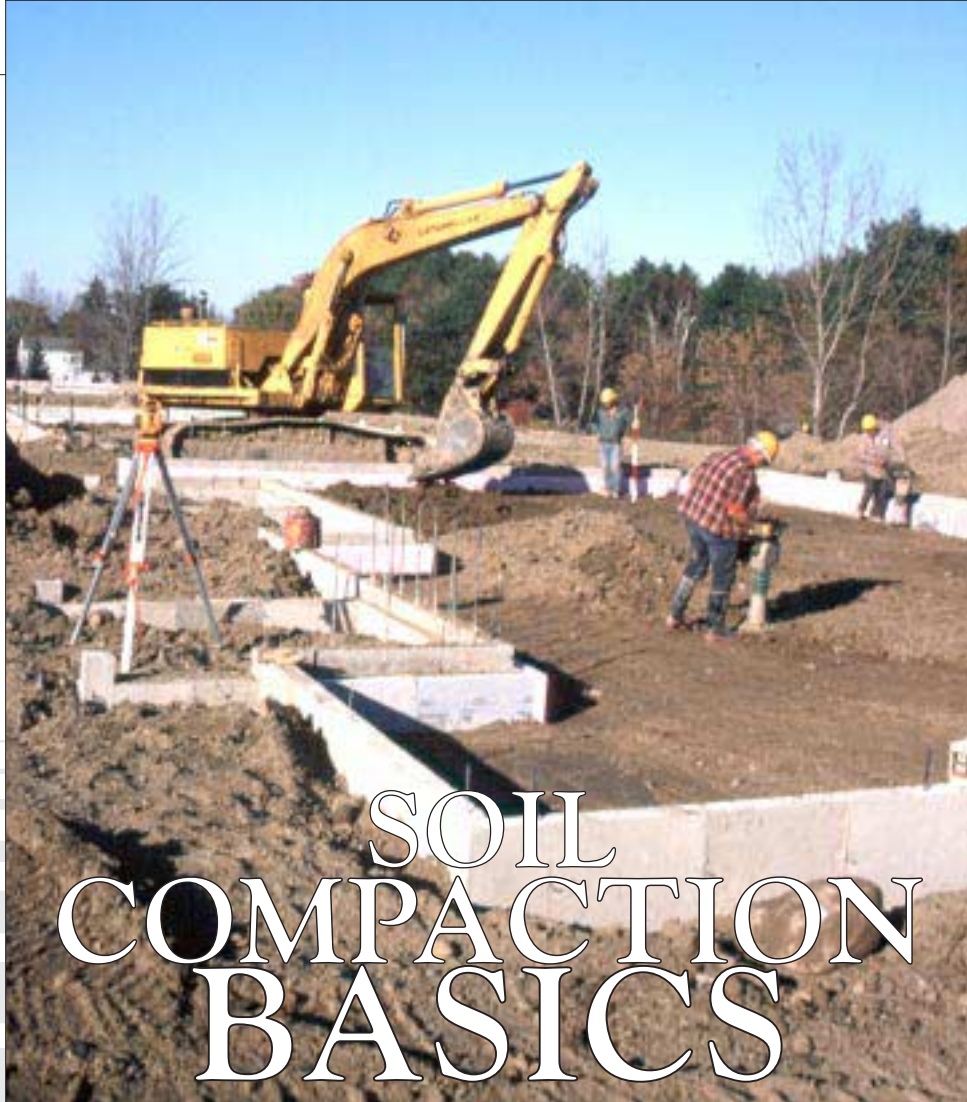




SOIL COMPACTION BASICS

Workers use jumping jacks to compact soil for a slab-on-grade.

Soil compaction is frequently overlooked on residential building projects. Yet much good effort and quality workmanship on framing and finishing a building can be offset when a slab or foundation settles. The resulting cracks and distortion may reflect serious structural problems, or they may simply be an eyesore and an inconvenience. But one thing is certain: The unhappy owner will be calling you to discuss repairs and compensation.

You can avoid this outcome by understanding a few basic principles of soil behavior and by developing a healthy respect for the consequences of not getting it right. Poorly compacted fill *will* compress and settle over a period of time, often with disastrous results. By contrast, properly compacted soil should be worry-free. In fact, it will probably be less prone to settling than most natural soil deposits.

So what's the mystery? Why is compaction easy to achieve in some cases and not in others?

Soil, Moisture, and Density

Builders frequently ask me if a particular fill material they plan to use can be adequately compacted. The answer is always yes, but the real question is how *easily* it can be done. Successful soil compaction depends on the type of soil, its moisture content, and how much effort you use to compact it.

Soil type and gradation. Soil is usually made up of eroded and decomposed particles of bedrock transported and deposited over the centuries by wind, water, glaciers, and gravity. But these solid particles make up only part of the volume soil occupies; the rest is taken up by empty spaces. The voids may be filled with

gas or air, or they may be partly or completely filled with water.

Soils are classified by gradation — grain size distribution — and to a lesser extent, by shape. In decreasing order of average diameter, the sizes are boulder, cobble, gravel, sand, silt, and clay. All but clay are known as granular soils. A soil deposit may contain mostly particles of one size — a fine sand, for example — or it may contain a mix of sizes — some silt and gravel as well as sand. Gradation has a major influence on the physical properties of soil, including the manner and ease

Controlling moisture content, testing the soil, and using the right equipment are the keys to compacting fill properly

by Roger Dorwart, P.E.

with which the soil particles can be mechanically pushed together and compacted.

Does Your Soil Make the Grade?



Figure A. In the standard Proctor test, a soil sample is mixed with water, then layered into a sturdy metal cylinder (left). A 5½-pound weight is dropped 25 times from a height of 12-inches to compact the sample. To get wet density, the volume occupied by the compacted sample is divided into its weight (above). After the sample is dried in an oven, the same calculation yields dry density.

To determine the optimum dry density of the soil you're working with, have a lab perform a Proctor test on a sample before you use it. Named after the engineer who introduced the concept of optimum dry density in the 1930s, the Proctor test subjects a sample of soil to a fixed compaction pressure at varying moisture contents.

In the standard Proctor (ASTM D698), a soil sample is mixed to, say, 6% moisture content, and placed in layers into a cylindrical mold (Figure A). Each of three layers of soil is pounded with 25 blows from a 5½-pound weight free-falling 12 inches. (A slightly different form of the test, called the "modified Proctor" — ASTM D1557 — results in a higher optimum density because it uses a 10-pound weight dropped from 18 inches on each of five layers.) The moist, compacted soil is weighed and the result is divided by the volume of the mold to find the wet density (also called wet unit weight). The sample is then dried in an oven, and the dry density is obtained by calculation.

This process is repeated four or five times at increasing moisture content, and the results plotted as a function of moisture content. The peak of the resulting curve (Figure B) is the optimum dry density for the soil being tested.

Field Testing

Once you know the optimum dry density, it's a simple matter to determine in the field what percentage of that optimum has been achieved by compaction.

Compaction specifications. The optimum dry density from the Proctor test gives you a benchmark against which to measure the compaction you achieve in the field. Compaction specifications commonly call for soil to be compacted to 95% of optimum dry density as mea-

sured by the modified Proctor test. When the in-place, compacted field density is divided by the optimum density, it yields the percent compaction in the field.

For years this field test was done by digging a small hole, weighing the excavated soil, and dividing the weight by the volume of the hole. (The volume was measured by either the sand cone method or the water-filled balloon method). But the resulting density was wet density, so the sample still had to be dried out to determine the moisture content and the dry density. This often meant that final results were not available until the next day, putting a lot of pressure on the field technician to decide whether or not to proceed with the work of backfilling.

Nuclear gauge. In the last 25 years, however, manual field-testing procedures have largely been replaced by the nuclear gauge, a device that can accurately measure in 60 seconds both the wet density and the moisture content of the soil (Figure C). A small radioactive source is sealed inside a retractable rod in the instrument. When the rod is inserted 8 to 12 inches into the soil, a counter in the gauge records the number of gamma rays that come to the surface over a given time interval. The fewer that get through, the denser the

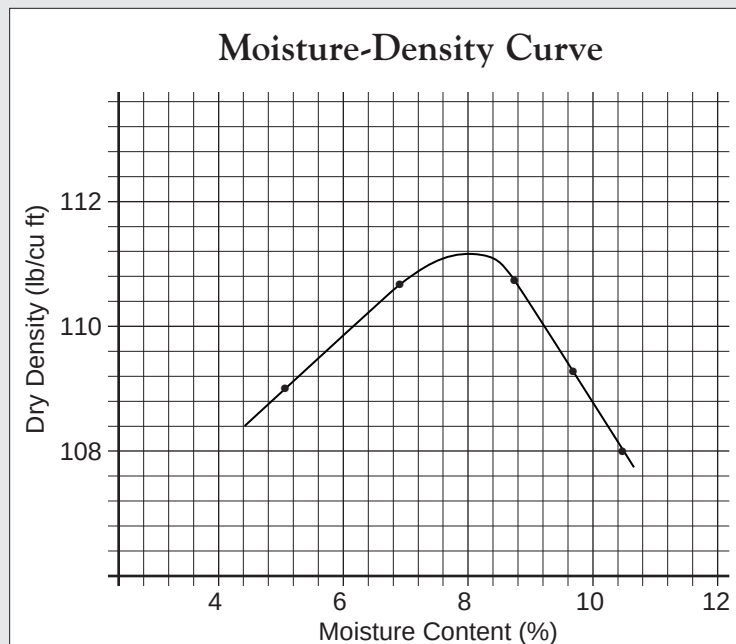


Figure B. In a soil compaction lab test, each measurement made in the Proctor test is plotted. The peak of the curve shows optimum dry density.

Soil, Continued



Figure C. To test soil density on site, field engineers use a nuclear gauge. With the keypad, the engineer can do the calculations for an immediate readout of percent compaction.

soil. The gamma ray count is converted by machine calibration to soil density.

The nuclear gauge also measures moisture content, and an immediate readout of dry density is available on the newer models. In fact, a keypad on the gauge allows you to input optimum density and perform the calculations for percent compaction, which is then displayed on the digital readout.

With a nuclear gauge, it is now possible to get immediate results when an area is ready to be tested for compaction. The test only measures the density in the top 8 to 12 inches of fill. But it takes just a couple of minutes for each test, so you can perform more tests over a larger area of fill using the nuclear gauge.

Incidentally, a compaction test in the low 80s is very low because compaction isn't measured on a zero to 100 scale. Loose sand might have a dry density of 80 pcf, but its standard optimum dry density might be 110 pcf. In its loosest possible state, the percent of optimum would be 73 ($80 \div 110 = .73$). That's the low end of the scale. At the upper end, however, it's entirely possible to achieve over 100% of optimum density in the field. That's because the Proctor test uses an arbitrary level of energy to compact the soil. If you raise the level of energy, you'll raise the optimum value.

— R.D.

Moisture matters. Moisture plays a major role in the compaction process. If the soil particles are absolutely dry, there's a lot of friction to overcome when trying to push the particles together, making the process difficult and inefficient. On the other hand, if the spaces between particles are full of water, the water absorbs some of the compaction energy — like a shock absorber. Then the soil particles don't get the full brunt of the compacting impact, and a lot of energy gets wasted.

Optimum density. Between these two extremes, however, moisture adhering to the soil particles acts as a lubricant. For a given compaction effort, there's a particular moisture content at which the soil particles will be packed together at maximum or optimum density. Below that moisture content, there's not enough lubricant and the particles don't pack together tightly enough. Above that moisture level, the water gets in the way of the process, with the same result.

Optimum density is calculated by dividing the soil's weight by its volume, yielding pounds per cubic foot (pcf). Because water adds weight, it's tempting to reason that the higher the moisture content, the higher the density. While this is true of total density (called "wet density"), it doesn't necessarily reflect how well the solid particles of soil are packed together.

What we really want to measure is *dry density* — the weight of dry solids divided by volume. Luckily, there's a nice relationship between wet and dry density: Divide wet density by one plus the moisture content to get dry density. This basic relationship is used in a simple lab test, called a Proctor test, to determine the optimum dry density for a particular gradation of soil (see "Does Your Soil Make the Grade?"). The optimum dry density from the lab test sets the benchmark by which to judge field compaction.

Getting Good Compaction

When a field test shows inadequate compaction, chances are good the problem is caused by soil gradation, poor compacting techniques, or moisture.

Choose the right soil. While every soil can be adequately compacted, the

amount of effort required varies greatly. Choose coarse, granular soils above silt and clay. Their moisture content is easier to manipulate, and they respond well to vibratory compactors. Given a choice, most earthwork contractors know instinctively that they would rather compact gravel than clay.

Between gravel and clay is a range of silt, silty sands and gravels, and clayey silts. Although silt is more permeable than clay, it's difficult to control the moisture content of both soil types. Generally speaking, the lower the percentage of silt and clay particles in the soil, the easier it will be to compact.

Under no circumstances should topsoil, roots, or other organic materials be incorporated into the fill. These materials will decay and decompose over time, eventually causing settling even in well-compacted soil.

Also be alert to changes in grain size in the fill material. If soil gradation changes, so will the optimum dry density. In some cases, gradation changes will be visually obvious, but the tip-off is usually field test results that don't make sense.

Compact shallow lifts. You should compact soil in layers from 6 to 10 inches thick. Even heavy rollers don't have much effect at depths over a foot.

A common mistake in backfilling foundations is to place a 3-foot or 4-foot-thick layer and then try to salvage the situation by pounding on the surface until it looks great. This might compact the top 8 inches, but 18 or 24 inches down, the percent compaction is still low. In this case, the fill will settle unless it is removed, and replaced and compacted in thin lifts.

Moisture problems. Sand and gravel dry out quickly in hot weather. Before compacting this type of soil, it may be necessary to use hoses or a water truck to sprinkle the soil with water to increase the moisture content, bringing it closer to optimum.

On the other hand, prolonged, heavy rain can create a quagmire in less permeable silt and clay. Once these soils are saturated, it's pointless to attempt compaction. The result is usually surface weaving, rutting, and the kind of disturbance that loosens up even previously compacted soil. Waiting out the wet weather is usually



Figure 1. Soil that's moist enough to compact well should hold shape when you ball it up in your hands. But the only sure way to determine optimum moisture content is to have the soil tested.

the only answer. Eventually, the moisture will slowly percolate downward and, when the sun reappears, evaporate. Opening wet clay soil to aeration by discing will help speed up the drying process. To keep wet soil stable, you can sandwich in layers of dry sand or gravel.

To judge whether or not the soil you are using is near the optimum moisture content, try forming a handful into a ball (Figure 1). If it crumbles easily, the soil is probably too dry; if moisture oozes out, it's too wet.

Avoid frozen soil. When temperatures dip below freezing, all bets are off. Frozen

sand or gravel acts just like dry material because the moisture no longer acts to overcome friction. If there's enough moisture in the soil, it will freeze solid. The same is true for fine-grained soils. Once frozen, they can't be moved, let alone compacted. And when silt freezes, it can expand and heave, negating the effect of compaction.

Use the right equipment. Heavy drum rollers, rubber tire rollers, and sheepfoot rollers work well when compacting clay. A jumping jack will also work in tight quarters. Vibratory rollers and plate compactors work best on sand and gravel (Figure 2), although rubber tire rollers and even loaded dump trucks can do the job.

A common error with hand-operated compactors is traveling too fast over an area and making too few passes. The more you pound on a particular spot, the better compacted it will be. The only way to be sure the soil is properly compacted is to test each lift.

Choosing the right equipment for a particular site and soil condition is important. Read the manufacturer's literature before you buy or rent a compactor. Discuss your needs with equipment suppliers and distributors. They usually have people on staff who can match the right machine to the problem at hand.

Test the soil. If you're placing more than a foot or two of fill that

will support a structure or a slab, have it tested. First, get a sample of the proposed fill material to a testing lab (to find a lab, look in the Yellow Pages under "Laboratories — Testing" or "Engineers — Testing"). This will give you the optimum dry density, the benchmark against which to measure field compaction. Then have the in-place fill tested by someone from the testing lab or by an engineering firm. It's not an expensive process: \$200 should cover the cost of a few hours on the job site plus the Proctor test.

If for some reason you can't test every lift, at least test compaction in the first lift so that if it's not right, you can adjust the compacting effort before it's too late. There's nothing more discouraging than finding out after 5 feet of fill is placed and compacted that the effort wasn't good enough. The only remedy at that point is to remove the fill and start over.

Keep a shovel handy during the field test. The technician should dig a few shallow test holes to verify that the fill matches the soil on which the Proctor was performed. Test holes are also a good way to check for organics, which should always be removed when detected. ■

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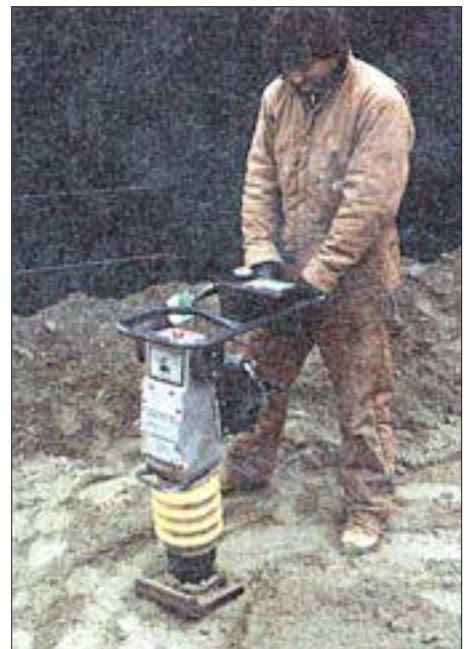


Figure 2. The large surface area of a vibratory plate compactor works well with sand and gravel. Here a worker moistens dry sand to speed compaction. The small footprint of a jumping jack (right) does a good job of compacting, particularly in tight spaces. Note the red horizontal lines on the foundation wall, used to estimate the thickness of each lift of soil.