

---

# 6

## AC Compaction

---

### Learning Outcomes:

- Understand the importance of compaction efforts
- Recognize paving influences outside of operators control (environmental factors and mix properties)
- Learn paving influences under operators control (roller speed, number of roller passes, rolling zone, and roller pattern)

### AC Compaction

Compaction is the process of compressing a given volume of asphalt concrete into a smaller volume. Compaction is accomplished by pressing the asphalt coated aggregate particles closer together, thereby reducing the air voids (space) in the mix and increasing the density (weight to volume ratio) of the mixture.

The single most important factor that affects the ultimate performance of asphalt concrete layers is compaction. Adequate compaction of the mix increases the fatigue life, decreases permanent deformation (rutting), reduces oxidation or aging, decreases moisture damage, increases strength and stability, and decreases low-temperature cracking. An asphalt mixture that has all the desirable mix design characteristics will perform poorly under traffic conditions if that mix is not compacted to the proper density level.

## Compaction Importance

The need for a pavement to be compacted to the required density is better understood when the effect of air, water, and traffic on an undercompacted layer(s) is realized.

The voids in an undercompacted mix tend to be interconnected creating open channels and permitting the intrusion of air and water throughout the pavement. Air and water carry oxygen which in turn, accelerates the oxidation of the asphalt binder in the mix, causing it to become brittle. Consequently, the pavement itself will ultimately fail as it can no longer withstand the repeated deflections due to traffic loading. The internal presence of water at freezing temperatures can also cause an early failure in the AC due to expansion and contraction of the freezing and thawing water.

A pavement which has not been adequately compacted during construction may push, shove and rut from traffic that is utilizing the pavement. However, unless the mix is properly designed and adequate voids remain in the compacted mix, the pavement will likely flush and tend to become unstable due to further reduction of void content under traffic and/or thermal expansion of the asphalt.

The desired constructed void content is approximately 8 percent or less for the dense-graded mixes. At this level, the voids are usually not interconnected. When the air void content is too high, the pavement will tend to ravel and disintegrate. When the air-void content is too low, there is a danger of the pavement flushing (leading to poor surface friction) and becoming unstable.

By pressing the aggregate particles closer together into a position in which the asphalt binder can hold them in place, compaction accomplishes two important goals:

1. It develops the strength and rut resistance of the mix
2. It closes passages through which water and air would otherwise penetrate thus causing faster aging, freeze-thaw damage, and stripping.

Compaction is the final stage of AC paving operations. It is the stage at which the full strength of the mixture is developed and the smoothness and texture of the mat is established. Therefore, the technician must be particularly observant of the compaction process.

The volume of air in an AC pavement is important because it has a profound effect on long-term pavement performance. An approximate "rule-of-thumb" is for every 1 percent increase in air voids

(above 6-7 percent) about 10 percent of the pavement life may be lost (Linden et al., 1989). Keep in mind that this rule-of-thumb was developed using limited project data, should be used with extreme caution and applies to air voids above 6 - 7 percent. According to Roberts et al. (1996), there is considerable evidence that dense graded mixes should not exceed 8 percent nor fall below 3 percent air voids during their service life. This is because high air void content (above 8 percent) or low air void content (below 3 percent) can cause the following pavement distresses (this list applies to dense-graded AC and not open-graded AC or SMA):

<b>Decreased Stiffness and Strength</b>	Kennedy et al. (1984) concluded that tensile strength, static and resilient modulus, and stability are reduced at high air void content.
<b>Reduced Fatigue Life</b>	Several researchers have reported the relationship between increased air voids and reduced fatigue life (Pell and Taylor, 1969; Epps and Monismith, 1969; Linden et al., 1989). Finn et al. (1973) concluded "...fatigue properties can be reduced by 30 to 40 percent for each one percent increase in air void content." Another study concluded that a reduction in air voids from eight percent to three percent could more than double pavement fatigue life (Scherocman, 1984a).
<b>Accelerated Aging/Decreased Durability</b>	In his Highway Research Board paper, McLeod (1967) concluded "compacting a well-designed paving mixture to low air voids retards the rate of hardening of the asphalt binder, and results in longer pavement life, lower pavement maintenance, and better all-around pavement performance."
<b>Raveling</b>	Kandhal and Koehler (1984) found that raveling becomes a significant problem above about eight percent air voids and becomes a severe problem above approximately 15 percent air voids.
<b>Rutting</b>	The amount of rutting which occurs in an asphalt pavement is inversely proportional to the air void content (Scherocman, 1984a). Rutting can be caused by two different mechanisms: vertical consolidation and lateral distortion. Vertical consolidation results from continued pavement compaction (reduction of air voids) by traffic after construction. Lateral distortion – shoving of the pavement material sideways and a humping-up of the asphalt concrete mixture outside the wheel paths – is usually due to a mix design problem. Both types of rutting can occur more quickly if the AC air void content is too low (Scherocman, 1984a).
<b>Moisture Damage</b>	Air voids in insufficiently compacted AC are high and tend to be interconnected with each other. Numerous and interconnected air voids allow for easy water entry (Kandhal and Koehler, 1984; Cooley et al., 2002) which increases the likelihood of significant moisture damage. The relationship between permeability, nominal maximum aggregate size and lift thickness is quite important and can change significantly as these parameters change.

Air voids that are either too great or too low can cause a significant reduction in pavement life. For dense graded AC, air voids between 3 and 8 percent generally produce the best compromise of pavement strength, fatigue life, durability, raveling, rutting and moisture damage susceptibility.

## Factors Affecting Compaction

AC compaction is influenced by a number of important factors:

- Some related to the **environment**,
- Some determined by **mix and structural design**, and
- Some under contractor and department control during the **construction process**.

### FACTORS AFFECTING COMPACTION

Compaction Variables Outside of Operator Control		Compaction Variables Under Operator Control
<p><b><u>Environmental Factors</u></b></p> <p>Temperature</p> <ul style="list-style-type: none"> <li>▪ Ground temperature</li> <li>▪ Air temperature</li> <li>▪ Wind speed</li> <li>▪ Solar flux</li> </ul>	<p><b><u>Mix Property Factors</u></b></p> <p>Aggregate</p> <ul style="list-style-type: none"> <li>▪ Gradation</li> <li>▪ Size</li> <li>▪ Shape</li> <li>▪ Fractured faces</li> </ul> <p>Volume</p> <p>Asphalt Binder</p> <ul style="list-style-type: none"> <li>▪ Chemical properties</li> <li>▪ Physical properties</li> <li>▪ Amount</li> </ul>	<p><b><u>Construction Process Factors</u></b></p> <p>Rollers</p> <ul style="list-style-type: none"> <li>▪ Type</li> <li>▪ Number</li> <li>▪ Speed and timing</li> <li>▪ Number of passes</li> <li>▪ Lift thickness</li> </ul> <p>Other</p> <ul style="list-style-type: none"> <li>▪ AC production temperature</li> <li>▪ Haul distance</li> <li>▪ Haul time</li> <li>▪ Foundation support</li> </ul>

---

## Compaction Variables Outside of Operator Control: Environmental and Mix Property

### Environmental Factors

Environmental factors are determined by when and where paving occurs. These factors are outside the operator's control of the process. Paving operations may have some float time, which allows a limited choice of "when" but paving location is determined by road location so there is essentially no choice of "where". Mix and structural design factors are determined before construction and although they should account for construction practices and the anticipated environment, they often must compromise ease of construction and compaction to achieve design objectives. Obviously construction factors are the most controllable and adaptable of all the factors affecting compaction. Although some factors like haul distance/time, AC production temperature, lift thickness and type/number of rollers may be somewhat predetermined, other factors associated with roller timing, speed, pattern and number of passes can be manipulated as necessary to produce an adequately compacted mat.

AC temperature has a direct effect on the viscosity of the asphalt cement binder and thus compaction. As AC temperature decreases, its asphalt cement binder becomes more viscous and resistant to deformation, which results in a smaller reduction in air voids for a given compactive effort. As the mix cools, the asphalt binder eventually becomes stiff enough to effectively prevent any further reduction in air voids regardless of the applied compactive effort. The temperature, at which this occurs, is commonly referred to as **cessation temperature**. In some literature it is reported to be about 175°F for dense-graded AC (Scherocman, 1984b; Hughes, 1989). Below cessation temperature rollers can still be operated on the mat to improve smoothness and surface texture but further compaction will generally not occur. Conversely, if the binder is too fluid and the aggregate structure is weak (e.g., at high temperatures), roller loads will simply displace, or "shove" the mat rather than compact it. In general, the combination of asphalt cement binder and aggregate needs to be viscous enough to allow compaction but stiff enough to prevent excessive shoving.

Mat temperature then, is crucial to both the actual amount of air void reduction for a given compactive effort, and the overall time available for compaction. If the initial temperature and cool-down rate are known, the temperature of the mat at any time after laydown can be calculated.

**BEST PRACTICE**

Based on this calculation rolling equipment and patterns can be employed to:

1. **Take maximum advantage of available roller compactive effort.** Rollers can be used where the mat is most receptive to compaction and avoided where the mat is susceptible to excessive shoving.
2. **Ensure the mat is compacted to the desired air void content before cessation temperature is reached.** This can be done by calculating the time it takes the mat to cool from initial temperature to cessation temperature. All compaction must be accomplished within this “time available for compaction”.

*Describes a best practice to be utilized when possible.*

Research work in the early 1970's determined the time available for compaction of various asphalt concrete mixes. The time available for compaction was defined as the time, in minutes; it took for a mix to cool from laydown temperature to a minimum compaction temperature. Laydown temperature is the mix temperature when the paver screed passes over the mix. Minimum compaction temperature for this study was set at 175°F. Below this temperature, it was found that the internal friction and cohesion of the mix increases to the point that little density gain is achieved with the application of additional compactive effort.

Six variables were found to have an effect on the rate of cooling (and, therefore, on the possibility of obtaining a required level of density) of a layer of asphalt placed on top of another existing layer of the same type of material.

Those variables are:

1. layer thickness
2. air temperature and base temperature
3. mix temperature
4. wind velocity
5. solar flux, and
6. laydown site conditions

<b>1. Layer Thickness</b>	<p>Layer thickness is probably the single most important variable in the rate of cooling of asphalt mixtures, especially for thin lifts. It is very difficult to obtain the desired density on thin lifts of mix in cool weather because of the rapid loss in temperature in the mix.</p> <p><i>For example, for a mix laydown temperature of 250°F and a base of 40°F, a 1 inch thick mat will cool from that 250°F temperature to the 175°F compaction cutoff point in less than 4 minutes. For a 2 inch thick layer, under the same mix and base temperature conditions, it will take about 10 minutes for the material to cool to 175°F.</i></p>
<b>2. Air and Base Temperature</b>	<p>A portion of the heat in the asphalt layer is lost to the air. All other factors being equal, an increase in the ambient air temperature decreases the rate of cooling of the mix. Heat in the mix is also lost to the layer on which the new material is placed. There usually is more rapid cooling of the mix downward into the base than upward into the air.</p> <p>Base temperature is actually more important than air temperature in determining the time available for compaction. It is often assumed that air and base temperature are the same. This is not necessarily true, particularly in cool weather. A moist base layer significantly increases the cooling rate of the new overlaying asphalt layer. Heat is lost from the mix to the moisture, turning water into steam and increasing the rate of heat transfer.</p>
<b>3. Mix Laydown Temperature</b>	<p>Asphalt mixes are usually produced at temperatures between 250°F and 350°F. Depending on environmental conditions and the length of haul, the mixture can lose between 5°F and 25°F from the plant to the paver. As the temperature of the AC being placed is increased, the time available for compaction is greater. The effect of mat laydown is more significant at lesser mat thickness and lower base temperatures.</p>
<b>4. Wind Speed</b>	<p>A thin layer of mix will cool more quickly in a strong wind than when there is little or no wind. Wind has a greater effect at the surface of the mix than within the mix, and can cause the surface to cool so rapidly that a crust will form.</p>
<b>5. Solar Flux</b>	<p>The amount of radiant energy available from the sun (solar flux) is a function of many variables, including the position of the sun above the horizon, the distance above sea level of the paving project, the amount of turbidity in the air, and the degree of cloud cover. A mix will cool more slowly on a sunny day compared with a cloudy one. The amount of solar flux is more important in its effect on base temperature than its effect on mix temperature.</p>
<b>6. Laydown Site Conditions</b>	<p>A number of factors at the laydown site directly affect the ability of the compaction equipment to gain the required level of pavement density. The relationship between lift thickness and nominal aggregate size in the mix is another variable that affects the amount of density that can be obtained. The uniformity of the lift thickness is another factor to be considered. It is easier to obtain a required level of density in an asphalt layer that has a constant thickness compared with a course that varies in depth. Asphalt leveling courses that, by their very nature and purpose are non-uniform in thickness, are often difficult to densify to a given air void content uniformly, especially when placed over a rutted or wavy road.</p>

## Mix Property Factors

### Aggregates - “The Rock Carries the Load”

Three properties of the coarse aggregate particles used in an asphalt mixture that can affect the ability to obtain the proper level of density are:

1. the particle shape of the aggregate,
2. the number of fractured faces, and
3. the surface texture

There is a simple statement that defines mix properties and the level of density: As the crushed content of the coarse aggregate increases, as the maximum size of the aggregate increases, and as the hardness of the aggregate (granite compared with limestone, for example) increases, the compactive effort needed to obtain a specific level of density also increases.

Angular particles offer more resistance to manipulation than do rounded aggregate particles. How well the mix will be compactive is also affected by the shape of the aggregate. A cubical or block-shaped aggregate needs a greater degree of manipulation than a rounded particle shape before achieving a given density level.

A continuously graded (dense-graded) aggregate, from coarse to fine, may be easier to compact than a mixture with any other aggregate gradation. A harsh mix typically requires a significant increase in compactive effort to obtain the desired level of density. An over sanded or finely graded mix, on the other hand, tends to be extremely workable. It still might be difficult to achieve density on such a mix, however, because of the inherent tender nature of such an over sanded mix. A mix designed with a high dust content will generally be more difficult to compact than a mix designed with a lower dust content.

At paving temperatures asphalt cement is a lubricating fluid. As cooling takes place, it becomes a glue-like binder.

**Asphalt Cement - “Binds the Rock Together”**

The grade and amount of asphalt cement used in the mix affects the ability to densify the mix. An asphalt cement that is higher in viscosity or lower in penetration will generally provide for a stiffer mix at a given mix temperature and therefore require a greater compactive effort. The degree of hardening that occurs in the asphalt cement during the manufacture of the mix affects the compactibility of that material. The asphalt cement content of the mix influences its compactibility. In general, a mix with too little asphalt cement may be stiff and require an increase in compactive effort, whereas a mix with too much asphalt cement may shove under the rollers.

**Mix Properties Summary**

- For a traditional AC mix, a mix that is placed at a higher temperature will be easier to compact than a mix that is lower in temperature.
- The workability of the mix is affected by the temperature susceptibility of the asphalt cement.
- The fluids content of the mix, not just the asphalt content, affects the compactive effort needed.
- Fluids content is the sum of the asphalt cement content plus the moisture content of the mix.
- The moisture content of the mix should be less than 0.5 percent, by weight of mix, when the mix is leaving the plant.

## Compaction Variables under Operator Control: Construction Factors

The roller operator is in control of more variables when using a vibratory roller and thus should be well educated in the proper selection and interaction of the variables. In addition to the roller speed, location on the layer being compacted, and number of passes made, both the nominal amplitude and the frequency of the vibratory impact can be varied. Roller speed and vibratory frequency are combined to determine the impact spacing. Further, for double-drum vibratory rollers, the operator can vibrate either one or both rolls. Care should be taken when operating a vibratory roller in areas where buildings are nearby. In addition, the use of vibration on the roller when underground utilities and drainage structures are directly under the pavement layer being compacted needs to be considered carefully.

The primary compaction variables for all types of rollers that can be controlled during the rolling process include:

- roller speed,
- number of roller passes,
- rolling zone, and
- roller pattern

In addition, for vibratory rollers the operator also has control over the vibration frequency, vibration amplitude, and direction of travel. Each of these factors has an effect on the level of density achieved under the compactive effort applied to the mix.

### TOOLS AND EQUIPMENT



There are three basic pieces of equipment available for AC compaction: (1) the paver screed, (2) the steel wheeled roller and (3) the pneumatic tire roller.

*Describes what tools, equipment and tests are required to complete the job safely and with the highest level of quality.*

Compaction is done by any of several types of compactors, or rollers - vehicles which, by their weight or by exertion of dynamic force, compact the pavement mat by driving over it in a specific pattern.

Compaction aims at producing a mat of specific density (target density) and smoothness. Although the compaction process appears rather simple and straightforward, it is, in reality, a procedure requiring skill and knowledge on the part of the roller operator and the technician. Both must have a thorough understanding of the mechanics of compaction and the factors that affect the compaction effort.

---

## Compaction Equipment

### How do Rollers Compact?

Rollers compact by applying their weight over the area of the drum/tires that touch the mat (contact pressure). The process packs the aggregate particles together and removes most of the air voids that exist. For example: If you walk across a new mat (not recommended) you will sink in because you exert a higher contact pressure (your weight divided by the area of the sole of your boots) than bearing capacity of the mix. As the roller passes over the mix repeatedly, the aggregate particles are packed closer together, the excess air is removed, the asphalt cement cools and acts more like a glue than a lubricant, and the bearing capacity of the mix increases.

When the bearing capacity of the mix equals the contact pressure exerted by the roller, the roller has “walked-out” of the mix. Further roller coverages may be necessary to further increase the mix density, orient the aggregate particles, seal the surface, and finally, “iron” out the roller marks.

In theory, that is how rollers compact. In practice, it isn’t quite so simple because of the many compaction variables involved. In addition, most high-type asphalt concrete mixes are difficult to compact and new techniques and methods are constantly being tried to achieve the specified density.

There are three basic pieces of equipment available for AC compaction: (1) the paver screed, (2) the steel wheeled roller and (3) the pneumatic tire roller. Each piece of equipment compacts the AC by two principal means:

1. ***By applying its weight to the AC surface and compressing the material underneath the ground contact area.*** Since this compression will be greater for longer periods of contact, lower equipment speeds will produce more compression. Obviously, higher equipment weight will also increase compression.
2. ***By creating a shear stress between the compressed material underneath the ground contact area and the adjacent uncompressed material.*** When combined with equipment speed, this produces a shear rate. Lowering equipment speed can decrease the shear rate, which increases the shearing stress. Higher shearing stresses are more capable of rearranging aggregate into more dense configurations.

**DEFINITION**

These two means of defining AC are often referred to collectively as “**compactive effort**”.

1. By applying its weight to the AC surface and compressing the material underneath the ground contact area. Since this compression will be greater for longer periods of contact,
2. By creating a shear stress between the compressed material underneath the ground contact area and the adjacent uncompressed material.

---

There are several variables associated with rollers that can be adjusted from job to job. These variables are:

- The sequence and number of rollers
- Roller speed
- The number of roller passes over a given area of the mat
- The location at which each roller works
- The pattern that each roller uses

Not all these variables are infinitely adjustable, but by adjusting a combination of them, a rolling plan can be developed that will optimize mat compaction.

AC compaction is typically accomplished by a sequential train of compaction equipment. This allows each piece of equipment to be used only in its most advantageous situation resulting in a higher quality mat (both in density and in smoothness) than could be produced with just a single method of compaction.

A typical compaction train consists of the following (in order of use):

<b>1. Screed</b>	The screed is the first device used to compact the mat and may be operated in the vibratory mode.
<b>2. Breakdown Roller</b>	The breakdown roller is the first roller behind the screed and, therefore, generally effects the most density gain of any roller in the sequence. Breakdown rollers can be of any type but are most often vibratory steel wheel and sometimes pneumatic tire.
<b>3. Intermediate Roller</b>	The intermediate roller is used behind the breakdown roller if additional compaction is needed. Pneumatic tire rollers are sometimes used as intermediate rollers because they provide a different type of compaction (kneading action) than a breakdown steel wheel vibratory roller. This can help further compact the mat or, at the very least, rearrange the aggregate within the mat to make it receptive to further compaction.
<b>4. Finish Roller</b>	The finish roller is last in the sequence and is used to provide a smooth mat surface. Although the finish roller does apply compactive effort, by the time it comes in contact with the mat, the mat may have cooled below cessation temperature. Static steel wheel rollers are almost always used as finishing rollers because they can produce the smoothest surface of any roller type.
<b>5. Traffic</b>	After the rollers have compacted the mat to the desired density and produced the desired smoothness, the new pavement is opened to traffic. Traffic loading will provide further compaction in the wheel paths of a finished mat. For instance, a mat compacted to eight percent air voids and then opened to heavy traffic (e.g., an interstate freeway) may further compact to about three to five percent air voids in the wheelpaths over time.

Each position in the roller train (breakdown, intermediate and finish) may be performed by one roller or several rollers in parallel. For instance, a large paving project may use two vibratory steel wheel rollers for breakdown rolling, one pneumatic tire roller for intermediate rolling and two static steel wheel rollers for finish rolling. The determination of the best rolling sequence and the number of rollers is generally made on a case by case basis and depends upon the desired final air voids, available rollers and their operating parameters, rolling patterns, mix properties, and environmental conditions.

### Static Steel Wheel Roller

Static steel wheel rollers normally range in weight from 3 to 14 tons and have compression drums or rolls that vary in diameter from approx. 40 inches to more than 60 inches. The gross weight of the roller can usually be altered by adding ballast to the roller, but this adjustment cannot be made while the roller is operating, and is not normally changed during the term of a paving project.

Effective weight or contact pressure, in terms of pounds per square inch of contact area, is the key variable for this type of equipment and is dependent on the depth of the penetration of the rolls into the mix. The greater the depth of penetration, the greater the contact area and then, the less the contact pressure.

The table below illustrates how the roller contact pressure increases as the mix's internal strength increases during the compaction process. Look at a typical ton roller. As the roller makes its first pass, the contact pressure may range from 48 to 36 psi as the drum sinks in 1/2 to 3/4 of an inch, depending on the initial stiffness of the mix. As additional passes are made, the mix becomes stiffer as the aggregate is packed together and the air voids are reduced. The drum eventually "walks out" of the mix and the contact pressure becomes extremely high. At 1/16 inch penetration, the contact pressure reaches 132 psi (A 266 percent increase over the original contact pressure at 3/4 inch penetration).

**Roller Contact Pressure at Penetration Depths In Pounds per Square Inch**

Static Roller Type	1/16 in.	1/8 in.	3/16 in.	1/4 in.	1/2 in.	3/4 in.
Two Axle Tandem 270 p.l.i. – Drive 190 p.l.i. – Guide						
8.5 ton (less ballast)	96	64	53	45	33	26
12 ton (less ballast)	132	88	74	63	46	36

Rollers with large-diameter rolls have lower drawbar pull (rolling resistance) because they do not tend to penetrate as far into the mix as does a roller with smaller-diameter rolls. Once the size and weight of a static steel wheel roller is selected, the variables under the control of the roller operator are the speed of the roller, the position of the roller on the mat in relation to the paver, operation with the drive wheel toward the paver, and the number of passes made with the roller.

### Pneumatic (Rubber Tire or Traffic) Roller

Most pneumatic rollers are operated in the intermediate roller position, behind a vibratory or static steel wheel breakdown roller and in front of a static steel wheel finish roller. These rollers are sometimes used, however, for initial rolling of the mix as well as occasionally for finish rolling.



### Vibratory Roller

Vibratory rollers come in a variety of configurations. Single-drum vibratory rollers are manufactured with both a rigid frame and an articulated frame. Double-drum vibratory rollers come in rigid-frame, single-articulated-frame, and double-articulated-frame models. These rollers can be operated in any one of three modes: static (with the vibrator off), with one drum vibrating and one drum static, and with both drums vibrating.

These rollers thus have two types of compactive force that is applied to the AC:

1. Static weight, and
2. dynamic (impact) force.



The compactive effort derived from the static weight of the rollers is caused by the weight of the roller and frame. The compactive effort derived from the impact force is produced by a rotating eccentric weight located inside the drum (or drums). As the eccentric weight rotates about the shaft inside the drum, a dynamic force is produced. Changing the eccentric moment arm or adjusting the eccentric mass has a directly proportional effect on the dynamic force.

The elements of comparison for dynamic component of a vibratory roller are the magnitude of the centrifugal force, its vibrating frequency, the nominal amplitude, and the ratio of the vibrating and non-vibrating masses acting on the drum.

**DEFINITION**

The **nominal amplitude** is defined as equal to the weight of the drum divided by the eccentric movement of the rotating weight and is a function of the weight of the drum and the location of the eccentrics.

Normal values of nominal amplitude range from 0.01 to 0.04 inches. Some rollers can operate at only one fixed amplitude. Other rollers have “high” and “low” amplitude positions. Still other rollers have 3 amplitude settings.

As the layer thickness increases, it is often advantageous to increase the nominal amplitude applied to the asphalt mix. Unless “high” amplitude is needed to achieve a particular density level, the vibratory roller should be operated in “low” amplitude.

The frequency of vibration is the number of complete cycles that the eccentrics rotate per minute. Simply stated, the faster the rotation of the eccentrics, the greater the frequency of vibration. Some vibratory rollers can operate at only one frequency or have a very limited selection of frequencies. Other vibratory rollers can alter the frequency of the applied load between 1600 and 3000 vibrations/minute.

**IMPORTANT/AWARENESS**

Frequencies below 2000 vibrations/minute are not normally acceptable to compact asphalt mixtures.

*Highlights a step in the procedure which is either unusual or very particular to this procedure. May also indicate awareness (additional information) or a cautionary concern in the procedure.*

The spacing of the impacts of the applied force is a function of the frequency of the vibration and the travel speed of the roller. A smaller impact spacing (a greater number of impacts per foot) is thus usually preferred.

A recent survey of major roller manufacturers recommended the following impact spacing. The impact spacing should be in the range of 10-12 impacts per foot (1.2 - 1.0 in. between impacts) to ensure the highest efficiency of the vibratory rollers and reduce the possibility of leaving ripples in the finished pavement.

**BEST PRACTICE**

In general, the vibratory roller should be operated at as high a frequency as possible. The use of the highest possible frequency of vibration increases the number of impacts per foot at a given roller speed.

*Describes a best practice to be utilized when possible.*

Prior to beginning paving operations, the Materials Section or Inspector must inspect the Contractor's compaction equipment to see that it meets all requirements of the Specifications and is in good working order. If the equipment meets Specifications and is in satisfactory operating condition a statement shall be entered in the Technician's Daily Diary.

Before any of the rollers are used on a project they should be checked to see that they are in good mechanical condition and to assure their compliance with project specifications, if any.

Compaction of the pavement material must begin immediately after the material is spread, struck off, shaped to the required width, depth, cross-section, and edge irregularities adjusted. The mix must be compacted to the required degree of compaction for the type of mixture being placed. Compaction must be carried out in such a manner as to obtain uniform density over the entire section. Perform compaction rolling at the maximum temperature at which the mix will support the rollers without moving horizontally. Complete the compaction (including both breakdown and intermediate rolling) prior to the mixture cooling below a workable temperature. Perform finish rolling to remove roller marks resulting from the compaction rolling operations.

Most asphalt mixtures compact quite readily if spread and rolled at temperatures that assure proper asphalt viscosity. Rolling should start as soon as possible after the material has been spread by the paver, but should be done with care to prevent unduly roughening the surface.

A mix that is relatively stable at high temperatures as it leaves the spreader is compacted by the vertical movement of the aggregate particles under the roller. On any paving mixture the roller wheel must settle into the mix until the area of contact between the wheel and mix multiplied by the resistance of the mix is equal to the weight on the roller wheel. If the AC is quite firm, the roller will not cause any horizontal mix displacement.

Horizontal displacement results from apparent crawling of the mix ahead of the roller and the forming of ridges on either side of the roller path. If there is no horizontal displacement, there will be virtually no crawl or ridges along the edge of the roller path.

Horizontal displacement also results in a rough and uneven surface, thus defeating the intentions of careful grade control and good screed operation of the asphalt paver. Horizontal movement of the mix often occurs due to the breakdown roller being operated too fast.

Mix temperature is a principal factor affecting compaction. Compaction can only occur while the asphalt binder is fluid enough to act as a lubricant. When it cools enough to act as an adhesive, further compaction is extremely difficult to achieve. The best time to roll an asphalt mixture is when its resistance to compaction is the least, while at the same time it is capable of supporting the roller without excessive shoving.

The best rolling temperature is influenced by the internal particle friction of the aggregates, the gradation of the mix, and the viscosity of the asphalt. Therefore, it can change if any of these factors change. The critical mix temperature in an asphalt concrete paving project is the temperature at the time of compaction. This should determine the temperature at which the plant is to produce the mixture. It is best to be able to compact the mix as quickly as possible after being spread, which means that it's best for the mixing temperature and the compacting temperature to be reasonably close to the same.

During rolling, roller wheels are kept moist with only enough water to avoid picking up material.



Fuel oil should not be used to moisten roller wheels since it will damage the mix.

## Phases of Rolling

Rolling freshly placed asphalt mix is generally done in the following order:

1. Transverse joints,
2. Longitudinal joints (when adjoining a previously placed lane),
3. Initial or breakdown rolling,
4. Second or intermediate rolling, and
5. Finish rolling.

### BEST PRACTICE



#### Compacting Transverse Joints

Good practice is to make an initial breakdown pass and then check the joint with a straightedge. In case the new mat is too high, the mix can still be reworked and then recompact. It is important to understand that the first pass will still leave the mat slightly high, but experience will determine if it is too high. The goal is to produce a transverse joint that rides as smooth as the rest of the mat.

#### Transverse Rolling

Ideally, it is best to compact transverse joints in the transverse direction. However, it is not always possible. If rolling in the transverse direction, run-off boards the thickness of the mat may be needed to keep the roller level. This drum should overlap the new mat with most of the drum on the cold mat and pinch the joint. Some contractors use multiple passes, each pass placing more of the drum on the hot mat. Again, the method that produces a dense, level joint most efficiently is the one to use.

#### Longitudinal Rolling

If a transverse joint is to be compacted in the longitudinal direction, it is important the first passes of the roller be made at very slow speeds. Higher speeds may force the new mix away from the joint creating a void or weakness. Some only roll in with one drum on the new mat and then reverse back. Angling the drum while entering the new mix can be effective also.

There is no one right way to roll a transverse joint; the method that works most efficiently and consistently is the one to use.

*Describes a best practice to be utilized when possible.*

There are three basic phases in the compaction process of asphalt pavements: 1) Breakdown, 2) Intermediate, and 3) Finish phases. Each method is described in detail below.

---

**Breakdown** Breakdown rolling is best accomplished with steel-wheeled rollers. Either static-weight or vibratory tandem rollers may be used. Vibratory rollers may be used in the vibratory mode on all mixes, except that on the final wearing surface the thickness must be 1 inch or greater before use is permitted. The weight of the roller used for breakdown rolling depends to a large degree upon the temperature, thickness, and stability of the mix being placed. Generally, a roller weighing from 8 to 12 tons is used for this operation.

It is important to start the rolling operation on the low side of the spread, which is usually the outside of the lane being paved, and progress toward the high side. The reason for this is that asphalt mixtures, when hot, tend to migrate towards the low side of the spread under the action of the roller. If rolling is started on the high side, this migration is much more pronounced than if rolling progresses from the low side. When adjoining lanes are placed, the same rolling procedure should be followed, by only after compaction of fresh mix at the longitudinal joint with a 6 to 8 in of roller width.

---

**Intermediate** Second or intermediate rolling should closely follow breakdown rolling while the asphalt mix is still plastic and at a temperature that is still well above the minimum temperature at which compaction can be achieved, preferably 225° - 250°F.

Pneumatic-tired, steel-wheeled static and vibratory rollers may be used for intermediate rolling. When using pneumatic rollers, keeping the tires hot is the most effective means of preventing pickup. Applying a small amount of non-foaming detergent or water soluble oil on the wetting mat of a pneumatic-tired roller at the beginning of rolling operations helps prevent asphalt from sticking to the tires until they warm up. Pneumatic-tired rollers have several advantages:

- They provide a more uniform degree of compaction than steel-wheeled rollers
- They improve the seal near the surface, thus decreasing the permeability of the layer; and
- They orient the aggregate particles for greatest stability, as high pressure truck tires do after using the asphalt surface for some time.

Tire contact pressures should be as high as possible without causing displacement of mix that cannot be remedied in the final rolling. Pneumatic-tired rolling should be continuous after breakdown rolling until all of the mix placed has been thoroughly compacted. At least three passes should be made. Turning of pneumatic-tired rollers on the paving mix should not be permitted unless it can be done without causing undue displacement.

Vibratory tandem rollers-of proper static weight, vibration frequency and amplitude are used to provide required densities with fewer roller passes than static-weight tandem or pneumatic-tired rollers (or combinations of the two). As mentioned previously, the vibratory roller may be used in the vibratory mode, at any time (subject to Specification requirements) on all pavement layers during the breakdown and intermediate phases of rolling.

---

**Finish** Finish rolling is done primarily for the improvement of the surface. It should be accomplished with steel-wheeled, static-weight tandems or non-vibrating vibratory tandems while the material is still warm enough for removal of roller marks. Only enough passes should be made to remove the roller marks and smooth the mat. Finish roller operators should be cautioned about over rolling the mat since it can decrease the mix density. Vibratory rollers operated in the vibratory mode are not permitted as finish rollers.

---

**NOTE:** Some SUPERPAVE™ mixes may exhibit a "tender zone" or lateral movement during compaction when the mix has cooled to the 250° - 210°F range. Because of this possibility, it is very important to obtain as much density as possible during the breakdown rolling phase. The use of vibratory rollers, more passes, additional rollers, compacting at a hotter temperature, adjusting the mix to get more "fines" in it, making certain that silicone has been added to the asphalt binder for surface mixes, excessive moisture in the aggregate, etc., are some things that may need to be considered. Some success has also been achieved by using rubber tired rollers during this "tender zone". If none of these solve the lateral movement problem, it may be necessary to hold back the intermediate and finish rollers until the mix has cooled below this "tender zone" temperature range and then continue rolling.

Rollers should move at a slow but uniform speed with the drive roller or wheels nearest the paver. The speed should not exceed 3 mph for steel-wheeled breakdown rollers or 5 mph for pneumatic-tired rollers. Rollers must be kept in good condition, capable of being reversed without backlash. The line of rolling should not be suddenly changed or the direction of rolling suddenly reversed, thereby displacing the mix. Any pronounced change in direction should be made on stable material.

If rolling causes material displacement, the affected areas are loosened at once with lutes or rakes and restored to their original grade with loose material before being re-rolled. Heavy equipment, including rollers, should not be permitted to stand on the finished surface before it has thoroughly cooled or set.

When paving in echelon, 2 or 3 inches of the edge that the second paver is following are left unrolled when the joint between the lanes is rolled. Edges should not be exposed for more than 15 minutes without being rolled. Particular attention must be given to the construction of transverse and longitudinal joints in all courses.

All final wearing surfaces except open-graded asphalt friction course shall be compacted using a minimum of 2 steel wheel tandem rollers. Steel wheel tandem vibratory rollers which have been specifically designed for the compaction of asphalt pavements may be used. Vibratory rollers, operating in the vibratory mode, may generally be used on all pavement layers 1 inch or greater in thickness during the breakdown and intermediate phases of rolling. Operation in the vibratory mode will not be permitted during the finish rolling phase on any mix type or pavement course or when the layer thickness is less than 1 inch.

Vibratory rollers must have variable frequency and amplitude capability. The rollers must be equipped with controls which automatically disengage the vibration mechanism before the roller stops when being used in the vibratory mode. Vibratory rollers used on asphalt mixtures should normally be operated at high frequencies and low amplitudes and specifically designed for asphalt compaction.

Rolling of open-graded asphalt friction course will consist of one coverage with a tandem steel wheel roller weighing a maximum of 10 tons with additional rolling limited to one coverage where necessary to remove roller marks. Excessive rolling should not be allowed inasmuch as this leads to possible breakdown of the aggregate, thereby reducing the drainage capacity of the friction course layer. Vibratory rollers may be used on friction course provided they are operated in the static mode.

On all other mixtures, the number and weight of rollers shall be sufficient to compact the mixture to the required density while it is still hot and in a workable condition. Vibratory rollers may be used, as specified in above paragraphs, provided satisfactory results are obtained, excessive displacement or crushing of the aggregate does not occur, and no vibratory roller marks (indentations) remain in the finished surface. The Engineer may prohibit or restrict the use of vibratory rollers where damage to the underlying pavement structures, drainage structures, utilities, adjoining structures, or the pavement itself is likely to occur or is evident.

The use of a pneumatic rubber tired roller is optional for compaction purposes on all mixes except for surface layers where it is required. Some Project Special Provisions may require additional use of a rubber tired roller, therefore, it is essential that the technician review all contract Project Special Provisions for this possible requirement.

While it is the Contractor's responsibility to determine roller requirements based on contract specifications, the technician is an essential part of this determination. The exact number of passes that will be required to obtain adequate density is initially unknown and this is due to some uncertainty about the mixtures rate of cooling, among other things. These uncertainties are cleared up by careful observation, measuring, and testing during the early stages of the paving operation.

## Roller Speed

Rollers are slow; for the fastest, operating speeds may reach about 7 mph. In order to provide complete and uniform mat compaction, rollers should be operated at a slow, constant speed. Operating at high speeds will reduce compactive effort while varying roller speed can cause non-uniform compaction.

The following table provides an indication of the range of roller speed for three different types of rollers and three different operating positions:

Type of Roller	Breakdown	Intermediate	Finish
Static Steel Wheel	2.0 – 3.5 mph	2.5 – 4.0 mph	3.0 – 5.0 mph
Pneumatic	2.0 – 3.5 mph	2.5 – 4.0 mph	4.0 – 7.0 mph
Vibratory Steel Wheel	2.0 – 3.0 mph	2.5 – 3.5 mph	not used

### Roller compactive effort comes in two forms:

1. material compression under the ground contact area and
2. shear stress between the compressed area and adjacent uncompressed areas

Compactive effort is significantly improved at slower roller speeds. Roller speed will also be governed by the lateral displacement or tenderness of the asphalt mix. If the mixture moves excessively under the rollers, the speed of the compaction equipment should be reduced. In addition, for vibratory compactors, roller speed also affects the impact spacing. Roller speed is usually established by the speed of the paver. Varying the speed of the compaction equipment merely causes variations in density. “Slow and steady” is the key to proper compaction.

Operating at lower speeds allows the roller to remain in contact with a particular mat location longer than it would at higher speeds. This results in more compression per roller pass and therefore increases compactive effort. Speed also affects the magnitude of shear stress developed. Lower speeds result in the shearing force between compressed and uncompressed areas being applied for a longer period of time for a particular area (giving a lower shear rate), which results in a higher shear stress. The higher the shear stress, the better able it is to rearrange aggregate into a denser configuration. Therefore, as roller speed decreases, shear stress increases and compactive effort increases.

Because speed affects compactive effort, varying roller speed will vary compactive effort resulting in uneven compaction. Varying roller speed typically occurs when operators are not closely monitoring their speed or when they speed up to roll an area more quickly so that they can catch up to the paver. If the mat is being laid down at a faster rate than it can be rolled, the solution should not be to speed up the rollers but rather should involve one of the following options (TRB, 2000):

1. **Slow down the paver.** This may involve adjusting production and material delivery rate as well.
2. **Use more rollers.** Adding rollers can increase the number of roller passes in a given time without reducing the compactive effort per pass.
3. **Use larger, wider rollers.** Wider rollers allow greater coverage per pass.

Finally, rollers should not be stopped on a fresh mat because they can cause large indentations that are difficult, if not impossible, to remove.

Roller speed directly affects compactive effort. The best compactive effort and most uniform densities are achieved by slow, consistent roller speeds. If rollers cannot keep up with the pace of the paving operation, they should not be operated at higher speeds because this reduces compactive effort. Rather, the paving operation should be slowed or more/larger rollers should be used.

## Number of Roller Passes

Generally, it takes more than one roller pass over a particular area to achieve satisfactory compaction. A roller pass over a specific mat area is defined as one complete trip over the area in question by the entire roller. This means that if the roller uses two steel drums, both drums must travel over the area in question to make “one pass”. In general, earlier passes over hotter AC will increase density (decrease air voids) more than later passes over cooler AC.

### SAFETY WARNING



In addition to keeping accurate detailed records and observing that the operation is performed safely, the Technician must also be sure that compaction is done properly and that the finished pavement meets all specifications. To achieve this, the technician must understand the compaction procedure and the equipment involved. The Technician must acquire samples of the compacted mat or take readings with special instruments to determine mix density and smoothness.

Describes a condition where personal safety may be at risk. This is used to alert personnel to operating procedures & practices which, if not observed, may result in personal injury.

## Chapter Summary

The compaction process, which must be closely controlled to achieve a quality pavement, is the last chance you will have to make or break a job. The best pavement design, the latest mix design, and the most sophisticated AC facility don't stand a chance unless you compact the mix (while it is hot) to the specified density. Compaction determines the ultimate performance of the mix and pavement. Although simple in concept, it is often very difficult to achieve in the field because of a number of variables that affect the ability of the rollers to densify the mix. You must understand what these variables are, and how to control them, in order to ensure that you can achieve density under a variety of conditions.

## Chapter Six Knowledge Check

1. The density of a material is simply the weight of the material that occupies a certain volume of space, typically described as pounds per cubic foot (lb/ft<sup>3</sup>)
  - a. True
  - b. False
2. A pass is defined as the entire roller moving over \_\_\_\_\_point(s) in the mat at one time.
  - a. One
  - b. Two
  - c. Three
  - d. Four
3. A dense-graded aggregate may be easier to compact than a mixture with any other aggregate gradation.
  - a. True
  - b. False
4. A thin layer of mix will cool more quickly in a strong wind than when there is little or no wind.
  - a. True
  - b. False
5. The primary compaction variables for all types of rollers that can be controlled during the rolling process are:
  - a. Roller speed
  - b. Number of roller passes
  - c. Rolling zone
  - d. Rolling pattern
  - e. All of the above
6. Compactive effort is significantly improved at slower roller speeds.
  - a. True
  - b. false

---

*Page intentionally left blank.*

---