# Fundamentals of Asphalt Compaction


CAT

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The hazards are identified by the "Safety Alert Symbol" and followed by a "Signal Word" such as "WARNING" as shown below.

**⚠ WARNING**

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**Attention! Become Alert! Your Safety is Involved.**

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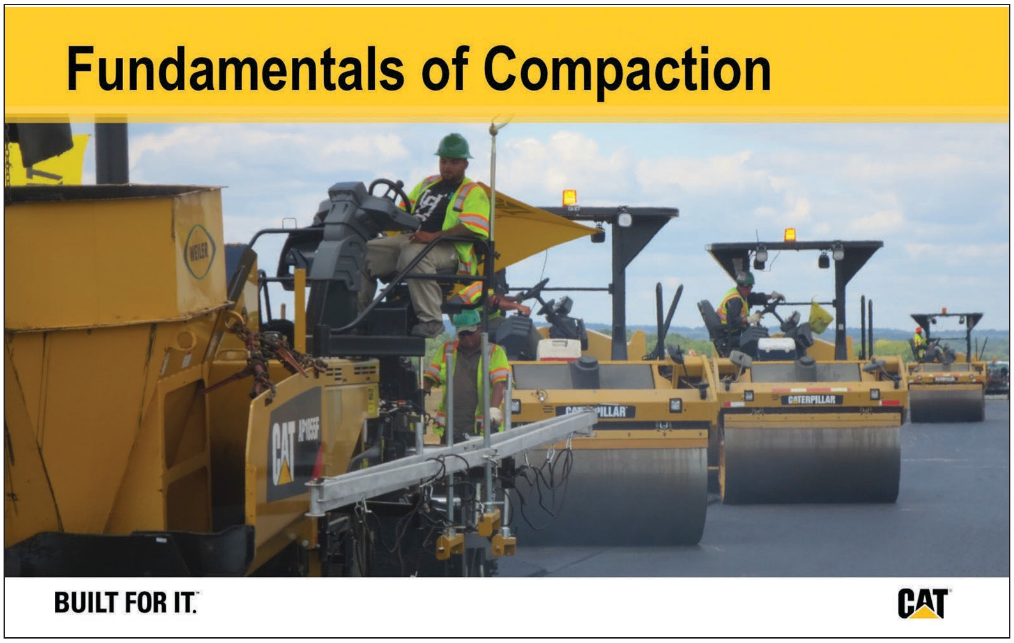



This presentation covers the basics of asphalt compaction followed by a discussion of the forces of compaction that operators and quality control personnel must understand. Various rolling patterns are presented along with transverse and longitudinal joint compaction techniques. The presentation ends with a look at some of the most common compaction issues. Although it is impossible to cover all situations and scenarios with respect to rolling patterns, if operators understand the fundamentals of compaction and the basic rolling patterns presented here, they will have the tools to think their way through any compaction situation to achieve the desired density, smoothness targets.

## What is Compaction?


- Mechanical Process
- Removes specified amount of air voids
- Develops stone on stone contact
- Builds strength

Asphalt compaction is a mechanical process. Various forces are used to make the asphalt layer more dense after it is placed by the asphalt paver. The purpose of compaction is to reduce the amount of air voids in the asphalt layer by moving the aggregate (rock, sand and mineral fillers) in the layer closer together. Strength is built into the asphalt layer by removing most of the air voids and developing what we consider for practical purposes to be stone-on-stone contact. In reality, there is a thin film or layer of asphalt binder coating each aggregate particle in the mix and providing the bonding agent to hold the asphalt mix together. This thin film of asphalt binder behaves in an incompressible manner when high compactive energy is applied, so we simply assume the compacted asphalt mix properties to exhibit "stone-on-stone" contact.

## What is Compaction?

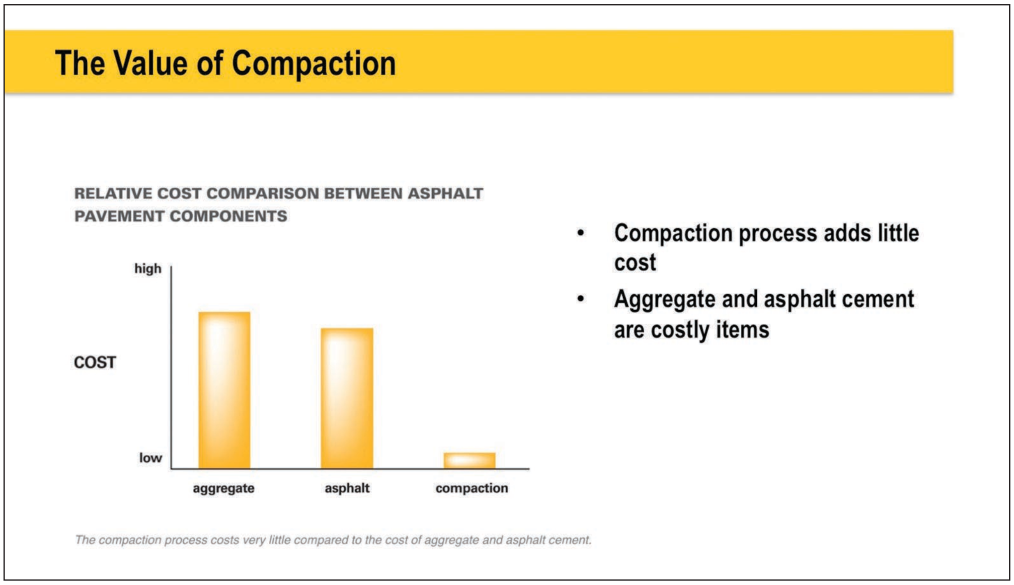
- Paver screed develops initial density
- Vibratory screed produces compaction energy
- Tamping and vibratory screed produces high compaction energy

The paver's screed begins the asphalt compaction process. For example, the density of an asphalt layer after it passes under a vibratory screed may be 85% of Theoretical Maximum Density, commonly referred to as TMD. On another project using a different mix design and the same paving equipment, the density of the asphalt layer may be as low as 78% TMD. Or, using paving equipment with tamping and vibrating screeds that deliver more energy to the asphalt layer, the screed laid density may be as high as 92% of Theoretical Maximum Density.

## What is Compaction?

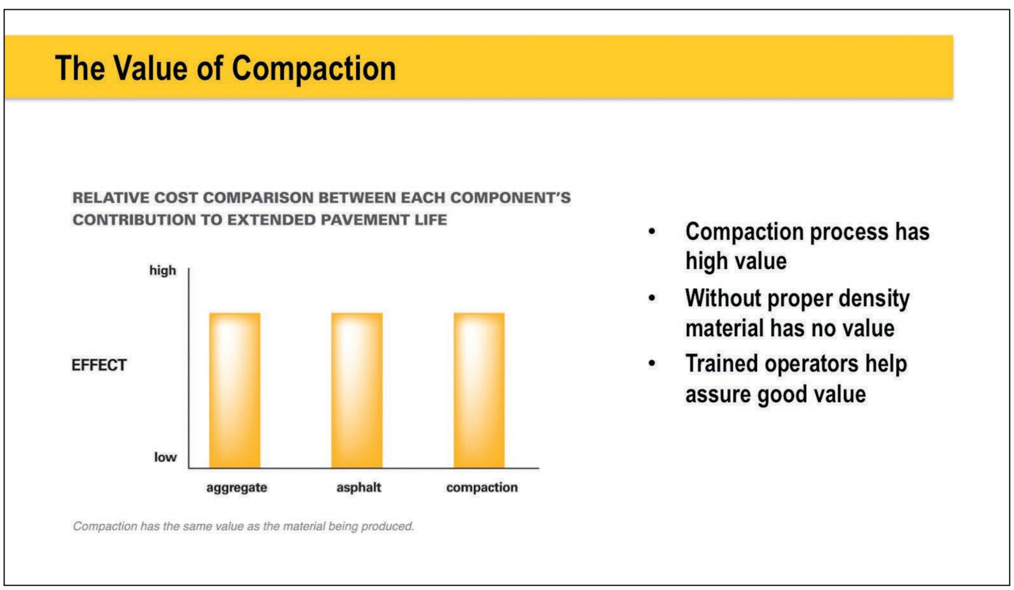
- Compaction starts immediately behind paver
- Asphalt layer at highest temperature
- Limited time to develop density
- Planning, preparation and operator training required

In most cases, the rollers being compaction at the highest temperature possible. Once the asphalt layer has cooled below a given temperature, additional density is difficult or impossible to achieve. Therefore, there is normally a short window of time to apply compactive forces and achieve the required density. Planning, preparation and operator training are extremely important for the compaction of asphalt in order to get the work completed in a timely manner.

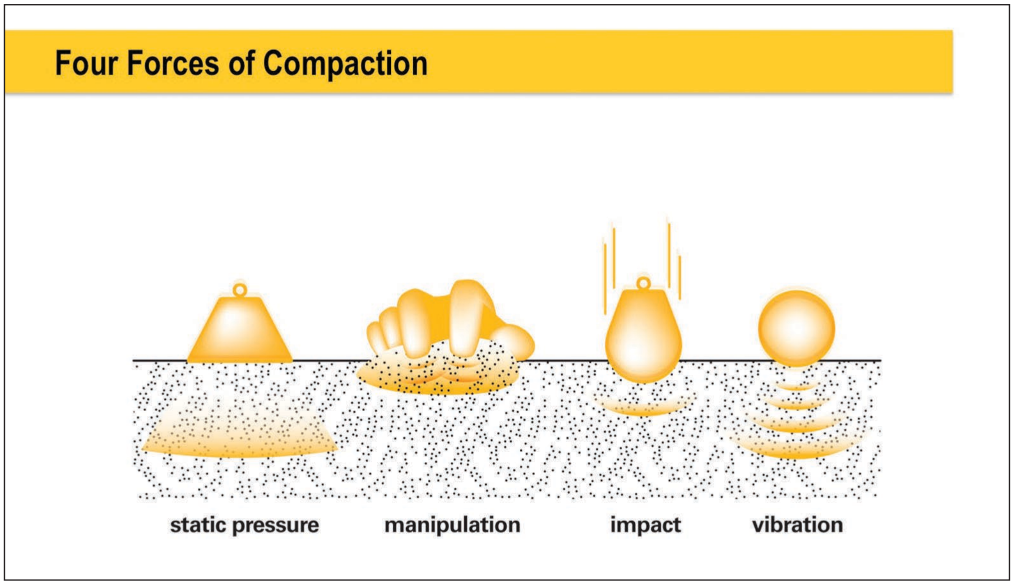



Many years ago, asphalt compaction was considered a necessary, but unskilled and unimportant process and did not really add value to the pavement structure. In most cases, roller operators have entry level operating skills and typically learned their skills on the job without any formal training.

In recent years, the cost of quality aggregates has risen as their availability has declined. The price of asphalt cement still continues to increase, consequently, the cost relationship between materials and the compaction process places most of the emphasis on material production and laydown. Compaction actually costs very little per ton of bituminous material.




Without meeting the specified in-place density, the asphalt mix will not perform for its intended service life. The compaction process is equally important as the production and placement of the asphalt mix. Roller operators need training to develop the necessary skills to meet compaction goals. Quality control personnel must be able to plan the compaction process and solve problems when density targets are not being achieved, or when the compaction process creates roughness in the surface layer.



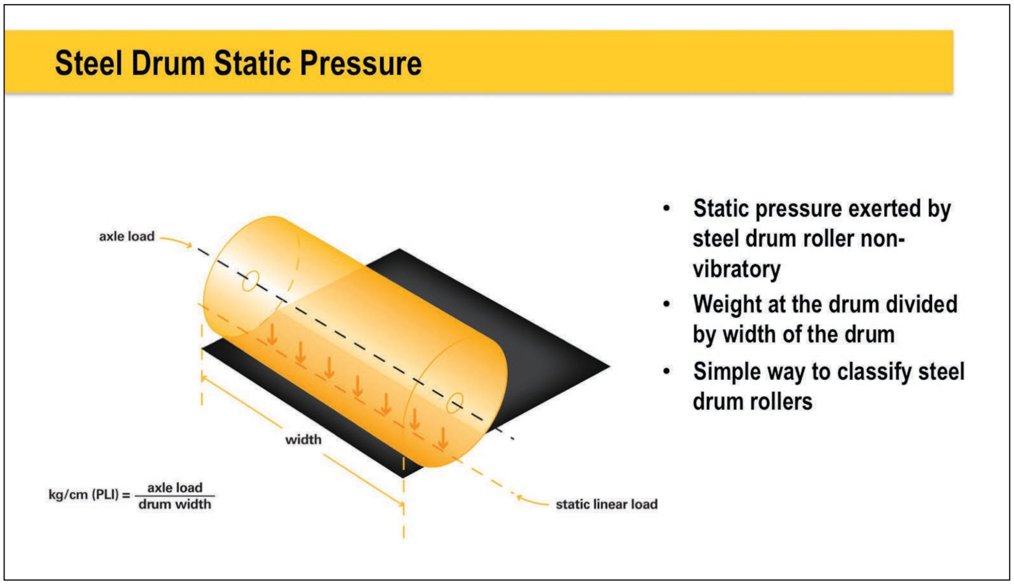

Four Forces of Compaction are used to expel air voids and create support in asphalt layers.

1. Static load
2. Manipulation
3. Impact
4. Vibration

Machine operators and quality control personnel must understand how to apply the four forces in order to create the required density in an efficient manner while maintaining the smoothness of the asphalt layer.

Static load and manipulation involve lower forces and are the easiest to understand. Static load is created by a steel drum roller operated in the static mode or by a pneumatic roller.

Impact and vibration are dynamic forces and typically generate higher compaction forces. Vibratory steel drum rollers develop impact and vibration forces and typically get most of the attention.




Steel drum rollers operated in the non-vibratory mode put static pressure on the asphalt mat . A simple way to look at static force is to divide the weight at the drum by width of the drum. This result is expressed as kilograms per linear centimeter or pounds per linear inch (PLI). It is important to remember that the highest machine weight does not always produce the highest static load.

## Static Force Comparison

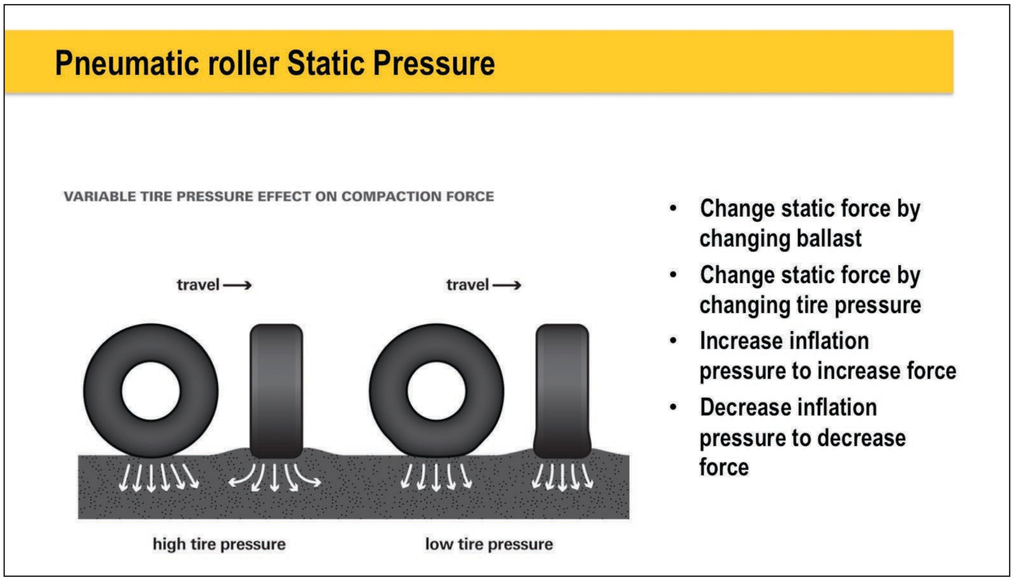
- **Heaviest model not always highest static force**
- **Narrower drum increases static force**

| | CB64 | CB54 XW | CB54 |
|---|---|---|---|
| Weight @ drum | 6490 kg<br>14,300 lb | 5949 kg<br>13,115 lb | 5402 kg<br>11,900 lb |
| Drum width | 213 cm<br>84 in | 200 cm<br>79 in | 170 cm<br>67 in |
| Static linear load | 31 kg/cm<br>170 lb/in | 30 kg/cm<br>166 lb/in | 32 kg/cm<br>178 lb/in |

The chart above shows three Cat® double-drum asphalt rollers. The heaviest machine is the CB64, a unit with 213 cm (84 in) wide drums. The next unit, the CB54XW, weights less and has drums that are 200 cm (79 in) wide. The lightest machine is the CB54 with 170 cm (67 in) drums.

What is interesting to note is that the lightest unit, the CB54, has the highest static linear pressure. This is often the case because the drums are narrower and the weight is distributed over less area.

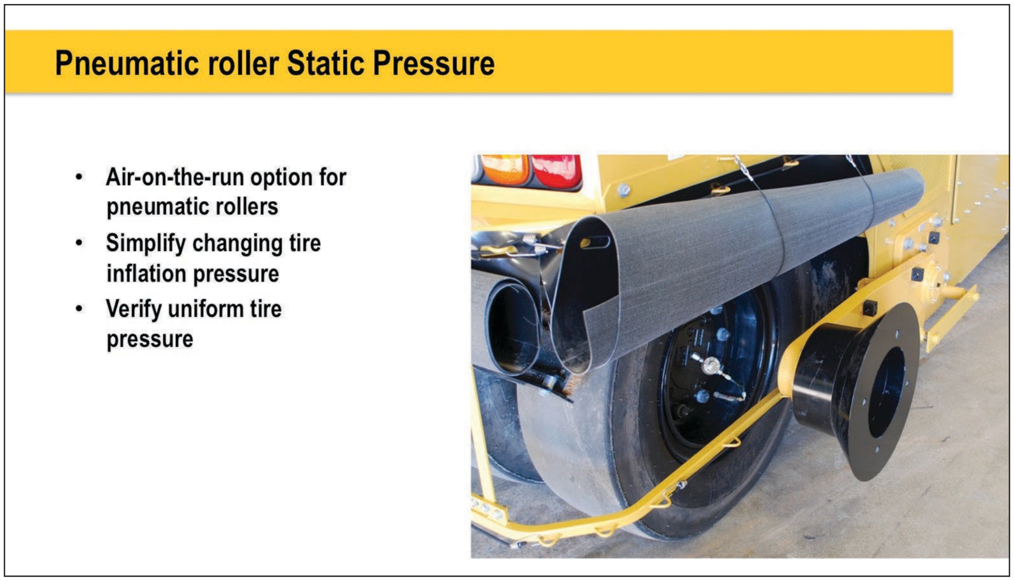
Therefore, if you are working on a project and you need a roller to deliver a relatively high static force, then you will probably want to use the narrowest drum model available so that you can still match the production requirement.



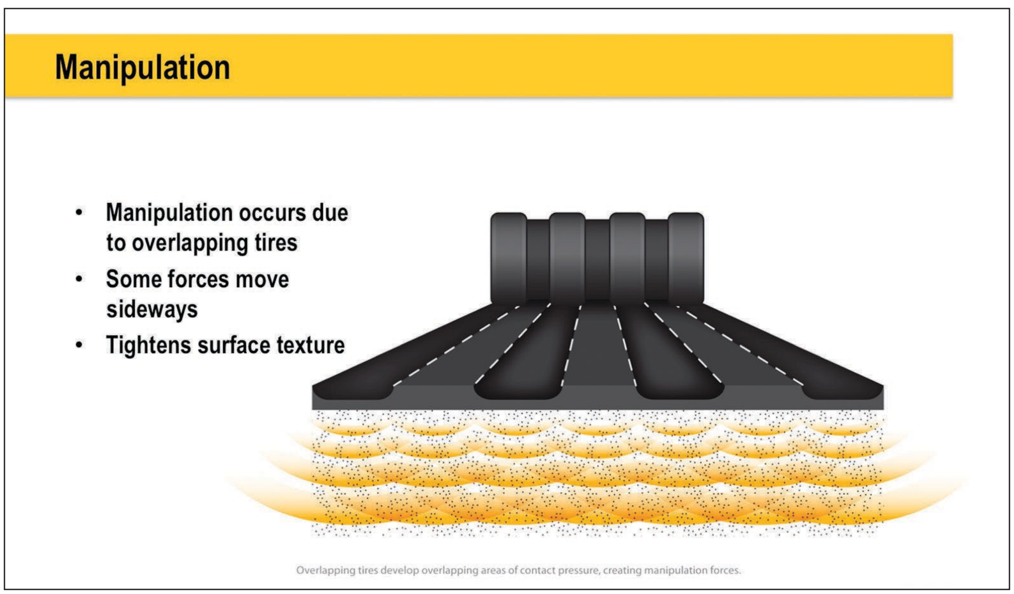

The other type of roller which exerts static force is a pneumatic, or rubber-tire roller. The amount of ground pressure depends on the weight at each tire and the area of the tire in contact with the mat.

The weight at each tire can be changed by changing the amount of ballast on the roller. Adding weight increases the load per tire and the static force will penetrate deeper into the mat.

The more common way to change static pressure is to change tire inflation pressure. When the tire pressure is decreased, the tire flattens more and the contact area is greater. Therefore, lower static force is transferred to the mat. When the tire pressure is increased, the mat contact area is less, resulting in higher static force transferred to the mat.

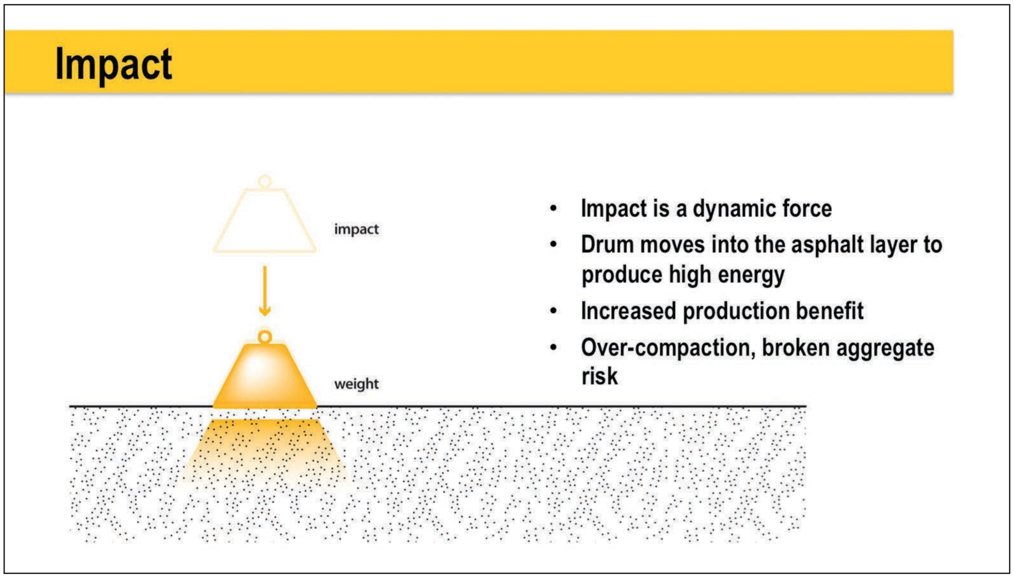



The air-on-the-run option makes it easier to adjust tire inflation pressure. When checking and adjusting tire pressures, be sure to inflate each tire to the same pressure. If tire pressures are variable, density across the mat will also be variable. You may notice, in addition, that hot asphalt will stick more readily to the under-inflated tire or tires. Tire maintenance and inspection is critical on pneumatic rollers.




Manipulation, which is also a static force, occurs when the forces exerted into the mat are not entirely vertical. Instead, the lines of force are sent in many directions. The benefit of manipulation is that the forces applied in different directions is more efficient at re-orienting (densifying) the aggregate particles in the mix and manipulation changes the surface texture by making it tighter. Manipulation is associated with pneumatic rollers.

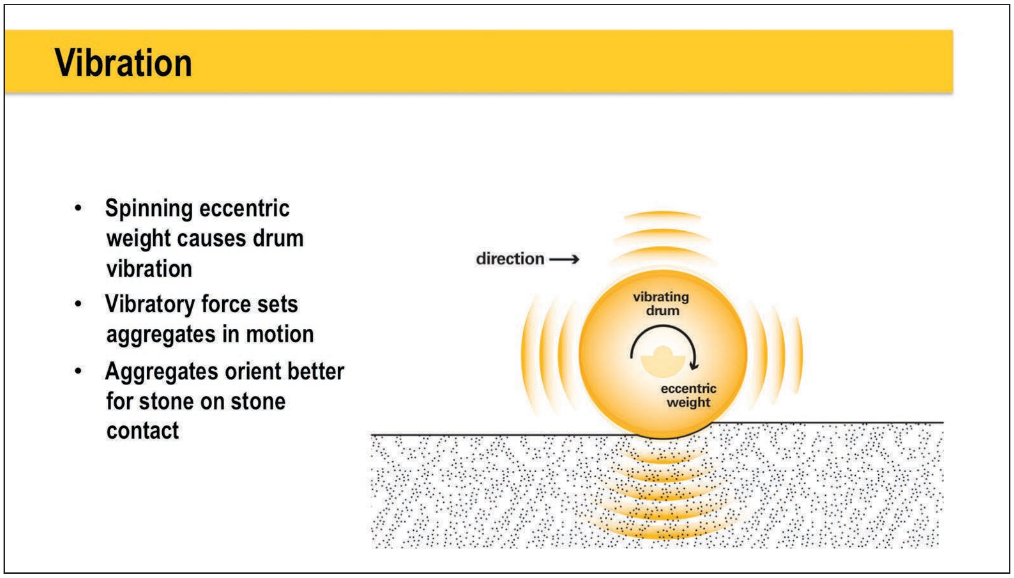
The staggered, overlapping tires on the axles of pneumatic rollers manipulate the mat under and between the tires in a confined manner. The lines of force are not only vertical but also move sideways. The vertical forces push down the large aggregate to increase density while the side-to-side forces create a tight surface finish that prevents moisture penetration.




Impact, the next compaction force, is dynamic and creates more force on the mat than an equivalent static load. On vibratory steel drum rollers, the drum actually moves into the mat. The static force of the drum is increased by drum movement or drum impact. The impact generates more energy. The impact energy is strongest at the surface of the mat and diminishes as it penetrates deeper into the mat.

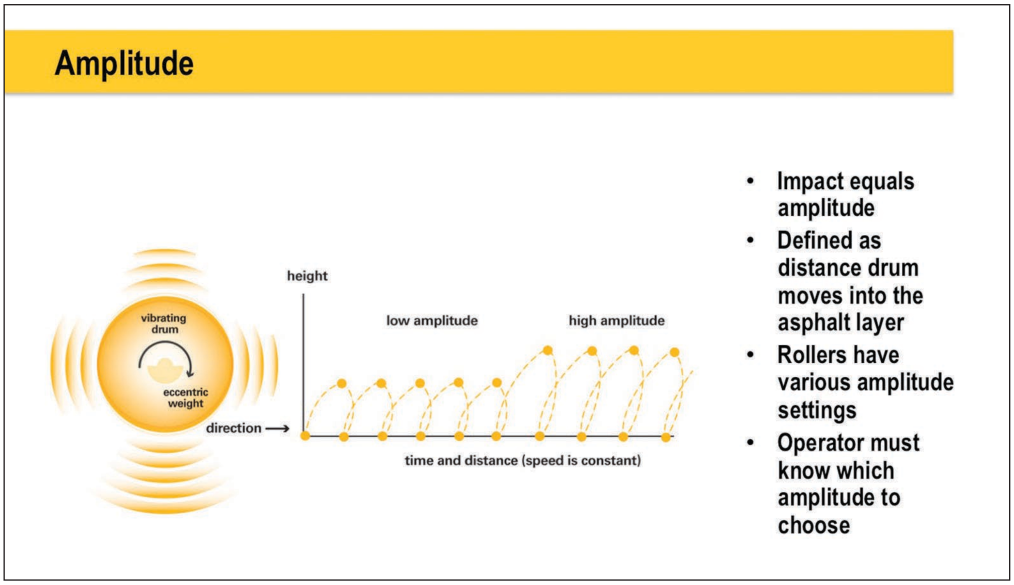
Impact forces create density in the mat faster than static forces. Increased production is the benefit of using vibratory steel drum rollers.

The risk of using impact force is that too much energy may damage the aggregates in the mat. It is possible to over-compact the mat by using too much impact force; mat density can actually decrease when too much force is applied.




The force of vibration is the most complex of the four compaction forces. Vibratory forces increase the energy developed by weight and impact.

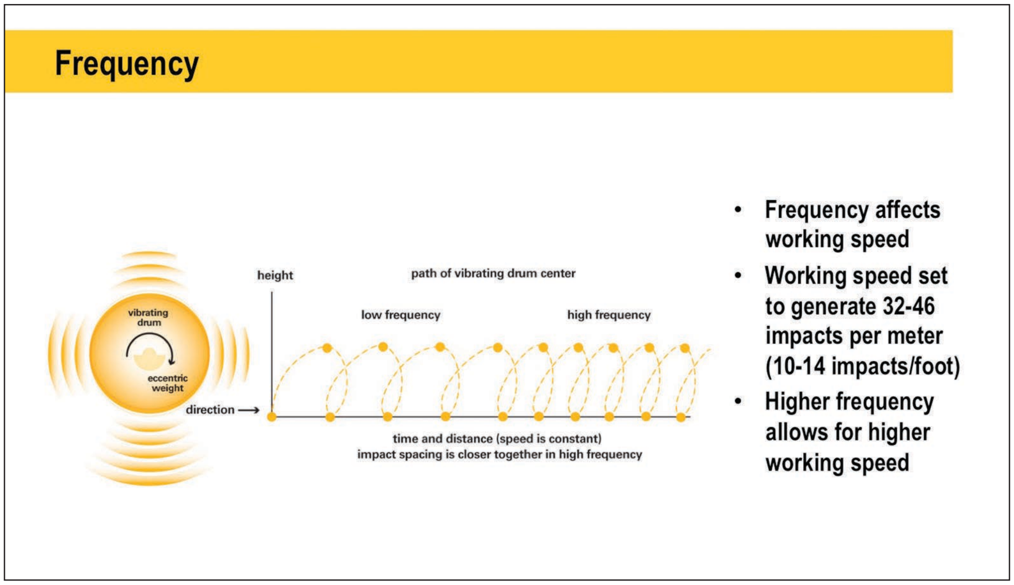
Inside the steel drum is a vibratory shaft. On the center of the vibratory shaft, there is an eccentric weight. When the vibratory system is activated, the vibratory shaft begins to spin rapidly. The rotation of the eccentric shaft causes the drum to move, or vibrate, in all directions. Vibration causes a series of pressure waves to go into the mat. The vibratory pressure waves cause the aggregates in the mat to move. Aggregate movement helps to reorient the larger aggregates so the impact force can more easily reduce the air voids between the aggregates and lock them into contact position.




The impact force caused by the drum moving into the mat is rated by the term known as amplitude. Amplitude is the distance that the drum moves into the mat. Amplitude is the most significant factor when discussing compaction effectiveness.

Most vibratory rollers offer a variety of amplitude settings. When the amplitude is changed by the operator, the configuration of the eccentric weight inside the drum is changed. When the eccentric weight is the most off-center, amplitude is the highest and impact force is increased. When the eccentric weight is more balanced, the amplitude is decreased and the impact force is smaller.

All personnel involved in the compaction process should know the amplitude capabilities of each roller on the job. At a minimum, an operator should understand the amplitude settings (for example, high, medium, low) and how to change the amplitude and frequency (see next slide) on the roller that they are operating. They should be able to develop a checklist to help them select the correct amplitude, if required. The Cat “Amplitude Selection App” for Apple and Android mobile devices is a helpful tool for selecting the correct amplitude setting based on various input parameters, such as mat thickness.




Frequency is defined as the number of times that the drum hits the mat and is rated in Hertz, or vibrations per minute.

The primary effect of vibratory frequency is its relationship to the compactor's working speed.  Because the drum is moving into the mat, you need to make sure that these impacts are properly spaced.  If the impact spacing is too wide, you can actually see impact marks at the surface of the mat. If the impact spacing is too narrow, you can see ridges in the surface of the mat. The correct impact spacing occurs when there are between 32 and 46 impacts per meter or 10-14 impacts per foot (ipf).  When the working speed is too high to maintain at least 8 ipf, both density and smoothness of the mat are compromised and it will be very difficult, if not impossible, to achieve the desired results.  A general "rule of thumb" for any vibratory roller is that a brisk walking speed (typically 4 to 5 miles per hour for most people) is the fastest speed that any roller can go in the highest frequency setting and maintain a minimum of 10 impacts per foot.

## Connecting Amplitude and Frequency

**High Amplitude (<0.80 mm) = Low Frequency (>47 Hz / 2800 vpm)**

**Medium Amplitude (0.5 mm – 0.8 mm) = Medium Frequency (47-57 Hz / 2800-3400 vpm)**

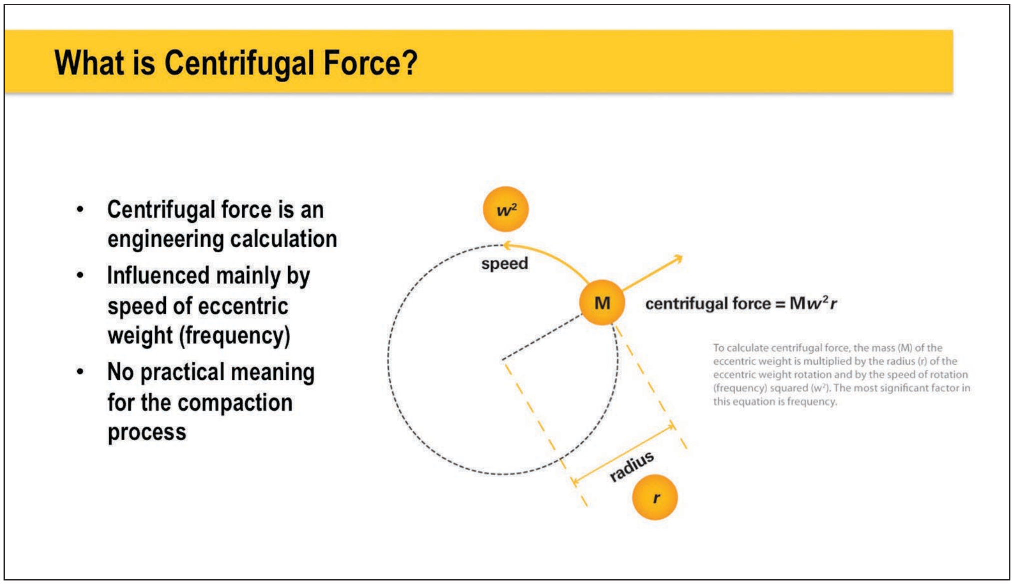
**Low Amplitude (0.2 mm – 0.5 mm) = High Frequency (<57 Hz / 3400 vpm)**

There is a relationship between amplitude and frequency. High amplitude is created when the eccentric weight is at its most off-center configuration. When the eccentric weight is in the most off-center or out of balance configuration, the eccentric weight shaft has to spin slowly in order to prevent excessive heat and wear on the weight shaft bearing. Therefore, the highest amplitude setting, and thus compactive effort, is associated with lower vibratory frequency. This is true for all rollers with multiple amplitude and frequency settings.

Low or medium amplitudes are created when the eccentric weight is in a more balanced configuration. When the eccentric weight shaft is more balanced, it can be spun more rapidly without damaging the vibratory drum components. Therefore, medium and low amplitudes can be associated with either medium or high vibratory frequency.

On the job, the compaction team has to determine what are the correct vibratory characteristics in order to achieve density effectively and efficiently. If the mat is going to require a lot of force or energy in order to reach the specified density, then the crew will select a medium or high amplitude. When higher amplitudes are selected, a lower frequency will always be in use.

Consideration must also be given to the effect of mix temperature. At higher temperatures, it is often possible to achieve the same density with a roller set on its highest frequency and a lower amplitude, thus faster working speed, whereas at cooler temperatures, it may be necessary to run the highest amplitude at a lower frequency and thus a slower working speed. Asphalt compaction is a multi-variable process, with one variable affecting other variables and processes. Ultimately, measuring density between roller passes and recording amplitude, frequency, roller speed and mix temperature at each pass will provide the best feedback for the appropriate roller settings under the given working conditions of ambient temperature, mix temperature, etcetera.




Centrifugal force is a calculation that helps roller designers establish the correct balance between drum weight, the mass of the eccentric weight and the speed of rotation of the eccentric weight. Centrifugal force has no practical meaning to the roller operator or to quality control personnel.

There is often confusion about the meaning of centrifugal force as shown in roller specification material. Many people think the higher the centrifugal force, the higher the compaction energy. This is an incorrect conclusion. A look at the formula for calculating centrifugal force will help clarify the situation.

To calculate centrifugal force, the mass of the eccentric weight is multiplied by the radius of the eccentric weight rotation and by the speed of rotation (frequency) squared. The most significant factor in this equation is frequency. If we increase frequency, we significantly increase centrifugal force.

## Centrifugal Force Comparison

Typical Cat Vibratory System

| Frequency | Amplitude | Centrifugal Force |
|---|---|---|
| 42 Hz (2520 vpm) | High: 0.86 mm (0.034 in) | 89 kN (19,980 lb) |
| 42 Hz (2520 vpm) | Medium: 0.73 mm (0.029 in) | 75 kN (16,965 lb) |
| 63 Hz (3800 vpm) | Low: 0.44 mm (0.017 in) | 108 kN (23,243 lb) |
| 63 Hz (3800 vpm) | Low: 0.33 mm (0.013 in) | 78 kN (17,438 lb) |

Note: Highest centrifugal force is generated in high frequency, but with a lower amplitude.

To help understand the concept of centrifugal force, look at the vibratory system specifications for the Cat CB54 equipped with dual frequency and four amplitudes.

On this machine, the highest centrifugal force numbers result when high frequency is selected. In high frequency, the amplitude, or impact force, is relatively small.

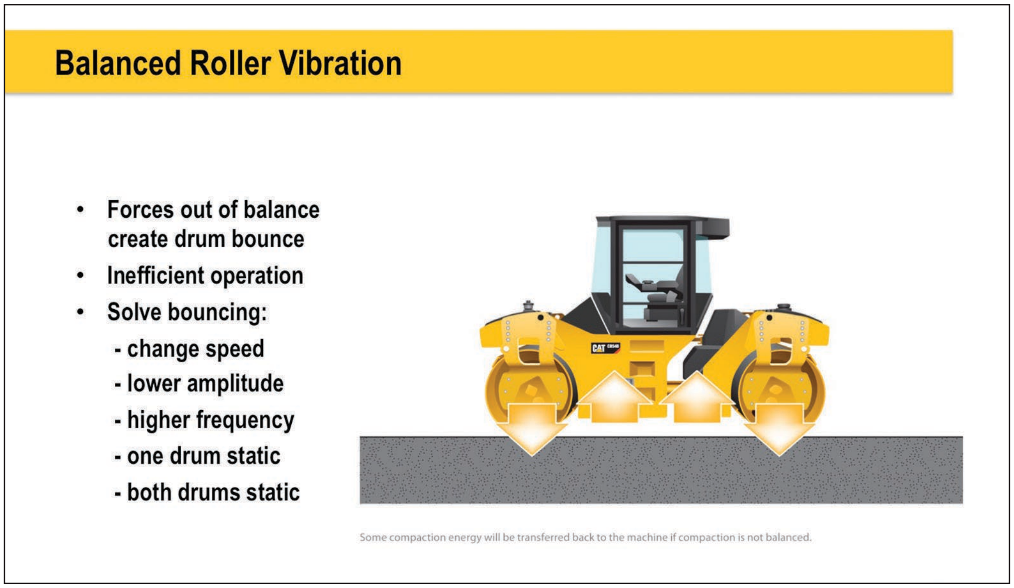
The lowest centrifugal force numbers result when low frequency is selected. As mentioned earlier, amplitudes are always higher when low frequency is selected. So, as the chart shows, higher centrifugal force does not necessarily correspond to higher compaction energy. Higher centrifugal force often means lower compaction energy. Roller operators and quality control personnel are advised to ignore centrifugal force when considering vibratory system characteristics.

## Balanced Roller Vibration

- Optimum compaction occurs when all forces are accepted by the asphalt layer
- Balance between forces of compaction and the asphalt layer

When compaction is balanced, most of the vibratory force is transmitted into the mat.

When everything is in balance – amplitude, frequency, machine speed and drum weight, then impact and vibration forces are accepted by the mat. All vibratory characteristics are working together close to what is called system resonance and the machine operates smoothly. In this condition, most of the vibratory force is transmitted into the mat. The transmitted compaction force is maximized for the most productive operation.




Using the same machine on the same mat you can select the same amplitude, but increase the frequency. Centrifugal force increases with the increase in frequency. The machine may no longer have the correct system resonance. In this condition, some of the compaction energy is not accepted by the mat, but instead is sent back up to the machine. The drums began to lose contact with the mat. When the drums bounce, the operator loses steering control. Unbalanced vibration provides less effective compaction, may damage the mat, and is uncomfortable for the operator.

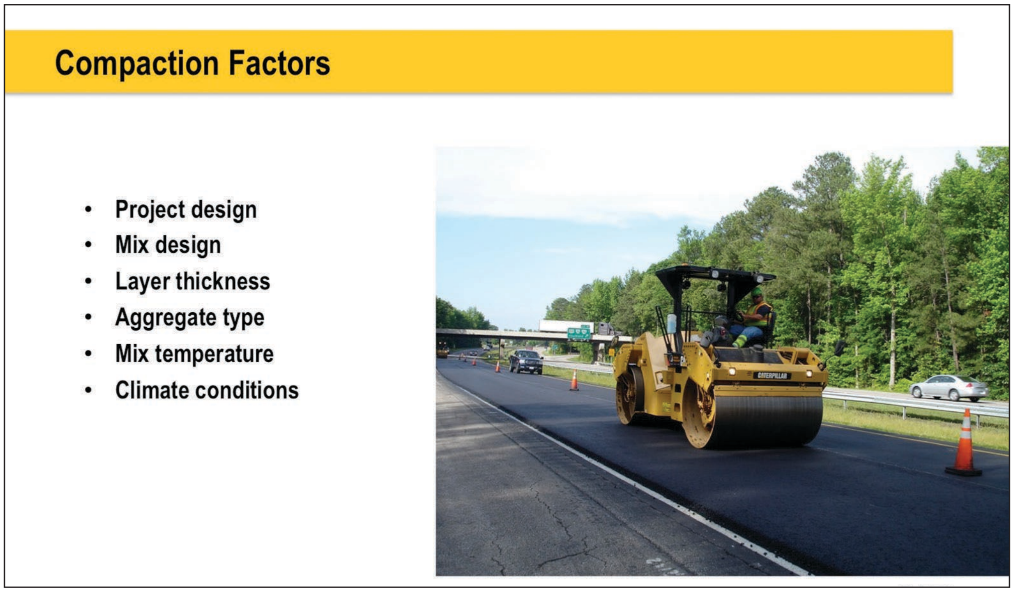
If drum bouncing occurs, try one of the following to restore smooth operation:

1. Check the working speed to make sure you are operating in the range that produces 32 to 46 impacts per meter (10-14 impacts per foot).
2. Switch to a lower amplitude setting.
3. If available on the machine, switch to a lower frequency.
4. Operate in the static mode.
5. Operate with one drum vibrating and one drum static.

## Summary

- Compaction forces are inter-related
- Crew must understand how asphalt layer accepts the forces
- Efficient compaction results when forces are in balance

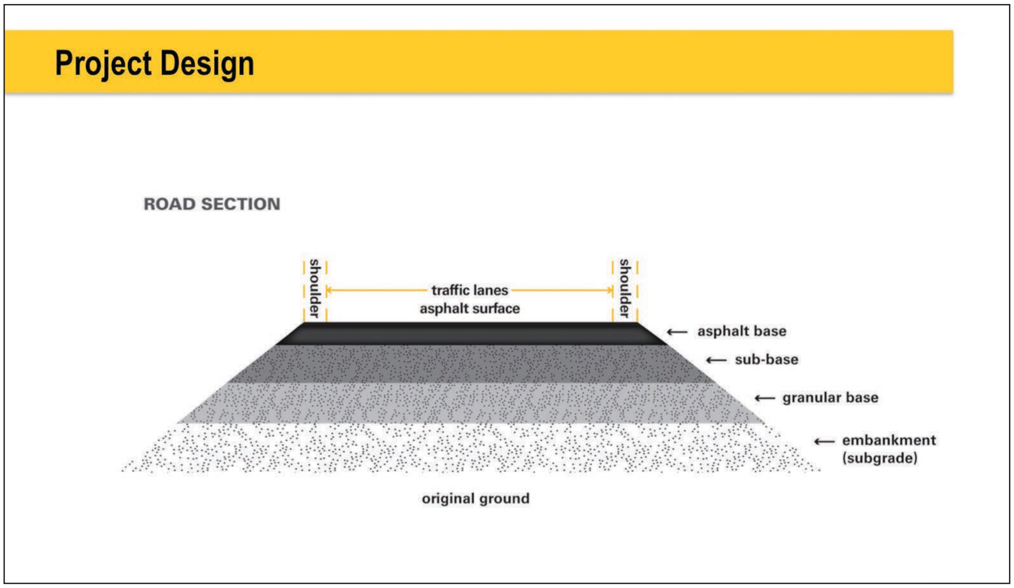
The four forces of compaction are all inter-related. When one force changes, that change often affects the other forces. Operators and quality control personnel must understand how the asphalt layer accepts or rejects the forces of compaction and must be prepared to change forces in order to create a balanced set of compaction forces.




Many other factors that affect asphalt compaction cannot be controlled by roller operators, on-site quality control or supervisors. Those factors include:

1. Project design
2. Mix design
3. Asphalt layer thickness
4. Aggregate type
5. Mix temperature
6. Climate conditions

It is important that operators and quality control personnel have information about these factors because they must consider them when developing the compaction techniques needed for each unique project.

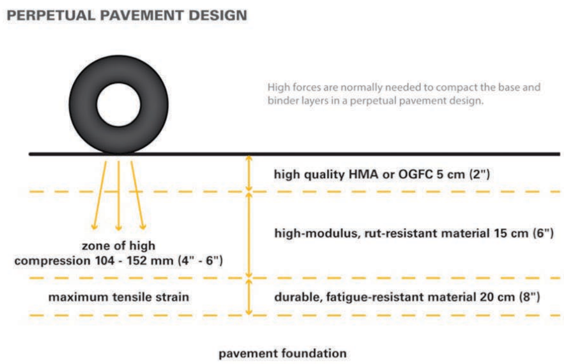



The design of the paving project affects compaction techniques. On new road construction or total reconstruction projects, there are typically multiple layers of asphalt. Each layer is made up of different material and has a different thickness. The first layer, called the base, is laid down on aggregate base or stabilized subgrade and normally consists of mix with fairly large aggregates. This is usually the thickest layer. It is being laid on a flexible base so high compaction energy is usually needed to get density.

Often a second layer of asphalt, called the binder or intermediate layer is used. The binder layer is usually thinner than the base layer and is made of smaller aggregate. The binder layer normally requires less compaction energy to get the desired density.

Finally there is a surface layer, sometimes called the wear layer or friction layer. The surface layer is ordinarily the thinnest layer made up of the smallest aggregate. The surface layer is designed to be the stiffest layer and to contribute the most to pavement strength. Because the surface layer is usually relatively thin and laid down over a rigid surface, lower compaction energy is needed.

## Project Design




- Perpetual pavement designed to resist fatigue and strain
- Thick lower layers need high compaction energy
- Thin surface layers need low compaction energy

Perpetual pavement is a term used to describe another, long-life structural design. Perpetual pavement is designed to withstand an almost infinite number of axle loads without structural deterioration. Thick asphalt layers, sometimes totaling up to 60 cm (22 in), limit the level of load-induced strain at the bottom of the asphalt layers. Perpetual pavement design usually uses high-quality, deformation resistant mixes. Most lower layers in the perpetual layer design require a high degree of compaction energy to reach the specified density.

## Project Design

- Thin layer pavement maintenance is a common application
- Typically 5 cm (2 in) or less
- High frequency, low amplitude to avoid drum bouncing

Another very common pavement compaction application is compacting one or two thin layers on a milled surface. Much of the work on asphalt structures now consists of maintenance through partial depth removal and repaving. Following the cold planing (often referred to as grinding or milling) step, there may be a leveling layer of asphalt and then a surface layer. Seldom are these layers in excess of 50 mm (2 in). Consequently, lower compaction energy is normally used for this application.

## Mix Design

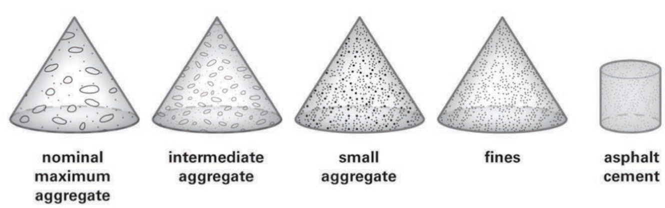
- Aggregates
- Fines
- Asphalt cement
- Modifiers
- Recycled material

Asphalt is a generic term that includes many different types of mixtures of aggregates, fines, modifiers and asphalt cement produced in an asphalt mixing plant at temperatures between 145°C and 190°C (300-350°F). A variation of traditional hot-mix asphalt is warm-mix asphalt. Warm-mix asphalt technology allows mix production and lay down at temperatures up to 40°C (100°F) lower than conventional hot-mix asphalt without sacrificing performance. In general, similar techniques are used for compaction of hot-mix asphalt and warm-mix asphalt designs.

## Mix Design

- Variety of aggregate sizes
- Larger aggregates surrounded by mastic of small aggregate and fines
- Less risk of fracturing stone due to high or medium amplitudes

DENSE-GRADED MIX




Dense-graded mixes are produced with continuously graded aggregate. In other words, there are a variety of sizes of aggregates in the design. The design formula includes asphalt cement and fines. Typically the larger aggregates are surrounded by a matrix or mastic composed of asphalt cement and fines. The asphalt cement may be modified by materials such as polymer or latex rubber to develop additional stiffness. Because the larger aggregates are surrounded by the mixture of asphalt cement and fines, there is less danger of damaging aggregates through the use of high compaction force. Depending on the layer thickness, medium to high amplitude is often selected when compacting dense graded mixes.

## Mix Design

**Coarse dense-graded**

- Aggregates 19 mm (3/4 in) or larger
- Usually layers 75 mm (3 in) or thicker
- High amplitude
- Heavy pneumatics

COARSE OR HARSH MIX

13 cm (5") mat

aggregate size up to 38 mm (1.5")

Dense-graded mixes with large aggregates are referred to as coarse mixes.

Dense graded mixes are often classed as either coarse or fine. Coarse mixes have a maximum aggregate size 19 mm (3/4 in) or larger. Coarse mixes are usually placed in layers 75 mm (3.0 in) or greater in thickness. Mats that consist of coarse mix are less likely to move around under heavy compaction energy. Vibratory rollers can be used in higher amplitude ranges and pneumatic rollers with higher ground pressures when working with coarse mixes.

## Mix Design

**Fine dense-graded**

- Aggregates 13 mm (1/2 in) or less
- More fines and asphalt cement
- Usually layers 5 cm (2 in) or less
- Lower amplitudes
- Lighter pneumatics

FINE OR TENDER MIX

5 cm (2") mat

aggregate size up to 13 mm (1/2")

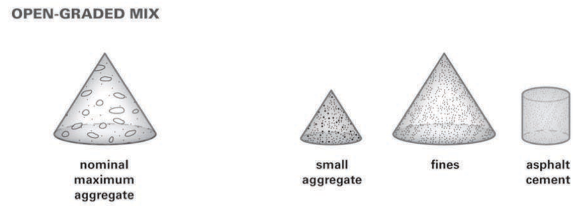
Dense-graded mixes with smaller aggregates are referred to as fine mixes.

Some dense graded mixes are classed as fine mixes. Fine mixes have a maximum aggregate size up to 13 mm (1/2 in) and typically a relatively high percent of fines and asphalt cement. Some fine mixes can be unstable during the compaction process, especially if layer thickness exceeds 50 mm (2 in). Static compaction may be needed to help stabilize fine mixes prior to vibratory passes. High compaction energy can damage layers of fine mix. Lighter rollers, either steel drum or pneumatic, are recommended for use on fine mixes.

## Mix Design

**Open-graded Mix**

- Permeable layers
- Lack intermediate size aggregates
- Often modified, high viscosity binder
- Stone-on-stone contact
- Less compaction energy

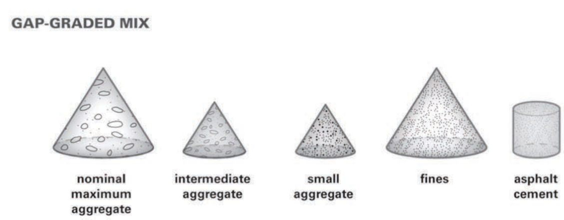



Opened-graded mixes have relatively uniform-sized aggregate typified by an absence of intermediate sized particles. Mix designs typical of this structure are permeable friction layers and asphalt-treated permeable bases. Because of their open structure, precautions are taken to minimize asphalt cement draining down to bottom of the layer by using modified asphalt cement, usually latex rubber or fibers. Stone-on-stone contact with a heavy asphalt cement particle coating is typical for open-graded mixes.

## Mix Design

**Gap-graded Mix**

- Primarily large aggregates and fines
- Smaller amounts of intermediate and small aggregate
- Stone-on-stone contact
- Less compaction energy



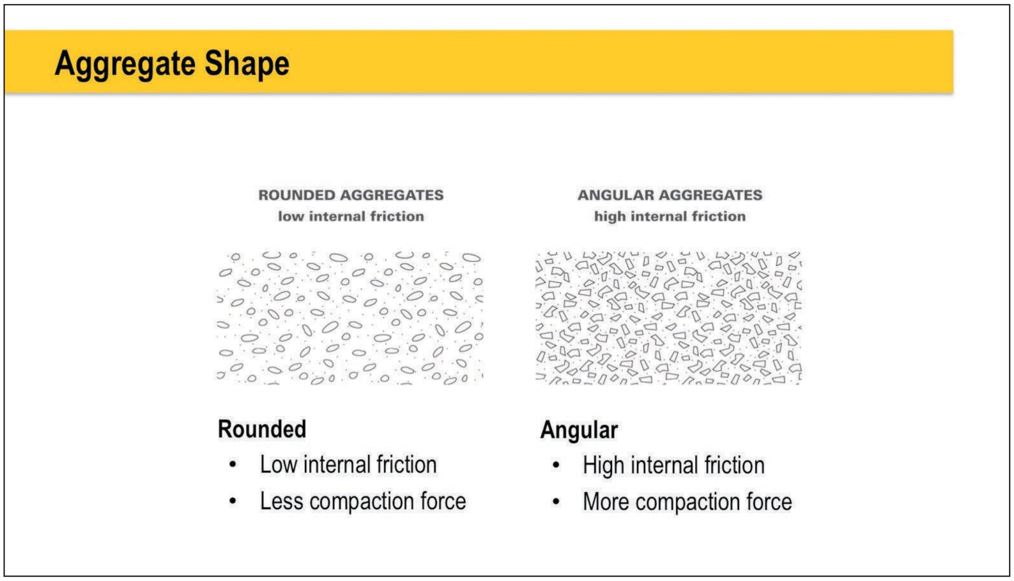

Gap-graded mixes use an aggregate gradation with particles ranging from large to fine with some intermediate and small sizes missing. Gap-graded mixes are also typified by stone-on-stone contact and are more permeable than dense graded mixes.

## Mix Design

**Stone-matrix Mix**

- Large aggregates, fines and binder
- Modified, high viscosity binders create stiff mixes
- Stone-on-stone contact
- Challenging compaction process
- Multiple passes, low amplitude

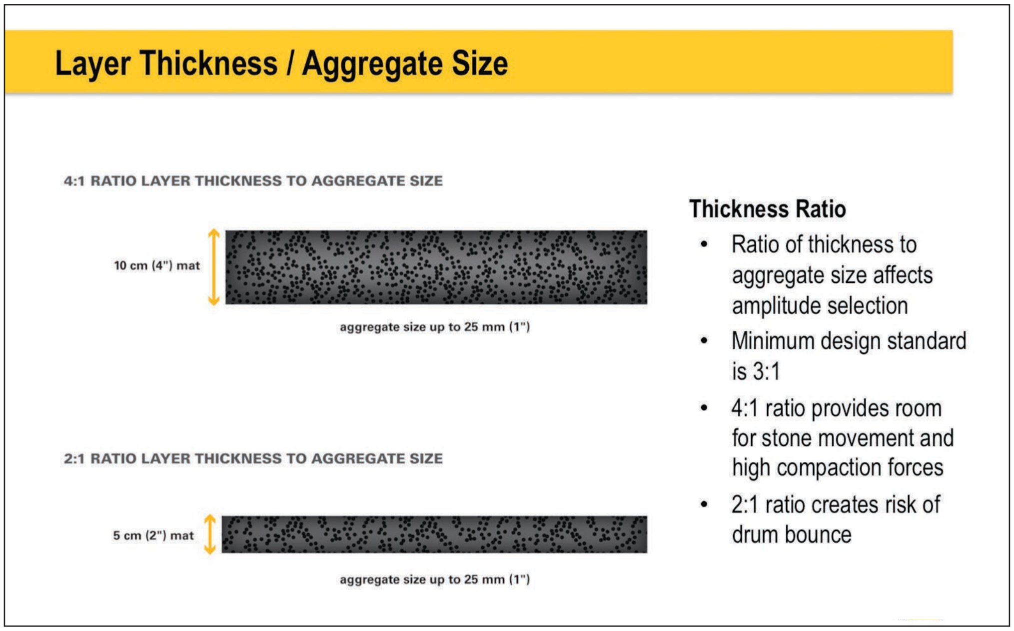

Stone matrix asphalt (SMA), like other open-graded mixes, will be missing most intermediate aggregated sizes. However, stone matrix asphalt mixes have a much higher proportion of fines. Modified asphalt cement combines with these fines to produce a thick mastic coating around and between the large aggregate particles. The asphalt cement is commonly heavily modified, creating a very stiff mix. There is a high degree of stone-on-stone contact. Stone-matrix mixes are often difficult to achieve the specified density. Often, multiple passes in high amplitude are required to create adequate density. The single most critical factor for achieving density with SMA mixes is a high mix temperature. Although temperature is critical with all asphalt mixes, SMAs are particularly sensitive to temperature due to the high fines and mastic content of the mix.




Aggregate shape also affects compaction. The shape of the aggregate determines the amount the internal friction between the particles.

Rounded aggregates have low internal friction and move closer together within the layer under less compaction energy, however, mixes with rounded aggregates tend to be unstable and move around under the weight of the roller. Therefore, when you know the shape of the aggregate is rounded, select low vibratory amplitude or a light static roller.

Angular aggregates, on the other hand, have high internal friction. Once they are moved into contact with each other, angular aggregates produce high pavement strength. More force and heaver rollers are needed to overcome the internal friction between the fractured faces of crushed stone aggregate. Most high traffic mix designs specify the use of crushed aggregates with a certain percentage of fractured faces.

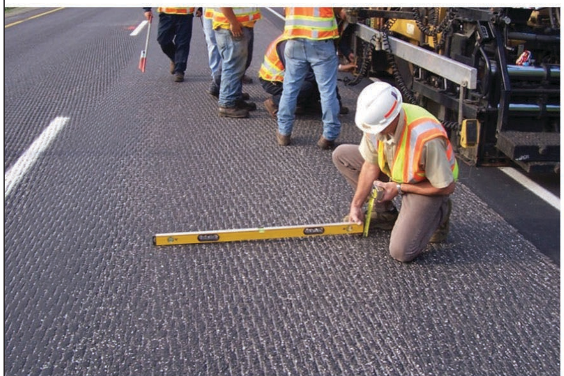



A very important factor is the ratio between the size of the largest aggregate in the mix and the thickness of the layer. This ratio strongly affects the ability of the mat to accept compaction energy and reach the specified density. This is due the "space" available for the aggregate particles to move around and position themselves into a more dense, packed configuration under the compactive force(s) exerted on the mix by the roller.

For example, a layer thickness of 10 cm (4 in) and a maximum aggregate size of 25 mm (1 in) is relatively easy to compact. You can use high compaction forces and not worry about damaging aggregates. With a 4:1 ratio, there is ample space for aggregate movement allowing the aggregates to re-orient. Many public works departments specify a 3:1 ratio as a minimum for high traffic mix design.

When the layer thickness to aggregate size ratio is less than 3:1, the compaction process becomes more difficult. In particular, when there are angular aggregates in the layer, it is likely that those aggregates will not move into the proper compacted orientation without being damaged. The roller operator is more likely to notice drum bouncing or the appearance of uncoated rock at the surface of the mat. Lack of density and damaged aggregates will lead to premature mat failure. When the ratio of layer thickness to aggregate size is less than 3:1, low compaction energy is needed.

## Layer Thickness / Aggregate Size



- Slope changes affect layer thickness & ratio
- Operator must be prepared for drum bounce when paver uses slope control
- Solve drum bouncing by operating in static or one drum vibratory

Even though the pavement design may call for the required minimum 3:1 ratio, there are instances when the layer thickness to aggregate size ratio will be less. The most common situation occurs when slope control is used on the paving equipment to create profile. Slope control of the paver screed means that mat thickness will probably be variable across the width of the mat. For example, the left half of the mat may be 75 mm to 50 mm (3-2 in) thick and the right half of the mat may be 50 mm to 25 mm (2-1 in) thick. The left side of the mat will compact normally, but the drums will probably began to bounce when the roller moves over to the right side. Less compaction energy is needed on the right side. The easiest solution to the problem is operating the roller with one drum vibrating and one drum static, or both drums static.

## Mix Temperature

- Creating density easiest at high temperature
- Upper limit about 160° C (320° F)
- Watch for layer movement in fine mixes
- Stay back if layer is tender due to high temperature


Creating density in any asphalt layer normally is the easiest at the highest possible temperature. At high temperature, the asphalt cement is at its lowest viscosity. The aggregates in the mix move closer together easily when the asphalt cement is fluid, or at its lowest viscosity. As the asphalt cement in the mix cools, the asphalt cement becomes more viscous, or stiffer. The aggregates in the mix lock in position and no more air can be forced out.

Depending on how a mix performs at high temperature, the upper limit that permits compaction is approximately 160° C (32° F). Some types of mixes may be unstable at high temperature and will move in front of the drum rather than consolidate under the drum. Mixes that are unstable at high temperature usually have a high percentage of small aggregate, fines and asphalt cement. When a mix deforms due to high temperature, the solution is to stay farther behind the paver to allow the mat to cool enough to permit normal compaction.

## Mix Temperature

- Reach target density before mat cools
- Lower limit about 90° C (190° F)
- Work close to paver
- Increase compaction energy
- Add initial phase rollers

With most mixes, the required layer density should be achieved by the time the mat cools to around 90° C (190° F). At this temperature the asphalt cement becomes too stiff so no additional aggregate movement and compaction is possible. While you may be able to clean up marks in the surface of the mat, it not likely that you will get additional density. If the mat is cooling before required density is reached:

- Work closer to the paver in a hotter temperature zone
- Increase compaction energy by increasing amplitude
- Add more rollers to achieve compaction before the mat cools further

## Mix Temperature

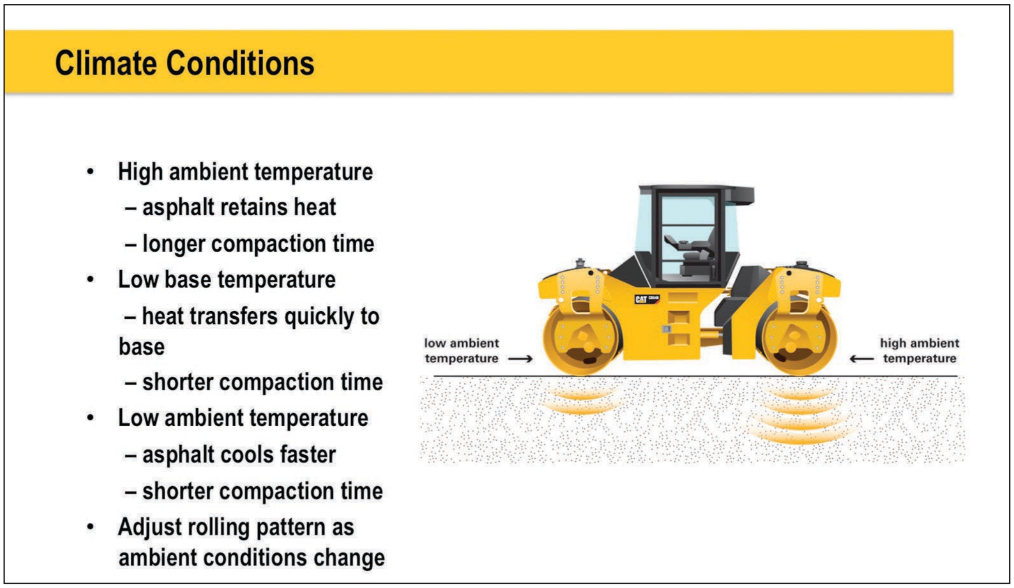
**Tender Zone**

- Some mixes get tender between upper and lower limits
- Surface moves under drums or tires and cracks appear
- Work ahead of tender zone and after


Some mixes have a tender zone that is between the traditional upper and lower temperature limits. The mat will compact normally in a very high temperature range. Then it will become unstable in an intermediate temperature range, called the tender zone. Tender zones are specific temperature ranges, for example ranging from 240°F to 190°F. The mix will behave normally under the action of the rollers above 240°F and below 190°F in this example.

One sign that the roller is working in a tender zone is a rolled over and cracked drum edge mark. If a roller operates on the mat during the tender zone, you will normally see the mat moving in front of the drum or pneumatic tires. Another sign that you are operating in the tender zone will be appearance of a rolled-over and cracked drum edge cut mark. Normally the drum edge leaves a straight cut mark. The rolled-over cut mark that indicates the roller is in the tender zone is probably easier for the operator to see.

When compacting a mix that has a tender zone, you need to get as much density as possible in the high temperature zone. Compaction should normally be stopped when the mat enters the tender zone. When the tender zone ends, the mat normally becomes stable again and more density can be achieved. The mat should be close to final density before the tender zone starts. When the tender zone ends and compaction starts again, select low amplitude to avoid drum bouncing on the cooler, dense mat.




The final factor that influences compaction is climate, primarily ambient temperature, base temperature and wind conditions. On hot, sunny days with high ambient temperature the mat retains its heat longer so the period of workability is increased. In the cooler times of year, particularly in the morning, the base on which we are paving is cool and heat is quickly transferred from the freshly placed mat, reducing the time available for compaction. On cool and windy days, the mat loses heat faster. A crust can actually form over the surface of the mix and prevent the compaction forces from uniformly penetrating into the mat.

Roller operators may have to adjust their rolling patterns as ambient conditions change throughout the day. In the morning when the temperature is normally the lowest, a short rolling pattern may be used in order to stay very close to the paver. As the ambient temperature increases and the mat stays hot longer, the roller operators can increase the length of their rolling patterns and not worry as much about staying close to the paver.

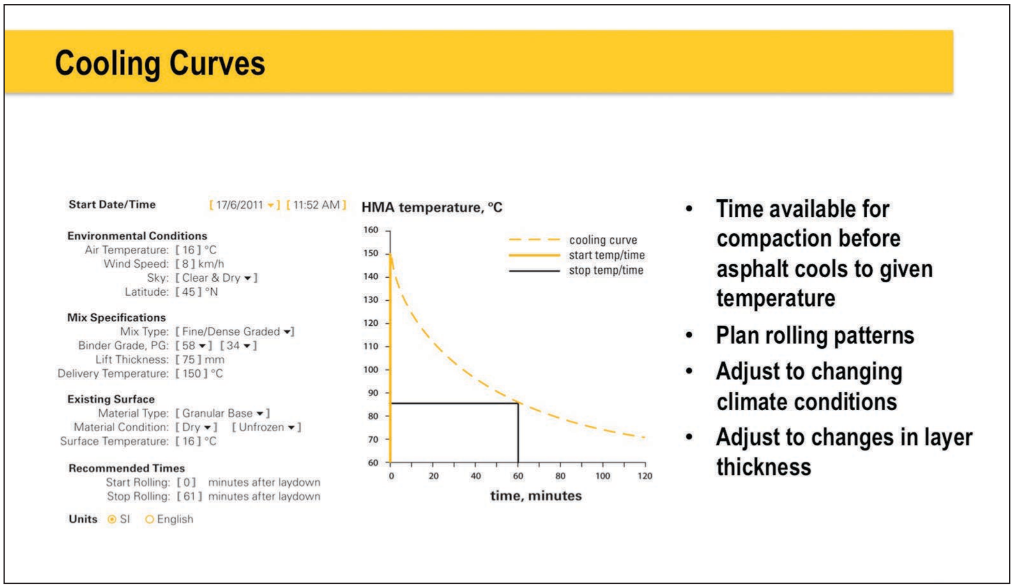
## Climate Conditions


**Checking temperature**

- Infrared scanners show surface temperature
- Add 5-8° C (10-15° F) to get core temperature
- Add 8-28° C (15-50° F) wind present
- Core temperature is better indicator of layer workability

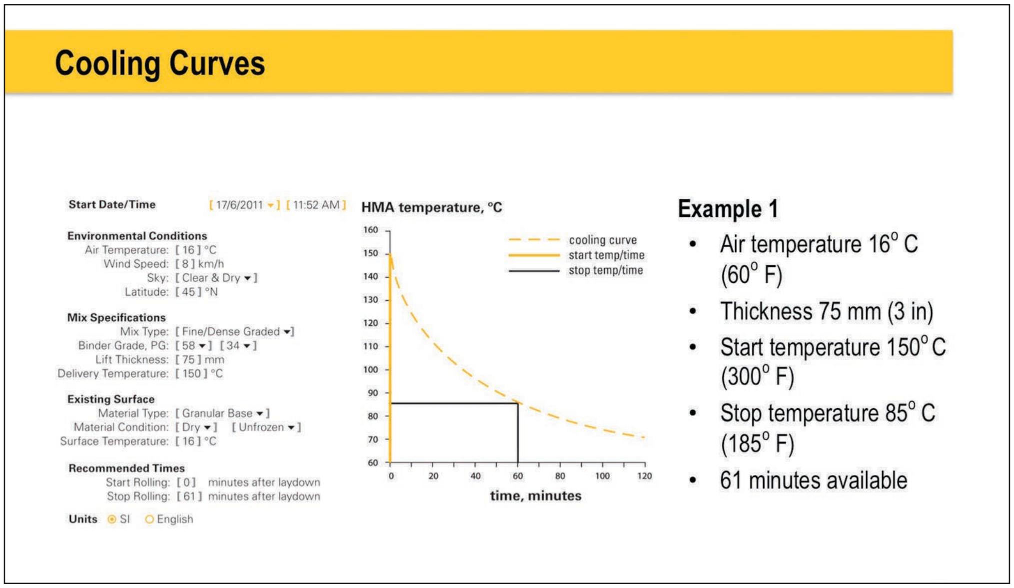
Checking mat temperature is done in two ways. The most common is to use an infrared thermometer to provide a quick check of the surface temperature at a given point. The operator or quality control technician can quickly monitor mat temperatures at various locations. The other way to check mat temperature is using a probe thermometer. The probe shows the internal temperature of the mat, which is a better indicator of how the mix will react to the forces of compaction.

Surface temperature is always lower than the mat's internal temperature. If available, use a probe to check internal temperature. Then use the infrared scanner to check surface temperature at the same location. You may find that the surface temperature is up to 8° C (15° F) cooler than the internal temperature immediately behind the screed. The difference becomes even larger as time passes. It is common to see 20° F to 50° F difference, especially under windy conditions, within a few minutes after the mat has been placed. Knowing the temperature differential will allow you to correlate the surface temperature shown by the infrared thermometer to the internal mat temperature.

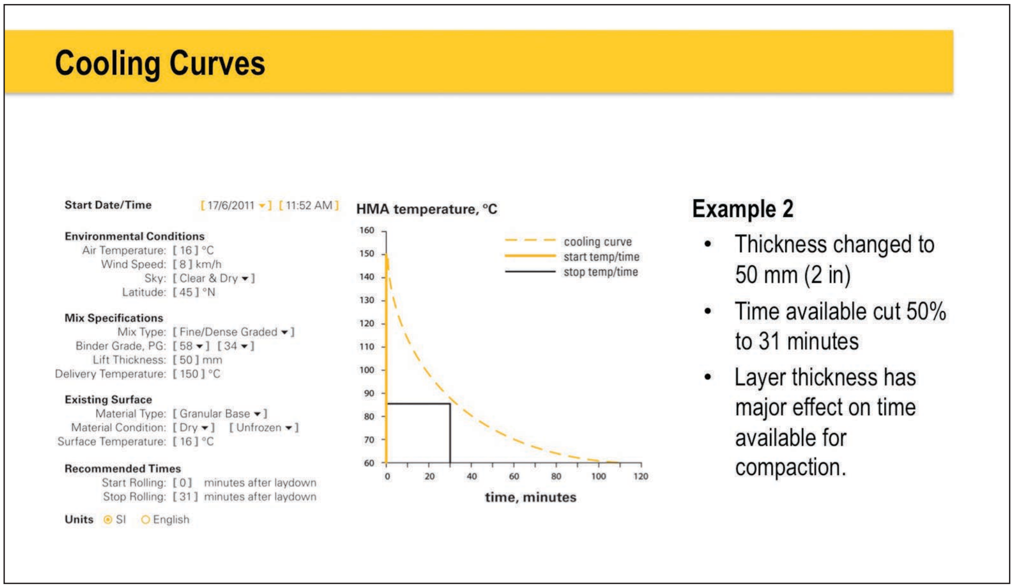



All these temperature and mix design factors are important because they determine how much time you have to get the required density before the mat cools to below 90° C (190° F). We can also use this information to determine how much time we have before the start of a tender zone, if any exists.

In the past, quality control personnel had to use engineering charts to determine the time available for compaction based on layer thickness, layer temperature behind the paver and ambient conditions. Today, there are software programs available to calculate the time available for compaction with more accuracy and faster. One free software is called PaveCool (PaveCoolVersion 2.400 copyright 2001-2005 Minnesota Department of Transportation).



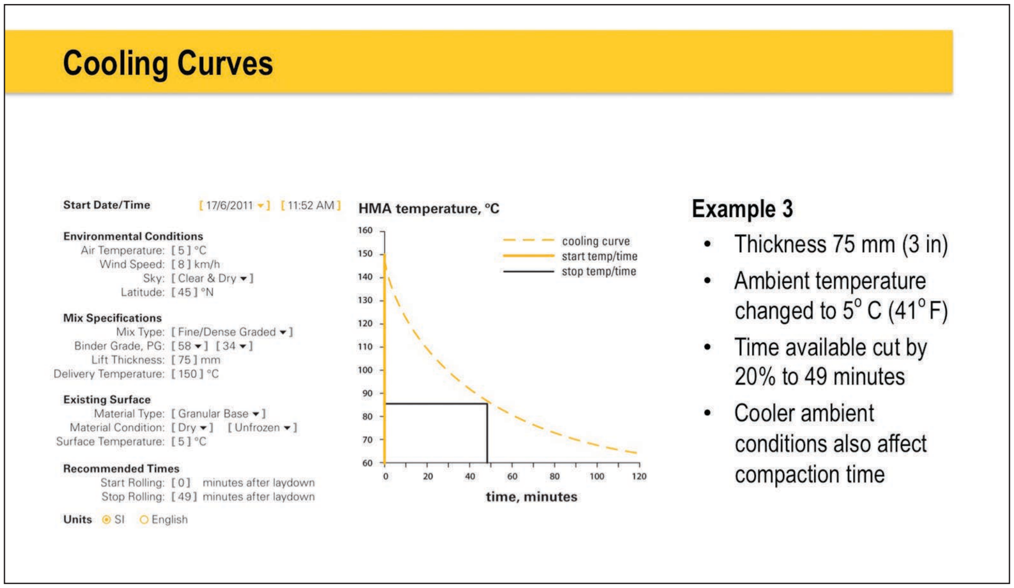

PaveCool software requires input on environmental conditions, mix specifications, and the existing surface. In the first example, the air temperature is 16° C (60° F), the wind is light, it is sunny and the project is located near Paris, France (45 degrees north latitude). The asphalt layer consists of dense-graded material laid 75 mm (3.0 in) thick, and passing under the paver screed at 150° C (300° F). The asphalt layer is being laid down on granular material that is also 16° C (60° F). The resulting cooling curve shows that there are 61 minutes for compaction before the mat cools to the minimum temperature that has been set at 85° C (185° F).



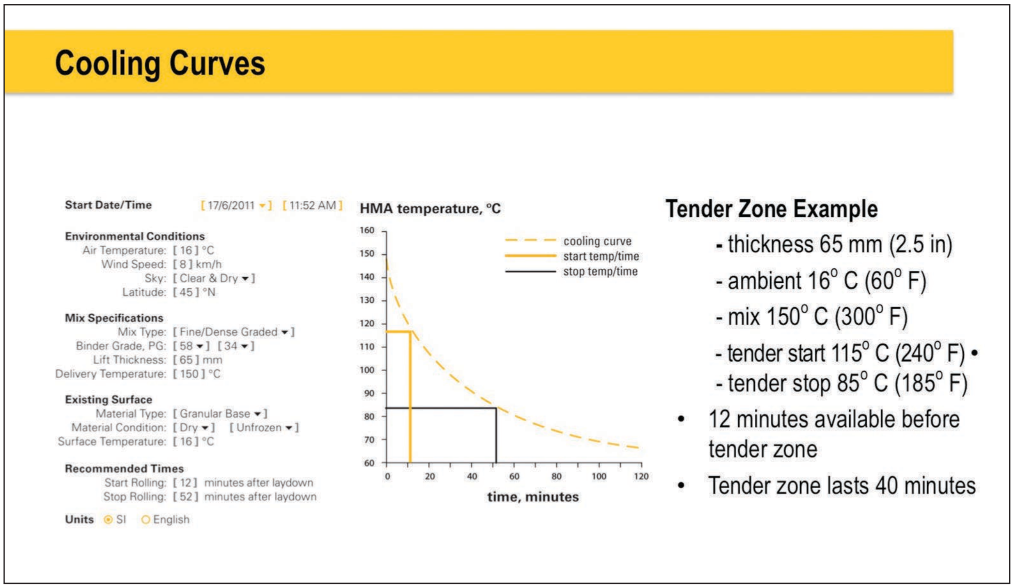

In the next example, all the inputs are the same except the layer thickness that has been changed to 50 mm (2.0 in). When the new cooling curve is calculated, the time available for compaction had decreased by 50%. Time available for compaction is now 31 minutes.

Layer thickness has a major impact on the time available for compaction. The thinner the layer, the more difficult the compaction process. Knowing how much time is available to get density on thin mats will help you determine rolling patterns and the number of rollers needed for the project.


Some rollers feature the ability to offset the front and rear drums to almost double the width of the compaction coverage. Therefore, fewer overlapping passes are generally required to cover the width of the mat. With the drums offset, the amount of compaction force delivered to the mat is reduced. However, thin mats require less compaction force and the roller is able to work closer to the paver where the mat is hotter and more susceptible to compaction.




Example 3 shows that lift thickness plays a significant role in the time available for compaction. In Example 1, we showed approximately 61 minutes time available for compaction. Here in Example 3, we have reduced the ambient air temperature from 15° C to 5° C and left all other variables the same. The time available for compaction is reduced by 12 minutes, or approximately 20%. PaveCool software can be used to run different scenarios and as a training tool to show the significance of changing certain variables.




In this example, the ambient temperature is 16° C (60° F). We are laying down a dense-graded mix at a depth of 65 mm (2.5 in). The mix is passing under the screed at 150° C (300° F). We have documented that the mix begins to display tenderness at 115° C (240° F). We have documented that the mat becomes stable again at 85° C (185° F).

The cooling curve shows that there are 12 minutes available for compaction prior to the start of the tender zone. We will want to get as much density as possible during this 12-minute period and then stay off the mat for 40 minutes. After the tender zone disappears, high frequency with low amplitude is commonly used to gain more density if needed. Or, static rolling to clean up any drum marks may be all that is necessary.

## Amplitude Checklist

| Factor | Lower Force 0.25 - 0.6 mm | Higher Force >0.6 mm |
|---|---|---|
| Layer Thickness | <50 mm (2.0 in) | >50 mm (2.0 in) |
| Base Support | Rigid | Flexible |
| Binder Viscosity | Low (unmodified) | High (modified) |
| Aggregate Shape | Rounded | Angular |
| Ambient Temperature | High | Low |

This checklist helps tie together all the compaction factors that have been covered so far, and will help determine how much compaction force is needed for a particular application. Down the left side are the application factors that would tend to lead us to select lower or medium amplitude settings. Down the right side are the application factors that would tend to lead us to select medium or high amplitude settings.

As a general rule, layer thickness less than 50 mm (2 in) will not accept high compaction energy. Therefore, amplitude settings in the range 0.25 mm to 0.6 mm (0.010-0.025 in) would typically be selected. When the asphalt layer is thicker than 50 mm (2 in), the mat can accept more compaction energy and we would tend to select amplitude that is 0.6 mm (0.025 in) or higher.

The type of base that we are paving over has an effect on amplitude selection. If the base is rigid, like a milled surface or an existing asphalt surface, too much compaction energy will cause drum bouncing more easily. If we are paving over granular material or stabilized subgrade, that type of base is more yielding. We would tend to select higher amplitudes for that application because the flexible base will absorb some of the compaction energy.

We need to consider the type of asphalt cement used in a particular mix design. If the asphalt cement has been modified with fibers or latex rubber, for example, the binder will have high viscosity, the mix will be considered stiff and will need higher forces. Unmodified asphalt cement has a lower viscosity and that mix will need lower compaction energy to get the required density.

Always consider the shape of the aggregate in the mix design. Most high traffic, highway class asphalt structures use mixes with all fractured faces. The angular aggregates produce high internal friction. We would tend to select higher amplitudes settings in order to move the rock and remove air voids. Most street and parking lot mixes have aggregates with some rounded faces. Since the aggregate moves more easily, these mixes require lower compaction energy.

Climate conditions are the final factor in the checklist. On hot, sunny days, asphalt layers tend to retain their heat longer and since we have more time we can use lower forces. When the ambient temperature is low and there are high winds, the asphalt layer will cool off rapidly. In order to get density before the mat loses too much temperature, we would select the highest amplitude setting to try to get density quickly.

## Summary

- Operators and quality control personnel must understand factors that affect compaction
- Gather information
- Evaluate information
- Plan the work
- Communicate the plan


Knowing the factors that affect asphalt compaction is a vital skill for operators, quality control technicians and supervisors. Much of the information about mix design is contained on the job mix formula that should be available from the asphalt plant. Items such as layer thickness and type of base for each layer will be shown on cross sections plans. Only climate conditions need to be analyzed for each shift.

If we gather enough information and know how to think about that information, we can make better decisions when setting up the compaction process. If we rely only past performance or experience, we may be ignoring new valuable information.

What we have learned about the forces of compaction and the factors that affect compaction will help us set up the compaction train.

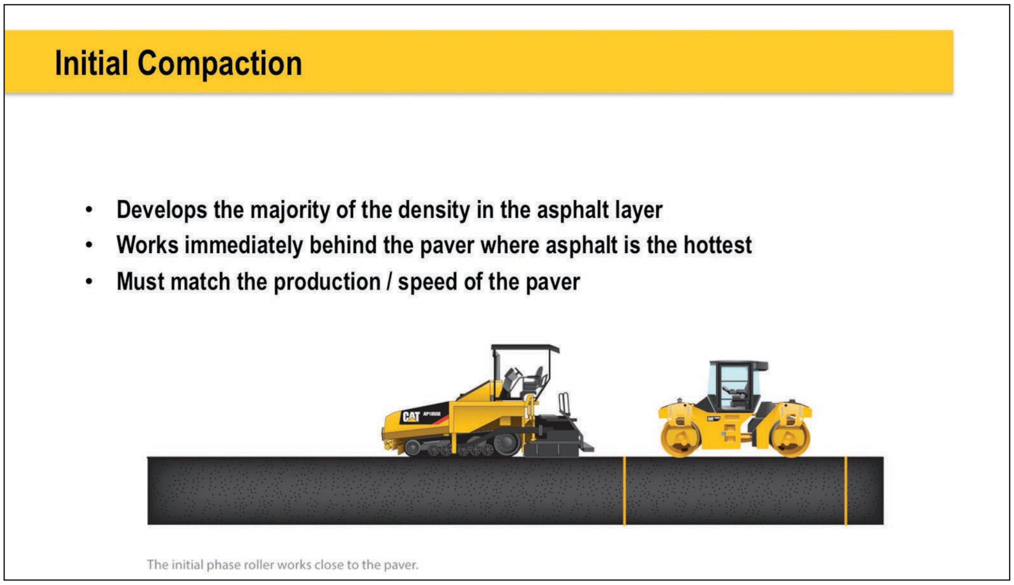
## Drum Width

- Cover mat in no more than 3 overlapping passes
- Applies to highways, roads, streets where production is a concern

Required Number of Overlapping Passes per Drum Width

| Paving Width (Meters / Feet) | Drum Widths | | | | |
|---|---|---|---|---|---|
| | 140 cm (55in) | 150 cm (59in) | 170 cm (67in) | 200 cm (79in) | 213 cm (84in) |
| 2.5 / 8 | 2 | 2 | 2 | | |
| 2.75 / 9 | 3 | 3 | 2 | | |
| 3.00 / 10 | 3 | 3 | 3 | 2 | 2 |
| 3.35 / 11 | 3 | 3 | 3 | 2 | 2 |
| 3.70 / 12 | (4) | 3 | 3 | 2 | 2 |
| 4.00 / 13 | | | 3 | 3 | 2 |
| 4.25 / 14 | | | 3 | 3 | 3 |
| 4.50 / 15 | | | | 3 | 3 |
| 4.80 / 16 | | | | 3 | 3 |
| 5.20 / 17 | | | | 3 | 3 |
| 5.50 / 18 | | | | | 3 |

When selecting rollers for a project, one general rule states that the drums must be wide enough to cover the width of the mat in no more than three overlapping passes. In some situations, the roller will need more than three passes. If this is the case, another roller should be added. This general rule applies to projects such as highways, roads and major street paving where production is usually an important factor. The rule typically does not apply for projects like parking lots or low production projects. The chart is a reference that is used to help select the correct drum width based solely on covering the mat in no more than three overlapping passes. Drum widths shown are minimum and maximum typically available for higher production projects.




Initial compaction is the first step in the compaction process and should produce the majority of the target density in the mat. For example, if the target density for final compaction is 95% of theoretical maximum density, the initial phase should produce at least 91% to 93% of theoretical maximum.

Initial compaction should begin at the highest possible mat temperature that supports the weight of the roller without distorting the mat. Remember, once the mat begins to cool, the asphalt cement in the mix gets stiffer and density is harder to achieve. For this reason, the initial compaction phase must occur in a zone very close to the paver. The paver and initial phase compactor(s) must have the same production rate.

## Initial Compaction

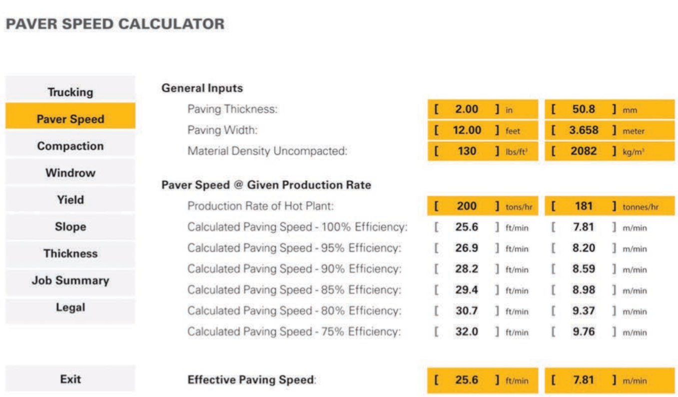
**Initial Phase Rollers**

- Vibratory steel drum rollers are most common
- Highest production rates
- Pneumatic rollers sometimes used on base or binder layers

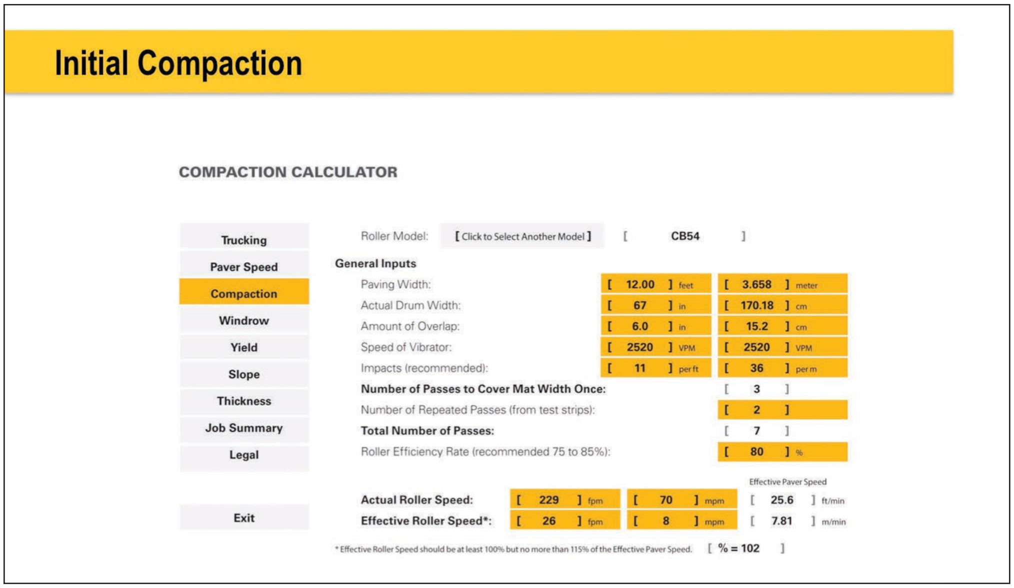

Steel drum, vibratory rollers are commonly selected for the initial phase of compaction. Because vibratory rollers combine weight and impact, they normally have the highest production rates. Pneumatic rollers are sometimes used in the initial compaction phase on base or binder layers.

Vibratory rollers have different vibratory characteristics as well as different drum widths. How we set up the vibratory system affects how well the initial phase roller will match the paver's production. Let's look at some examples from the Cat Interactive Production Calculator.

## Initial Compaction



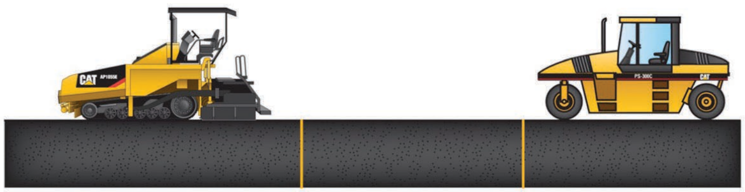

In this example the production rate is 181 tonnes per hour (200 tons per hour). The paving width is 3.66 m (12 ft) and the paving thickness is 50 mm (2 in). The weight of the material as it passes under the screed (vibratory energy only) is 2082 kg/m$^3$ (130 lb/ft$^3$). If a material transfer device is being used on the project, the actual paving speed may be as low as 7.8 meters per minute (25.6 feet per minute). If mix is being transferred directly from haul units to the paver, the actual paving speed is calculated at 9.8 meters per minute (32.0 feet per minute). At a 75% efficiency rate, the effective speed is 7.8 meters per minute (25.6 feet per minute). Therefore, the production rate of the initial roller must be high enough to match the effective paving speed.




On this project, a Cat CB54 Asphalt roller is available. The CB54 has 170 cm (67 in) wide drums that can cover the mat in three overlapping passes. Low frequency, 42 Hz (2520 vibrations per minute), has been selected. From work with similar mix on test strips, it is estimated that two repeat passes will produce the target density for the initial phase. Three overlapping passes with two repeat passes creates a seven-pass pattern. An 80% efficiency rate accounts for water refill stops and roller stops for reversing. An actual working speed of 70 meters per minute (229 feet per minute) will match the effective paving speed. The production calculator also shows that the impact spacing is well within the desired range, which is 32 to 46 impacts per meter (10-14 impacts per foot).

## Intermediate Compaction

- Normally immediately after initial phase compaction
- Goal is to develop final target density



Intermediate compaction closely follows the initial phase.

Intermediate compaction follows immediately after the initial phase on most mixes. The goals of intermediate compaction are to achieve the final target density in the mat and to begin the process of cleaning up marks left by the initial phase roller.

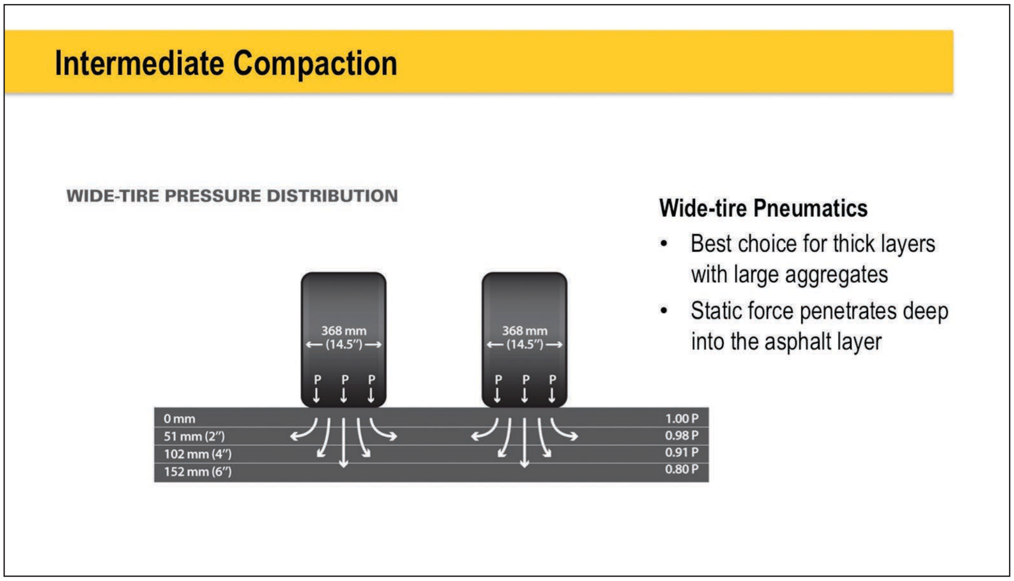
The mat should be hot enough to allow some aggregate movement so usually intermediate rollers work in the temperature zone just behind the initial phase temperature zone. Depending on the thickness of the mat, you have to be careful about the type and amount of force you apply. Remember, the mat in the intermediate phase is already close to the final target density and you're trying to increase density by one to three percent.

## Intermediate Compaction

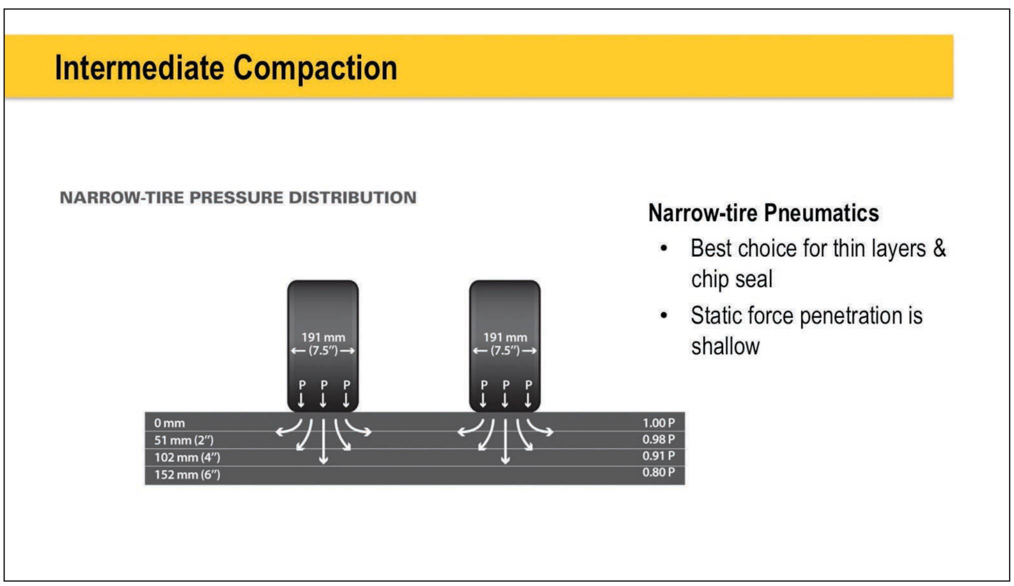
**Intermediate Phase Rollers**

- Pneumatic rollers do not impact asphalt layer
- Less risk of damage to asphalt layer

Pneumatic rollers are a common choice for intermediate compaction because they can exert high static pressure without delivering impact forces. The type of pneumatic roller selected for the intermediate phase depends on mat thickness and asphalt mix formula.




For thick, harsh mat compaction, a pneumatic roller with wide tires is the best choice. The wide tires can withstand much higher loads that are needed to get final density in harsh mixes that are characterized by large aggregates. Notice that even at a depth of 100 mm (4.0 in) the compaction pressure is till 90% effective. Wide tire pneumatic rollers are a good choice for base and binder layers that are normally the thickest layers in the pavement structure.




Pneumatic rollers with narrow tires exert high ground contact pressure, but that pressure is most effective on thin, stiff mats. Notice that the pressure diminishes rapidly when mat depth exceeds 50 mm (2.0 in). Pneumatic rollers with narrow tires are a good choice for wear layers that are typically the thinnest and made of the stiffest material.

## Intermediate Compaction

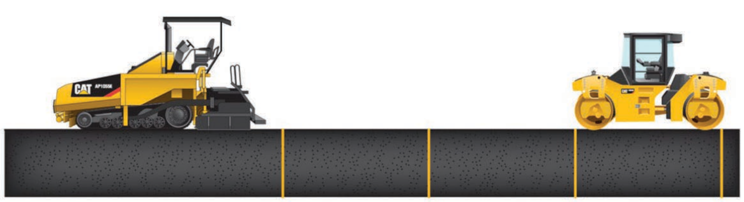
**Intermediate Phase Rollers**

- Steel drum vibratory
- Set in high frequency, low amplitude
- Layer is cooler and close to final density
- Be alert for drum bounce

If steel drum vibratory rollers are selected for the intermediate phase of compaction, be careful not to use too much impact force. The mat is already close to final density so high frequency combined with the lowest amplitude is probably going to work the best. Also, the mat temperature in the intermediate zone will have cooled to around 110° C (230° F). Vibrating aggressively on cool mats can result in impact marks that do not clean up during the finish phase or can cause fractured aggregates at the surface of the mat.

## Finish Compaction

- **Goal is to clean up marks left by previous rollers**
- **Mat just warm enough to allow clean up at the surface**
- **May get some density gain**



The finish roller may be an hour behind the paver where the mat is cool.

The final phase is finish compaction. The primary goal of the finish phase is to remove any drum stop marks or pneumatic tire marks. There may be small gains in density from the finish phase, but if you depend on getting more density during the finish phase, you are taking a risk.

The finish phase normally takes place when the mat is still warm enough to allow the removal of marks in the surface. If the finish roller is leaving its own stop marks, the mat is still too warm and finish compaction should be delayed even more. It is common for the finish roller to be as much as an hour behind the paver. Finish roller operators benefit from on-board temperature sensors or hand-held temperature scanners to help them stay in the correct temperature zone.

## Final Compaction

**Finish Phase Roller**

- Double drum rollers in static mode are most common
- Narrow drums are good choice
- Long, slow passes

Double drum rollers operated in the static mode are the most common finish rollers. Remember, the narrower the drum width, the higher the static force exerted. It is common to see smaller rollers used in the finish position.

Vibration should <u>not</u> be used in the finish phase. If additional density is required, the problem needs to addressed in the initial and intermediate phases. The goal of the finish phase is smoothness not density gains. The finish roller should make long, slow passes to make the mat smoother. If the finish phase on a portion of the mat is completed and the finish roller needs to park and wait, park only a portion of the mat or an adjoining surface that is cool enough to support the machine without deforming the mat.

## Test Strips

- Verify equipment and patterns develop required density
- Plan each phase of compaction
- Communicate plan to all crew members

On many projects, the public works department in charge of the project will require that a test strip be successfully completed before the start of full production on the project. The requirements for test strips vary greatly from one location to another. In general, the test strip verifies that asphalt production meets the job mix formula, that the paving equipment lays down a satisfactory mat, and that the selected compaction equipment achieves the specified density.

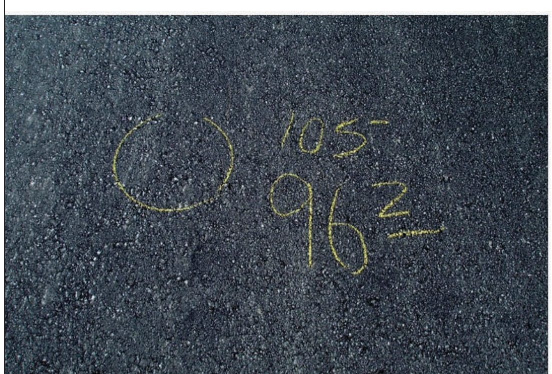
The quality control technician or supervisor should have planned a rolling pattern for each phase of compaction and for the initial phase roller should have selected vibratory amplitude, vibratory frequency and working speed. The vibratory characteristics are determined by type of mix and thickness of the asphalt layer and the working speed of the paver.

## Test Strips

- Check screed laid density
- Monitor temperature of the asphalt layer
- Document start and stop of tender zone, if any


As soon as the paver pulls off the starting joint, begin to collect data. Once the paver has reached planned paving speed and the correct mat thickness has been established, check the temperature of the mat directly behind the paver screed. Throughout the length of the test strip continue to check and document mat temperature. Consistent mat temperature is one of the keys to creating consistent mat density. If the mix used on the project has a tender zone, you will be able to document the temperature for the start of the tender zone and the temperature when tenderness disappears.

## Test Strips




- Check density across width of the asphalt layer
- Check density after each initial phase pass
- Outline the gauge placement
- Write numbers that operator can see

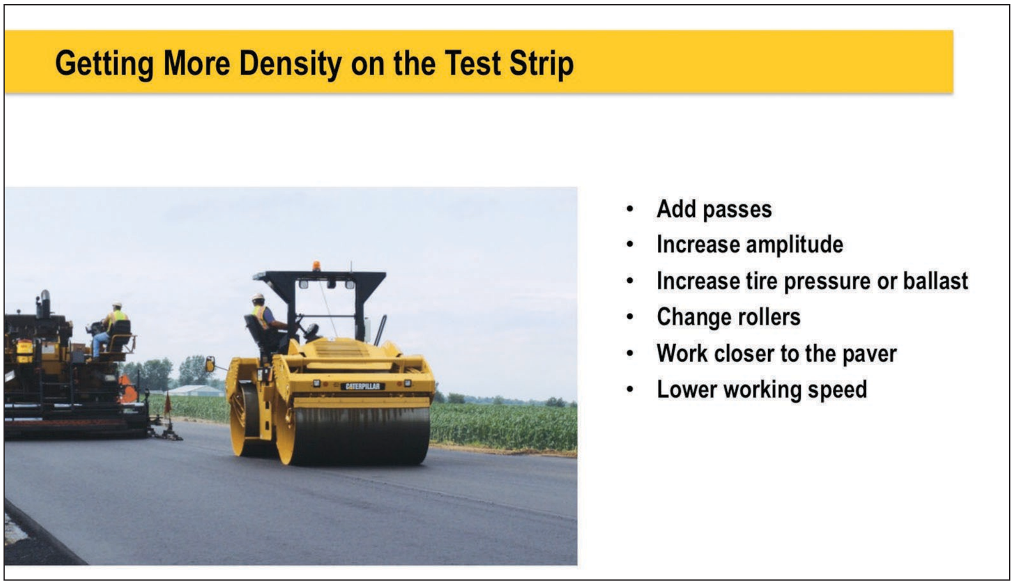
Check density at several places across the width of the mat. Check the density of the mat after each pass made by the initial phase roller. Continue to make passes with the initial phase roller until you have reached the target for the initial phase.

When you place the density testing gauge on the mat to make the first density check, draw an outline around the base of the gauge with chalk or lumber crayon. The chalk outline will help you put the gauge in exactly the same spot after each pass. Write the tested density on the asphalt layer in numbers big enough for the roller operators to see. The operators should not stop on the hot asphalt to discuss issues with the quality control technician.

## Test Strips

- Pull core as soon as possible
- Verify accuracy of on-site testing gauge

The test strip has been successfully completed from the standpoint of density measurements taken in the field. Cores extracted from the asphalt layer and analyzed in a laboratory will confirm the densities and allow us to further calibrate the density testing gauge, if necessary.




If the initial phase roller using the selected vibratory settings and rolling pattern does not achieve the required density, changes will be necessary. Sometimes you can continue working on the same area of the test strip if the mat is still hot enough. Following is a list of ways to increase density:

Add more passes. You can add more passes only if you can continue to match the paving speed.

Increase amplitude. If a higher amplitude setting is available and the asphalt layer will accept the additional force without causing drum bounce, select the higher amplitude.

Increase tire pressure or ballast weight. If a pneumatic roller is used for initial compaction, you should be able increase the compaction force without damaging the mat.

Use a higher production roller. If one is available, a roller with wider drums or higher amplitude may be substituted. A roller with wider drums may cover the mat in fewer overlapping passes and create a faster pattern that makes it easier to add passes.

Work closer to the paver. By keeping the initial roller very close to the paver you will be working on the hottest asphalt. You may have to shorten the length of the rolling pattern to accomplish this.

Slow the working speed of the roller. A slower working speed delivers more force to the area being covered because the impact spacing is closer. This assumes that the slower speed will still allow the roller to keep up with the paver.

## Summary

- Meeting end result specifications requires planning and communication
- Each project is different
- Each project requires analysis

Setting up the compaction process and successfully meeting end result specifications requires planning and gathering data.  Assuming a process that was successful on one project will also be successful on another project is very risky.  True experience is a good teacher, but there are many variables that affect density. Each project deserves a full analysis prior to starting work.

## Rolling Patterns

- Series of movements made by rollers on a fresh layer
- Need to be consistent to produce uniform density
- Should not change unless conditions change

***Note:*** *Pass is defined as one movement from Point A to Point B*


A rolling pattern is a series of movements made by a roller or rollers on a freshly-laid, uncompacted asphalt layer. The rolling pattern is intended to be consistently repeated in order to produce uniform density in the asphalt layer.

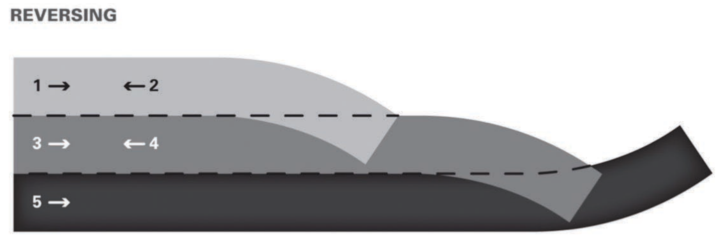
The rolling pattern covers a certain area of square meters (feet) defined by the length and width of the pattern. It is assumed that the thickness of the asphalt layer is relatively consistent from one edge of the mat to the other within the pattern. The temperature of the asphalt mix within the rolling pattern will also be reasonably consistent as long as the area covered by the pattern is always in the same relationship to the paver as the paver moves forward. Therefore, a rolling pattern with a consistent number of passes, a consistent working speed and consistent compaction forces should produce uniform density.

In this presentation, the term “pass” shall mean the movement of the roller in one direction. In other words, when the roller begins a pattern by moving forward from a starting point to a point closer to the paver, that movement is considered one pass. When the roller reverses to return to the starting point of the pattern, that movement is considered another pass.

Once a rolling pattern has been established it should not be altered unless there are changes in the paving process in front of the roller, changes in the mix formula, or changes in climate conditions.

## Basic Rolling Pattern

- Roller stops always made at an angle
- Next pass forward rolls through stop mark
- Stop marks are staggered as roller moves ahead to keep up with paver




There are certain techniques that are common to any rolling pattern. One technique is stopping and reversing a double drum roller at the end of a pass. In the drawing shown above, it is assumed that the mat has two unconfined edges or that there is no adjacent cold mat to roll onto. The roller operator must stop and reverse on the hot mat.

At the end of Pass One, the operator turns toward the center of the mat and stops slowly with both drums turned at least 30 degrees leaving the stop mark at angle to the direction of compaction. The operator reverses in the same path for Pass Two.

Pass Three is down the center of the mat with some overlap on the coverage of passes one and two. Pass Three is longer than Pass One in order to keep up with the paver and to clean up the stop mark left at the end of Pass One. At the end of Pass Three, the operator turns toward the uncompacted edge, being careful to not push out the edge of the mat. Again, the stop mark is left at an angle to the direction of compaction. The operator reverses in the same path for Pass Four.

Pass Five is along the other unconfined edge with some overlap on the coverage of passes three and four. Pass Five continues through the stop mark left at the end of Pass Three. At the end of Pass Five, the operator turns toward the center of the mat leaving an angled stop mark where the next pattern will clean it up. The operator reverses in the same path for Pass Six.

Pass Seven will reposition the roller to start another pattern. This is called a seven-pass pattern. This pattern results when it takes three overlapping passes to cover the width of the mat and it takes two passes per coverage to create the required density.

## Basic Rolling Pattern

**Staggered Stop Marks**

- Don't stop in same area
- Major smoothness issue
- Roll through stop marks

When reversing on a hot asphalt layer, avoid stopping to reverse in the same area. Leaving stop marks close together can distort the hot asphalt and create bumps that do not clean up during the intermediate and finish phases. Roll through stop marks during successive passes, always moving forward closer to the paver with each pass.

## Basic Rolling Pattern

**Stopping Near the Paver**

- Worker safety is the primary consideration
- Be aware of personnel around the paver
- Stop at least 5 m (15 ft) behind the paver
- Shut off vibratory system as roller slows down

Initial phase rollers are always stopping to reverse in proximity to the rear of the paver. There are no absolute rules that dictate how far behind the paver the roller should stop. Workplace safety should be the primary consideration. A reasonable guideline would be for the compactor(s) to stop at least 5 m (15 ft) behind the paver. Remember, there may be laborers or screed operators working on the mat behind the paver.

When stopping a steel drum roller to reverse direction, whether on a hot mat or a cold adjacent mat, always shut off the vibratory system as soon as you begin to slow down. Remember, it is important to maintain drum impact spacing. As the machine speed decreases, the impacts may be too close together. You can manually deactivate the vibratory system or you can select the “AutoVibe” feature that will automatically stop and start the vibratory system when the working speed reaches programmed levels.

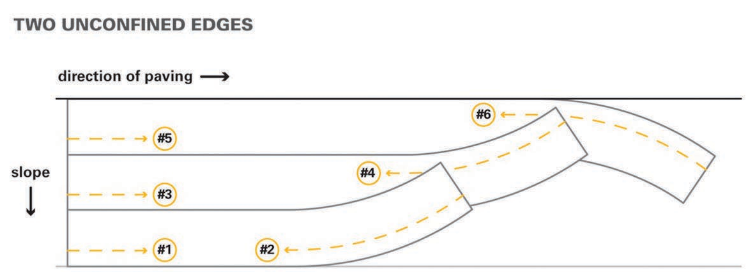
## Basic Rolling Pattern

**Pneumatic Roller Stops**

- Do not turn during stops
- Stop slowly
- Finish roller should be able to clean up stops marks

Unlike steel drums, the rubber tires on pneumatic rollers should not be turned when bringing the roller to a stop. Aggressive turns with pneumatic rollers will tear the mat. The pneumatic roller should stop slowly without turning. There will be a slight stop mark in the mat, but usually the finish roller will clean up those marks completely.

## Pattern for Two Unconfined Edges




- **Start at the low side of the sloped asphalt layer**
- **Reduces the amount of asphalt distortion**

When the structure to be compacted has two unconfined edges and a sloped surface, Caterpillar recommends making the first passes along the lower edge of the structure. The next series should be in the center of the mat. The final passes should be along the upper unconfined edge. Compaction from the low side to the high side tends to build strength in the mat and reduce the amount of mat deformation.

## Pattern for Two Unconfined Edges

**Steel Drum Roller**
- First pass 15 cm (6 in) off edge
- Overlap following passes
- Watch for cracking

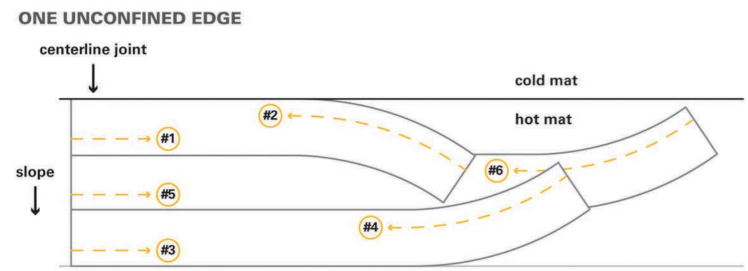

**Pneumatic Roller**
- Never overlap unconfined edge
- Roll 15-30 cm (6-12 in) off edge

In general, the first pass along any unconfined edge should be made with the drum edge at least 15 cm (6 in) away from the edge. The second pass, typically the return pass in the same coverage area as the first pass, should be made with the drum slightly overlapping the edge. This sequence also helps minimize mat distortion.

When compacting unconfined edges, watch for cracks in the mat along the drum edge when the drum edge is set back from the unconfined edge. Some mixes with large aggregates and low asphalt cement content will show deep cracks if the edge is not overlapped during the first pass. When cracks appear, immediately change the rolling pattern to overlap the unconfined edge with every pass along the edge of the mat.

Pneumatic rollers should not overlap unconfined edges. The rubber tires should be at least 15 cm (6 in) away from the unconfined edge to avoid rolling over or distorting the edge of the mat.

## Pattern for Two Unconfined Edges




- Best joint density – start at hot / cold joint; overlap Pass Two
- Move to low side unconfined edge to build strength
- Finish pattern in the center

In this example, we assume that the left edge of the mat is matching an adjacent mat along the centerline of the structure. The adjacent mat is compacted and is cold. There are traffic cones set adjacent to the centerline edge on the cold mat and traffic is present on the cold mat. There is a two percent slope from the centerline down to the unconfined edge.

For best longitudinal joint density, the first pass should be along the left edge of the mat to take advantage of the highest mat temperature to get the highest joint density. Both drums should be completely on the hot mat about 15-30 cm (6-12 in) away from the cold mat. During Pass Two, the return pass along the left edge, the drums should be positioned to overlap the hot / cold joint by about 15 cm (6 in). The overlap will begin the process of sealing the longitudinal centerline joint.

Passes Three and Four will be along the unconfined edge to build strength and minimize mat deformation at the unconfined edge.

Passes Five and Six are made in the center of the mat. This portion of the mat will be the coolest by this time, but the center portion of the mat will have, in effect, two confined edges to aid in compaction.

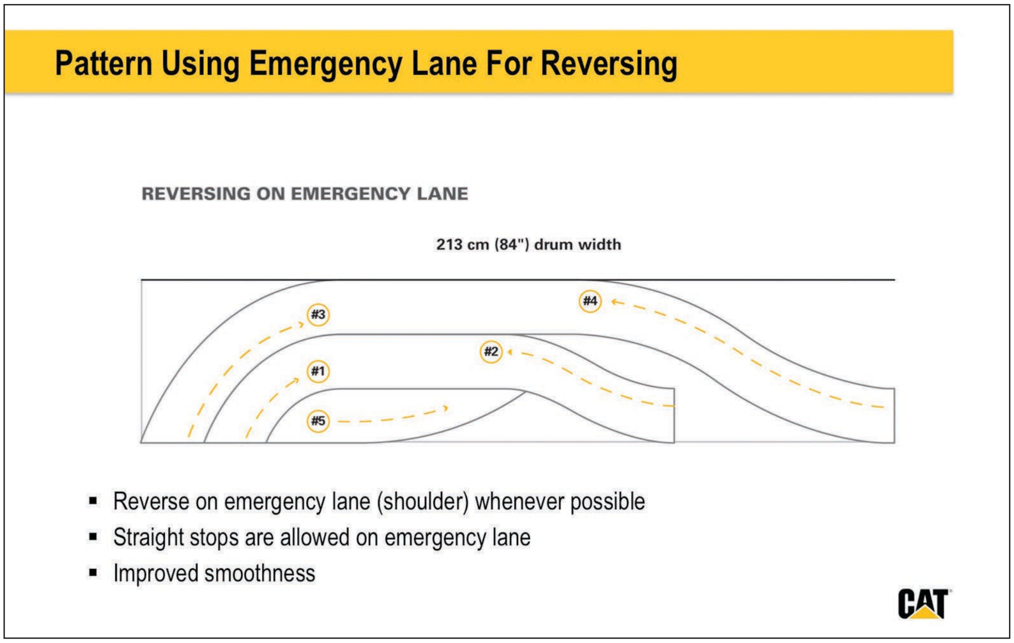
## Pattern for One Unconfined Edge

**Hot/Cold Confined Edge**

- Make stops on cold side when possible
- Pilot vehicle may be leading traffic on cold side—be alert
- Laborers / inspectors may be present—be alert

On some projects, the edge of the mat that is matching a joint will be adjacent to a cold, compacted mat. Whenever it is possible, the roller operators should roll off the hot mat and onto the cold mat to stop and reverse direction. By reversing direction on the cold mat, there will be no stop marks left on the hot asphalt layer and smoothness will be improved.

The roller operator must be aware of several safety issues when rolling off the hot mat to stop and reverse. First, there may be traffic using the adjacent lane. Pilot vehicles may be leading traffic through the work zone. The operator should never pull onto the adjacent mat if there is traffic present. Second, there may be workers around the paver. In particular, laborers may be raking the joint behind the paver. Be sure to pull off the mat far enough behind the paver if there are workers present.




If the emergency lane is at least 1.50 m (5.0 ft) wide, the emergency lane can be included in the initial phase pattern and can be used for all roller stopping and reversing.

The rolling pattern will resemble a series of half circles. After each pass, forward and backward, the roller operator will arc slowly across the driving lane and straighten out on the emergency lane with both drums on the emergency lane. The roller operator will stop straight. Stopping straight is generally permitted on emergency lanes since there is no smoothness specification for emergency lanes. If a pneumatic roller is part of the compaction train, the pneumatic roller will continue to stop straight on the driving lane and will not turn off onto the emergency lane. The finish roller should use the emergency lane for stopping and reversing, too.

## Echelon Compaction Patterns


**Echelon Patterns**

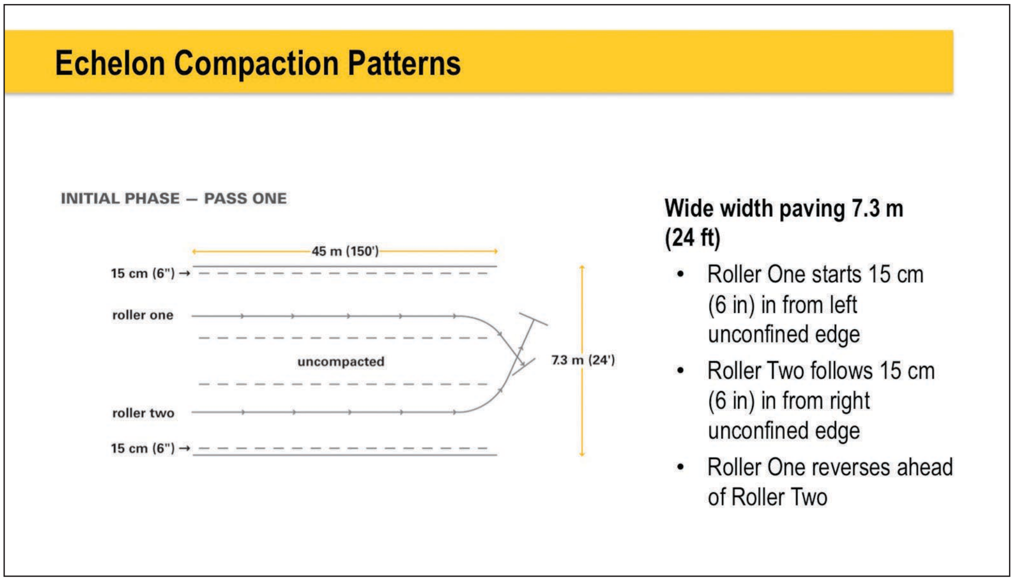
- Paving width exceeds 6 m (20 ft)
- Stiff mix requiring many passes
- Limited time for initial phase of compaction

On some projects, two or more rollers may operate in the initial compaction position directly behind the paver. There are several reasons why an echelon pattern should be selected.

Wide width paving. When the paving width exceeds 6 m (20 ft), it is unlikely that one roller will be able to cover the paving width in three or fewer passes. Therefore, in general, one initial roller will not be able to match the paver production.

Stiff mix requiring many passes. Some mix designs, especially those including modified asphalt cement, are very stiff and require many passes to bring density up to required levels. In that situation, the pattern needed for one roller will cause that roller to fall behind the paver.

Limited time for initial compaction. The time available for initial compaction may be limited by the thickness of the mat, ambient temperature, or the appearance of a tender zone in the mat. Sometimes, more than one initial roller is needed to cope with rapid temperature loss and a short opportunity to get initial density.

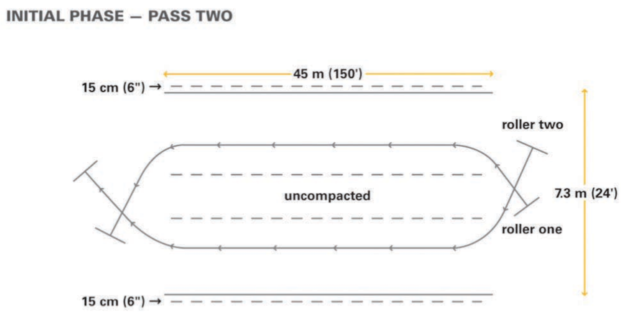



In the first example, assume that the paver is laying down 275 tonnes per hour (300 tons per hour) at a width of 7.30 m (24 ft) and at a depth of 50 mm (2.0 in). The effective paving speed is 6.0 meters per minute (20 feet per minute). There are two 200 cm (79 in) wide double drum rollers available for initial compaction. It takes two passes to bring density to the initial compaction phase target.

Roller One starts first along the left edge with the outer drum edge about 15 cm (6.0 in) away from the unconfined edge. Roller Two begins just after Roller One and operates along the right edge, also staying away from the unconfined edge. Roller One comes to a slow stop at an angle in the center of the mat and reverses. Roller Two moves slightly past the Roller One stop and also turns toward the center and reverses.

When employing an echelon pattern the lead roller should be far enough in front of the second roller that he can complete his stop and reverse maneuver before the second roller starts to turn and reverse.

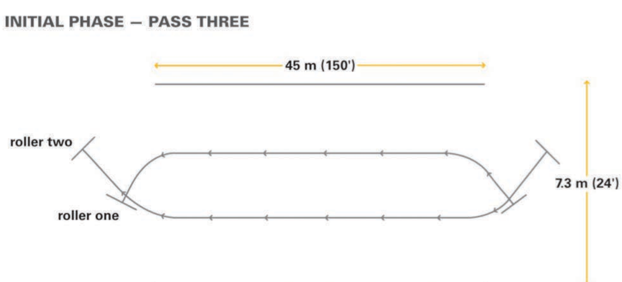
## Echelon Compaction Patterns




- Return to starting point with slight overlap on unconfined edges
- Outer edges compacted twice; center uncompacted

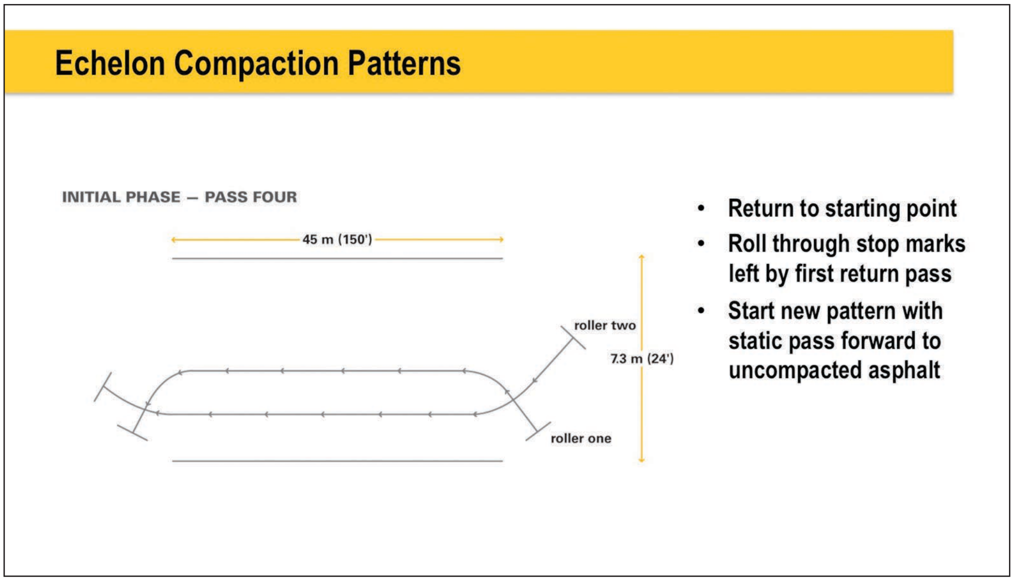
During Pass Two, the return to the starting point, Roller One is in the lead with Roller Two slightly behind. During Pass Two, the outer drums slightly overlap the unconfined edges. Again, both rollers turn toward the center of the mat to make the stop and reverse. At this point, the outside edges of the mat have been compacted twice. There is a strip in the center of the mat that is about 3.5 m (11.5 ft) wide.

## Echelon Compaction Patterns




- Roller One right center portion rolls past stop mark left by Roller Two
- Roller Two left center portion rolls past stop mark left by Roller One

For Pass Three, Roller One goes first and operates on the left center of the mat with a slight overlap of the left drum edge onto the area covered in the first two passes. Roller One will pass straight over the drum stop mark left by Roller Two, moving forward about 8 m (25 ft) past the stop mark before turning toward the right edge to stop and reverse. Roller Two is slightly behind and operates on the right center portion of the mat with the right drum edge slightly overlapping onto the area covered in the first two passes. Roller Two will clean up the first stop mark left by Roller One, continue forward another 8 m (25 ft) past the stop mark and turn toward the left edge to stop and reverse.




During Pass Four, the two rollers return in the same area back to the starting point with Roller One slightly ahead of Roller Two. It is recommended that they roll straight through the stop marks they left at the end of Pass Two before stopping and reversing.

Pass Five will be a static pass moving forward toward the paver. Each roller operator should position his machine along the edges of the fresh mat and start the vibrator systems when the rollers enter the uncompacted zones. There should be a new pattern area about 36 m (120 ft) long in front of the old pattern.

## Echelon Compaction Patterns

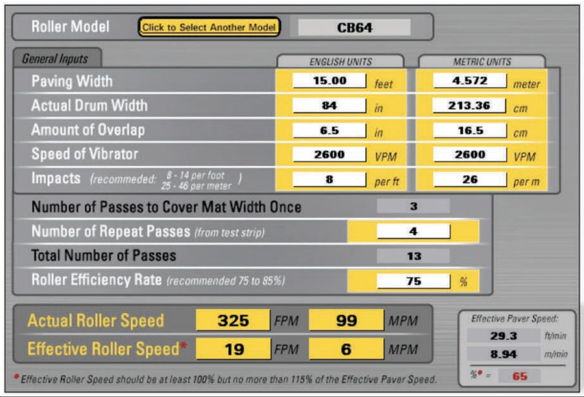
**Stiff Mix Example**

- 4.5 m (15 ft) wide
- 75 mm (3 in) uncompacted
- Paving speed 8 m (27 ft) per minute
- 4 passes in medium amplitude to reach target density for initial phase
- Tender zone starts at 115° C (240° F)

Let's look at another echelon pattern using two rollers on a mat that is 4.60 m (15 ft) wide. The paver is laying down 360 tonnes per hour (400 tons per hour) at a loose depth of 75 mm (3.0 in). A material transfer device is feeding mix to the paver and the paving speed is 9.0 m per minute (29 ft per minute). The density of the mat passing under the vibratory screed is 80% of theoretical maximum density. On the test strip, we verified that it takes four vibratory passes at medium-high amplitude to get target density for the initial phase.

The temperature of the asphalt layer as it passes under the screed is consistently around 150° C (300° F). When the mat cools to around 115° C (240° F), it becomes tender. The tenderness persists until the mat has cooled to 85° C (185° F).

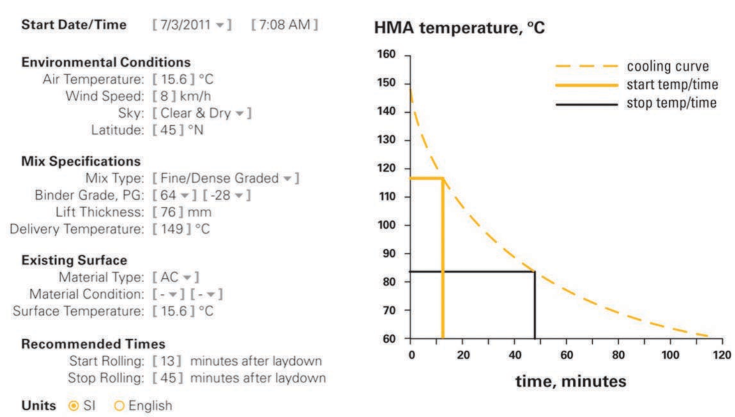
## Echelon Compaction Patterns



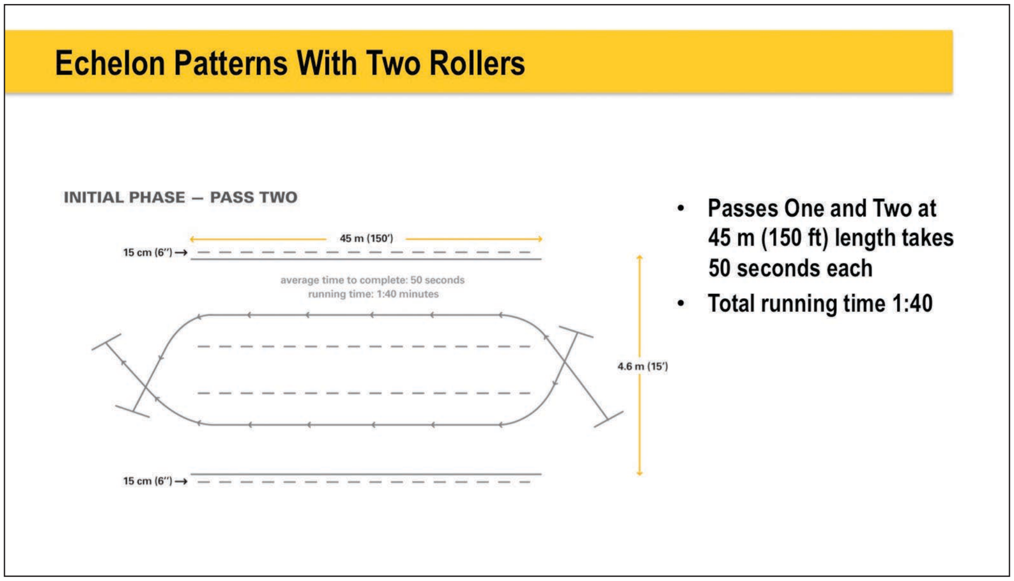

- One roller making four passes cannot match paver production
- Two rollers are required

The Cat Production Calculator reveals that one high production steel drum roller cannot match the paver’s production. Even operating at the highest speed possible while generating an acceptable impacts per meter (foot) rating, one roller will fall behind the paver. Two rollers operating in echelon will be required.

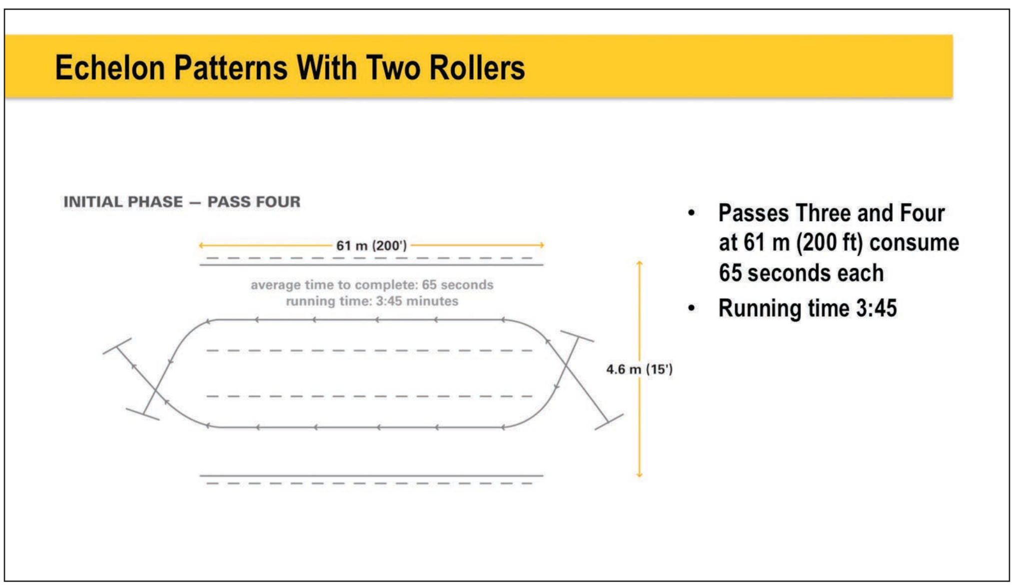
## Echelon Patterns With Two Rollers



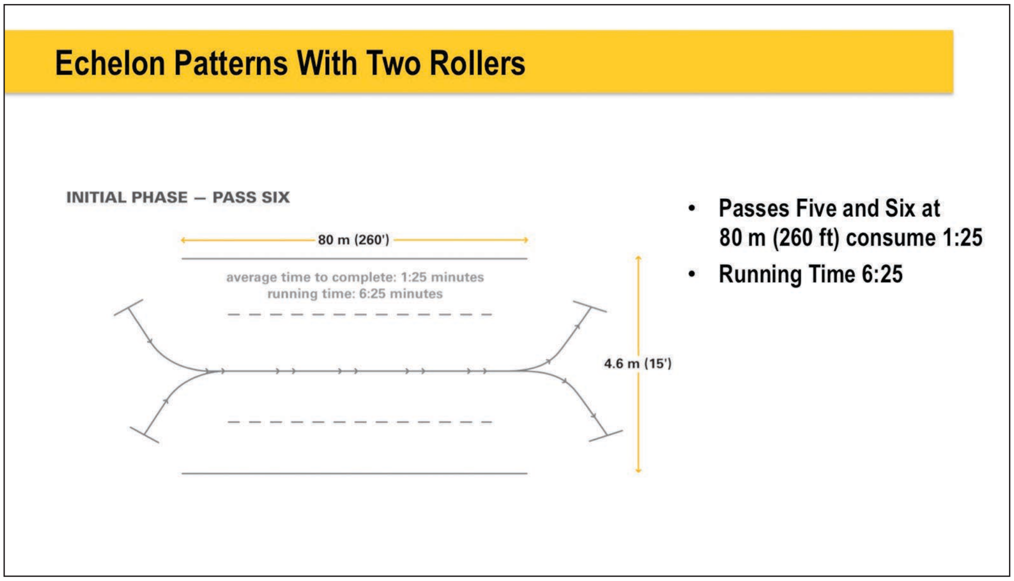

The next question to answer is how much time is available for the two rollers working in the initial phase prior to the start of the tender zone? With the ambient temperature 16° C (60° F), the asphalt layer will cool to 115° C (240° F), the start of the tender zone, in 13 minutes.



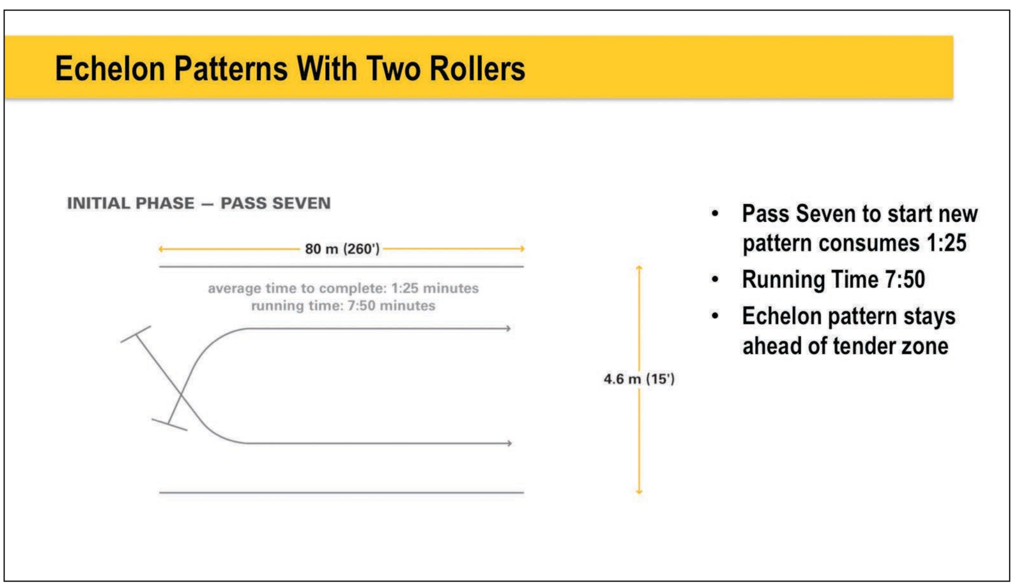

The first two passes in this example are about 45 m (150 ft) long. Adding in the time it takes to stop and reverse, it takes about 50 seconds to complete each pass. Total running time is about one minute and 40 seconds.




Because the rollers are moving ahead to stay up with the paver, the length of passes three and four increase to about 61 m (200 ft). It takes each roller about 65 seconds to complete each pass. Total running time after passes three and four is about three minutes and 45 seconds.




The length of passes five and six increased to around 80 m (260 ft). Each pass takes about one minute and 25 seconds. Running time is about six minutes and 25 seconds after pass six.




During pass seven, each roller will move up in the static mode to start a new echelon pattern. The total of the 7-pass echelon pattern will be just under eight minutes. Since the tender zone starts 13 minutes behind the paver, the two-roller echelon pattern will meet the time frame as well as the density and production goals.

## Summary

- Create rolling patterns
  - get specified density
  - match paver production
  - maintain smoothness
- Use production calculator
- Create cooling curves


Roller operators and quality control personnel should understand how to set up rolling patterns that accomplish three goals. First is to achieve the specified density. Second is to match the production rate of the paver. Third is create patterns that take advantage of opportunities to ensure mat smoothness. By using the Cat Interactive Calculator and creating cooling curves, you can plan successful patterns prior to the start of the project.

## Asphalt Pick-Up On Dry Drum Surfaces

- Most common cause of downtime
- Film of water must cover steel drum
- Small amount of pick-up becomes big problem


The most common cause of downtime on double drum, asphalt rollers is a malfunctioning drum spray system. If any part of the steel drum does not have a water film on the surface, hot asphalt is likely to stick to drum. The stickier the asphalt mix, the more severe is the problem. A small amount of asphalt pick-up on the drum quickly becomes a large problem. With each drum rotation, the amount of pick-up increases and the mat will begin to show divots.

When asphalt begins to stick to a drum surface, operation of that roller must be terminated until the drum is completely clean and any problem with the drum spray system is repaired. Continuing to operate the roller will result in severe mat damage that will require extensive handwork to fill in and level divots left in the mat.

## Asphalt Pick-Up On Dry Drum Surfaces

- Use clean water
- Change spray system filter
- Maintain inlet filter
- Clean spray nozzles
- Maintain water distribution mats
- Understand system capabilities
- Protect during cold weather

The primary cause of dry areas on the drum surface is a plugged spray nozzle. Good maintenance and clean water supply are the keys to preventing plugged spray nozzles.

Use clean water. Whenever possible, fill water spray reservoirs with water from approved sources. If you have to use pond water, for example, increase the frequency of maintenance steps.

Change main spray system filters. Follow the filter change interval shown on the machine's Operation and Maintenance Manual. When the main spray system filter is plugged, water bypasses the filter and unfiltered water goes to the spray bars. Unfiltered water is more likely to cause spray nozzles to plug. Always have a spare filter stored on the roller or in the maintenance vehicle.

Maintain inlet filters. Most water reservoirs have an inlet filter inside the reservoir fill port. The inlet filter is the first stage of water filtration. Do not discard the inlet. Place the water supply hose inside the inlet filter.

Clean spray nozzles. The spray nozzles have internal brass or plastic screens. Nozzle screens should be examined daily for contamination. Clean nozzle screens thoroughly as needed. If you use contaminated water, increase the frequency of nozzle maintenance. If only one side of the nozzle is plugged, the spray pattern will be smaller and can cause the dry strip that picks up asphalt.

Maintain water distribution mats. The drum will have some type of water distribution mat to help spread the water film evenly on the drum surface. As the distribution mats wear, you may have to adjust them to have good drum contact. Replace distribution mats according to wear indicators.

Understand spray system capabilities. Most water spray systems offer full-time or intermittent spray. Never sacrifice water coverage in an effort to conserve water. It is better to stop more frequently for water refills than to stop for drum cleaning.

Protect the water spray system during cold weather. There is an optional water spray system anti-freeze kit. The kit includes a separate reservoir for anti-freeze. At the end of the shift, the operator can circulate anti-freeze through the system to prevent overnight freezing.

## Asphalt Pick-Up On Rubber Tires

- Hot asphalt sticks to cold rubber tires
- Affected by the stickiness of the binder
- Affected by the temperature difference between asphalt and tires
- Stop and correct problem when pick-up occurs

Asphalt can stick to rubber tires. The severity of asphalt sticking to rubber tires depends primarily on the stickiness of the asphalt. Tire pick-up is also affected by the difference in temperature between the surface of the asphalt layer and the rubber tires. Typically, when the temperature difference between the contacting surface of the rubber tires and the pavement surface is less than 25° C (45° F), there are no problems with pickup on the tires. When asphalt begins to stick to the rubber tires of a pneumatic roller, the operator must immediately stop and correct the problem.

## Asphalt Pick-Up On Rubber Tires


- Use biodegradable release agent
- Check tire scrapers and mats
- Heat tires and move up to desired temperature zone
- Keep tire surface within 25° C (45° F) of mat surface temperature

Release agents are sometimes used to help prevent hot asphalt from sticking to rubber tires. Always confirm with the public works department what release agents are permitted. Use a biodegradable release agent at the start of the compaction process or to clean the affected tires.

Be sure the water distribution mats (also known as cocoa mats) and tire scrapers are properly positioned and in good repair.

Move the pneumatic roller on the asphalt layer in an area where the surface temperature is relatively low. Heat the tires by operating on the warm mat before moving ahead to a higher temperature zone.

## Asphalt Pick-Up On Rubber Tires

- Once tires are hot – keep them hot
- Tire skirts
- Don't park during interruptions


Getting the rubber tires heated and keeping them at the correct temperature is very important. Tire covers help keep heat confined around the front and rear axles. Caterpillar recommends using tire covers on pneumatic rollers for all asphalt compaction applications. Tire covers are especially important when compacting asphalt that contains modified asphalt cement. If tire covers are not installed, the tires are exposed to the ambient conditions and lose can heat rapidly.

Once the tires are heated, keep them heated. If there is an interruption to the paving and compaction process, do not park the pneumatic roller. Move the roller to a place on the asphalt layer where it can continue to roll in order to keep the rubber tires heated.

## Deep Pneumatic Tire Marks

- Marks left during intermediate phase clean up easily
- Be careful when using modified binders – sticky asphalt

Ordinarily, a pneumatic roller is used during the intermediate phase of compaction on an asphalt layer that is already close to final target density. The tire marks it leaves in the mat are normally shallow and can be smoothed out by the finish phase roller. However, asphalt layers containing modified binder may leave deeper marks or piles of material when coming to a stop for reversing.

## Deep Pneumatic Tire Marks

- Deep marks left in thick, hot layers
- Deep marks left during initial phase
- Difficult to clean up
- Stay back or decrease tire pressure

However, if the roller is used during the initial compaction phase or if the pneumatic roller rolls an area where the mat is thicker and hotter than normal, the rubber tires can leave deep marks that do not clean up easily during finish compaction.

Using a pneumatic roller during the initial phase is usually done when compacting a base or binder layer that is going to have another layer laid on top of it. In that instance, the tire marks and loss of smoothness are less of an issue.

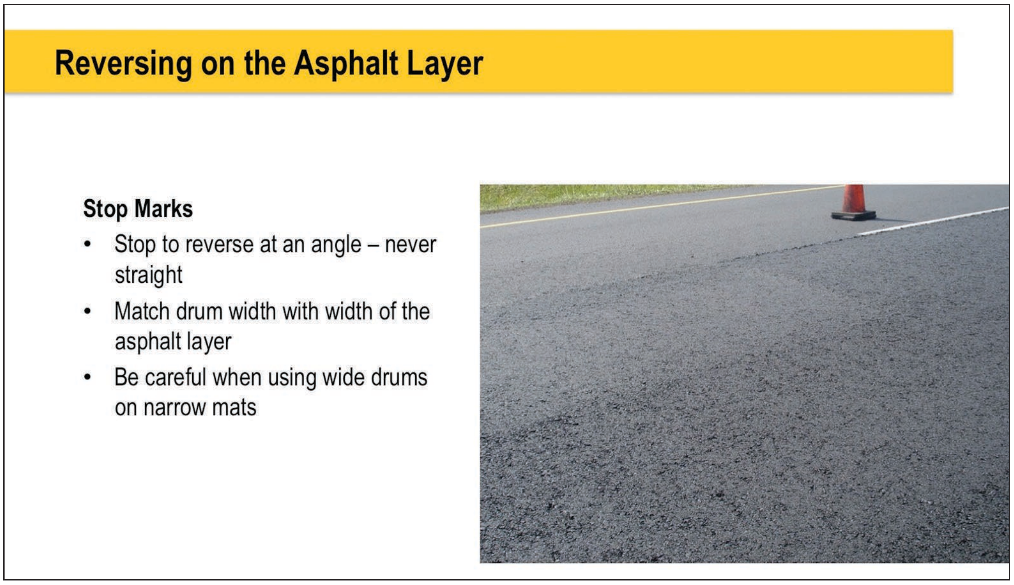
Using a pneumatic roller during the initial phase on the final layer (wearing layer) of asphalt is not common because the final layer is often measured for smoothness. A pneumatic roller is normally in the intermediate position when compacting the final asphalt layer.

If deep tire marks appear during the compaction of the final layer, move the pneumatic roller farther behind the paver where the asphalt layer is cooler, or decrease tire pressure to flatten the tires somewhat and reduce the tire contact pressure.

## Vibratory Drum Impact Marks

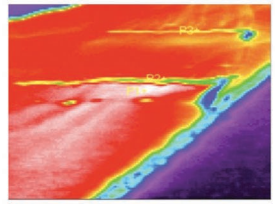
- Too much force
- Speed too slow
- Cannot use roller to correct height mismatch

When too much vibratory compaction energy is applied to an asphalt layer, impact marks that do not clean up during the finish phase may appear on the surface of the asphalt layer. In the illustration, it is obvious why the asphalt layer has drum impact marks. The roller made numerous, slow vibratory passes over the joint between the asphalt layer and the concrete gutter in an effort to knock down the asphalt layer for a better height match. It is certain that the drums were bouncing in this area. You can even see the characteristic, white powdery surface that indicates fractured aggregate. In this case, the problem was created by the paving crew that paved the joint height too high. The roller can only reduce the thickness of the layer so much. When the layer becomes dense, the drums will begin to bounce and leave impact marks.




A steel drum roller always stops at an angle on the fresh asphalt layer when reversing at the end of a pass. Leaving a stop mark that is at least a thirty-degree angle will make it easier for the next roller to clean up the stop mark. Be sure to use a roller with drum width that makes it possible to complete an angled turn while stopping to reverse. The operator will have a hard time stopping and reversing on a relatively narrow mat when using a roller with drums that are 200 cm (79.0 in) wide or wider. Prior to the start of a project, be sure to understand all the paving widths that the compaction crew will encounter. When production requires you to select rollers with wider drums that cover a mat in two overlapping passes, be sure to help the roller operators establish a pattern that does not distort the hot asphalt.

## Parking on the Asphalt Layer



- Never park on hot asphalt
- Leaves dents that will not clean up
- Park on cold asphalt
- Park on shoulder, if available

An asphalt roller of any type should not be stopped to wait on an asphalt layer until that layer is completely compacted and has cooled below 20° C (70° F). It is especially important to not stop and wait on an asphalt layer that will measured for smoothness. Make every effort to find a place to park the roller that will not be affected by a long stop.

A view of the mat where the roller had been parked reveals that water has pooled in the area where the drums sat and where the mat has been dented. A thermal image shows that the steel drums caused significant heat loss in the mat where the drums sat. The temperature of the mat is 65° C (150° F) where the two steel drums were located. The mat has two more compaction phases remaining, intermediate and finish. However, the temperature of the mat in this area is now much lower than found in the normal patterns and it is unlikely that the stop marks will clean up.

## Stopping for Water Refill

- Plan water refill stops
- Stop on shoulder or turnout or cold asphalt – never on driving lane
- Make sure water hose is long enough for all situations

Depending on the size of the water spray system reservoirs and the climate conditions, a steel drum roller must stop for water refill one or more times per shift. It is important that the crew plan for water stops to avoid long interruptions to the compaction process and to avoid stopping the roller on any portion of the asphalt layer that is part of the driving lane. Park the roller on a cold, compacted surface or on the shoulder when stopping to refill water spray system reservoirs. Often this means that the water supply truck must have a long hose. In some situations, the water supply truck must park on a cold surface and the water hose must extend across the 3.65 m (12.0 ft) wide driving lane to reach a roller parked on the opposite shoulder. Plan ahead by knowing the maximum hose length that will be required for water refills on the given project. Make sure the water supply hose is long enough for every situation.

## Stopping for Water Refill

- If necessary, use boards to allow roller to get off hot asphalt during water refills

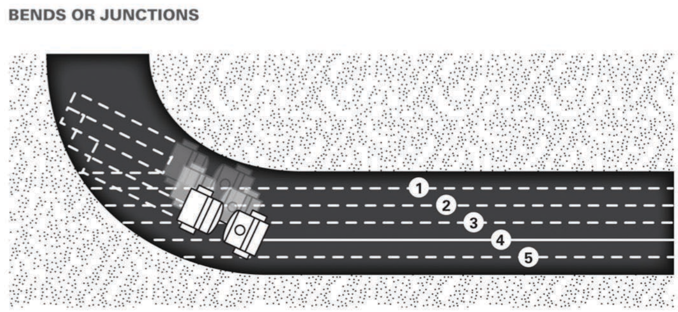

On some projects, the mat will have two unconfined edges without a shoulder for the roller to stop on. Or, the mat may have one unconfined edge and no room on the opposite side for the roller to get off the mat. In those situations, plan to provide sturdy boards to place along the unconfined edge of the mat. The roller can go off and onto the mat by using the boards for support and not crush the unconfined edge of the mat.

## Tight Radius Compaction

- **Wide, solid drum will distort hot asphalt compacting tight radius**
- **Outer edge of drum stretches the hot asphalt**

In some applications, most notably streets and parking lots, there will be areas where the roller will be working on curved surfaces such as cul-de-sacs and around dividers and other obstructions. Anytime the mat has a tight radius, the mat will be distorted if a conventional, high-production, steel drum roller makes a continuous pass around the radius. The outer edge of the drum is covering a longer distance than the inner edge of the drum. Consequently, the outer edge stretches the mat in an effort to turn the radius at the same speed as the inner edge.

## Tight Radius Compaction




- **Make multiple straight passes with angled stops**
- **Reposition roller and complete radius with another pattern**

If the only available roller is a conventional, high-production model, then a unique rolling pattern must be used to avoid distorting the mat.

The operator should work toward the radius along one edge of the mat. Roll forward (1) into the radius, stopping at angle close to the outer edge of the radius. Reverse back along the same path. Move toward the center of the mat (2) overlapping the first pass slightly and roll forward into the radius, again stopping at angle close to the outer edge. Reverse back along the same path. Repeat this pattern as many times as necessary (3, 4, 5) to cover the width of the mat.

Reposition the roller at the start of the radius so the roller is at an angle to the passes already completed in the radius area. Roll forward and backward to finish the remainder of the radius area.

Then, reposition the roller to begin straight passes going forward out of the middle of the radius.

## Tight Radius Compaction

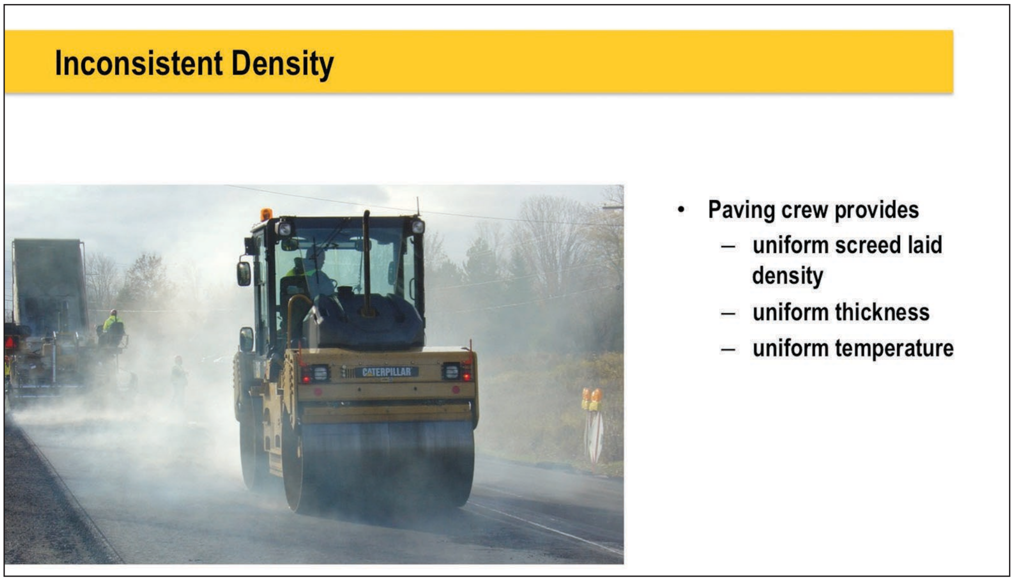

- Use utility class roller
- Drums less than 1 m (40 in) turn on fresh asphalt without distortion

Utility class rollers with drums less than 1.0 m (40 in) wide can turn sharper on a fresh mat without tearing the mat. For cul-de-sacs, city streets, parking lots and other lower production projects, a utility size roller provides versatility and usually enough productive capability to keep up with the paving process.

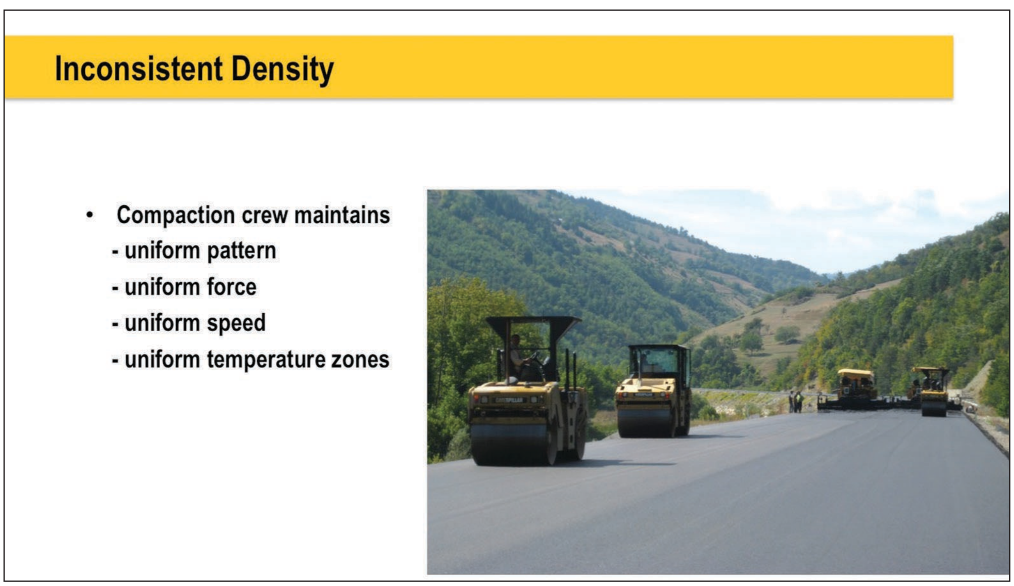
## Tight Radius Compaction

- Split drum rollers
- Drum halves turn at different speeds when steering around radius
- Outer edge turns faster to avoid distortion


Another option in some areas is the split drum asphalt roller. These units have unique propel systems which synchronize steering and drum speed to move one half of the drum at a faster speed than the other half. When the steering wheel is turned, the outer half of the drum (along the larger arc of the radius) speeds up in comparison to the inner drum half (along the smaller arc of the radius). The more the steering wheel is turned, the greater is the difference in the speeds of the two drum halves. Thus, the drum halves cover different distances but in the same time frame. The fresh mat gets dense without being distorted.




Many public works departments now require not only high asphalt layer density but also consistent density. There may be pay factors associated with standard deviation derived from multiple core measurements or percent within engineering limits derived from multiple core measurements. One of the responsibilities of the paving crew is to present a uniform asphalt layer to the initial phase roller. Behind the paver, as much as possible the mat should be: uniform screed laid density; uniform thickness; and uniform temperature.




Each roller in the compaction process, especially the initial phase roller, must also be consistent in the approach to achieving consistently high density. Each roller must work in such a manner that creates: uniform pattern; uniform compaction force; uniform working speed; and uniform temperature zone.

## Inconsistent Density

- **Quality Control verifies:**
  - **density behind each phase**
  - **communicates results to operators**
  - **communicates changes to operators**

Quality control personnel are responsible for verifying density on the project. They check the density of the asphalt layer after every phase of compaction. Then, they communicate the results to the roller operators and discuss any changes in the process that are required to improve quality. If density is inconsistent, quality control is responsible for finding reasons for the inconsistency.

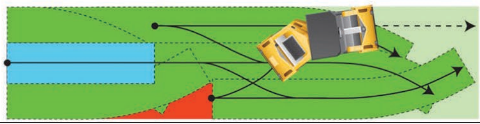
## Inconsistent Density

- Maintain pattern and working speed
- Paving crew and initial phase roller operator communicate
- All paving speed changes are approved and told to roller operator

Some operators have difficulty repeating the same pattern as they follow the paver. They do not always hit each portion of the mat the same number of times. Therefore, density checks made by the quality control technician will vary. When this happens, the quality control technician or supervisor must work with the roller operator to define the pattern and make sure that the pattern is being repeated.

Verify that the paving speed has not been changed. Very often changes in paving speed are not communicated to the compaction team and the quality control team. A rolling pattern that has been working well is suddenly causing the roller to fall behind the paver and to be working in a lower temperature zone, for example. The roller falls behind because the paving speed has been increased. And, the operator tries to alter his or her rolling pattern to stay close to the paver. Never change paving speed without doing two things. First, communicate the speed change to the compaction team. Second, verify that the initial phase roller can keep up if the speed is being increased.

## Inconsistent Density



- Optional systems aid operator consistency
- GPS shows operator machine position and counts passes
- Screen turns colors as passes are completed
- Removes guesswork
- Allows corrective action

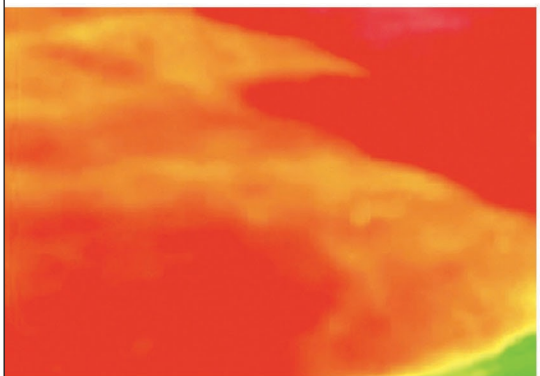
There are options available for asphalt rollers to help operators maintain uniform rolling patterns. Screens in the operator's compartment can be programmed to show the operator where the roller is located on the mat and how much of the pattern has been completed. Global positioning systems provide very accurate maps of rolling patterns. The control can be programmed with the required number of passes. Then, the screen will display different colors as the passes are completed. The operator no longer has to guess at the end of a pass for reversing. And, there is less chance that the operator will miss any of the areas in the pattern because the screen provides immediate feedback for corrective action.

## Inconsistent Density

- Optional temperature sensors help confirm temperature uniformity
- Located ahead of front and rear drums
- Activated by direction of operation
- Operator checks display to see if machine is in proper zone


Infrared temperature sensors are another option for some asphalt rollers. On Cat models, sensors are installed on front and rear drum yokes. The front sensor is activated when the machine is going forward. The rear sensor is activated when the machine is operating in reverse. The sensors are continually cleaned by compressed air that keeps dust, fumes and moisture away from the sensor lenses. The temperature systems are accurate and provide constant, visual reference at the operator's station display for the roller operator. Not only does the operator know where the machine is located in relation to the defined rolling pattern, the operator knows where the machine is located relative to the desired temperature zone.

## Inconsistent Density

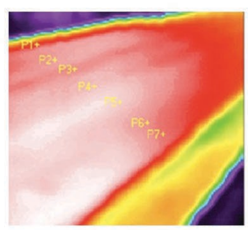


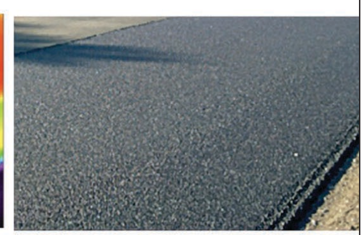
- Large temperature variations caused by paver stops
- Variations greater than 15°C (25° F) cause density variations
- Reduce paving speed to minimize long stops

Large temperature variations are caused by long paver stops. The portion of the mat under the screed remains hot because it is confined. The portion of the mat just behind the screed loses heat because it is exposed to the elements. Heat loss depends on mat thickness, air temperature and wind speed. If the mat temperature varies by more than 15° C (25° F), there is likely to be significant density variation. To help promote uniformity of density, limit paver stops to no more than five minutes. If there are frequent interruptions to paving longer than 5 minutes, reduce the paving speed.

## Inconsistent Density

- Variations in mat thickness cause temperature variation
- Thin layer on shoulder lost heat quickly
- Density checks on shoulder were low
- Density checks on driving lane were good





In some instances, mat thickness varies across the width of the mat. The thinner portion will lose heat at a faster rate than the thicker portion. In the example shown above, the shoulder was higher than the driving lane in this area of the project. The mat laid over the driving lane was the specified 50 mm (2.0 in). The mat thickness diminished to around 25 mm (1.0 in) over the shoulder. The density of the mat varied significantly due to temperature variation and also due to the thin mat having a low ratio of layer thickness to aggregate size. In this instance, all density checks taken in the shoulder failed to meet the minimum requirement while all density checks taken in the driving lane passed the density requirement.

## Summary


- Spray system maintenance
- Project planning
- Equipment selection
- Operator training
- Project design and variables
- Communication

Compaction issues can be caused by a range of factors. Poor drum spray system maintenance, lack of planning, incorrect equipment selection, and inadequate operator training are just some of the factors that can cause problems during the compaction process. Certain mixes are more difficult to lay down and compact than others. Some project have built-in issues that need to be addressed by work starts. In those cases, experimentation on the job may be the only solution when a mix is being used for the first time. What a crew learns from working on one project should be remembered and put to use on others when similar issues are encountered. Finally, good communication between the paving, the compaction crew and quality control personnel is essential.

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