Compaction Improves Pavement Performance

Compaction is the simplest, most economical method of increasing a road's life and improving its load-carrying capacity. Done during construction compaction costs very little, and it can reduce future maintenance and add years to the life of a road. This bulletin discusses the benefits of compaction, describes some of the methods and equipment used in compacting soils and asphalt, and explains how to measure compaction.

Compaction increases the density of a material. You can use rollers or other devices to expell air from the spaces in the material and force the particles closer together, making it denser. Density is measured as weight; the more dense the material the more it will weigh. For example, a hot-mix asphalt material may weigh less than 100 pounds per cubic foot before compaction and 145 pounds per cubic foot after compaction.

Increasing density gives soils or asphalt:

- greater strength for supporting heavier loads
- reduced settlement over the life of the road
- less permeability to water and air
- resistence to rutting

If water passes through the surface, it increases the moisture content of the subgrade. This weakens the subgrade, causing the pavement to settle and the surface to crack. Air entering the surfacing mix oxidizes the asphalt cement causing the surface to weaken and crack extensively.

Wheelpath ruts change the surface both vertically and laterally—shoving pavement material sideways and humping it up outside the wheelpaths. Inadequate compaction can cause rutting. If rollers do not compact the pavement to the proper density, traffic will do it, causing rutting. **It is not true that extensive air voids should be left after rolling to allow for additional compaction by traffic.** Proper pavement mix design and compaction will prevent additional densification under traffic loads.

Increasing the density of the pavement during construction costs very little—cents per ton of pavement material—and can generate significant savings on future maintenance and resurfacing costs.

How to achieve proper compaction

You must use different procedures and equipment to compact each soil type and still others for asphalt. This section describes how to compact the different soil types, special techniques for culvert backfills and utility trenches, and detailed instructions for compacting asphalt surfacing.

Soils

In constructing roads you must compact each layer: subbase, base and surface. Depending on the type of road you are constructing, one, two or all three of these layers may be composed of the natural soils of the area. In order to compact them properly you must understand the two major factors which influence soil compaction: soil type and moisture content. Soil type dictates the relative number of passes required, the thickness of compaction layers, the type of compaction equipment, and how moisture affects compaction.

Clays are not very porous and, consequently, require much effort to expell air from the voids (which is what the compaction process does). **Sands,** on the other hand, are quite porous and so need much less effort for compaction. Repeated light loads are most effective in compacting clay soils, while a few passes of very heavy loads work best with sand. Clay soils should be compacted in layers, six to eight inches deep, while sand may be effectively compacted in eight to ten inch layers.

Which compaction device you use also depends on the soil type. Sheepsfoot rollers are most effective on clay soils, while pneumatic-tired rollers are most effective on sandy soils.

Sheepsfoot rollers are hollow metal drums with tamping feet attached. They are usually pulled by a tractor, although special self-propelled units have been used. You may increase pressure on the feet by filling the drum with water or sand. The tamping feet first penetrate the soil and compact the bottom of the layer; then as consolidation proceeds they "walk out" until the layer is consolidated and the feet barely penetrate.

These rollers vary from the *light standard* which weighs 6,000 to 10,000 pounds for an eight foot width to *giant* rollers which, fully loaded, weigh up to 75,000 pounds for a ten foot width. Pressures on the feet vary but a minimum of 150 pounds per square inch is recommended.

Pneumatic-tired rollers use rubber tires mounted on a frame which places a uniform load on each tire. Compaction comes from the kneading action of the rubber tires. Pneumatic rollers for highway work generally weigh six to eight tons, although the load can be increased by placing weights on the roller body.

Pneumatic and steel wheel rollers, have long been used to compact coarse materials—sand or aggregate. (They are also used for asphalt mixtures.) These work from the top downward. The tamping (sheepsfoot) roller is used only for silt or clay soils and works from the bottom up.

Hand-operated vibratory compactors are useful for smaller backfill projects where compaction is done in close quarters. Studies show that vibration is most effective in compacting sandy soils.

Construction traffic from hauling and leveling operations can provide subgrade soil compaction. In some cases this may be entirely sufficient and may eliminate the need for special compaction equipment. You should test to verify the final density, however.

Moisture content is important to compaction because moisture lubricates soil particles, allowing them to be pushed together more easily. There is, however, an optimum moisture content. Too much moisture keeps particles apart; too little moisture means poor lubrication. At optimum moisture content, proper compaction will yield the maximum density for the soil. Laboratory testing is necessary to determine the relation between moisture and density for each material.

Steps for major soil compaction projects:

- Sample the soil and determine the type (i.e. clay or sand) and natural moisture content.
- Determine the density and optimum moisture content in a laboratory based on AASHTO test designation T99.
- Modify moisture content to aid compaction:

  If the moisture content is below optimum for the type of compaction equipment you have available, add moisture to the soil.

  If it is above the optimum, add dry soil or aerate existing soil.
- Compact soil in proper depth layers and use the right type roller as dictated by soil type.
- Test compacted soil for proper density.

Base

The *base,* the layer immediately below the surfacing material, provides support and drainage. The load-carrying capacity of the base is critical in a road's design and performance. To give the base strength, the material used must be compacted to the prescribed density. Some pavement failures can be traced to low density materials lying close to the pavement surface.

The base is generally compacted by rolling until the aggregate reaches a specified density. Often you must add water during compaction to achieve the desired density. Watering, blading, and compacting in six inch layers will produce the best results.

Compaction equipment depends on the size of the project and the type of base material. Very small projects usually rely on hand-operated vibratory tampers. On larger projects, pneumatic rollers are usually used, although vibratory and steel-wheel rollers are also sometimes used.

Asphalt surfacing

Asphalt surfacing is compacted to obtain the desired density for maximum strength and wear, and to provide a smooth, sealed riding surface. How effective your asphalt compaction operation will be is determined, in every case, by the type of equipment you use and the time you have available for compaction.

Equipment types

Three types of self-propelled compactors are currently used for asphalt compaction: steel-wheeled static rollers, pneumatic-tired rollers, and vibratory steel-wheel rollers.

For **steel-wheel static rollers,** axle load, roll diameter, and rolling speed influence compaction performance. Axle load measures the compaction capacity; heavier axle loads compact more. Roll diameter influences surface finish. Smaller diameter rollers tend, more than larger rollers, to shove material ahead of them causing ridges and surface cracks. Rolling speed influences the time available for compaction and the ability of the roller to keep up with the paver. Thicker individual layers require slower rolling speeds or more passes. Thinner layers can be rolled faster or with fewer passes.

For **pneumatic-tired rollers,** contact area, gross weight, and rolling speed influence performance. Compacting effectiveness increases with the area of each tire footprint as well as the gross weight of the roller. Contact pressure, which includes both tire pressure and gross weight, is the primary element in determining the compacting effectiveness of this roller type. As with the steel-wheeled static roller, rolling speed affects compaction time and ability to keep up with the paver.

For **vibratory steel-wheeled rollers,** amplitude, frequency of vibration, and rolling speed influence performance. Amplitude, the amount of vertical movement of the vibrating drum, and frequency, the number of vibrations of the drum per minute, combine to determine the compactive energy generated by the roller. Variable amplitude and frequency controls enable the operator to alter the amount of compactive energy generated in order to achieve specified densities in the fewest passes. Generally, on thin lift material (one inch or less), the operator should select a low amplitude combined with a high frequency. The lower amplitude produces less dynamic force which in turn avoids fracturing the aggregate and damaging the finished surface. Thicker lifts require higher amplitudes and lower frequencies.

Speed will determine the distance between successive impact points on the pavement. Fast speed and low frequencies will cause a rippled effect on the asphalt surface. Therefore, given a particular amplitude and frequency, the operator must select the appropriate speed to produce a smooth surface finish. A rule of thumb is to select a speed which gives about ten drum impacts per rolling foot. Thus, a roller with a vibration frequency of 1,800 vibrations per minute should move along at about two miles per hour.

Time

For the contractor, time is the most important factor. This is how long it takes for the asphalt mixture to cool from laydown temperature to a minimum compaction temperature, usually 175° F. Below this temperature, further attempts to compact the asphalt mixture normally will not be effective and may fracture the aggregate in the mix, decreasing pavement density and frustrating the purpose of compacting.

Seven variables affect the cooling rate of a layer of asphalt mix: layer thickness, air temperature, base temperature, base moisture content, mix laydown temperature, wind velocity, and the amount of sunshine.

Layer thickness is probably the single most important variable in cooling rate. Thicker layers increase the time available for compaction. A four inch layer takes considerably longer to cool than a two inch layer. For early spring and late fall operations, thin asphalt surfacing layers (less than two inches) are more susceptible to premature pavement failure and reduced durability. It is more difficult to produce an adequate density on thin layers in cool weather because the material cools very rapidly.

Research shows an asphalt pavement layer loses heat in two directions. The surface cools as heat is transferred to the air. The bottom cools as heat is transferred to the base.

Base temperature —the temperature of the layer on which you lay the new layer—is more important than air temperature in determining time available for compaction because the layer cools downward more rapidly than upward.

All other factors being equal, however, warmer **air temperature** slows the material's cooling rate, allowing more compaction time.

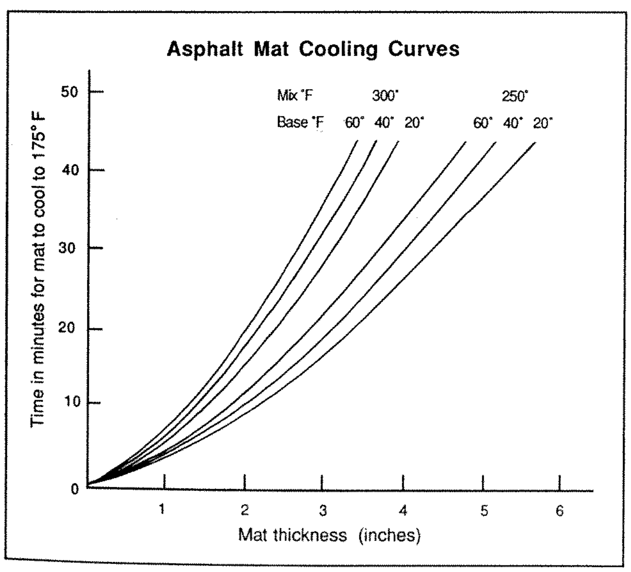
People often assume that air and base temperatures are the same, but this is usually not true, particularly in cool weather. In early spring, the early morning base temperature may be as much as ten to twenty degrees Fahrenheit less than the air temperature. Base temperatures are usually warmer in late fall than early spring at the same overnight low air temperature. Thus, the asphalt pavement layer loses less heat to the base in fall than spring.

A **moist base layer** significantly speeds up cooling of the overlying layer. Just as water cools skin faster than air, moisture in the base speeds heat transfer out of the asphalt mix. The moisture may even turn into steam. Paving a wet surface will significantly hinder your ability to compact the asphalt mix to its proper density.

Hotter **mixture laydown temperatures** will give you more compaction time. A mix laid at 275° F takes longer to cool than the same thickness of mix laid at 250° F. Asphalt mix usually leaves the plant at 275–325° F. Depending on environmental conditions and length of haul, it can lose five to twenty-five degrees between plant and paver. (In cold weather it is a good idea to cover the haul trucks and use insulated boxes to reduce heat loss.)

An asphalt layer will cool more quickly in high **winds** than when it's relatively calm. Wind has more affect on the surface of the layer than its interior. A strong wind can cause the surface to cool so rapidly that a crust forms. You must break this crust down with the roller before you can begin compacting.

A mix will cool slower on a **sunny day** than on a cloudy day (other factors remaining constant). Sunshine probably affects base temperature more than mix temperature. The base will be warmer on a sunny day than on a cloudy day with the same air temperature, significantly slowing a new layer's cooling rate.



Source: *Time Available for Compaction,* James A. Scherocman, **Better Roads**, April 1984

The cooling curves in the chart show available compaction time for different combinations of conditions. These curves assume that air temperature and base temperature are equal; that the wind velocity of ten knots (11.5 mph) is constant; and that sunshine is constant at 50 BTUs per square foot per hour. The graphs give the time available for compaction before the new layer cools to 175° F. To use the curves you must know the laydown temperature, the base temperature, and the new layer thickness. For example, for a laydown temperature of 250° F and a base temperature of 40° F, doubling the layer thickness from one to two inches will increase available compaction time from four to ten minutes.

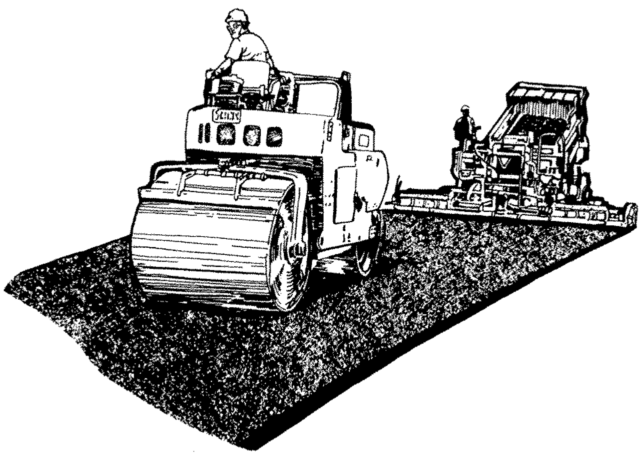
Steps in compacting asphalt surfacing

Asphalt pavements are usually compacted in three steps: breakdown rolling just behind the paving machine, intermediate rolling, and finish rolling which smooths out surface ruts and other deformities.

For **breakdown rolling** you can use static steel-wheeled rollers, vibrators, or pneumatic-tired compactors. Except for single drum vibratory rollers, operate the drive wheel of all compactors toward the paver. This tucks the material under the drive wheel, reducing shoving or displacement. Begin rolling at the highest possible mix temperature at which the rollers will not cause shoving and cracking of the newly laid material. This could be as high as 300° F, depending on the mix. At these temperatures the asphalt mix is more fluid, making it easier to reorient its particles and produce greater densities.

Begin **intermediate rolling** immediately after breakdown. This achieves design density and begins smoothing the surface. Very often the same equipment can be used for both breakdown and intermediate rolling.

Finish rolling smooths the surface, removing roller marks. It also tightens the surface texture which can improve its imperviousness to water. Roll with steel-wheeled rollers while the material is still warm. Once the pavement has reached the density and texture you want, stop rolling. Continued rolling wastes labor and, in some cases, can harm the pavement.



Rolling procedures

Rollers should move at a moderate but uniform speed with the drive wheel closest to the paver. Going too fast during breakdown rolling can harm the surface. Rollers should be in good mechanical condition and able to reverse direction without backlash.

Pay close attention to rolling longitudinal joints. You want to crowd or force the new, hot material into voids on the adjacent cold mat while producing a level connection between the two mats.

Always operate rollers back and forth in the direction of the paving, except for the last few feet. Roll this area at a slight angle to erase any dents or marks pressed into the mat by the roller's stopping, starting, and reversing.

Culvert backfill

The capacity of any culvert to carry loads depends on proper backfilling. The soil surrounding the culvert provides critical support to it. For maximum strength, and to prevent wash outs and settling, the backfill must be properly placed and carefully compacted.

Begin by placing backfill equally on both sides of the culvert in six to eight inch layers. Next, compact the layers to maximum density at optimum moisture content. Usually you will use a hand-operated vibratory tamper for this. Compacted layers should extend a distance equal to at least one diameter of the culvert on each side of it, if possible, or at least to the side of a trench or the natural ground line.

The most common problem with backfilling operations is that the filling crew works too fast and the tamping crew never has a chance to adequately compact the first material before more is placed in the trench. To prevent this, instruct filling crews to wait until a layer is fully compacted before adding another layer.

Utility trenches

In some cases the trench will be backfilled with the original material. This should also be compacted in six inch layers. The size of the project will generally dictate whether to use a hand-operated compactor or a larger machine. Either way, the backfill should be as dense on completion as the material surrounding the trench.

If you do not use original material, then a granular material will be easier to compact. However, placing a sand backfill in a clay or silt area may cause the trench to become a drainage channel. Fill the sand or gravel in six to eight inch layers, and tamp each layer to maximum density. Again, the size of the job will usually dictate the type of roller to use.

Measuring compaction

There are several common field compaction tests including the sand-cone method and the nuclear method. The sand cone procedure involves digging a hole in the compacted material and filling it with a special sand. By comparing the weight of excavated material to the volume of sand used, you can calculate the density of the compacted material.

The nuclear method uses a special field density measuring device. This nuclear guage is placed on the ground and the probe inserted. You can read both moisture content and density from the automatic displays. For accurate results the equipment must be calibrated and the operator must be experienced.

Test limitations

The sand-cone test's accuracy is limited by possible variations in the sand's unit weight and its inability to completely fill the test hole.

With the nuclear test you must take the normal precautions for handling radioactive material. False readings sometimes occur in organic soils or in materials with high salt content.

If they are done properly, either one of the tests can give you adequately accurate results. Which test you use will depend on what equipment is available.

Summary

Compaction is the simplest, most economical method of improving the load-carrying capability of roads. When done during construction it costs very little per ton of pavement material and can significantly reduce future maintenance costs. Compaction also gives a road greater strength for supporting heavier loads, reduces settlement over its lifetime, and reduces its permeability to water and air and its susceptibility to rutting.

General steps to proper compaction

- Compare properties of the material to be compacted with compaction equipment available, and use proper machinery. Compact granular soils and asphalt pavements with vibratory and static steel wheel, or pneumatic-tired rollers, and clay soils with sheepsfoot rollers.
- Moisture content is critical to achieving optimum density in soils.
- Use thin soil layers to achieve maximum density and avoid settlement. Soil layers of six to eight inches are recommended.
- Compact asphalt at the proper temperature. Complete breakdown rolling before asphalt becomes cold.
- Test compacted material to insure it is the desired density.

Sources

Hewes, L.J. and C.H. Oglesby, **Highway Engineering,** John Wiley and Sons, New York, 1960.

Compaction Handbook, Hyster Company, Construction Equipment Division, Kewanee, Illinois, 1978.

Installation Manual for Corrugated Steel Drainage Structures, National Corrugated Steel Pipe Association, Washington, D.C., 1984.

Superintendent's Manual on Compaction, National Asphalt Association, Riverdale, Maryland.

Pavement Cuts for Utilities: A Guide for Their Management, Highway Extension and Research Project for Indiana Counties and Cities, No. H-84-6, Purdue University in cooperation with the Indiana Department of Transportation, 1984.

Scherocman, James A., *Guidelines for Compacting Asphalt Concrete Pavement,* **Better Roads,** March 1984.

Scherocman, James A., *Compaction Pointers Increase Life of Asphalt Concrete Pavements,* **Better Roads,** April 1984.

Scherocman, James A., *Time Available for Compaction,* **Better Roads,** May 1984.

Starry, Jr., Dale W., *Part 2 of 2: A Beginner's Guide to the Art of Asphalt Pavements,* **Highway and Heavy Construction,** pp. 45-48, June 1985.

Wisconsin Transportation Bulletin is a series of fact sheets providing information to local town, municipal and county officials on street and highway design, construction, maintenance and management. These fact sheets are produced and distributed by the Transportation Information Center, a project of the University of Wisconsin–Madison, Department of Engineering Professional Development, with assistance from the Federal Highway Administration, Wisconsin Department of Transportation and UW–Extension. UW–Madison provides equal opportunities in employment and programming, including Title IX requirements.

Copies free while available from the ***Transportation Information Center,*** UW–Madison, Department of Engineering Professional Development, 432 N. Lake Street, Madison, WI 53706. Phone 800-442-4615.