounds per cubic foot

V_{soil} = Volume of soil to condition in cubic feet

W_{target} = Target moisture content in percent

W_{actual} = Actual moisture content in percent.

When the soil is properly conditioned, backfill the excavated area evenly with suitable equipment and in the appropriate lift heights, depending on the type of material, the depth of the excavation, and the compaction equipment being used.

5.3 OPERATING A MACHINE-MOUNTED COMPACTOR

Note: Compaction results will vary, depending upon the type and condition of material being compacted, the configuration of the area to be compacted, the type of compaction equipment being used, and the operator's technique.

Note: The suggested operation technique for vibratory plate compactors that follows should be considered as a starting point and general guideline.

LIFT HEIGHTS

The lift height or depth of the soil layer being compacted affects the degree of compaction that can be achieved and the amount of time required to reach the specified compaction level (specified percentage of Proctor). If the lift is too thick, it will either take too long to reach the desired level of compaction or the desired level will be unattainable.

Soil may also be over-compacted. This wastes time, causes "cracking" of the compacted layer, and creates unnecessary wear on the compaction equipment as excessive impact force is transferred back into the compactor. Overworking the soil also pulls moisture to the surface. This may cause the moisture content to shift from the optimum range and affect compaction results.

MACHINE POSITIONING, PATTERN, DURATION, DOWN-FORCE, FINISH PASS

General

Position the compaction plate on an area to be compacted. Apply enough down-force with the carrier boom to stretch the rubber spring mounts on the compactor approximately one-half their width. This is necessary to adequately transfer the compaction energy to the soil. Activate the compactor. As soil density increases, the energy is transmitted deeper into the material.

During compaction, lower the boom to "follow" the material and maintain the one-half-width rubber spring deflection. Keep the compactor compaction plate in full view of the operator. Hold the compaction plate parallel to the work surface and maintain full contact with the material being compacted.

Continue to apply the compaction plate to the same area until refusal (until further compaction is no longer apparent). Depending on the type of material, the size of the compactor and the height of the lift, it may take approximately 10 to 15 seconds. This gives the material adequate time to respond to the energy being applied.

When the entire area has been compacted once, make a second pass. Apply the compaction plate to one area at a time again until further compaction is no longer apparent.

Finally, make a light finish pass to smooth out high spots and establish the final grade. While the compactor is vibrating, make a "troweling" motion with the compaction plate, keeping it in contact with the compacted surface while swinging the carrier boom.

Confined areas

Position the compaction plate over the area to be compacted, keeping the entire plate over the non-compacted area. If part of the compaction plate rests on undisturbed material next to the area to be compacted, the undisturbed material will prevent the compaction plate from thoroughly compacting the material in the excavation.

Trenches

When compacting trenches, straddle the trench with the carrier and position it in line with the direction of work. Keep the compaction plate entirely over the fill material, in the same way as described in the above discussion on confined areas.

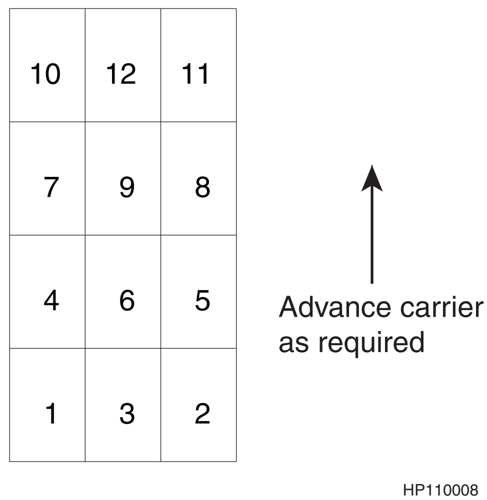
An efficient technique for compacting pipe trenches is to slope the backfill. With this technique, the compaction operation can follow closely behind the pipe placement operation. With the carrier on the compact material, begin by compacting fill material into a corner, against a manhole, or against already compact material. Then place fill material to create a slope in the trench from the pipe, or trench bottom, to a grade level at approximately 45 degrees. Compact the fill material starting at the bottom and working up the slope. The resulting compacted backfill provides a stable slope against collapse. Repeat this process with another layer of fill moving forward along the trench.

Embankments

Begin at the bottom of the embankment, holding the compaction plate in line with the desired slope of the embankment. When a complete pass has been made along the base of the embankment, begin working up the slope. Continue making passes along the edge of the already compacted material until the top of the embankment is reached. Smaller lifts may be necessary to avoid non-compacted fill material from sliding down the embankment.

Open areas

When compacting open areas too large to cover without moving the carrier onto the compacting area, start at the edge of the excavation and compact the back-filled material within reach of the boom before moving the carrier onto the compacting area. Continue to compact ahead of the advance of the carrier, compacting completely around the edge of the area. Then work toward the centre of the area, continuing to compact along the edge of the remaining non-compacted material until the entire area has been compacted. See the illustration for an open-area compaction sequence.



PRECAUTIONS DURING OPERATION

General construction safety precautions must be observed, such as locating existing underground service and utility lines, establishing pedestrian barriers, and utilizing proper personal safety equipment including safety glasses and ear protection for all personnel in the immediate area.

Note: The operator must read the operator's manual provided with the equipment and follow all operating instructions while operating the compactor.

Damage to the compactor and the carrier may result if the compactor's compaction plate is not evenly positioned on the material to be compacted. Unequal deflection of the rubber mounting springs may allow the metal components of the dynamic assembly to impact the mounting frame, possibly damaging the components of the compactor and transferring harmful vibrations into the carrier boom. Eventual damage to the rubber springs will also occur.

Investigate any unusual noises, excessive vibrations or erratic operation and remedy the cause(s) prior to continuing. See the Operator's manual for possible causes.

6. COMPACTOR PERFORMANCE DATA

Note: This performance data is for reference purposes only. Results may vary depending on different factors, such as soil conditions and variations in operator technique. It is recommended that you perform tests with the actual material to be compacted prior to starting a job to determine specific output rates and degrees of compaction.

6.1 DATA GATHERING PROCEDURE

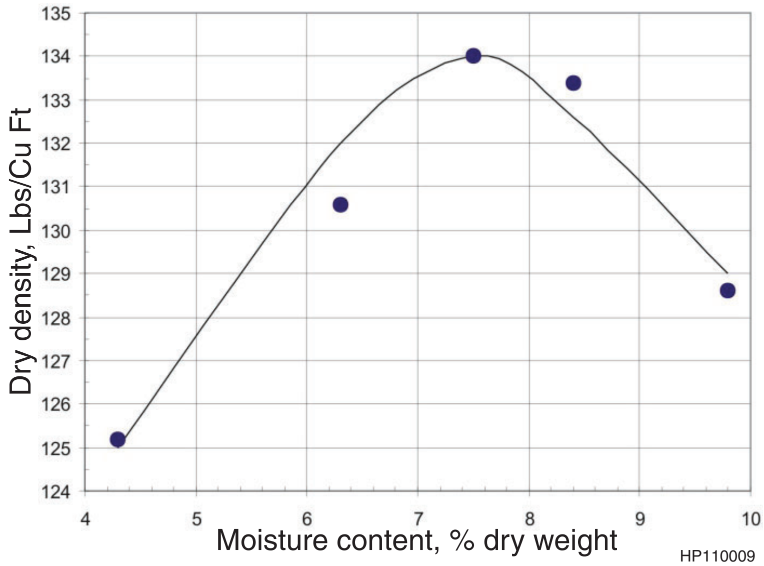
Data presented here for vibratory compactors was gathered at the Construction Products test facility in Marblehead, Ohio.

1. A pit was excavated and the excavated material was discarded.
2. Provision was made to remove any water that might accumulate in the pit from rain or other sources.
3. A supply of ODOT #411 (Ohio Department of Transportation) graded limestone aggregate was obtained and subjected to a standardized Proctor test (ASTM D698-00a METHOD C) by a certified construction materials testing firm to establish maximum density and optimum moisture content.
4. Prior to compaction, the moisture content of the #411 aggregate was measured and adjusted to bring it to within 2% of the optimum moisture content.
5. Measurement of the average depth of the empty pit was taken.
6. The pit was then filled with the prepared aggregate in various lift heights, depending on the compactor tested.
7. A measurement of the surface level of the non-compacted material was taken to determine the average height of the lift.
8. The material was then compacted with the compactor model being tested. See “Operating a machine-mounted compactor” on page 23.
9. The surface level of the compacted lift was measured to determine the average compacted height of the lift.
10. Measurements were taken and recorded at four points at a prescribed depth below the surface with a nuclear density gauge by a certified construction materials testing firm to establish the density, moisture content, and percentage of Proctor of the compacted material.
11. A layer of compacted material approximately equal to the length of the nuclear density gauge probe was carefully removed.
12. Steps 10 and 11 were repeated until the desired depth was reached or density readings fell below 95% of Proctor.

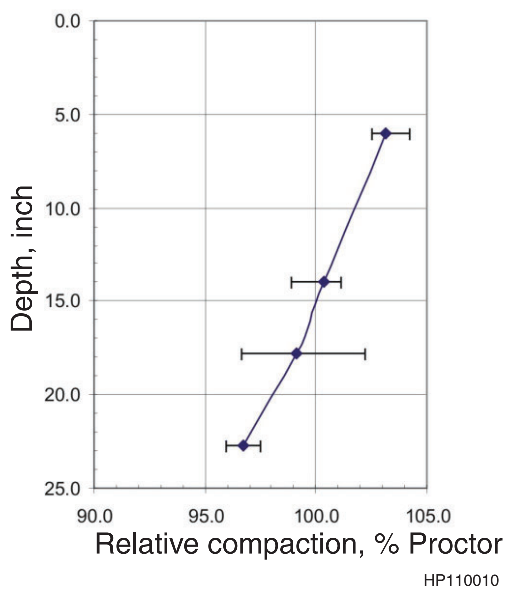
Data was summarized and plotted for each model. See “Compactor performance data” on page 27.

6.2 COMPACTOR PERFORMANCE DATA

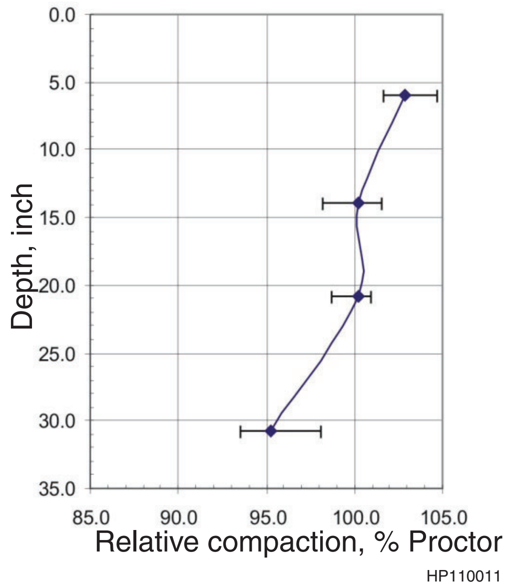
ODOT #411 PROCTOR TEST RESULTS, OPTIMUM DRY DENSITY VS. MOISTURE CONTENT



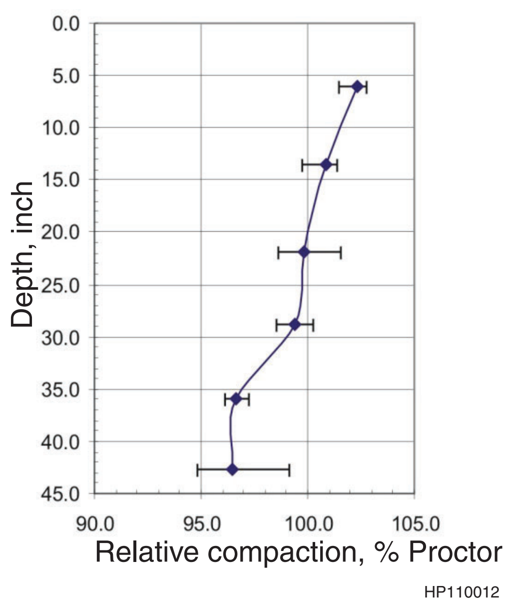
COMPACTION RESULTS MODEL 500 WITH 1X 23" LIFT OF #411 STONE



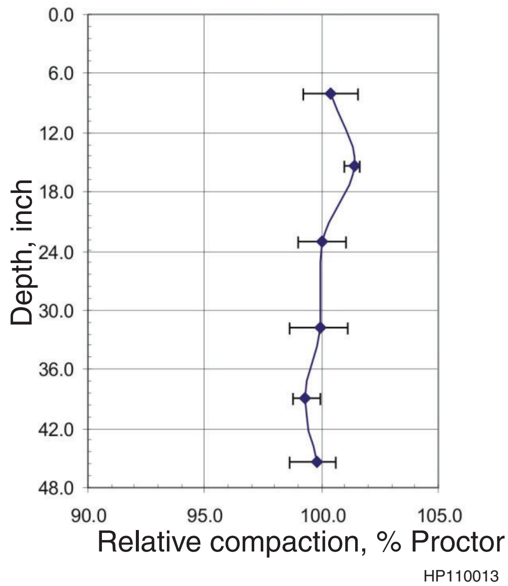
COMPACTION RESULTS MODEL 1000 WITH 1X 30" LIFT OF #411 STONE



COMPACTION RESULTS MODEL 1600 WITH 1 X 45" LIFT OFF #411 STONE



COMPACTION RESULTS MODEL 2300 WITH 1 X 45" LIFT OF #411 STONE



7. OTHER OPERATIONS WITH COMPACTING EQUIPMENT

Compactor /drivers may be used for certain other operations in addition to soil compaction.

7.1 PILE DRIVING

Compactors and drivers may be used to drive and extract load bearing pilings, posts, and sheet piling. Timber posts, steel sheet piles, and "H' or "I" beams can be driven into many different soil conditions including clay, sand, and rocky soils. Successful installations in lengths of up to 60 feet have been reported. Results are dependent on compactor model, post/pile material, and soil conditions.

7.2 THEORY

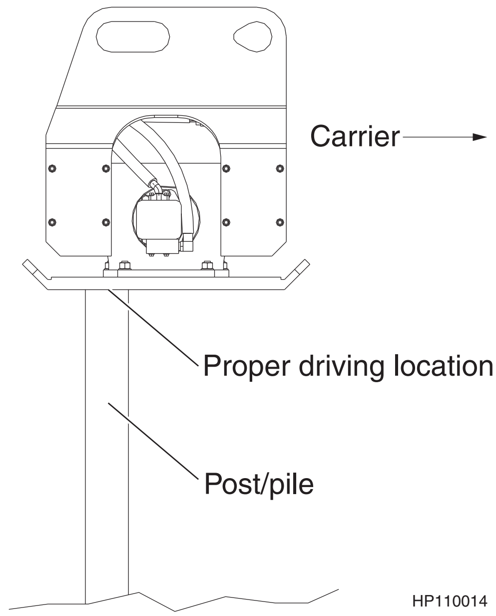
Direct contact between the vibrating compaction plate and pile transfers motion to the pile. The pile vibration induced by the compactor is then transferred to the surrounding soil.

Within a specific frequency and intensity range, the vibrating soil particles will tend to easily move past and around one another, or liquefy. This liquefaction also results in reduced friction on objects in contact with the vibrating soil. Therefore, with relatively moderate down pressure, a pile can be inserted into normally compact soil. Since this driving technique relies on soil particle movement, the effectiveness of vibration pile driving is better with granular soil content and is not well suited for soil with high clay content.

Once the pile is inserted to the desired depth and the vibration is ceased, the irregular soil particles stop moving and interlock with one another again. Friction increases to normal static conditions between the particles and on the object (pile or post) within the soil. For most piles, the majority of bearing capacity is developed through skin friction with the soil.

Unlike traditional hammer pile driving where 'Blows-per-Foot' is commonly used to determine a pile load-carrying capability, there is no direct correlation between the compactor vibration capability and pile load capacity. To determine load capacity, either static loading or traditional pile driving techniques must be performed to verify the pile's capacity for specific soil conditions.

7.3 TECHNIQUE



Post driving

When driving posts and piles, the best results are achieved when the compactor is in contact with the post/pile and down pressure is applied. Position the compactor with the front 1/4 to 1/3 of the compaction plate in contact with the post/pile. The compactor is most effective when positioned perpendicular to the post/pile. Limit the down pressure to avoid over stretching the spring mounts or contacting the upper with the compaction plate.

A deep rumbling sound will result when the compactor is operating effectively. For hard soil conditions, it may be necessary to use the front edge of the compaction plate. This increases the vibration amplitude, but it also makes positioning more difficult. While a small amount of "slapping" is acceptable, excessive "slapping" can result in excessive vibrations and compactor, carrier, or post/pile damage.

Brackets or guides may be welded onto the bottom of the compactor's compaction plate to assist the operator with proper engagement. Contact your local dealer for more information.

A compactor can also be used to extract a post/pile. In this application, a mechanical stop must be added to the compactor to prevent over-stretching the spring mounts as the post/pile is pulled upward.

Special piling, post driver, and extractor attachments are available. For more information, contact your local dealer.

7.4 OTHER APPLICATIONS

Vibratory compactors may also be used for other operations such as compacting waste and breaking up frozen material (that is, coal and gravel).

8. REFERENCES AND FURTHER READING

- American Society of Testing and Materials, D698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort

  Website: www.astm.org

- "Construction and Materials Specifications", Ohio Department of Transportation (ODOT), Office of Construction Administration

  Website: https://www.transportation.ohio.gov/wps/portal/gov/odot/working/publications/spec-book

- Model 3430 Manual of Operation and Instruction, Troxler Electronic Laboratories, Inc.

  Website: www.troxlerlabs.com

- Chapter 8, Soil Compaction, FM 5-410 Military Soils Engineering, U.S. Army Corp of Engineers

  Website: https://armypubs.army.mil/

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