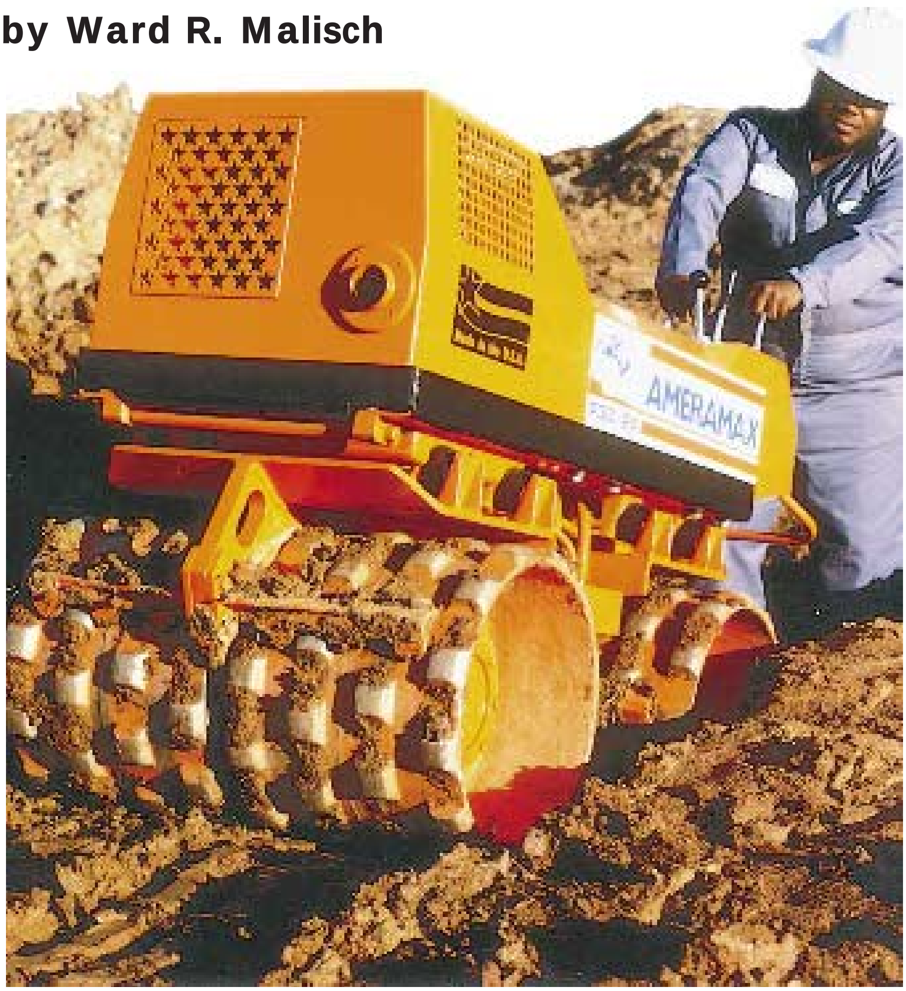
Compacting
Problem Soils

by Ward R. Malisch



For good results, match compaction equipment to soil type and moisture content

A padfoot roller penetrates deeply on the first pass in cohesive soils. As the soil strengthens, however, the roller eventually "walks" out of the soil, indicating adequate compaction.

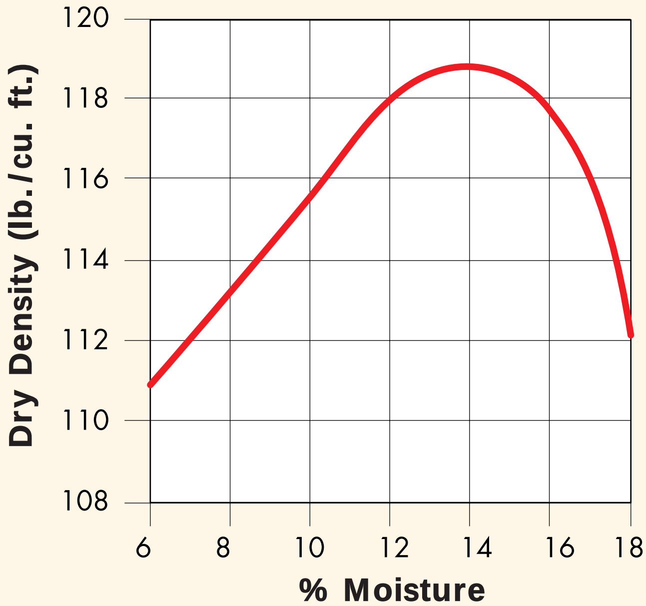
Without proper soil compaction, many concrete structures are doomed to perform poorly. Cracked pavements or floors, leaking concrete basements, and settled foundations are just a few of the problems caused by inadequate soil compaction. The goal of compaction is straightforward — pack as many soil solids as possible into a given space. Increasing the concentration of solids makes the soil stronger, less permeable, and less likely to settle excessively. Achieving those goals requires an understanding of three interrelated factors that affect the degree to which a soil can be compacted: soil type, soil moisture content during compaction, and the kind of compaction equipment used. It also requires an ability to measure the results, so that adequate compaction can be verified at the job site.

Soil Type

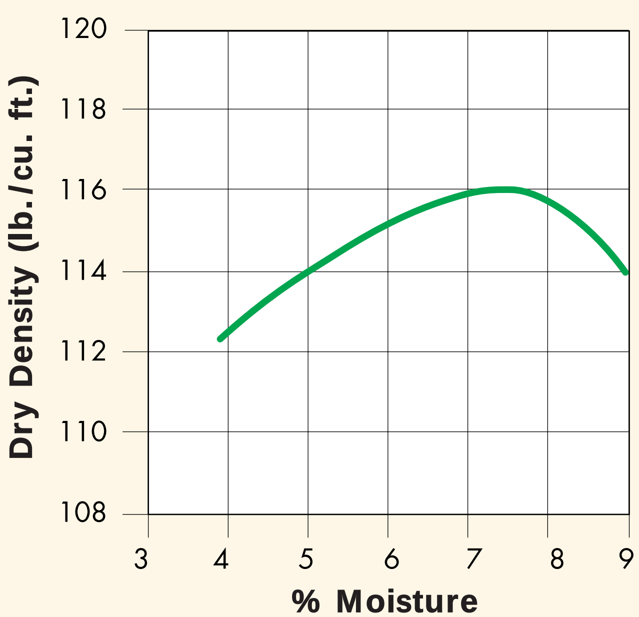
For compaction purposes, soils can be divided into three groups — organic, granular, or cohesive.

Organic soils. Most topsoils fall into this category. Organic soils have a distinctive odor, are dark brown to black, and feel spongy when compressed. Removing organic soils is the first step in building a

Reading a Soil Test



Sample: Silt for base soil
Opt. Dry Density: 119 PCF
Opt. Moisture Content: 14.0%



Sample: Washed sand from drainage layer
Opt. Dry Density: 116 PCF
Opt. Moisture Content: 7.5%

Figure 1. **The moisture-density curves in these laboratory soil tests show the optimum moisture content that produces maximum dry density. A sharply peaked curve (top) indicates that the bearing capacity of the soil is sensitive to changes in moisture content; a flat curve (above) indicates that moisture won't affect bearing capacity much.**

floor, sidewalk, driveway, or other slab on grade, because organic soils can't be adequately compacted. Even in areas that are to be filled, organic soils and other organic materials must be removed to provide a firm base against which to compact.

Granular soils. Granular soils contain primarily gravel, sand, and silt. These types of soil feel gritty when rubbed between the fingers, have little or no plasticity when wet, and crumble readily and have no cohesive strength when dry.

Most granular soils can be compacted to a high density. Granular soils with a good distribution of particle sizes compact to a higher density because smaller particles fill the voids between larger particles. This also applies to aggregates used as base-course material: Crusher-run material with a range of particle sizes compacts to a higher density and bearing strength than pea gravels or sands.

Cohesive soils. Cohesive soils contain very fine, platelike clay particles that have a strong attraction to water and to other clay particles. These soils feel smooth and greasy when rubbed between the fingers. They are plastic when moist, meaning they can be manipulated between palms and fingers and rolled into long, thin threads. They are very strong when dry. The ease with which cohesive soils can be compacted depends on their moisture content and plasticity. Highly plastic cohesive soils are especially hard to compact.

Mixed soils. Many soils are mixtures of granular and clay particles, with properties that depend on the relative amount of each component. However, it's usually easy to recognize the general type of soil to be compacted. Most of the particles in granular soils are visible to the naked eye. Squeezed when moist, the granular soil will form a cast that's easily crumbled but has little or no strength when dry.

Individual particles in cohesive soils can't be seen. Squeezed when moist, the cohesive soil will form a cast that retains its form and becomes stronger after drying.

Effect of Moisture

Dry soils don't usually compact well. Adding water to the dry soil lubricates the particles, helping them to "slide" closer together so more of them are packed into a given space. Soil density increases as moisture content increases — but only up to a point. If too much water is added, it starts taking up space that could be occupied by solid particles; the result is decreased density.

The best or optimum moisture content for compaction is the one that produces the highest dry density. Optimum moisture content is determined in the laboratory by mixing soil samples with differing amounts of water and compacting them in a mold with a standard-sized compaction hammer dropped from a standard height. The dry density (weight of soil solids in a given volume) and moisture content (weight of water expressed as a percent of soil solids weight) are measured and plotted on a graph. Optimum moisture content is the moisture content giving maximum dry density (see Figure 1).

The optimum moisture content gives approximate information on the clay content of a soil. Cohesive soils have lower maximum dry densities and higher optimum moisture contents than granular soils. The overall shape of the moisture-density curve also indicates the sensitivity of the soil to changes in moisture content. A sharply peaked curve indicates a soil with a load-supporting ability that changes markedly with small changes in moisture content. A relatively flat curve indicates that load-supporting ability doesn't change much with a change in moisture content.

Vibratory Compactors

Most machines compact soil through vibration or a ramming action. Granular soils and subbases are best compacted by vibration methods. Vibration agitates the particles, reducing friction at the contact surfaces and allowing the granular material to settle into a denser configuration with fewer air voids.

Two characteristics of vibratory compactors — frequency and amplitude — affect the compaction force that's applied to the soil. In both a roller drum or a baseplate compactor, rotation of an eccentric shaft creates the vibration. Frequency of vibration, in blows per minute, is determined by the speed at which the shaft rotates. When operating at optimum frequency, vibrators supply maximum compaction force.

Rotation of the eccentric shaft causes the roller drum or baseplate to move up and down. Amplitude is defined as one-half of the vertical distance traveled during this movement, and it usually varies inversely with frequency: The higher the frequency, the lower the amplitude. The amplitude for a given machine also varies with the degree of compaction, increasing as the soil density increases.

For large areas, vibratory rolling is the fastest, most efficient way to compact granular materials. Smooth-drum vibratory rollers are most commonly used (Figure 2).

For smaller areas or areas that are hard to reach, vibrating plate compactors work best (Figure 3). Frequencies of these devices generally range from 2,000 to 6,000 blows per minute. Use lighter-weight, high-frequency plate compactors for fine to medium sands, and heavier, low-frequency compactors for coarse sands, gravels, and soil mixtures that contain some clay. Reversible plate compactors are useful for trench work and simplify spot compaction, because you can change the compactor direction without bringing the plate to a stop.

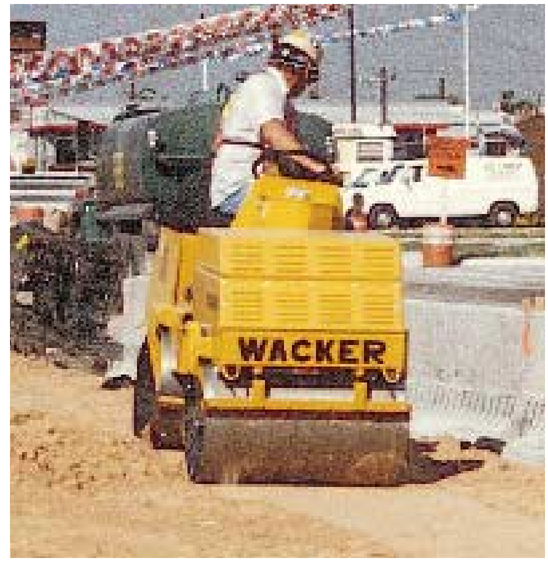


Figure 2. Smooth-drum vibratory rollers work best for compacting large areas of granular materials such as sands.

Figure 3. Lightweight, high-frequency vibrating plate compactors work best for fine to medium sands. Plate compactors are useful for trenches and other hard-to-reach areas.

Impact Compactors

Impact-type machines that shear the soil are best suited for cohesive materials. The kneading action of these compactors expels air voids, bringing platelike clay particles closer together. Hand-held ramming machines normally operate at 500 to 800 blows per minute with a $1^1/_2$- to 4-inch stroke (stroke is the maximum distance between the compaction plate and the compacted soil surface during rammer operation). Heavier models permit compaction of thicker soil lifts.

Hand-held rammers work well for small areas and for places that larger, mobile equipment can't reach (Figure 4). Most are gasoline- or diesel-powered, but pneumatic versions are also available. Hand-held rammers can also be used to compact granular materials in a confined area such as a trench.

Walk-behind and ride-on padfoot rollers work well when compacting large areas of cohesive soils (see photo first page). Some models offer a choice of padfoot heights to better match soil conditions. Heavy clays are compacted more readily with a greater padfoot height: The feet punch full depth into cohesive soil during the first pass, but compaction strengthens the soil during following passes so penetration isn't as deep. When the roller walks out of the fill, it indicates adequate compaction.

Field Tests and Visual Observation

Field testing is needed to verify that the soil is being compacted at or near the optimum moisture content and that the desired degree of compaction has been achieved. This can be done by digging out a sample of compacted material, weighing the removed soil, determining its moisture content, and measuring the volume of the hole. The volume measurement is done with either a balloon apparatus, which determines the volume of fluid required to fill the hole, or with a sand-cone device, which determines the volume of loose sand required to fill the hole.

Getting immediate compaction and moisture-content data is important if equipment and workers are idle while waiting for test results. The balloon or sand-cone methods take time — often several days — to both measure the volume of the hole and the moisture content of the removed soil. More expensive but faster nuclear moisture-density testers can give results within a minute after the surface is prepared. Another approach is to use a special compaction meter that has a sensor placed at the bottom of the excavation. The sensor continuously sends signals to a hand-held meter, which translates them into density readings. When the desired maximum density is achieved, a light goes on. When backfilling is complete, the wire can be cut, leaving the disposable sensor buried in the soil.

Regardless of the test method used to determine in-place density, testing should be accompanied by visual inspection of the compaction methods being used. Visual inspection will reveal problems such as pumping or heaving of cohesive soils, which indicates that the fill material is too wet. Tests can then confirm the results of visual observations. An inspector who makes tests without observing soil placement and compaction can attest only to the quality of the test result and not to the quality of the fill. ■

C. BATES

Figure 4. **The kneading action of hand-held rammers compacts cohesive soils, and also works well on confined granular materials.**

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