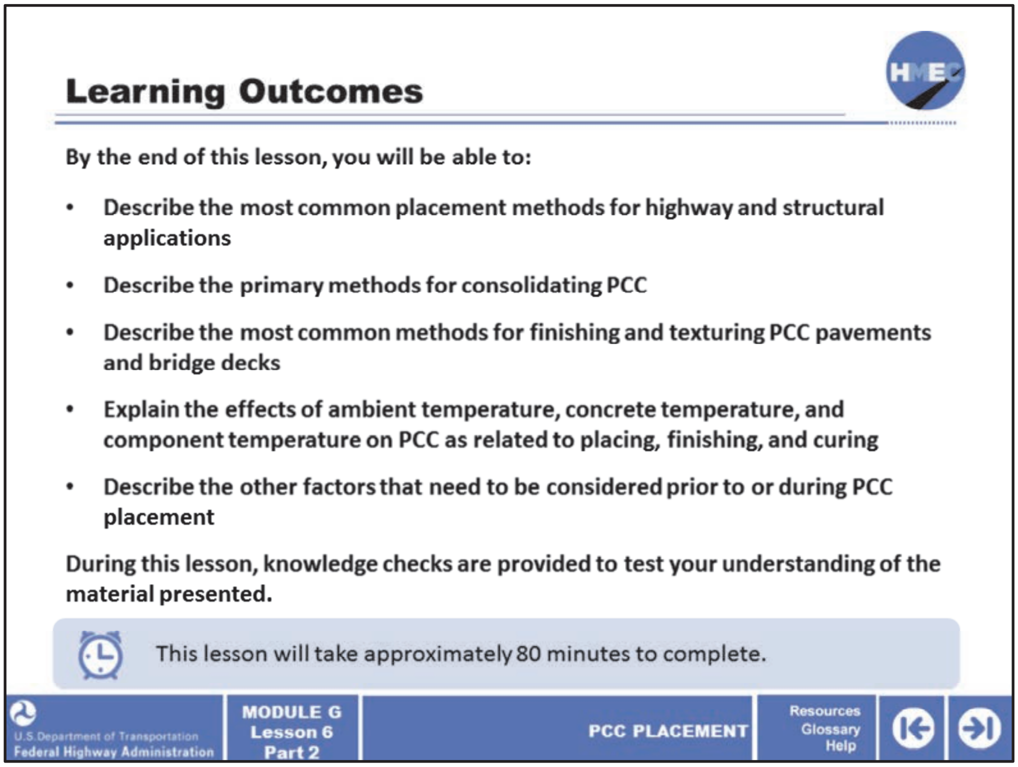
Welcome to the Highway Materials Engineering Course Module G, Lesson 6: Construction Practices, Part 2 of 3. This lesson will provide information on Portland cement concrete (PCC) placement.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. Only the slides for this lesson are available.

If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.

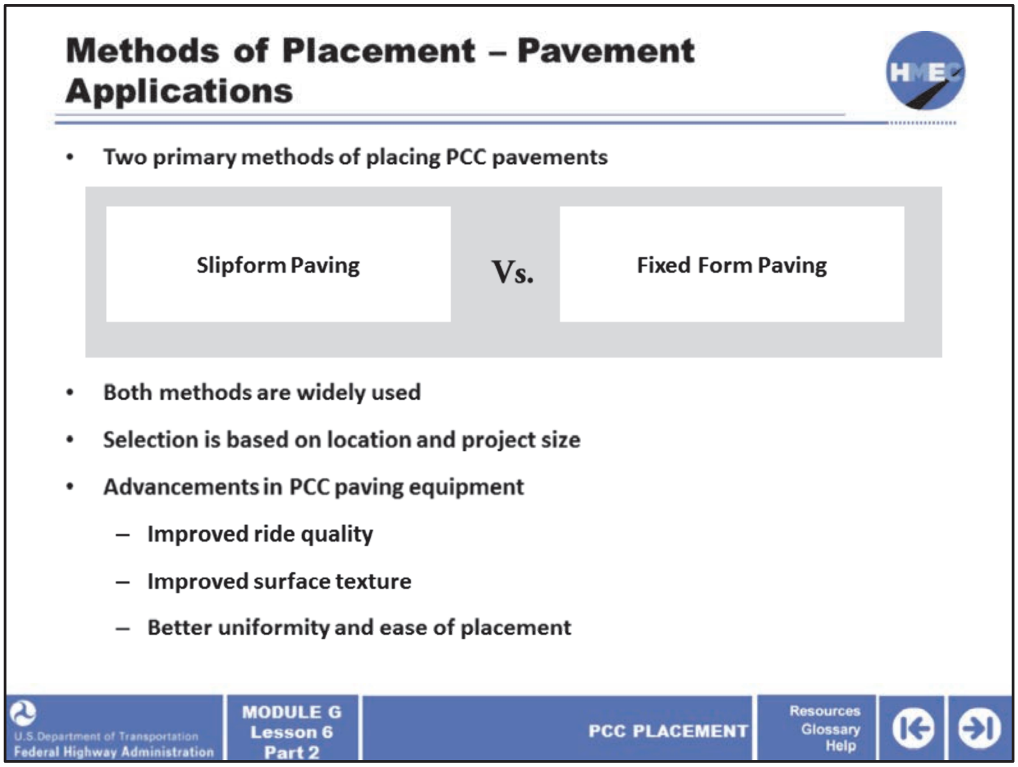


By the end of this lesson, you will be able to:

• Describe the most common placement methods for highway and structural applications;
• Describe the primary methods for consolidating PCC;
• Describe the most common methods for finishing and texturing PCC pavements and bridge decks;
• Explain the effects of ambient temperature, concrete temperature, and component temperature on PCC as related to placing, finishing, and curing; and
• Describe the other factors that need to be considered prior to or during PCC placement.

During this lesson, knowledge checks are provided to test your understanding of the material presented.

This lesson will take approximately 80 minutes to complete.



Now let's get started with methods of placement. There are two primary methods of placing PCC pavements:

1. Slipform paving; and
2. Fixed form paving.

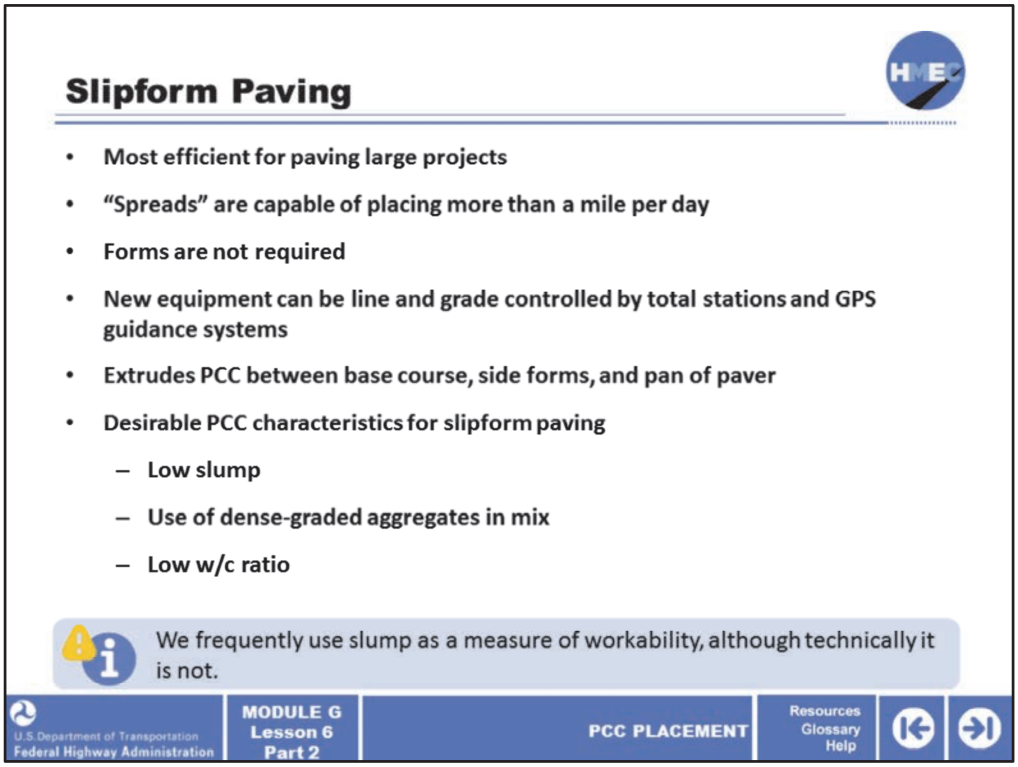
Both of these methods are widely used. The selection as to the most appropriate technique is often based on location and project size. Advancements in PCC paving equipment are largely responsible for improved ride quality, improved surface texture, better uniformity (thickness and consolidation), and ease of placement. Hand placement is sometimes used for small fill-in pours, typically in urban areas.

The photo on the left shows a slipform paver placing a two-lane highway pavement. This equipment is adjustable for width and can place a wide range of thicknesses.

The photo on the right shows a slipform paver using the existing lane as a form edge while the outer edge of the pavement is slipformed.

Image description: Photo of a slipform paver placing a two-lane highway pavement.

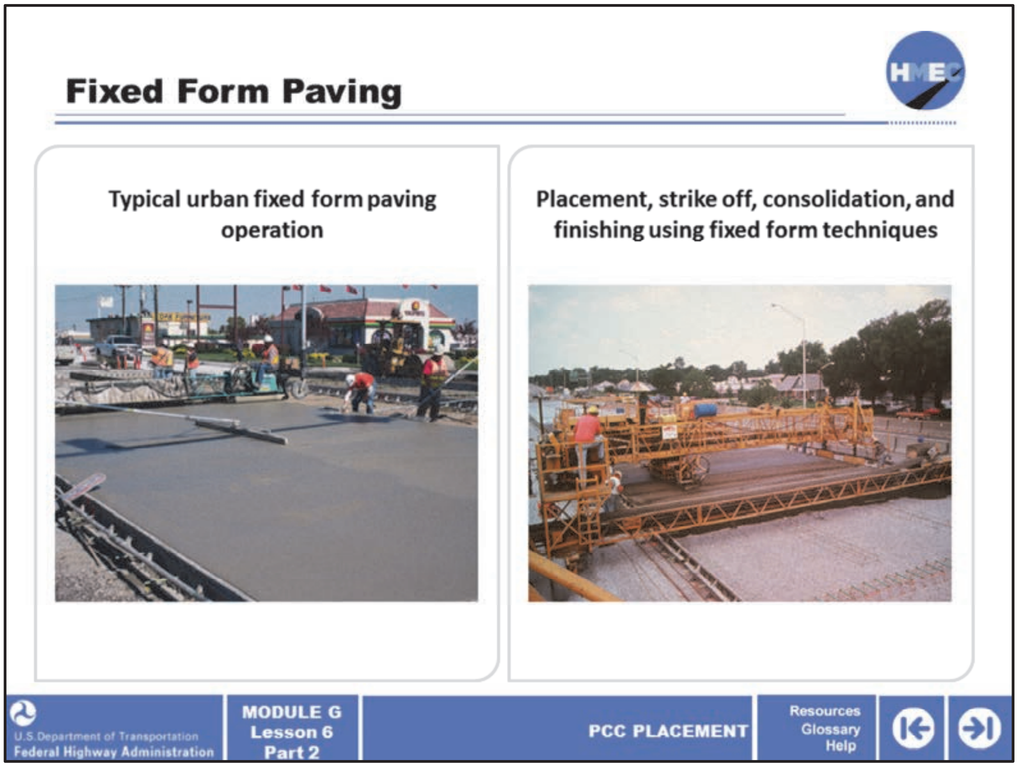
Image description: Photo of a slipform paver using the existing lane as a form edge while the outer edge of the pavement is slipformed.



Slipform pavers are the most efficient method for paving large projects. Large slipform paving "spreads" are capable of placing more than a mile per day of full-width pavement (multiple lane). Forms are not required and new equipment can be line and grade controlled by total stations and GPS guidance systems. This equipment is used for highways, airfields, streets and roads, and parking areas. Slipform paving equipment extrudes PCC between the base course, side forms, and pan of the paver. Desirable PCC characteristics for slipform paving include:

- Low slump (typically 1½ in.);
- Use of dense-graded aggregates in the mix (although gap-graded aggregates are frequently used); and
- Low water-cement (w/c) ratio (and total water content).

Technological advances in paving equipment translates into higher production as well as smoother, more uniform pavements. At the time of placement, the most important PCC characteristics are batch to batch consistency and uniform workability. Note that we frequently use slump as a measure of workability, although technically it is not. The best measure of workability is if the slipform paver can place, consolidate, and finish the PCC while retaining vertical edges.

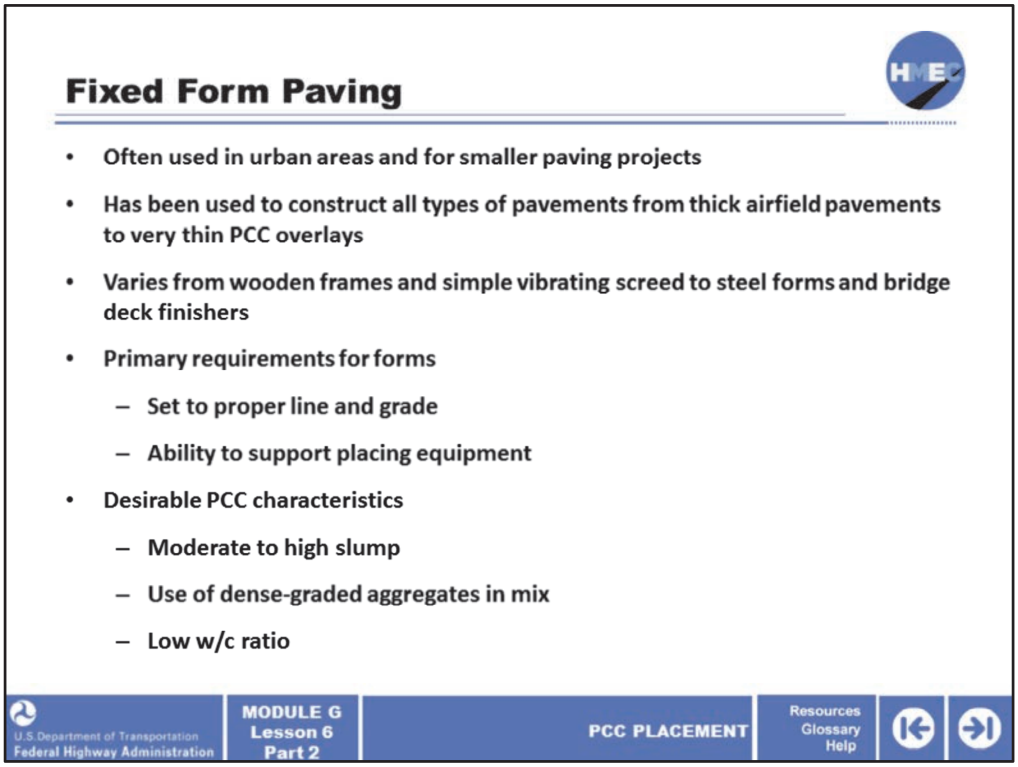


The photo on the left shows a typical urban fixed form paving operation. The steel forms are visible in the foreground. Various widths of pavements may be placed with modern fixed form equipment including irregular or “leave out” areas.

The photo on the right shows one of a great number of options for placement, strike off, consolidation, and finishing using fixed form techniques.

Image description: Photo of a typical urban fixed form paving operation.

Image description: Photo of one of a great number of options for placement, strike off, consolidation, and finishing using fixed form techniques.



Fixed form paving operations are often used in urban areas and for smaller paving projects, but fixed form paving can be used for virtually any project. Fixed form paving has been used to construct all types of pavements, ranging from thick airfield pavements to very thin PCC overlays. From an historical perspective, much of the early interstate highway pavements were constructed using fixed form methods until the advent of slipform pavers. Fixed form paving equipment varies greatly from wooden forms and a simple vibrating screed to large scale operations using steel forms and bridge deck finishers.

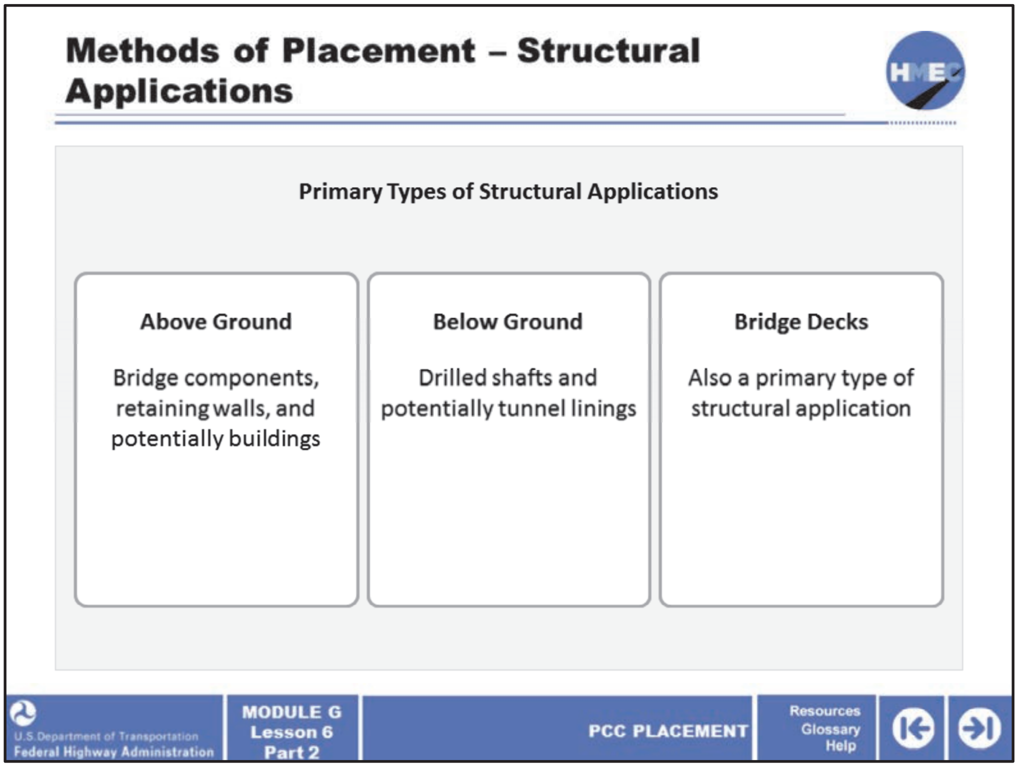
The primary requirements for the forms include:

- Set to the proper line and grade; and
- Ability to support the placing equipment.

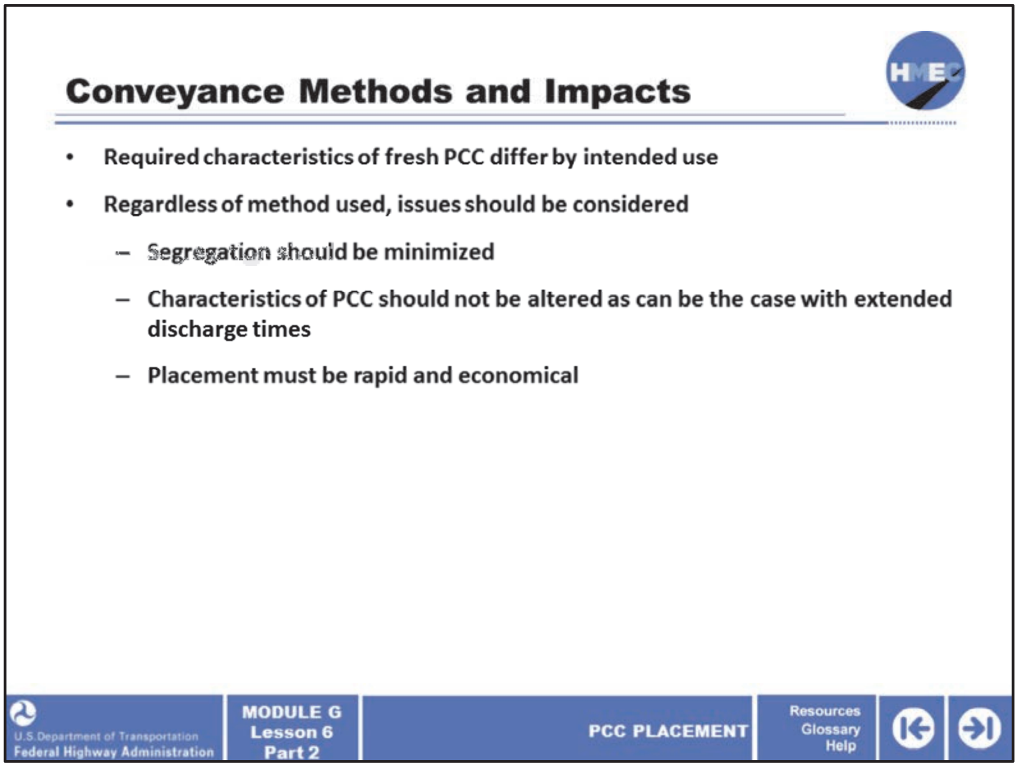
Desirable PCC characteristics for fixed form paving include:

- Moderate to high slump (typically 4 in. or more depending on the equipment used);
- Use of dense-graded aggregates in the mix (although gap-graded aggregates are frequently used); and
- Low w/c ratio (and total water content).

At the time of placement, the most important PCC characteristics are batch to batch consistency and uniform workability. It is necessary to have relatively high slump PCC for fixed form placement. It is highly recommended that the w/c ratio be kept as low as possible and the slump increased through the use of water reducing admixtures.

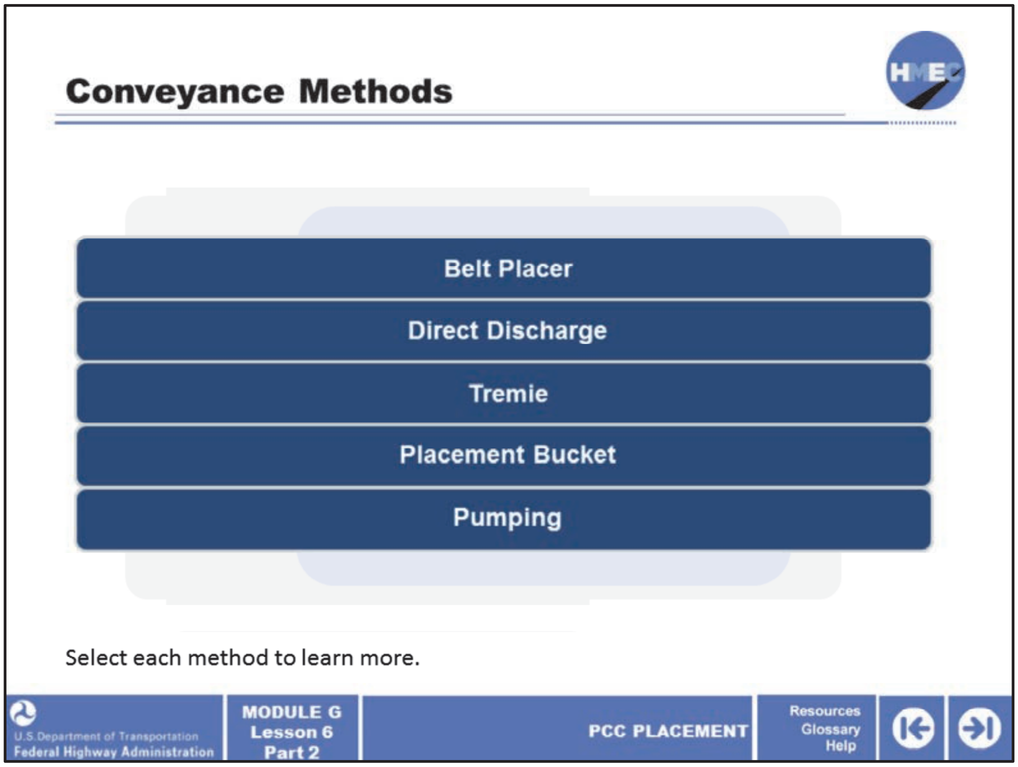


The primary types of structural applications are highlighted in this section. Conveyance methods for placement of each of these uses is included in the following section. The primary above-ground structures include bridge components, retaining walls, and potentially, buildings. The primary type of below-ground structures include drilled shafts and potentially, tunnel linings. Bridge decks are also a primary type of structural application.

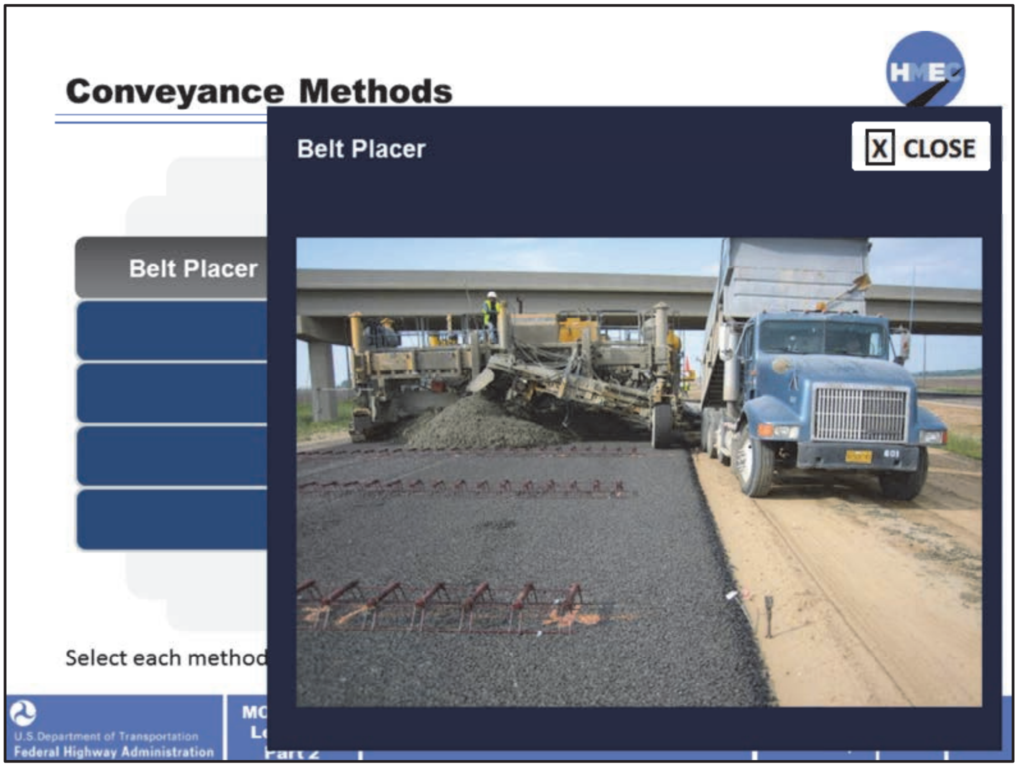


The required characteristics of fresh PCC differ by the intended use. In other words, PCC suitable for slipform paving applications is not well suited for placement in a heavily reinforced retaining wall. Due to differences in PCC workability and placement constraints, there are a number of different conveyance methods available. Regardless of the method used, the following issues should be considered:

- Segregation should be minimized;
- The characteristics of the PCC should not be altered as can be the case with extended discharge times; and
- Placement must be rapid and economical.



Here are some conveyance methods. Take a moment to read the slide and select each method to learn more.



This photo shows a high-speed belt placer delivering PCC in front of a slipform paving spread. This method allows for rapid unloading of the haul truck and does not require that the delivery trucks back downgrade to discharge, a major advantage when set ahead steel is in place as shown in the photo.

Belt placers typically have minimal impact on the properties of fresh PCC:

- The time from truck discharge to actual placement is very short.
- The low slump PCC required for slipform paving operations has a minimal risk of segregation and is normally not a concern. However, the PCC should not be allowed to free fall more than a few feet at the discharge.
- The entrained air content is similarly not effected by the belt placer.

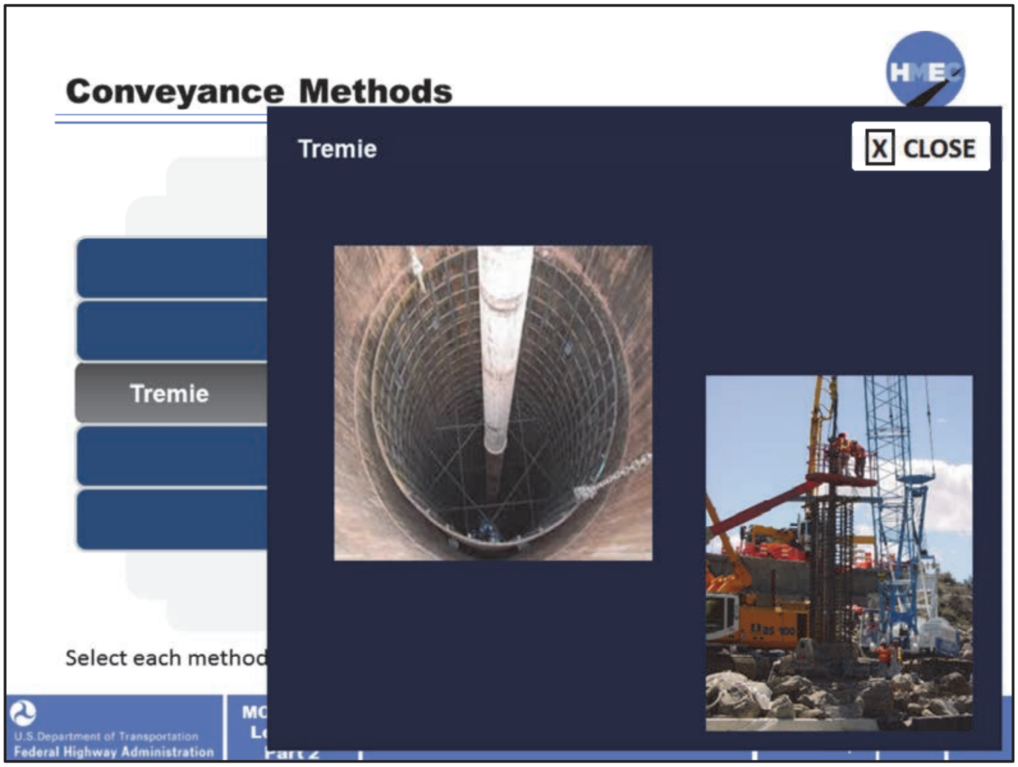
Image description: Photo of a high-speed belt placer delivering PCC in front of a slipform paving spread.

This photo shows a transit mix truck discharging directly on the grade. The primary advantage of this is method are that additional conveyance equipment is not required.

Direct discharge can have significant impact on the properties of fresh PCC depending on the operator:

- The time of discharge is based on the type of placement but is generally fairly rapid.
- A wide range of slumps can be delivered are possible with transit mix trucks and the likelihood of segregation generally increases with increasing slump.
- The entrained air content is usually not effected by direct discharge unless the drop height is excessive.

Image description: Photo of a transit mix truck discharging directly on the grade.



The photo shows a tremie being used to place PCC in a drilled shaft. Tremies can be used to pour wall sections, deep placements (as shown in the photo), underwater pours, and a variety of similar uses. The tremie consists of multiple sections of smooth walled steel pipe that is intended to limit the amount of free fall of the PCC as shown in the photos. When a tremie is used for under water placement, the tremie end is placed below the water line and in close proximity to the level of the pour, thereby displacing the water with the PCC.

Placement with a tremie can have an impact on the properties of fresh PCC depending on the level of expertise of the operator:

- The chance of segregation is increased for high slump PCC but can be controlled by managing the discharge height relative to the level of the PCC. In other words, the free fall distance should be minimized.
- The entrained air content can be reduced with long tremie tubes.

Image description: Photo of a tremie being used to place PCC in a drilled shaft.

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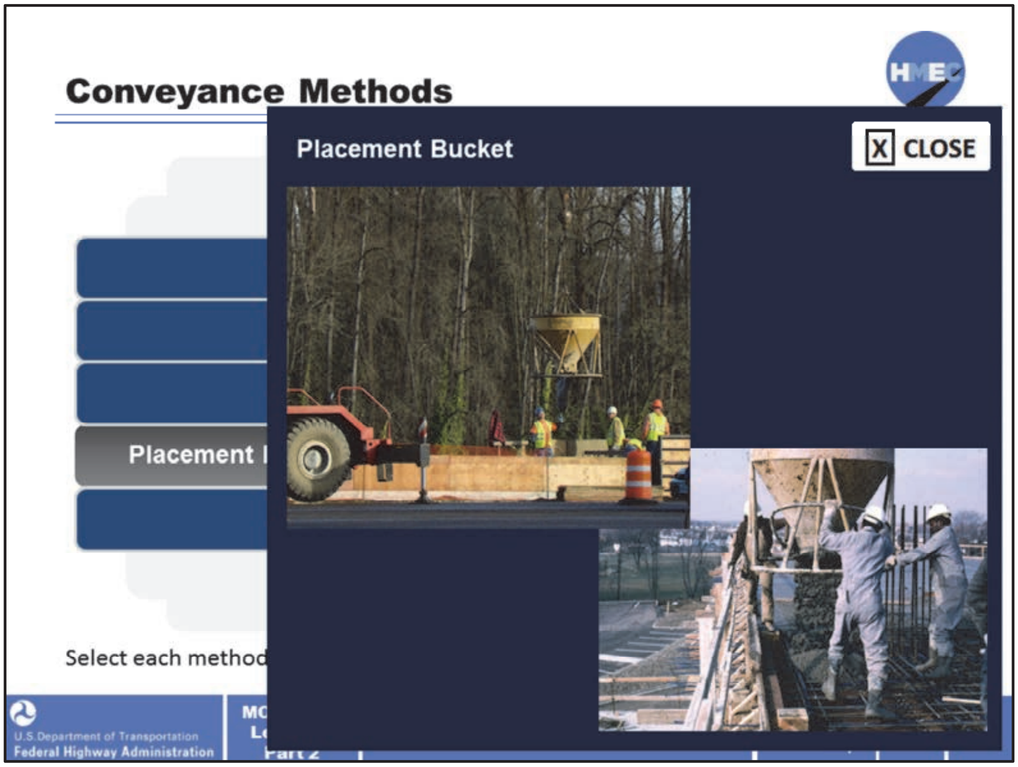

These photos show the use of a large PCC placement bucket.

Buckets typically have minimal impact on the properties of fresh PCC:

- The time from loading to discharge is typically very short.
- The PCC should not be allowed to free fall more than a few feet at the discharge.
- The entrained air content is generally unaffected unless excessive free fall is allowed.

Image description: Photo of the use of a large PCC placement bucket.

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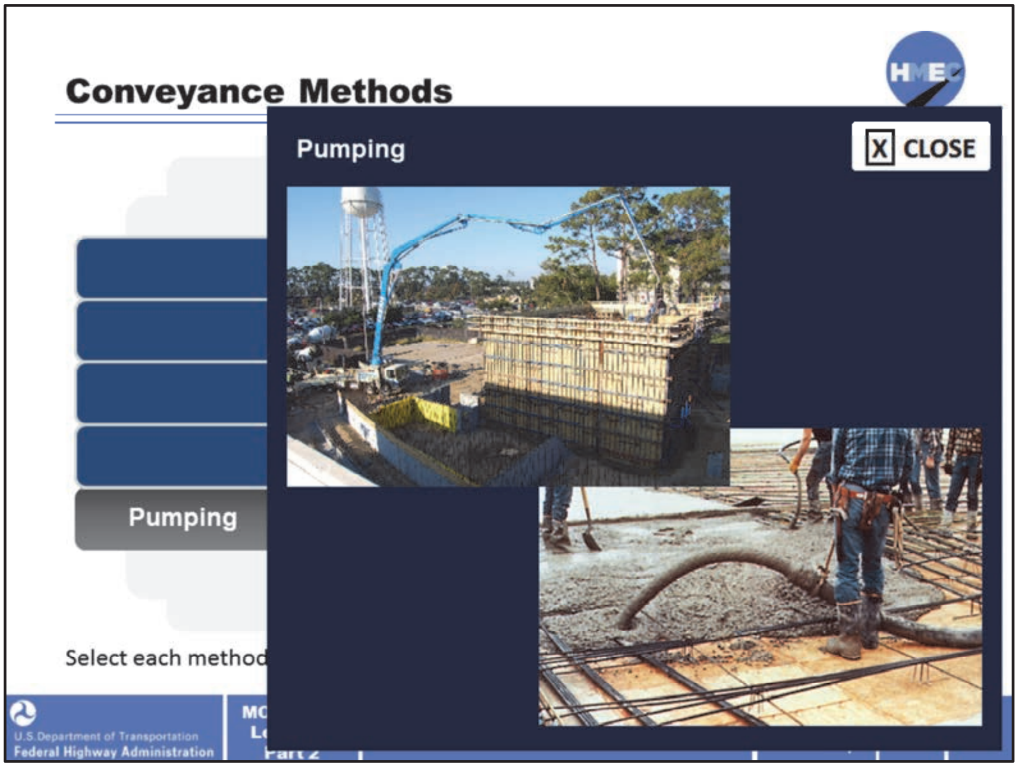


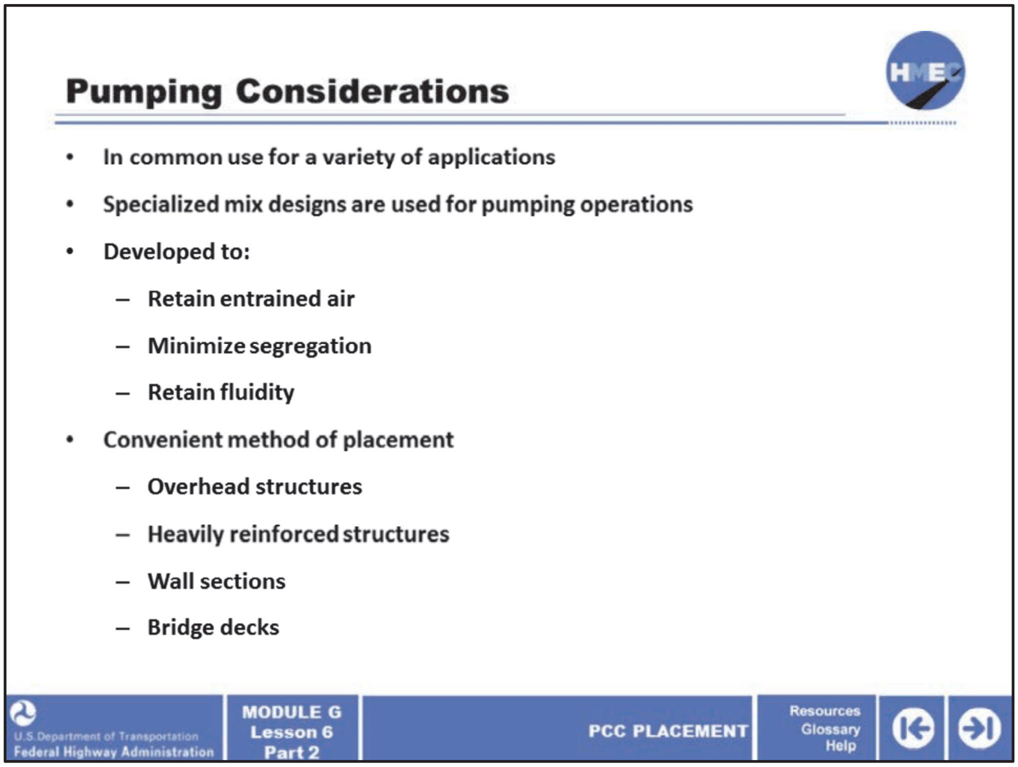
Pumping is becoming the go-to method of placement for overhead structures or where access to the pour is difficult. Note the fluidity of the PCC mix in the bottom photo.

Pumping can have significant impact on the properties of fresh PCC:

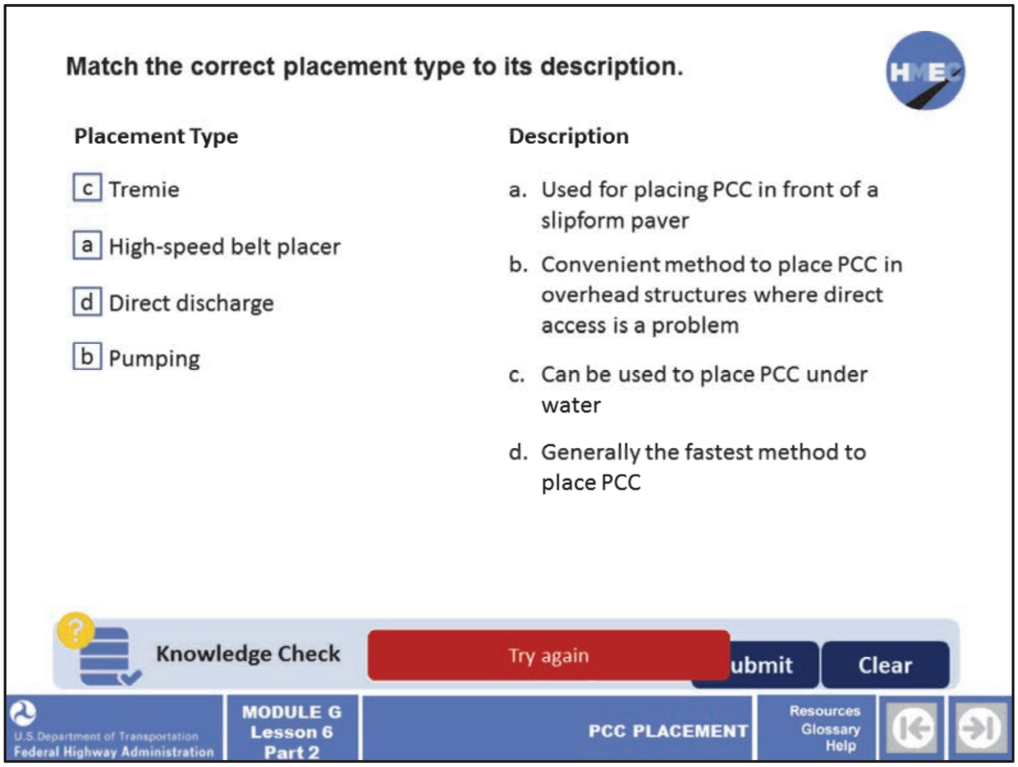
- The pumping time is variable depending on the type of placement but is generally fairly rapid.
- The PCC should not be allowed to free fall more than a few feet at the discharge.
- The photo on the lower right illustrates appropriate practice for horizontal discharge and should minimize segregation and loss of entrained content.
- The photo on the upper left illustrates a vertical discharge. The opportunity for segregation and loss of entrained air is increased with this configuration subject to the boom configuration and drip height.
- Testing should be conducted at the discharge in order to determine the effects of a particular pumping configuration and mix characteristics.

Image description: Photo of a vertical discharge.

Image description: Photo of appropriate practice for horizontal discharge.



PCC pumping is in common use for a variety of applications. Specialized mix designs are typically used for pumping operations. These mixes are developed to retain entrained air, minimize segregation, and retain fluidity to allow pumping at considerable distances both horizontally and vertically. Pumped PCC is a convenient method of placement for overhead structures, heavily reinforced structures, wall sections, bridge decks, and similar uses where direct access to the pour is difficult. The speed, convenience, and relative cost make it a viable alternative for many structural placements.



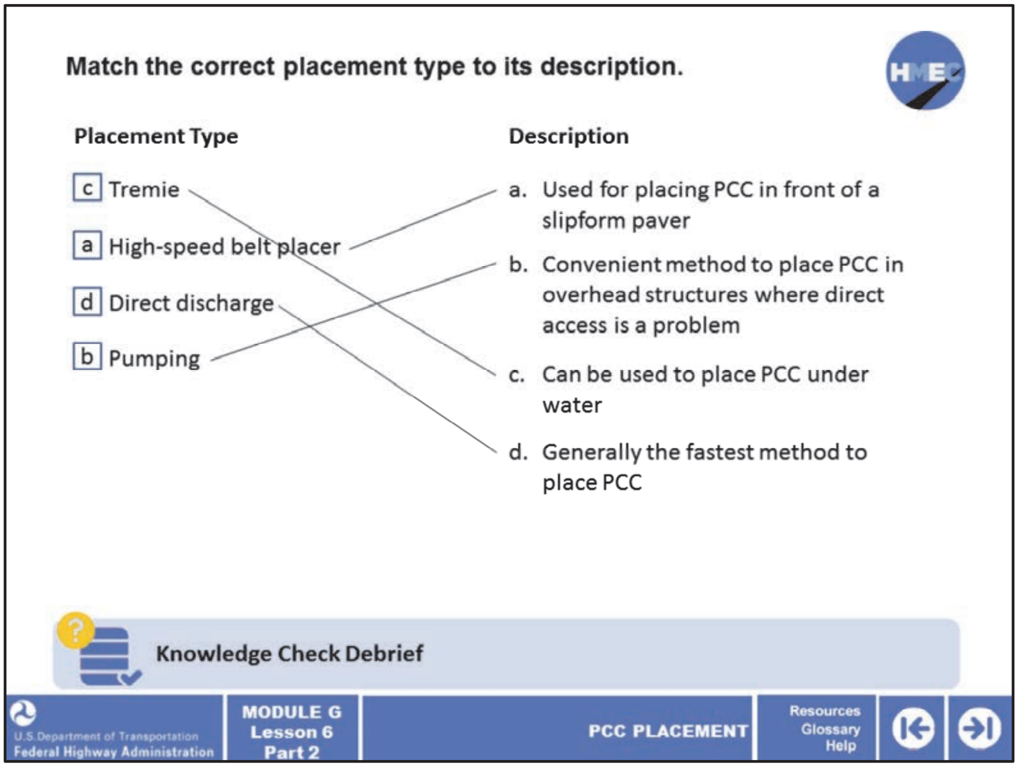
Match the correct placement type to the following descriptions.

Placement type:

- Tremie;
- High-speed belt placer;
- Direct discharge; and
- Pumping.

Description:

a) Used for placing PCC in front of a slipform paver;
b) Convenient method to place PCC in overhead structures where direct access is a problem;
c) Can be used to place PCC under water; and
d) Generally the fastest method to place PCC.



The correct answers are:

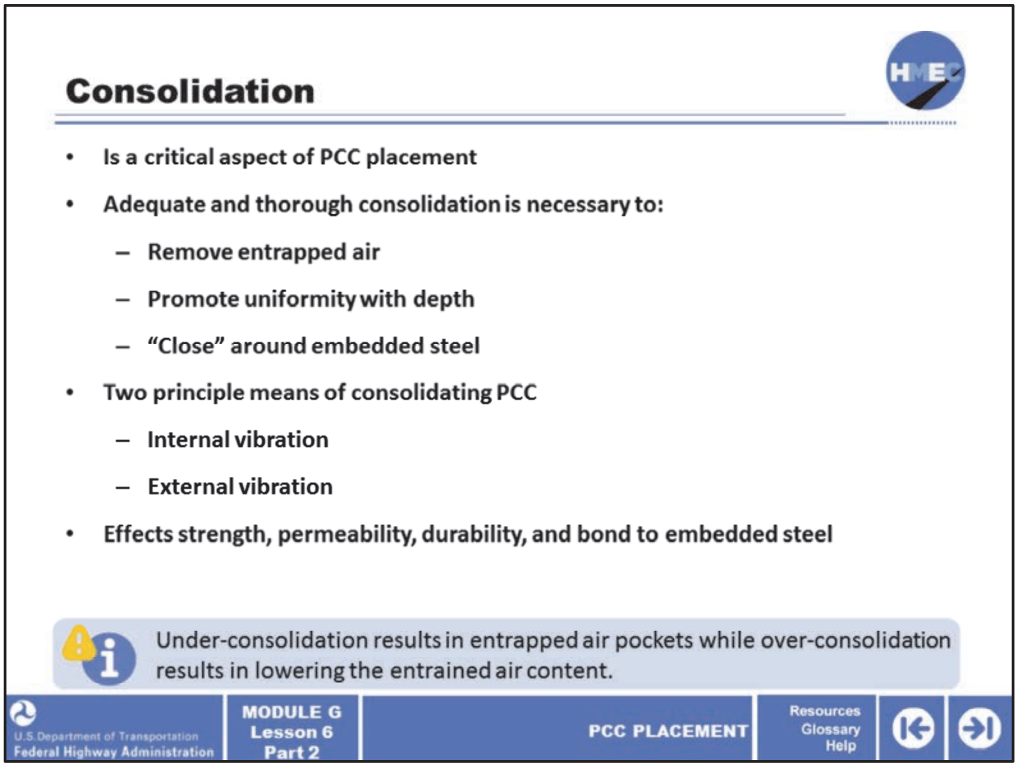
- Tremie is c) Can be used to place PCC under water;
- High-speed belt placer is a) Used for placing PCC in front of a slipform paver;
- Direct discharge is d) Generally the fastest method to place PCC; and
- Pumping is b) Convenient method to place PCC in overhead structures where direct access is a problem.

Tremies are used to place PCC under water by lowering the tremie tube to a depth with virtually no free fall allowing the PCC to displace the water.

The most efficient method to place PCC in front of a slipform paver is the high-speed belt placer, particularly where set ahead steel does not allow the delivery vehicles to back down grade.

Direct discharge is generally the quickest method of placement since the dump truck or transit mix truck simply unloads at the point of use.

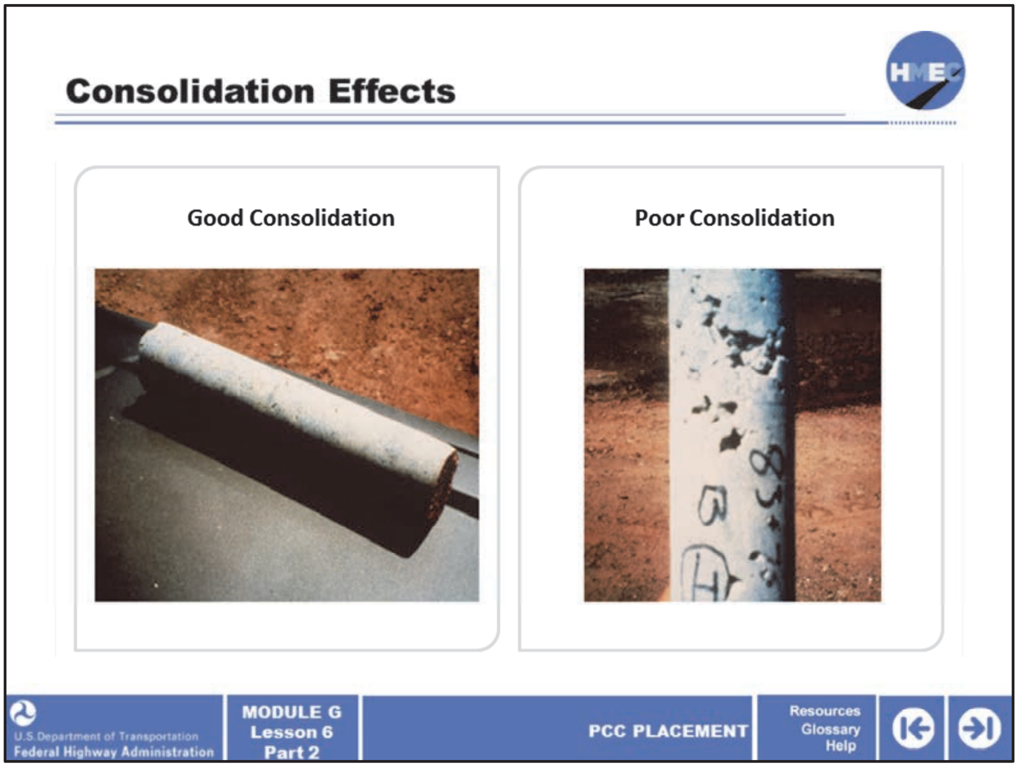
Pumping is a convenient and economical method to place PCC in overhead structures since the discharge hoses and booms can be configured for the specific requirements of the job.



Consolidation is a critical aspect of PCC placement. Adequate and thorough consolidation is necessary for the following reasons:

- Remove entrapped air (not to be confused with entrained air);
- Promote uniformity with depth; and
- "Close" around embedded steel.

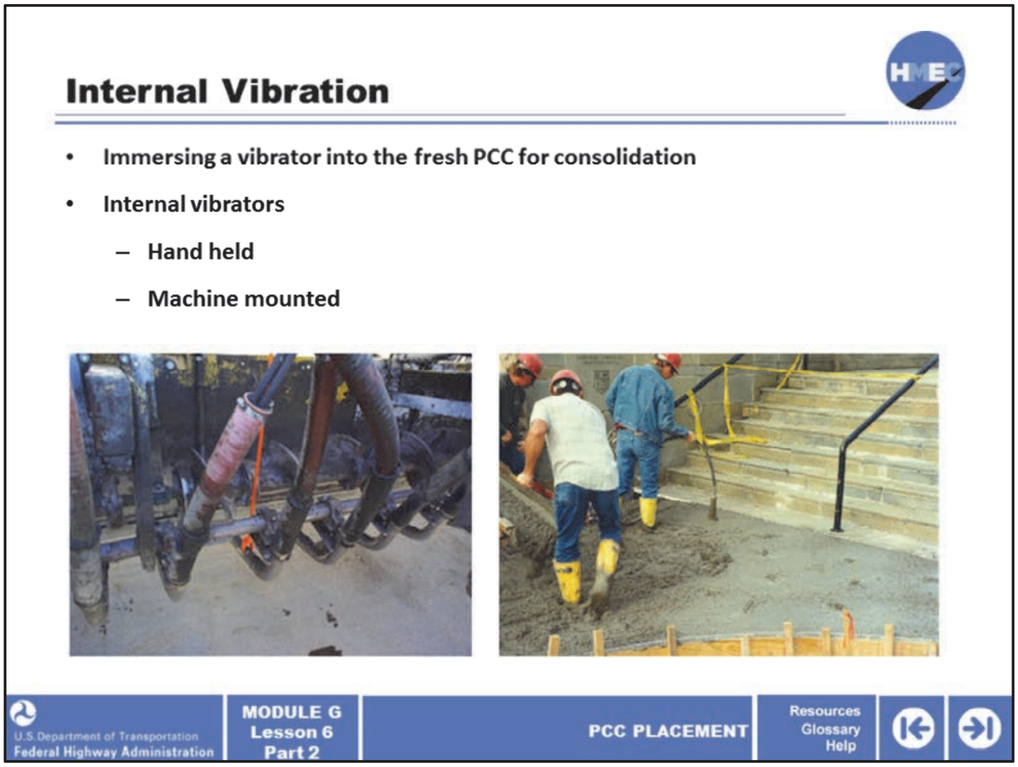
There are two principle means of consolidating PCC: internal and external vibration. Consolidation effects strength, permeability, durability, and bond to embedded steel. From a construction standpoint, consolidation effects yield. Under-consolidation results in entrapped air pockets while over-consolidation results in lowering the entrained air content, both of which negatively impact performance.



The effect of good consolidation, in this case from internal vibration, can be seen in the photo on the left. Note the uniformity and lack of entrapped air. The photo on the right shows the effects of poor consolidation. The large voids are clearly visible, resulting in a significant reduction in both strength and durability.

Image description: Photo of the effect of good consolidation, in this case from internal vibration.

Image description: Photo of the effects of poor consolidation.



Internal vibration is the result of actually immersing a vibrator into the fresh PCC for consolidation. Various sizes of internal vibrators are available for a variety of applications ranging from slab-on-grade construction to reinforced structures. Internal vibrators may be hand held or machine mounted depending on the application. The vibrator frequency and/or amplitude should be as low as possible while still providing good consolidation. Over-vibration can cause segregation and loss of entrained air.

The photo on the left shows an array of internal vibrators mounted to a slipform paver. The photo on the right shows a hand-held vibrator being used to consolidate a PCC slab.

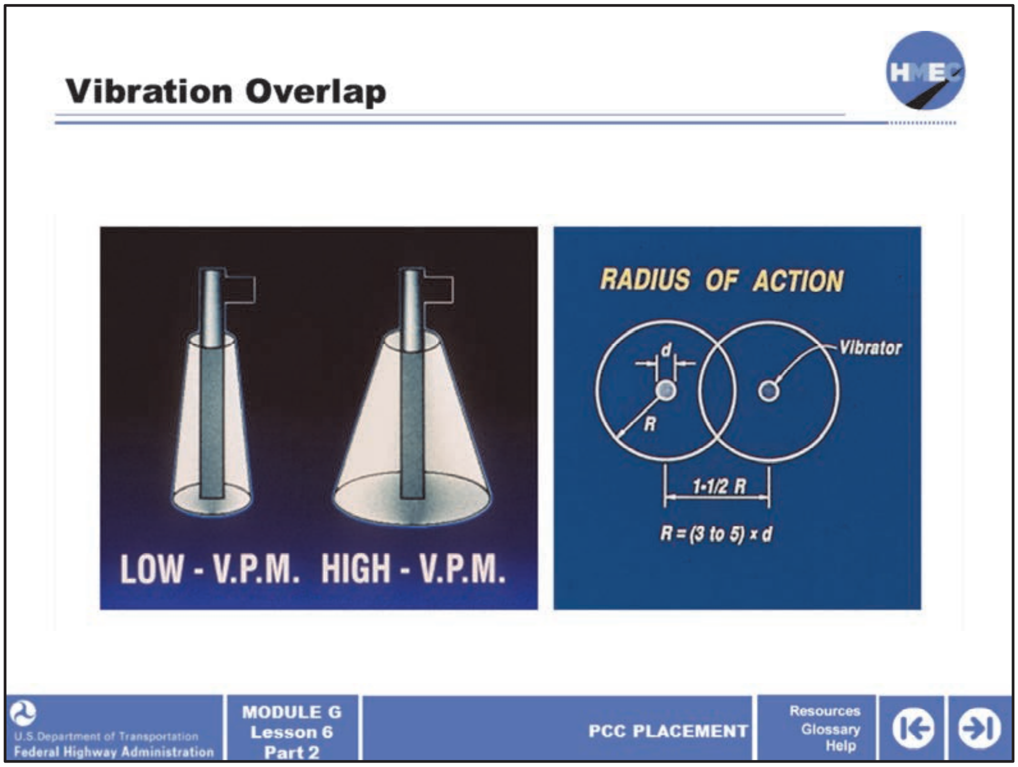
Proper technique calls for:

• Vertical insertion of the vibrator;
• In the case of wet on wet lifts, the vibrator should penetrate the existing lift;
• Not using the vibrator to move or drag the PCC horizontally;
• Positioning the vibrator so the zone of influence of the vibrator insertions overlap;
• Not contacting any embedded steel; and
• Vibrating only long enough for uniform consolidation (usually 5 to 15 seconds);

Note that the insertion pattern and time are partially dependent on the vibrator diameter and vibration frequency.

Image description: Photo of an array of internal vibrators mounted to a slipform paver.

Image description: Photo of a hand-held vibrator being used to consolidate a PCC slab.



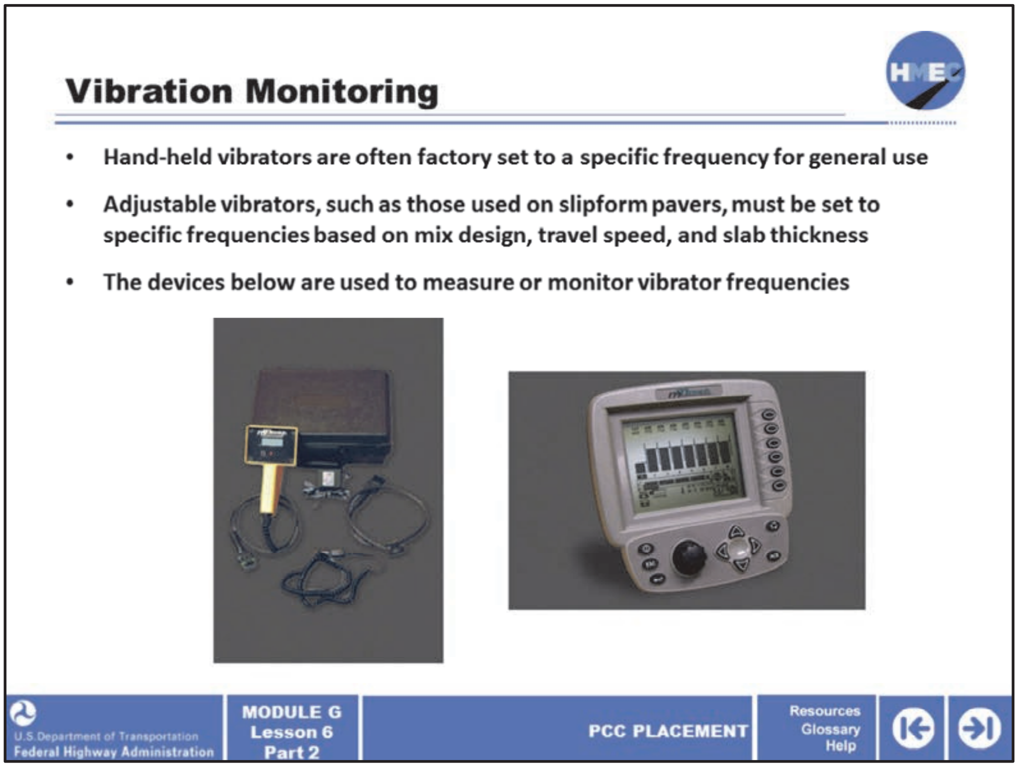
The diagram on the left shows what is commonly known as the zone of influence for slipform paver-mounted internal vibrators.

As can be seen, at low frequency (low vibrations per minute or VPM), the zone of influence is relatively small. As the VPM increases, so does the zone of influence. The goal is to have sufficient overlap of these zones to ensure uniform consolidation.

The figure on the right shows a similar effect for hand-held, vertically inserted vibrators.

Image description: Diagram showing what is commonly known as the zone of influence for slipform paver-mounted internal vibrators.

Image description: Diagram showing a similar effect for hand-held, vertically inserted vibrators.



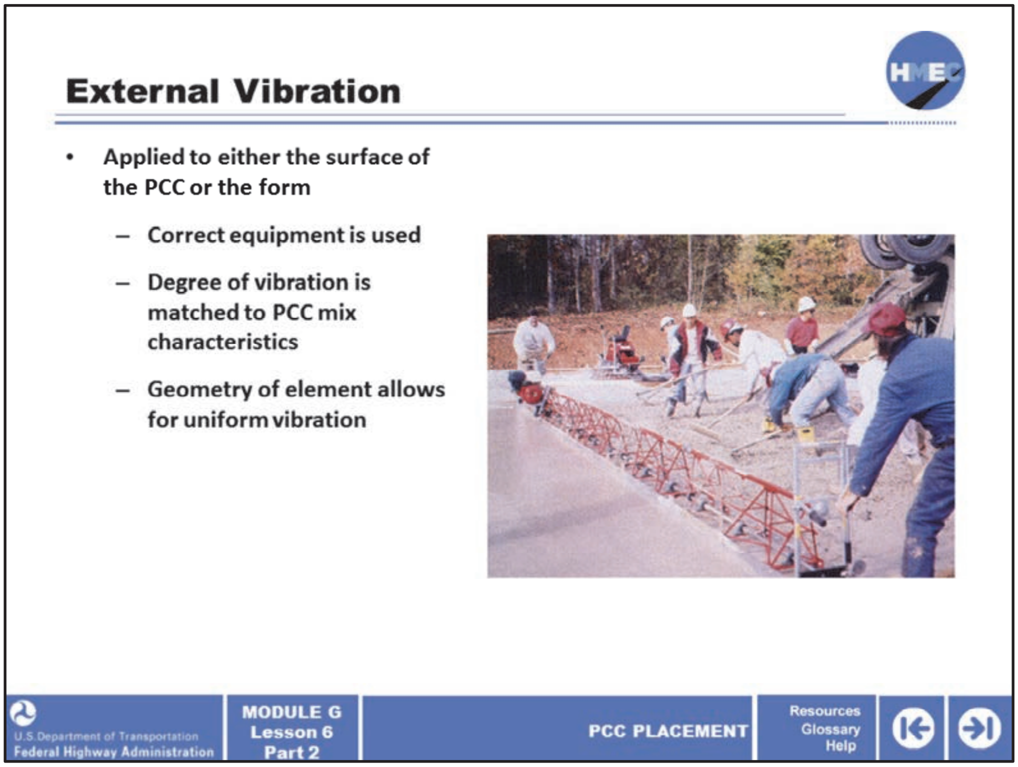
Hand-held vibrators are often factory set to a specific frequency for general use.

Adjustable vibrators, such as those used on slipform pavers, must be set to specific frequencies based on mix design, travel speed, and slab thickness.

The tachometer pictured on the left is used to measure the frequency of individual vibrators. The device on the right is used to monitor and control an array of vibrators simultaneously, in this case, on a slipform paver.

Image description: Photo of a tachometer used to measure the frequency of individual vibrators.

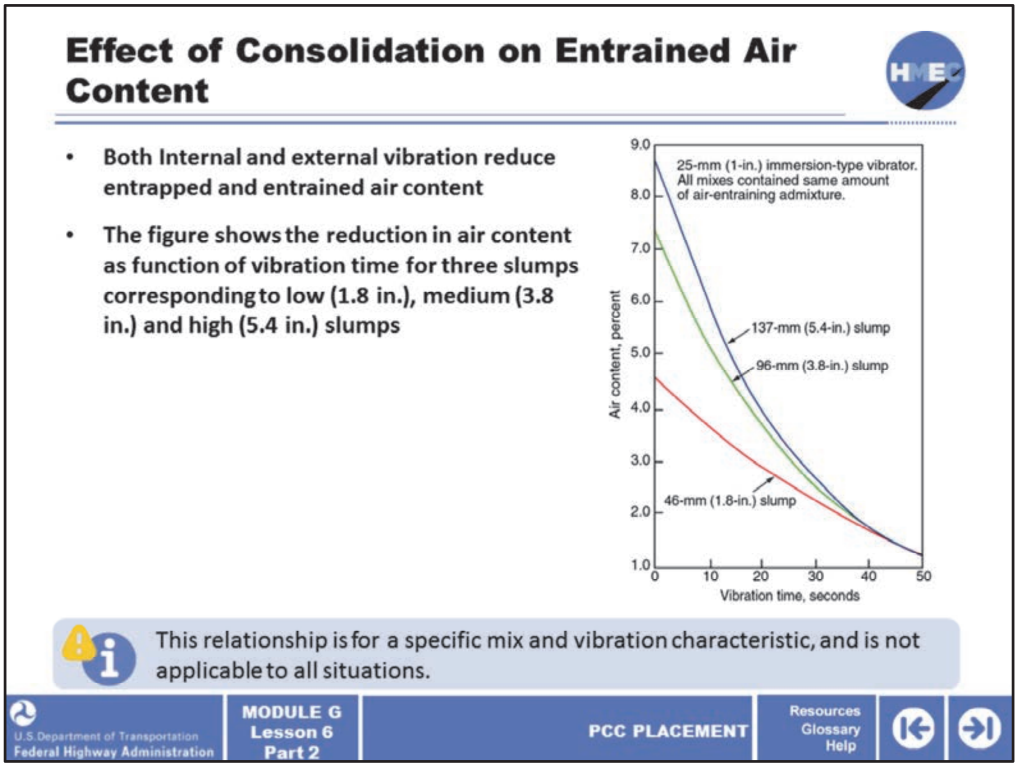
Image description: Photo of a device used to monitor and control an array of vibrators simultaneously, in this case, on a slipform paver.



External vibration is applied to either the surface of the PCC or to the form for certain structural pours. External vibration can be very effective, provided the correct equipment is used, the degree of vibration is matched to the PCC mix characteristics, and the geometry of the element allows for uniform vibration.

The most common type of external vibrator for slab-on-grade construction/pavements is a vibrating screed. The truss screed unit pictured is used to strike off and consolidate the PCC pavement in a single operation. External vibration is limited by the depth of the PCC and may require additional vibration with internal vibrators or placement in multiple lifts. Remember that the goal is to have uniform consolidation throughout the PCC mass.

Image description: Photo of a truss screed unit.



Both internal and external vibration reduce entrapped and entrained air content. The amount of air content reduced by vibration varies depending on the type of vibrator (internal or external), vibrator frequency, and time, as well as the mix characteristics of the concrete.

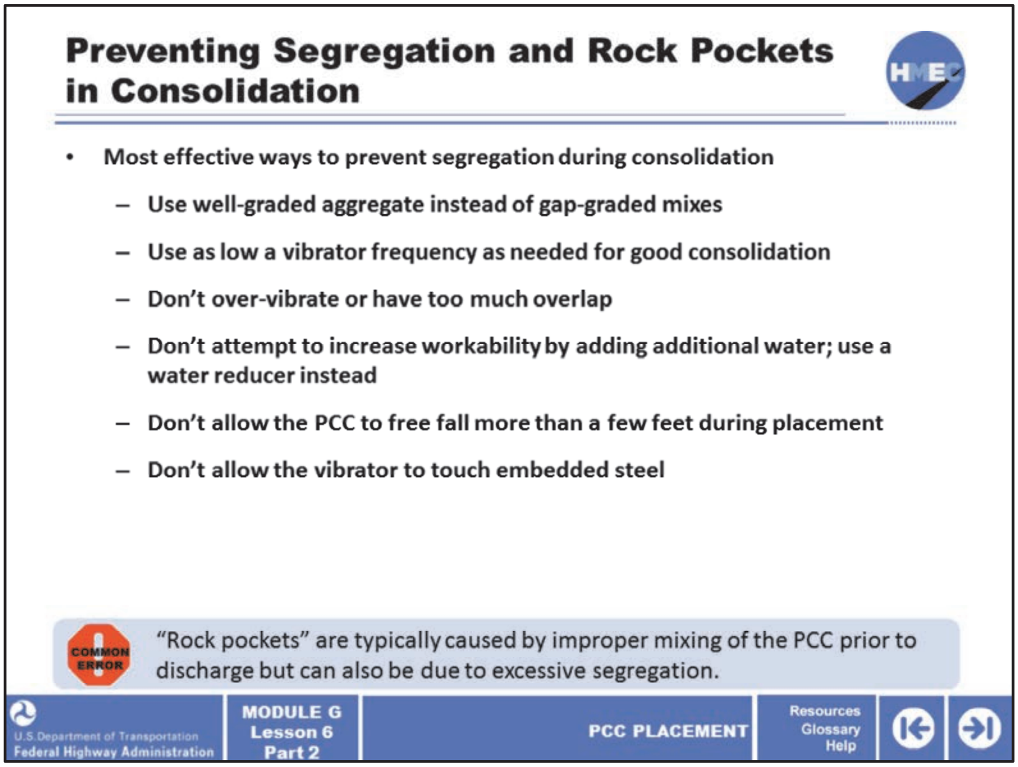
The figure shows the reduction in air content as a function of vibration time for three slumps corresponding to low (1.8 inches), medium (3.8 inches) and high (5.4 inches) slumps.

Note that as slump increases, the capacity to lose air as a function of vibration also increases.

This graph was developed for a specific mix and vibration characteristics and is not applicable to all situations. It does however, show the relative behavior that would be expected of most mixes.

The graph clearly illustrates that even low slump concrete can show a reduction of one or more percent as a result of the internal vibration in a typical slipform paving operation.

Image description: Graph showing the reduction in air content as a function of vibration time for three slumps corresponding to low (1.8 inches), medium (3.8 inches) and high (5.4 inches) slumps.



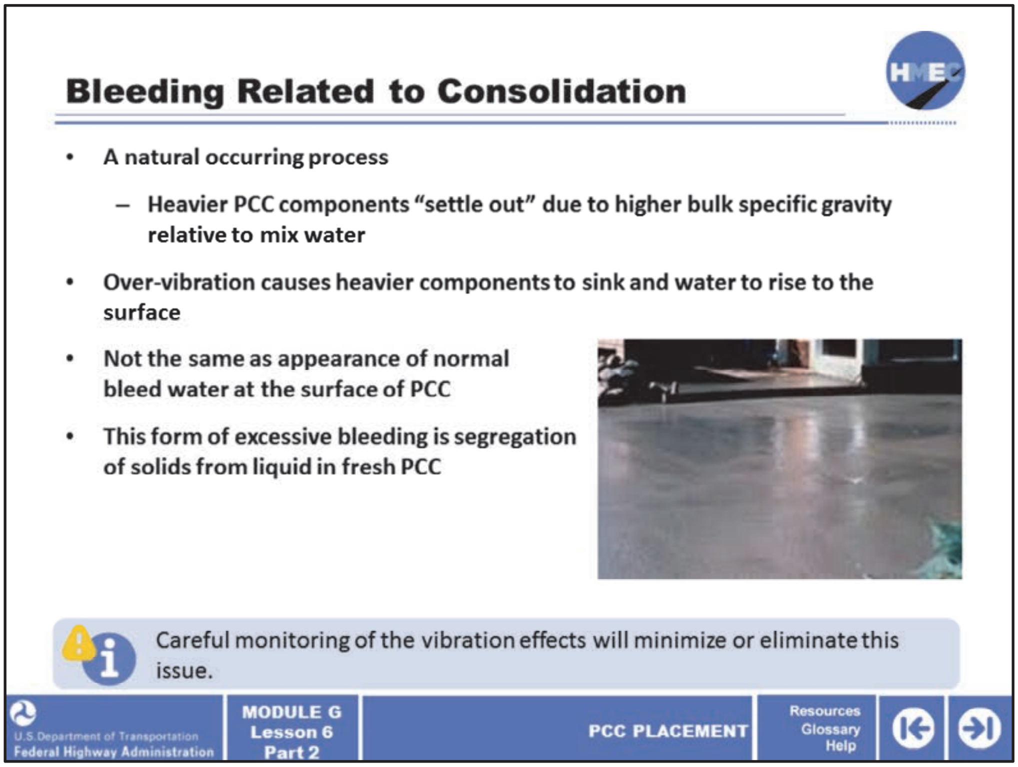
Here are some of the most effective ways to prevent segregation during consolidation:

• Use well-graded aggregate instead of gap-graded mixes;
• Use as low a vibrator frequency as needed for good consolidation;
• Don't over-vibrate or have too much overlap;
• Don't attempt to increase workability by adding additional water, use a water reducer instead;
• Don't allow the PCC to free fall more than a few feet during placement; and
• Don't allow the vibrator to touch embedded steel.

Segregation is rarely a problem with low slump PCC. However, the likelihood of segregation increases as the slump increases. The most important factor, in most cases is to design the mix using an appropriate aggregate gradation and low w/c ratio. Adding water to increase slump will increase segregation potential, sometimes substantially. Increasing the slump with superplasticizer does not increase segregation potential.

"Rock pockets" are the effects of segregation in the mix where honeycombed areas that are predominantly larger rocks with very little fines and paste are created.

"Rock pockets" are typically caused by improper mixing of the PCC prior to discharge but can also be due to excessive segregation. Preventing rock pockets begins with determining the source and taking the appropriate remedial steps.

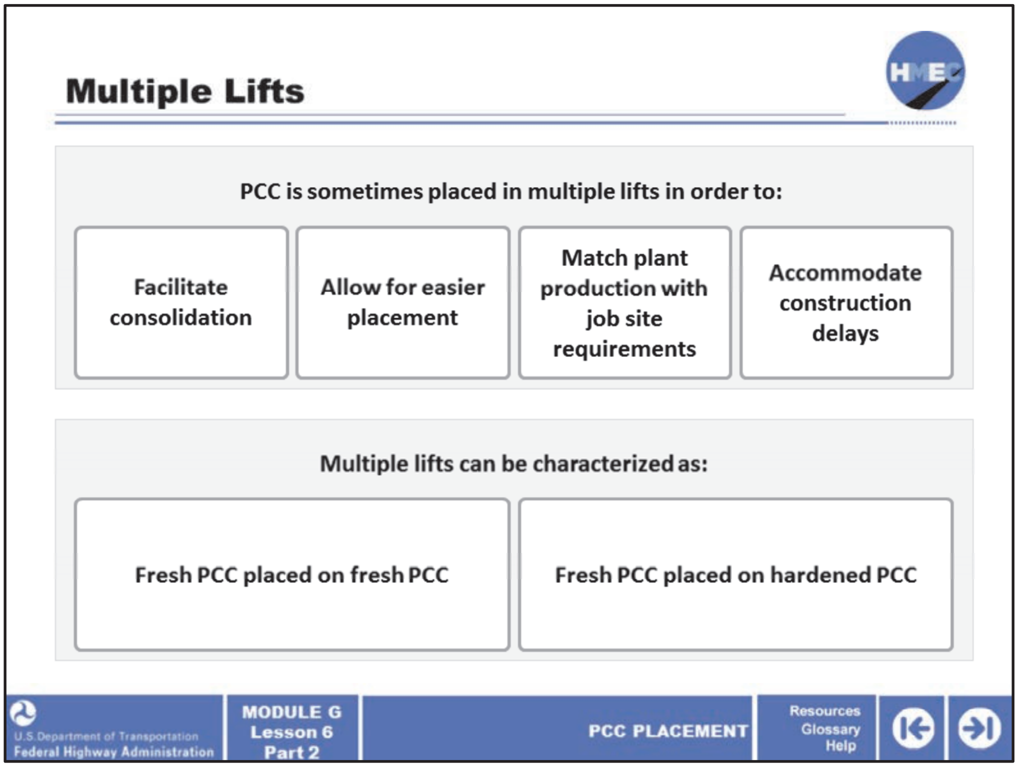


Bleeding is a natural occurring process where the heavier PCC components "settle out" due to their higher bulk specific gravity relative to the mix water. This process occurs in almost all PCC placements with the exception of extremely low w/c ratio mixes. This process is a necessary step in the initial set, prior to finishing but can be altered by over-vibration.

Over-vibration essentially causes the heavier components to sink and the water to rise to the surface before the initial set takes place, thereby altering the hydration process. The bleeding due to over-consolidation is not the same as the appearance of normal bleed water at the surface of the PCC. This form of excessive bleeding is essentially segregation of the solids from the liquid in the fresh PCC. Careful monitoring of the vibration effects will minimize or eliminate this issue.

The photo illustrates bleed water on the surface of a PCC slab. Note that bleed water is no longer a common occurrence for the very low w/c ratio mixes prevalent in transportation-related projects.

Image description: Photo of bleed water on the surface of a PCC slab.



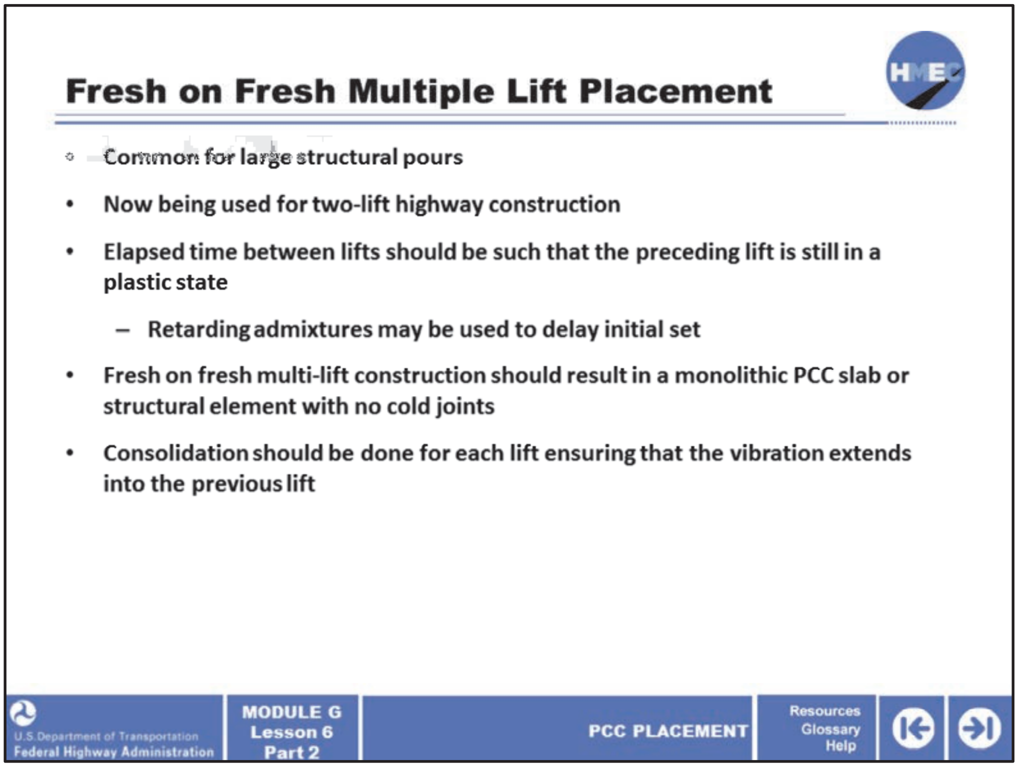
PCC is sometimes placed in multiple lifts in order to:

- Facilitate consolidation;
- Allow for easier placement;
- Match plant production with job site requirements; and
- Accommodate construction delays.

Multiple lifts can be characterized as:

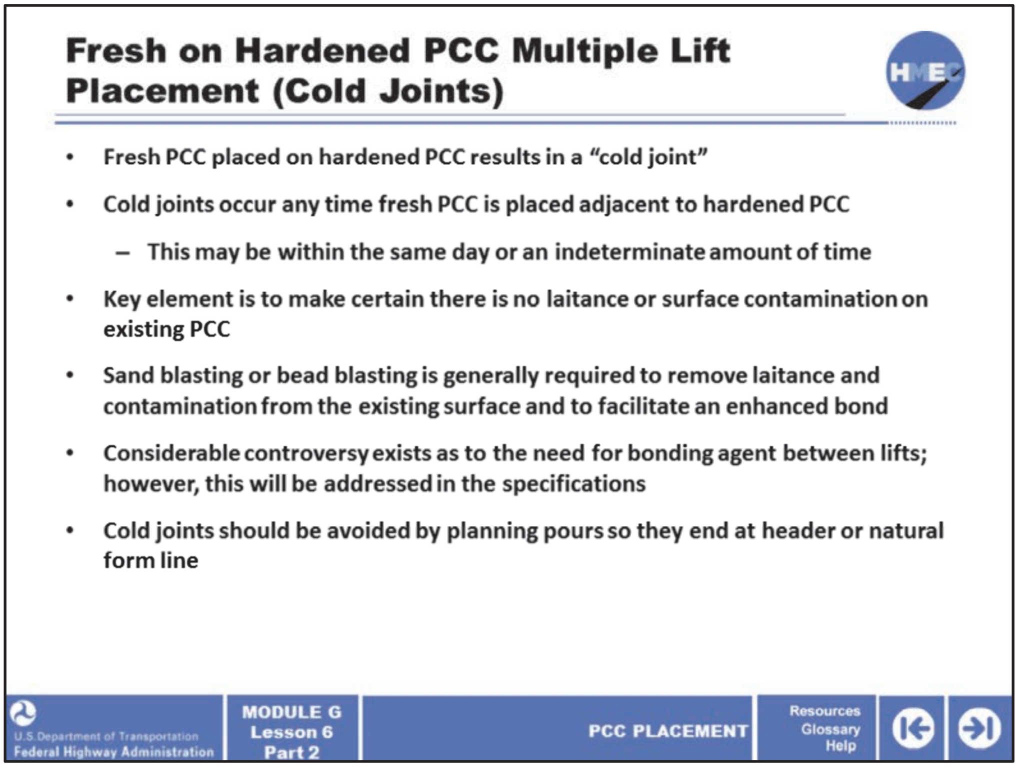
- Fresh PCC placed on fresh PCC (commonly referred to as wet on wet); and
- Fresh PCC placed on hardened PCC.

In general, if PCC can be placed monolithically, it is advantageous to do so.



This type of placement is common for large structural pours and is now being used for two-lift highway construction. The time between lifts may be as minimal as the next haul truck pulling into position, or it may be considerably longer depending on the mix and environmental conditions.

The elapsed time between lifts should be such that the preceding lift is still in a plastic state. Retarding admixtures may be used to delay initial set and provide more working time between lifts. Fresh on fresh multi-lift construction should result in a monolithic PCC slab or structural element with no cold joints. Consolidation should be done for each lift ensuring that the vibration extends into the previous lift.



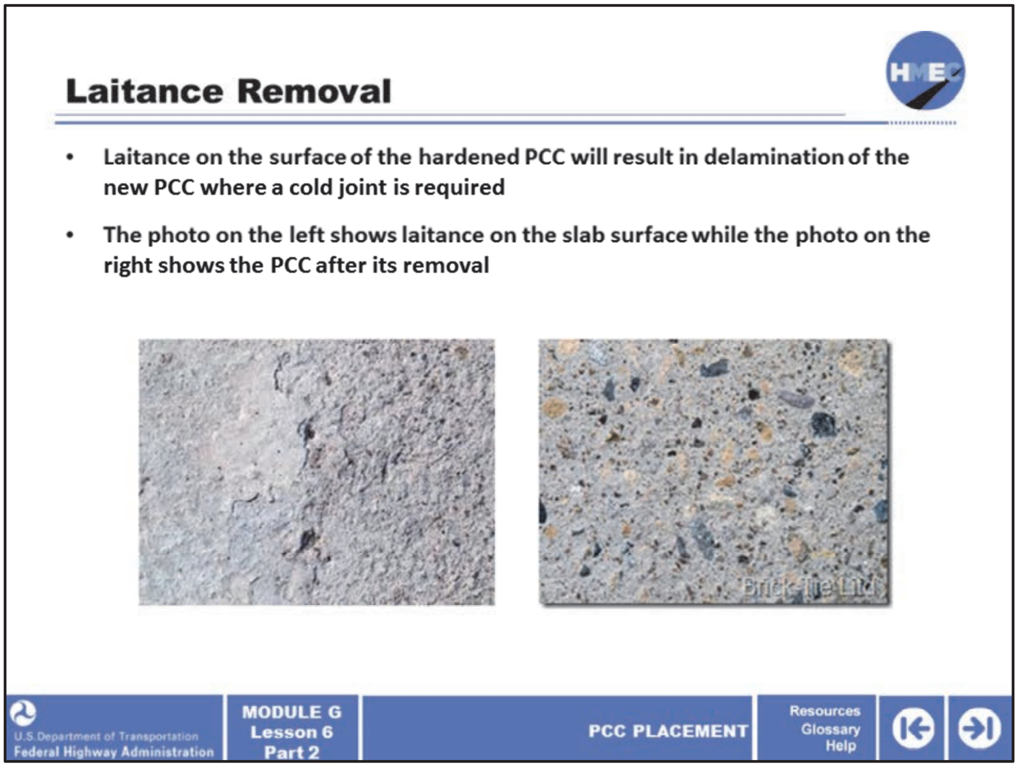
There are many occasions where fresh PCC is placed on hardened PCC resulting in a "cold joint." This type of multi-lift placement does not result in monolithic PCC as did fresh on fresh. However, if done correctly, the cold joint is not problematic. Although not as desirable as fresh on fresh, this type of multi-lift construction is often necessary for constructability reasons.

Cold joints occur any time fresh PCC is placed adjacent to hardened PCC. This may be within the same day or an indeterminate amount of time.

Sand blasting or bead blasting is generally required to remove laitance and contamination from the existing surface and to facilitate an enhanced bond.

Considerable controversy exists as to the need for bonding agent between lifts. However, this will be addressed in the specifications.

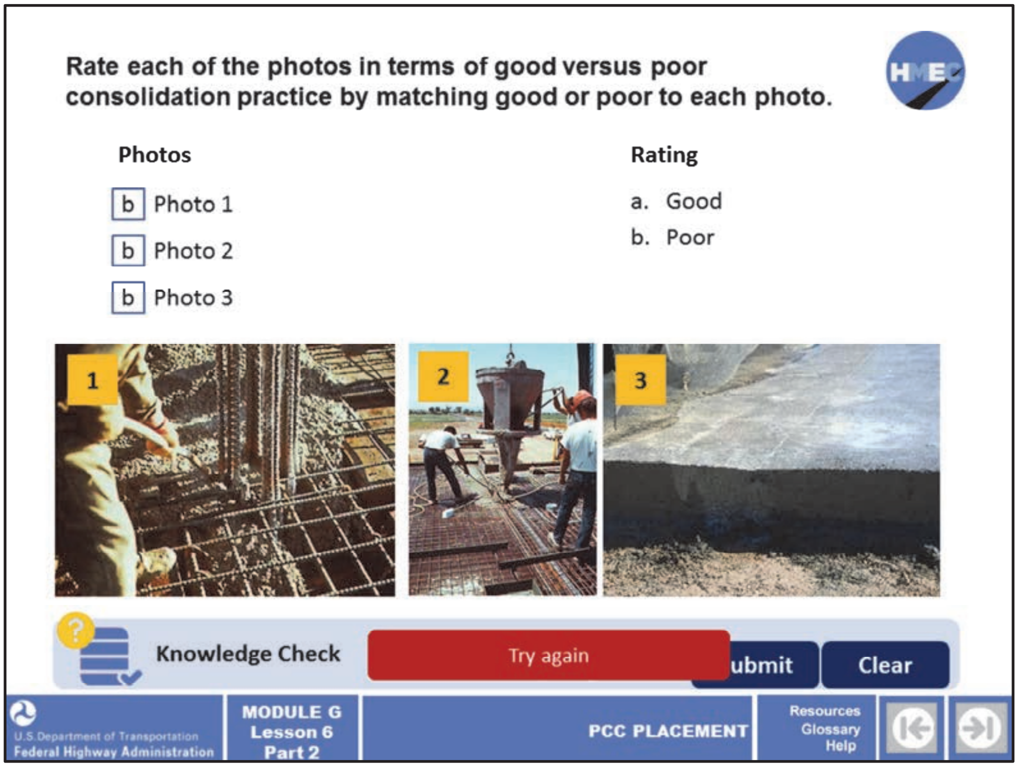
If possible, cold joints should be avoided by planning pours so that they end at a header or natural form line. If cold joints are necessary, it is advantageous to balance the thickness of the lifts rather than having one thin and one thick lift.



Laitance on the surface of the hardened PCC will result in delamination of the new PCC where a cold joint is required. The photo on the left shows laitance on the slab surface while the photo on the right shows the PCC after its removal.

Image description: Photo of laitance on the slab surface.

Image description: Photo of the PCC after the removal of the laitance.

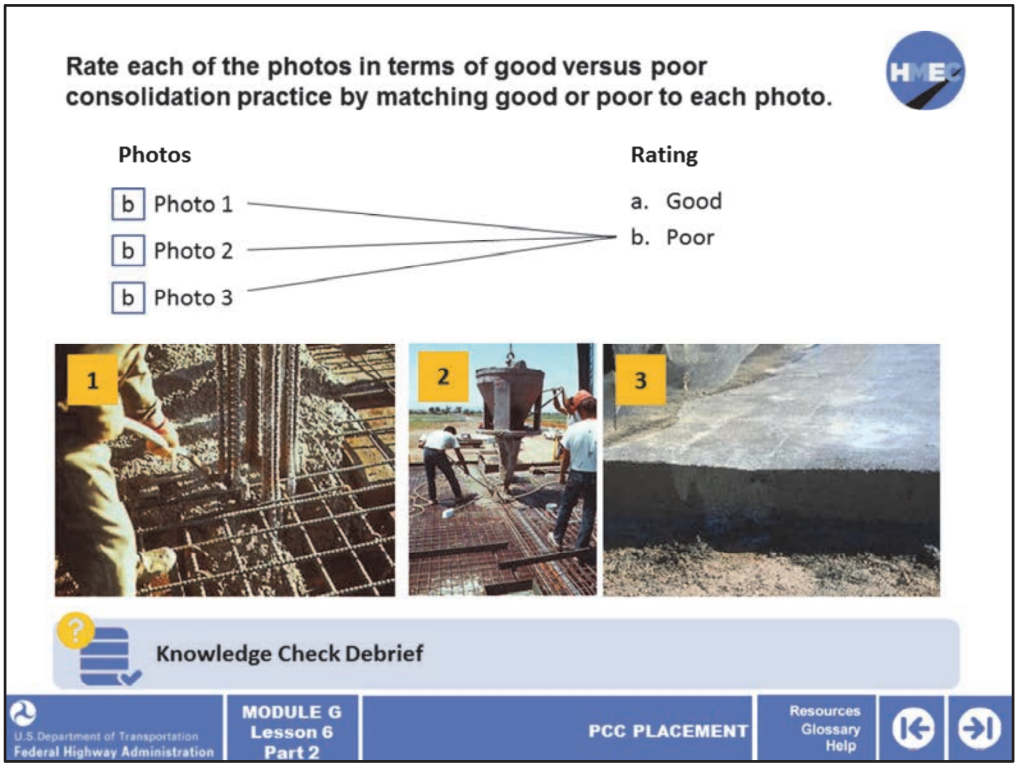


Rate each of the photos in terms of good versus poor consolidation practice by matching good or poor to each photo.

Image description: Photo of consolidation.

Image description: Photo of consolidation.

Image description: Photo of consolidation.



The correct answer is that all three photos show poor consolidation practices.

Photo 1 illustrates poor practice by inserting the vibrator at a 45-degree angle rather than near vertical. In addition, the vibrator appears to be touching the steel, which will result in a high w/c ratio layer immediately surrounding the bars, thereby lowering the bond strength.

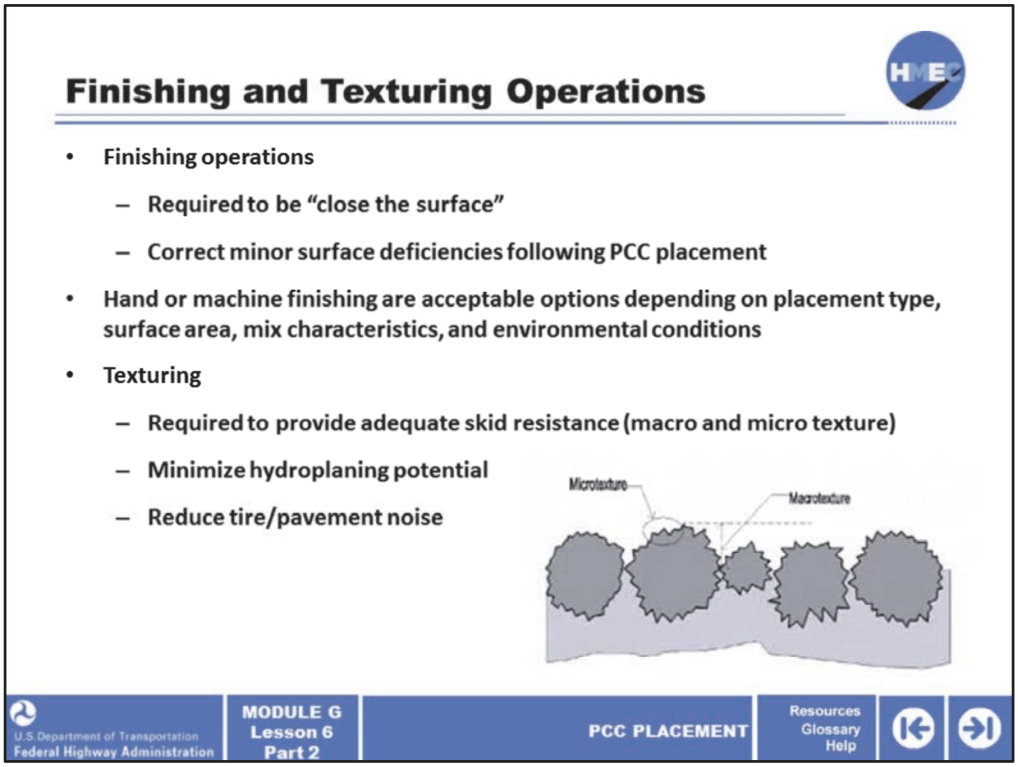
Photo 2 shows the vibrator being used to drag the PCC under the placement bucket. This will likely result in segregation, particularly since the material appears to be fairly high slump.

Photo 3 shows the effects of segregation in the mix. The honeycombed areas are predominantly larger rocks (commonly called rock pockets) with very little fines and paste. These segregated areas result in lower strength and reduced durability. Note that this problem is sometimes partially remedied by increasing the level of vibration.

Image description: Photo of consolidation.

Image description: Photo of consolidation.

Image description: Photo of consolidation.



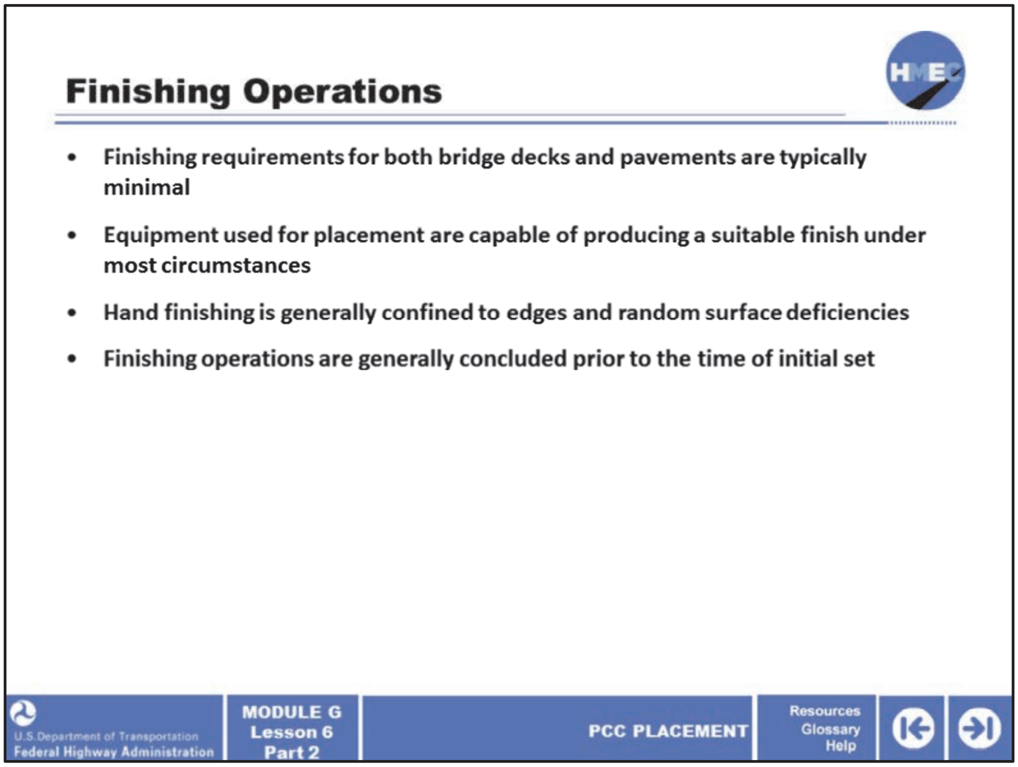
Finishing and texturing operations are equally important for both bridge decks and PCC pavements.

Finishing operations are required to "close the surface" and correct minor surface deficiencies following PCC placement. Hand or machine finishing are acceptable options depending on placement type, surface area, mix characteristics, and environmental conditions. Texturing is required to provide adequate skid resistance, minimize hydroplaning potential, and potentially reduce tire/pavement noise.

Unlike the hard trowel finish that is common in residential and industrial slab-on-grade construction, the micro and macro textures for bridge decks and pavements are purposely rough to provide adequate friction for skid resistance. The diagram of micro and macro texture illustrates the basic differences in terminology. The micro texture is more a function of aggregate properties while the macro texture is "built" using the techniques we will discuss, i.e., drag finishes, tining, etc.

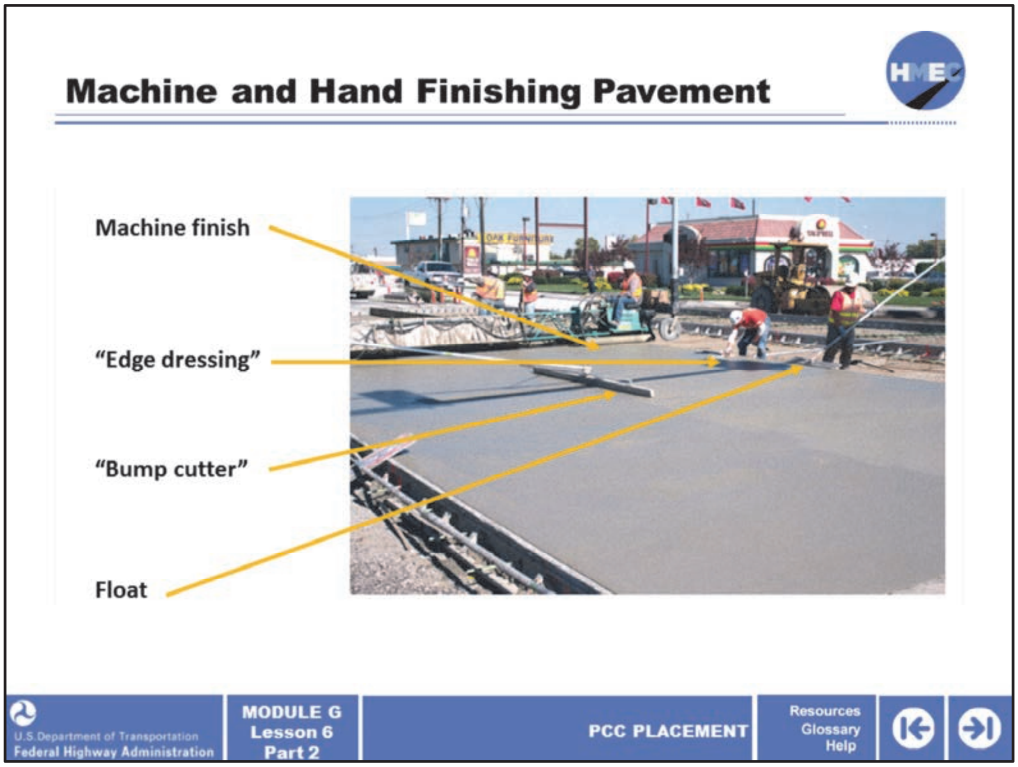
We will briefly examine the most common types of finishing and texturing operations used throughout the US.

Image description: Diagram of micro and macro texture illustrating the basic differences in terminology.



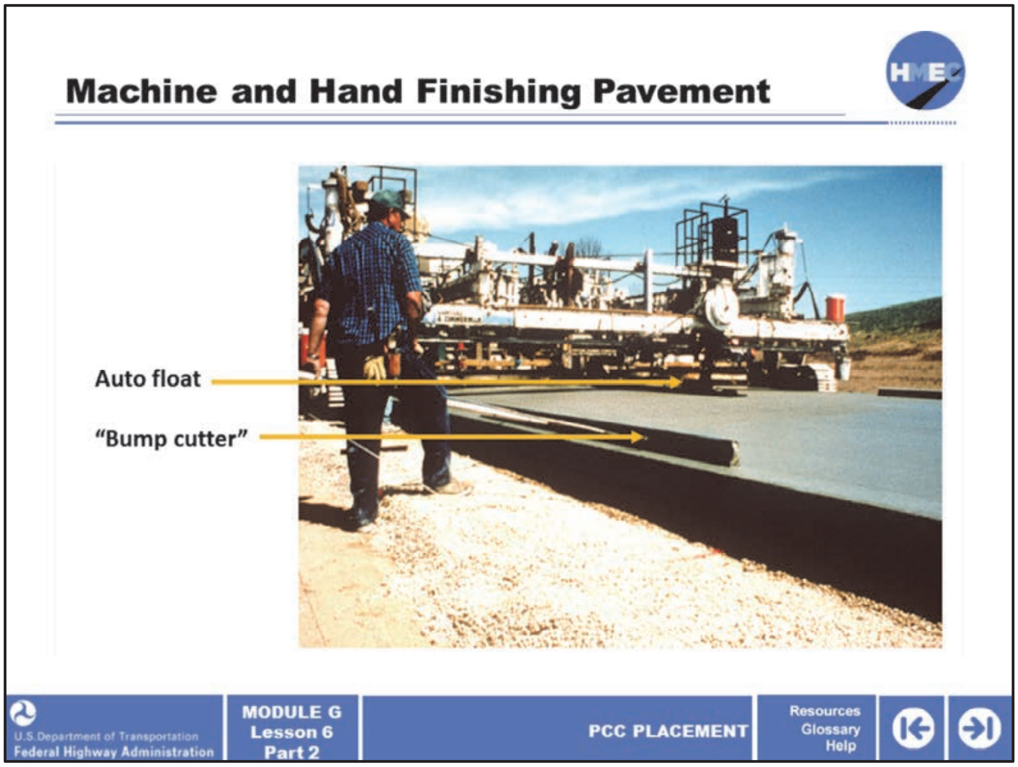
Finishing requirements for both bridge decks and pavements are typically minimal. The equipment used for placement, i.e. bridge deck finishers, slipform pavers, power screeds, etc. are capable of producing a suitable finish under most circumstances. Hand finishing is generally confined to the edges and random surface deficiencies. Finishing operations are generally concluded prior to the time of initial set.

The majority of concrete finishing is carried out by the equipment used for placement. Other than hand finishing at the edges and to correct minor surface deficiencies, modern equipment produces a finish superior to hand finishing. In order for the finish to be acceptable, the mix characteristics, uniformity of the concrete, equipment selection, set-up, and careful monitoring are required.



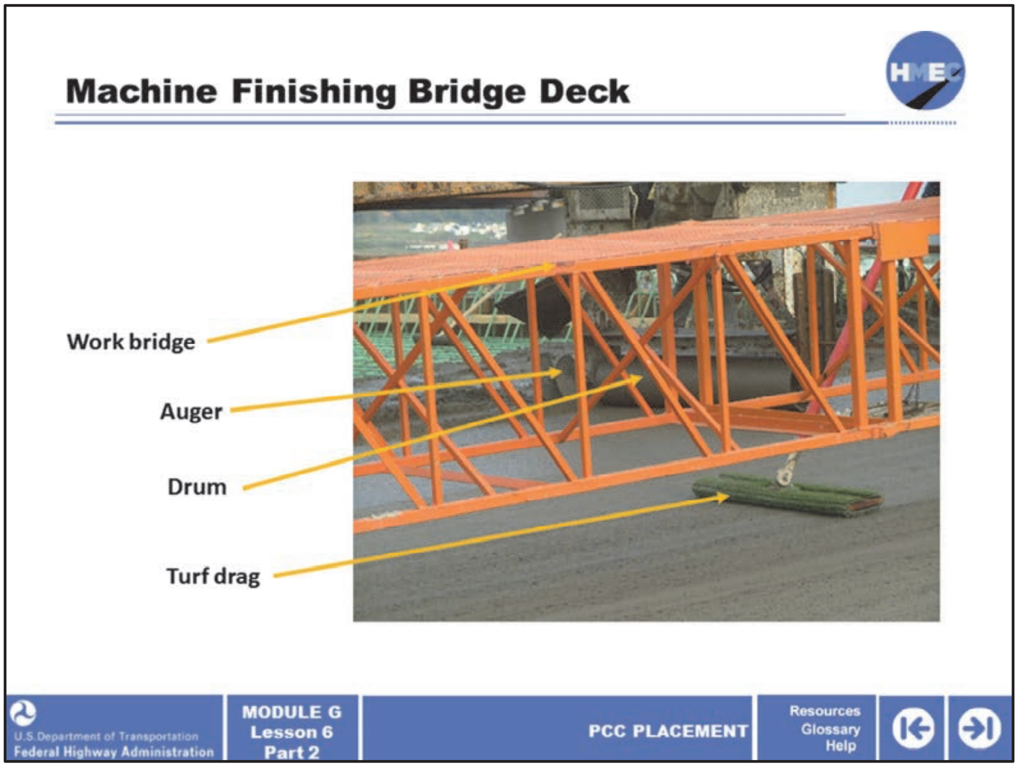
This photo illustrates several operations of interest. The initial finish is provided by the placing equipment. As can be seen by examination of the pavement, very little additional finishing is required after placement, strikeoff, and consolidation. Hand finishing operations include floating the surface, “dressing” the pavement edge, and the use of a “bump cutter” to improve ride quality.

Image description: Photo of several operations of interest.



A 12 to 16 ft. straightedge is often used to remove high spots and fill in low spots following machine placement. The equipment has already effectively "closed the surface" of the PCC, and the sole purpose of this technique is to improve ride quality. This straightedge or bump cutter is not the same as a float.

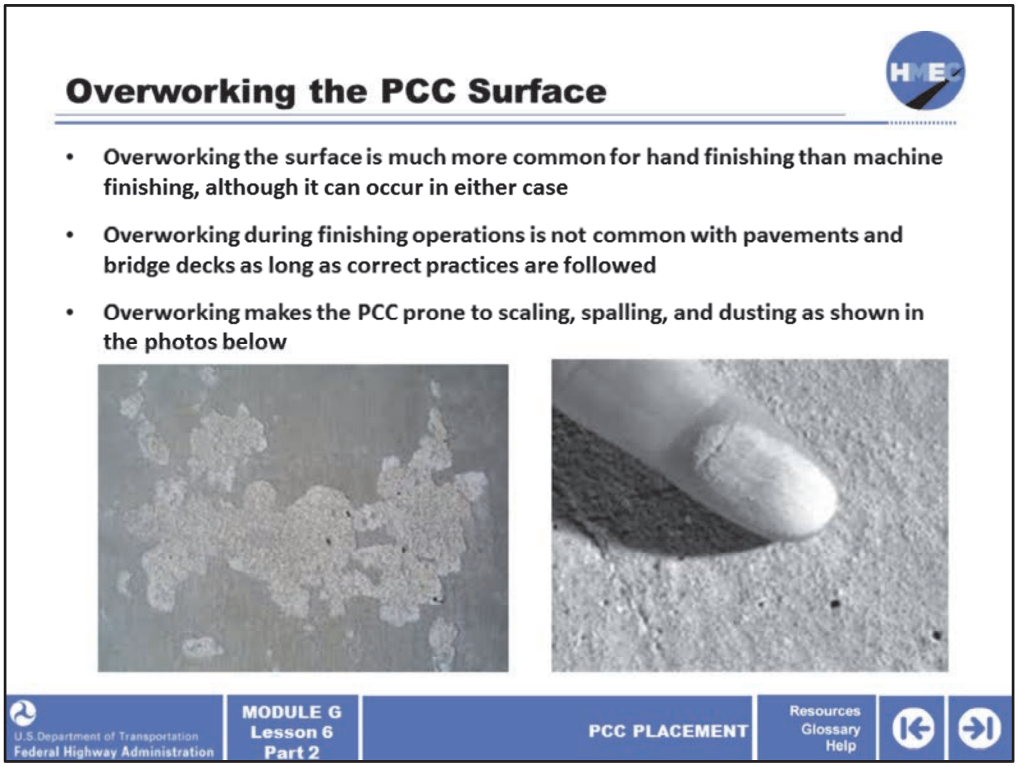
Image description: Photo of a paving operation highlighting the auto float and bump cutter.



After the deck concrete is placed by the finishing machine auger and drum (center of photo), the concrete is given a roughened texture for traction. This is done by dragging a piece of artificial turf mounted to a pole across the fresh PCC. The orange work platform provides access above the newly placed PCC and travels closely behind the finishing machine.

The photo is from NYDOT I-86, Route 15 intersection project.

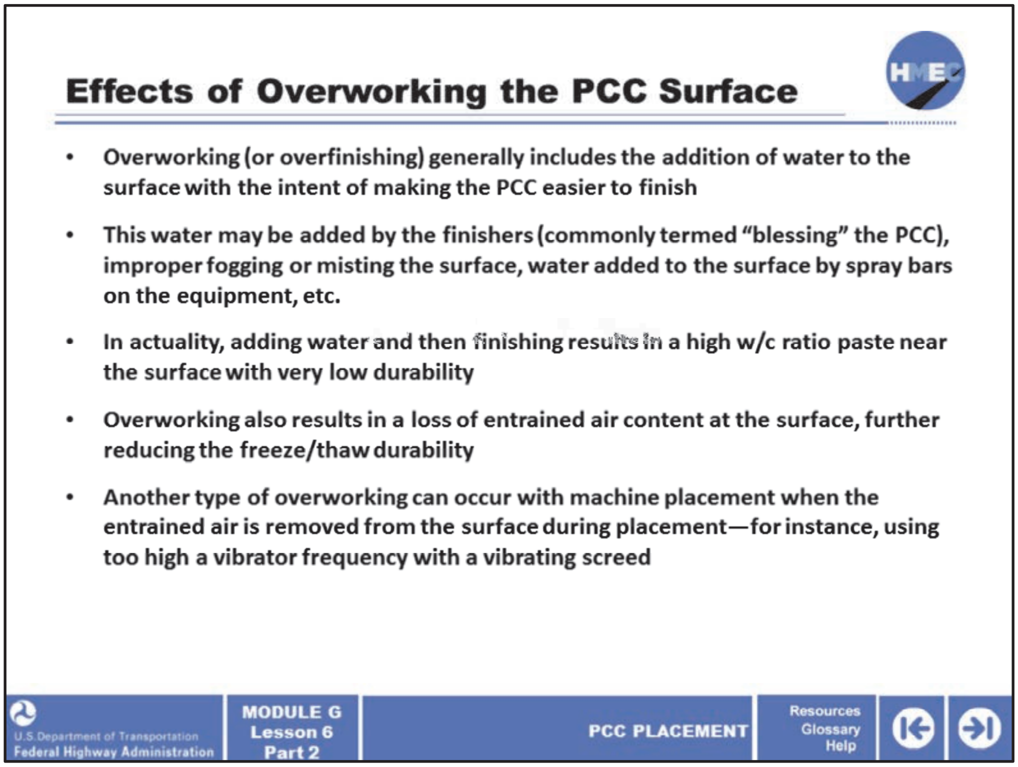
Image description: Photo of paving operation highlighting the work bridge, auger, drum and turf drag.



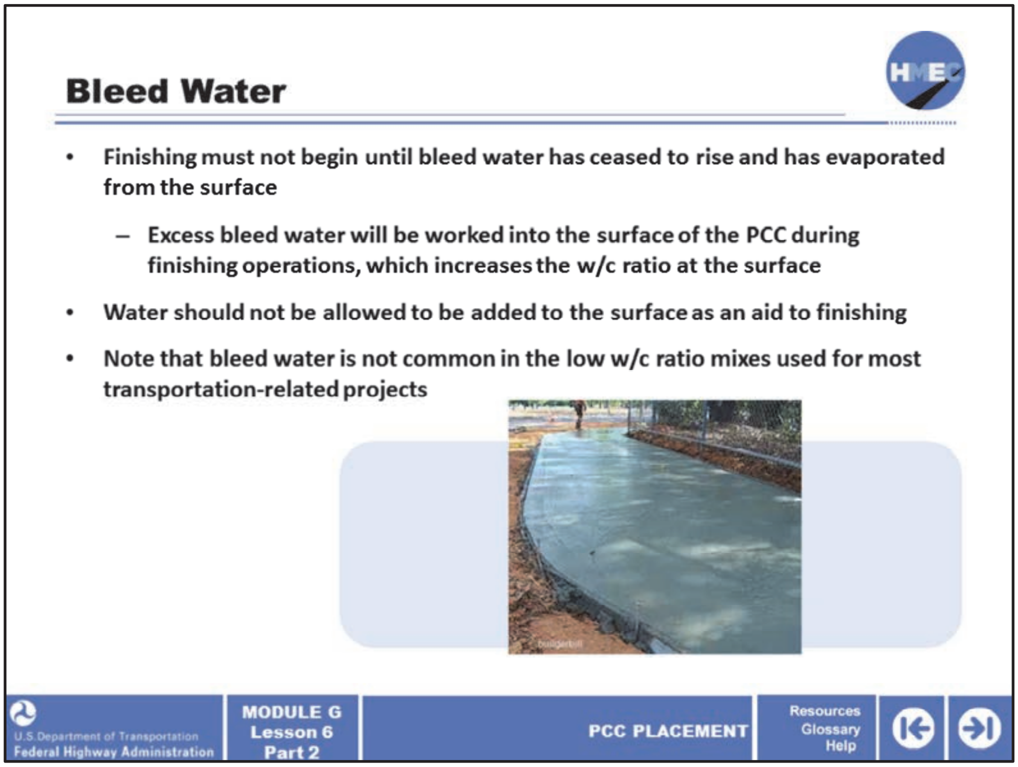
Overworking of the surface is much more common for hand placements than machine placements. Overworking the surface of the PCC during finishing operations is not common with pavements and bridge decks due to the limited need for hand placement. However, when this problem occurs, surface durability is negatively impacted.

Image description: Photo of overworked pavement.

Image description: Photo of overworked pavement.



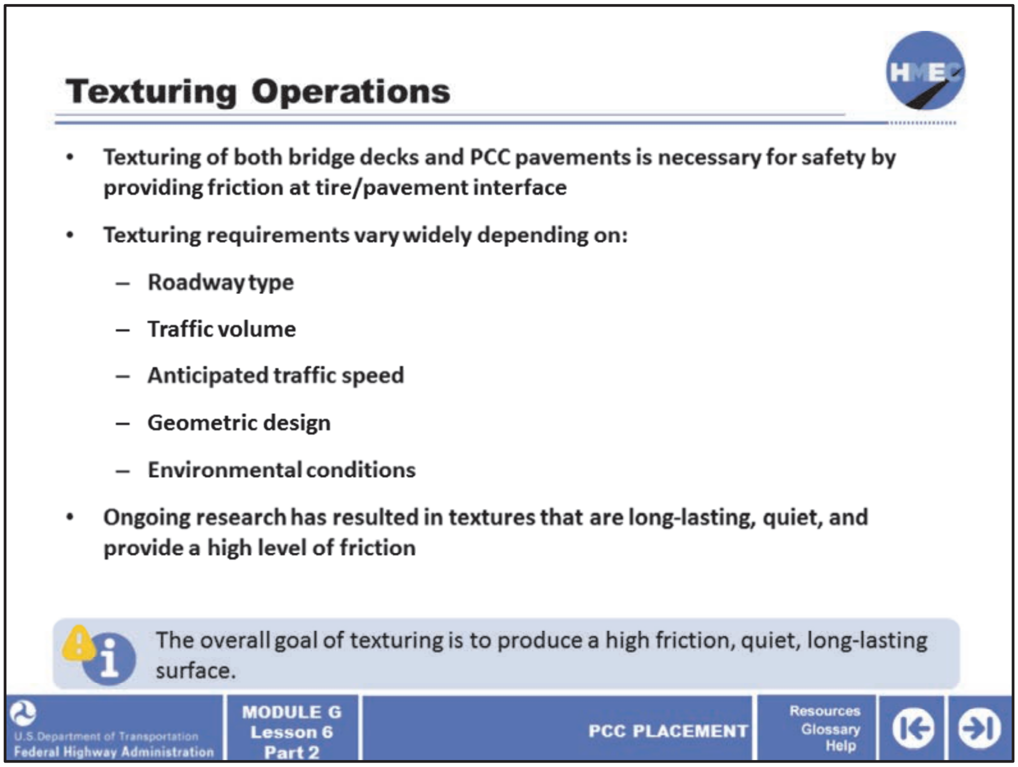
Overworking generally includes the addition of water to the surface with the intent of making the PCC easier to finish. Adding too much water, which is typically due to improper fogging or misting, tends to form a thin, non-durable layer of high w/c ratio paste to the surface. Overworking also results in a loss of entrained air content and makes the PCC prone to scaling, spalling, and dusting. To avoid overworking, you should use the minimum amount of water required for finishing.



Finishing must not begin until the bleed water has ceased to rise and has evaporated from the surface, otherwise excess bleed water will be worked into the surface of the PCC during finishing operations, which increases the w/c ratio at the surface. Water should not be allowed to be added to the surface as an aid to finishing.

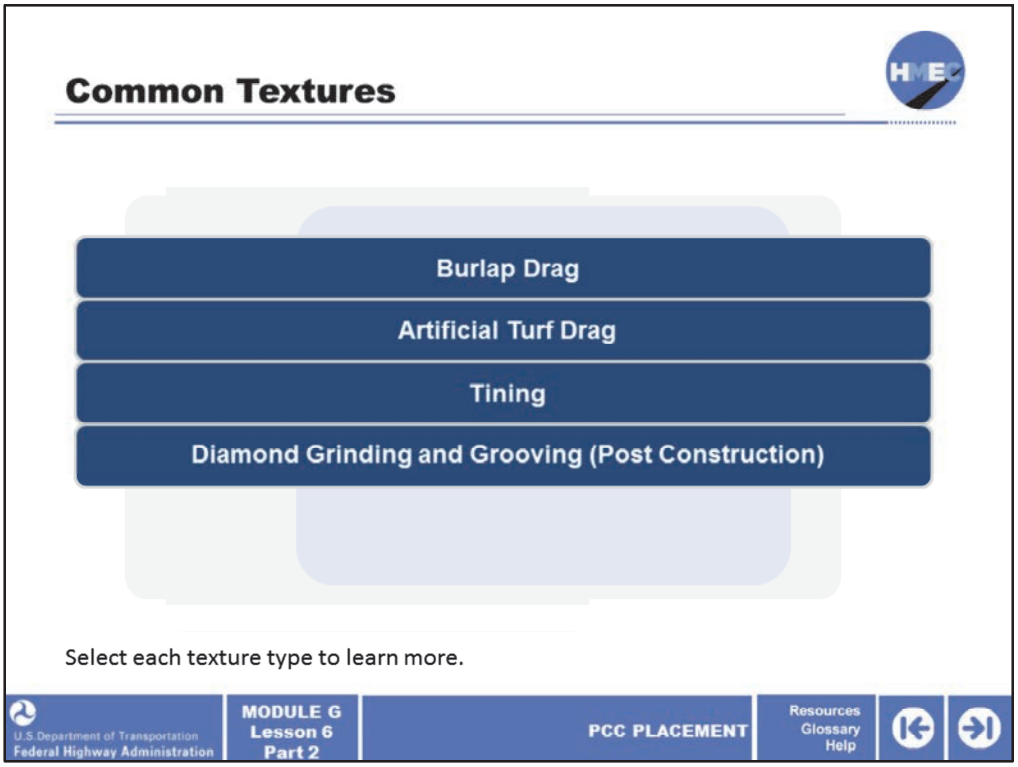
Note that bleed water is not common in the low w/c ratio mixes used for most transportation-related projects.

Image description: Photo of wet pavement.



Texturing of both bridge decks and PCC pavements is necessary for safety because they provide friction at the tire/pavement interface. Texturing requirements vary widely depending on roadway type, traffic volume, anticipated traffic speed, geometric design, and environmental conditions. Ongoing research has resulted in textures that are long-lasting, quiet, and provide a high level of friction, which is the overall goal of texturing.

The friction is often assessed through skid resistance measurements under both wet and dry conditions. Sophisticated methods for determining the noise levels of various textures are also available and have had a significant impact on the textures currently being constructed. Texturing requirements vary widely across the US in terms of type, orientation, depth requirements, and numerous other factors.

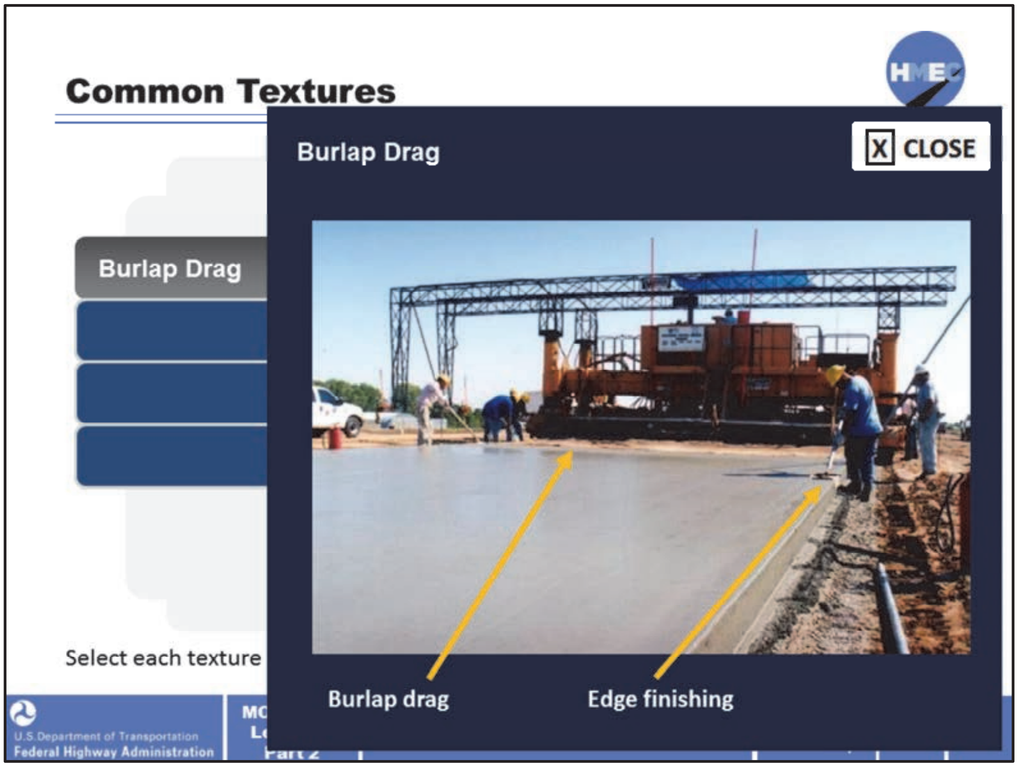


The most common texturing types for concrete pavements and bridge decks are:

- Burlap drag;
- Artificial turf drag;
- Tining; and
- Diamond grinding and grooving (post construction).

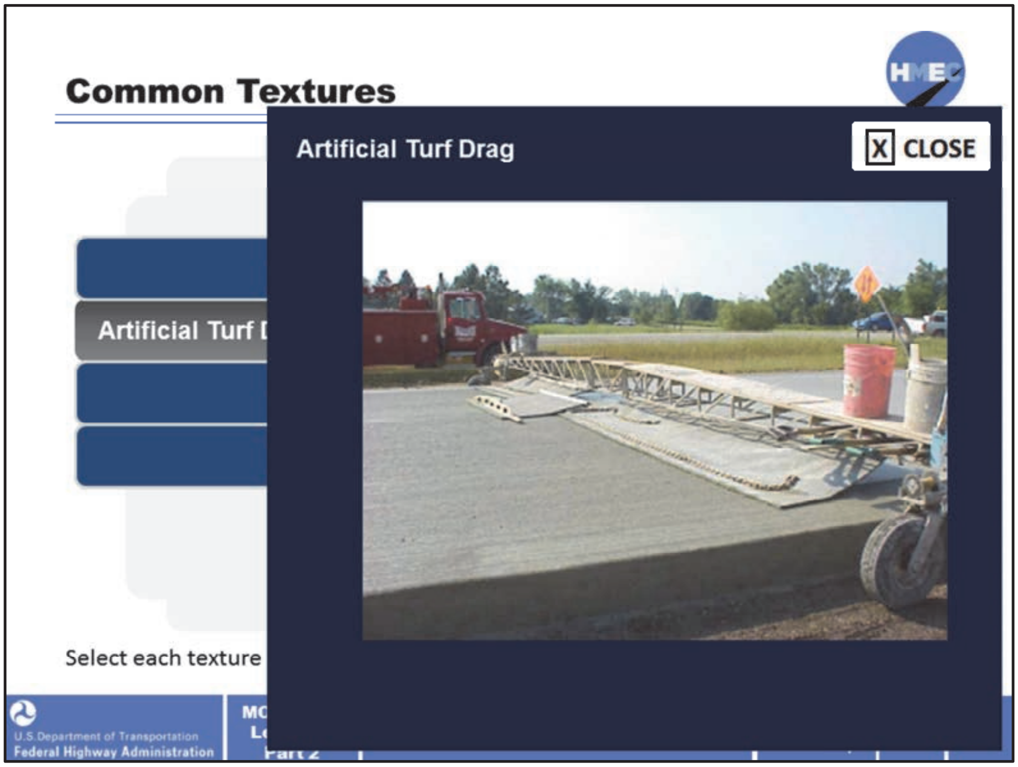
The textures listed here are basic categories and can be tailored to suit specific conditions and agency requirements. Think about the common practices in your State.

Select each texture type to learn more.



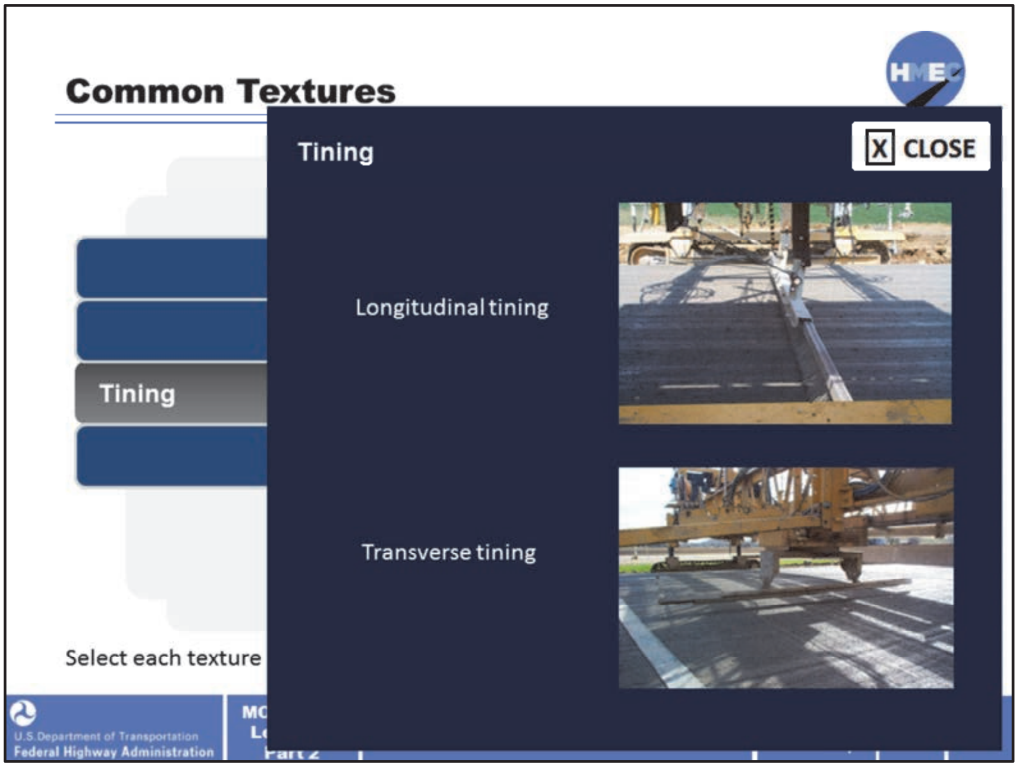
This slipform paving operation photo shows the use of a burlap drag following the paver. This is common practice for both slipform and fixed form paving. Note the uniform surface and the minimal hand finishing required.

Image description: Photo of a slipform paving operation highlighting the burlap drag and edge finishing.



The purpose of texturing is to provide safety by increasing the skid resistance, therefore reducing hydroplaning. A number of methods are used to accomplish this. Smoothness and noise are two competing factors that need to be taken into account when texturing a surface.

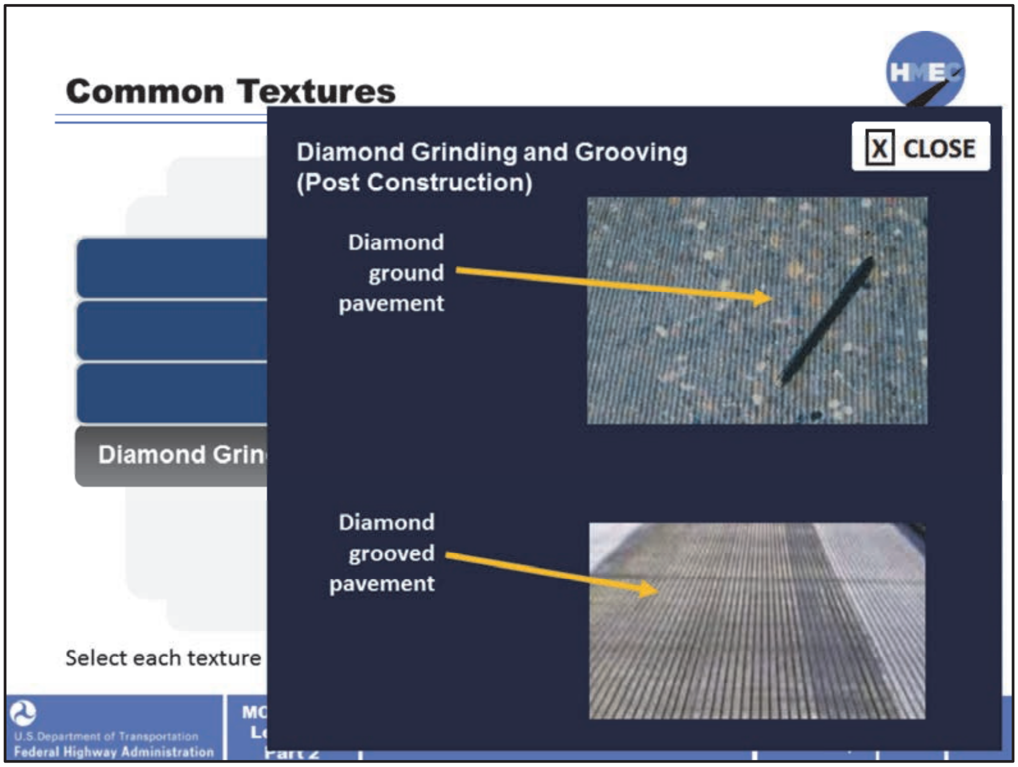
Image description: Photo of an artificial turf drag.



Tining can be constructed longitudinally (preferred) or transversely and at different spacing, tine widths, and depths. In the case of tining, a very stiff mix is difficult to tine to a uniform depth while a more fluid mix may be easy to tine but has a tendency for the tine grooves to narrow or close. The top photo illustrates longitudinal tining while the bottom photo depicts randomly spaced transverse tining.

Image description: Photo of longitudinal tining.

Image description: Photo of transverse tining.



Diamond grinding is often used to correct surface deficiencies and roughness in existing in-service pavements. However, this technique is also sometimes used for new construction to promote a specific surface texture or improve pavement smoothness.

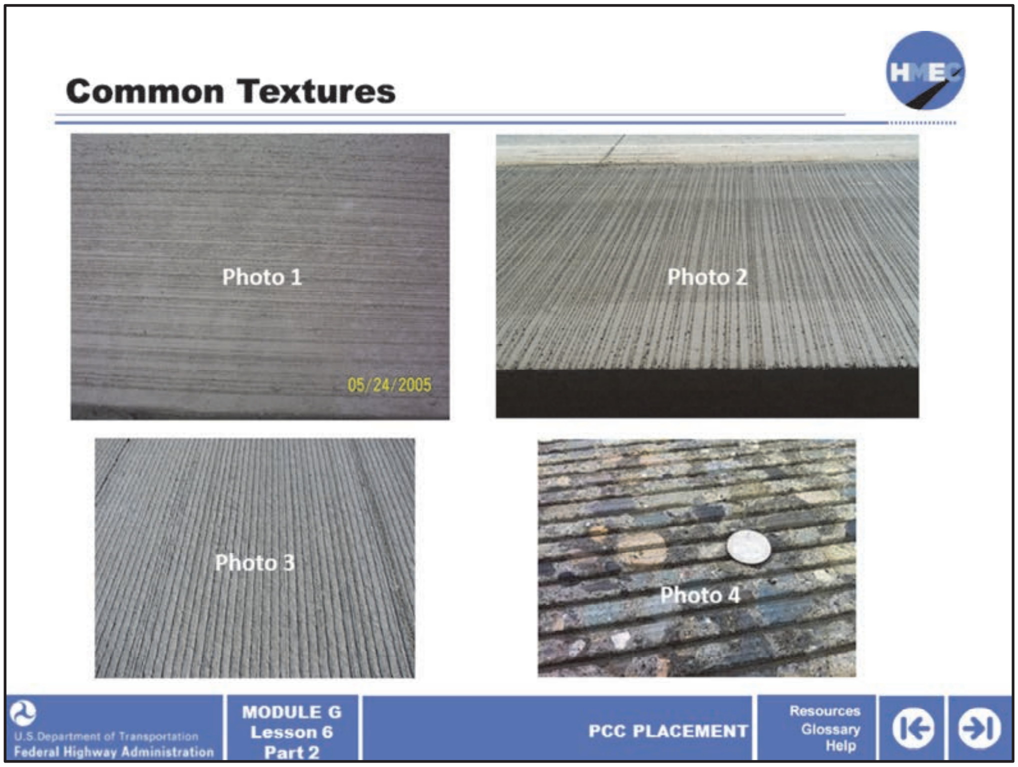
Through the use of state-of-the-art construction techniques, PCC pavements can be built to very high levels of ride quality (smoothness). However, in cases where roughness is an issue, diamond grinding is the preferred method to achieve acceptable ride quality.

Diamond grinding can provide a quiet, smooth, and long-lasting pavement texture with very good frictional characteristics. Note that diamond grinding is performed on the hardened concrete while all of the other textures are developed during construction.

Diamond grooving is used to provide improved skid resistance and reduce hydroplaning potential. Note that the grinding uses closely spaced diamond blades that re-contour the surface while grooving uses widely spaced blades that do no change the surface profile.

Image description: Photo of diamond ground pavement.

Image description: Photo of diamond grooved pavement.



Here are some common textures.

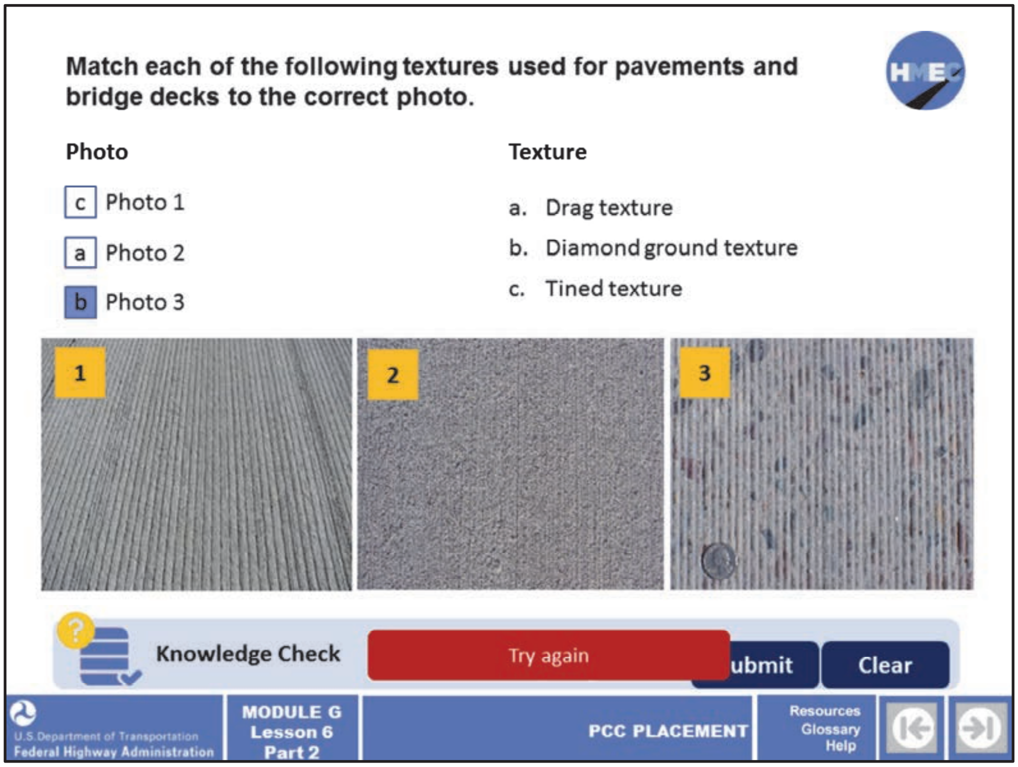
- Photo 1 shows an artificial turf drag texture.
- Photo 2 is a randomly spaced transverse tined texture.
- Photo 3 is a uniformly spaced longitudinally tined texture.
- Photo 4 is an example of a next generation concrete surface (NGCS) that combines diamond grinding and grooving. This texture has been developed to reduce noise while improving skid resistance of PCC pavements.

Image description: Photo of an artificial turf drag texture.

Image description: Photo of a randomly spaced transverse tined texture.

Image description: Photo of a uniformly spaced longitudinally tined texture.

Image description: Photo of an example of a next generation concrete surface (NGCS) that combines diamond grinding and grooving.

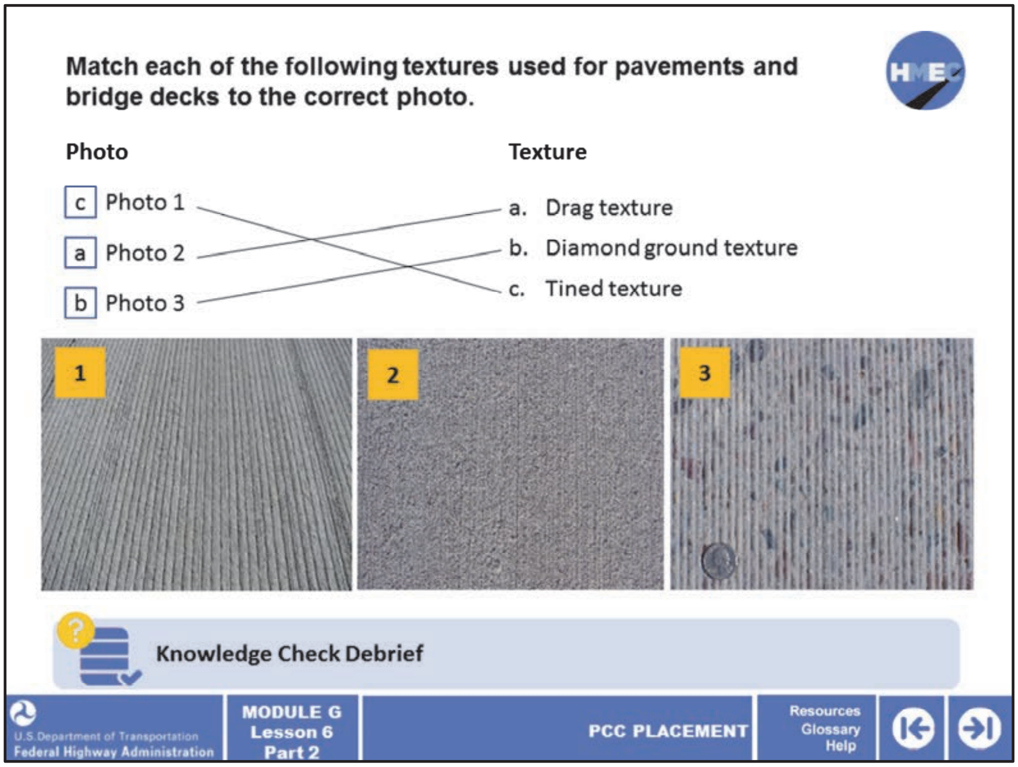


Match each of the following textures used for pavements and bridge decks to the correct photo.

Image description: Photo of textures.

Image description: Photo of textures.

Image description: Photo of textures.



The correct answers are: photo 1 is c) Tined texture; photo 2 is a) Drag texture; and photo 3 is b) Diamond ground texture.

• Photo 1 shows a uniformly spaced, longitudinally tined texture.
• Photo 2 shows a drag finish. Because the texture is relatively shallow, this is likely the result of a burlap drag.
• Photo 3 shows a diamond ground surface. The ridges (lands) are visible between the closely spaced cuts by the diamond blades (valleys).

Image description: Photo of tined texture.

Image description: Photo of drag texture.

Image description: Photo of diamond ground texture.

Considerations for Hot and Cold Weather Placement

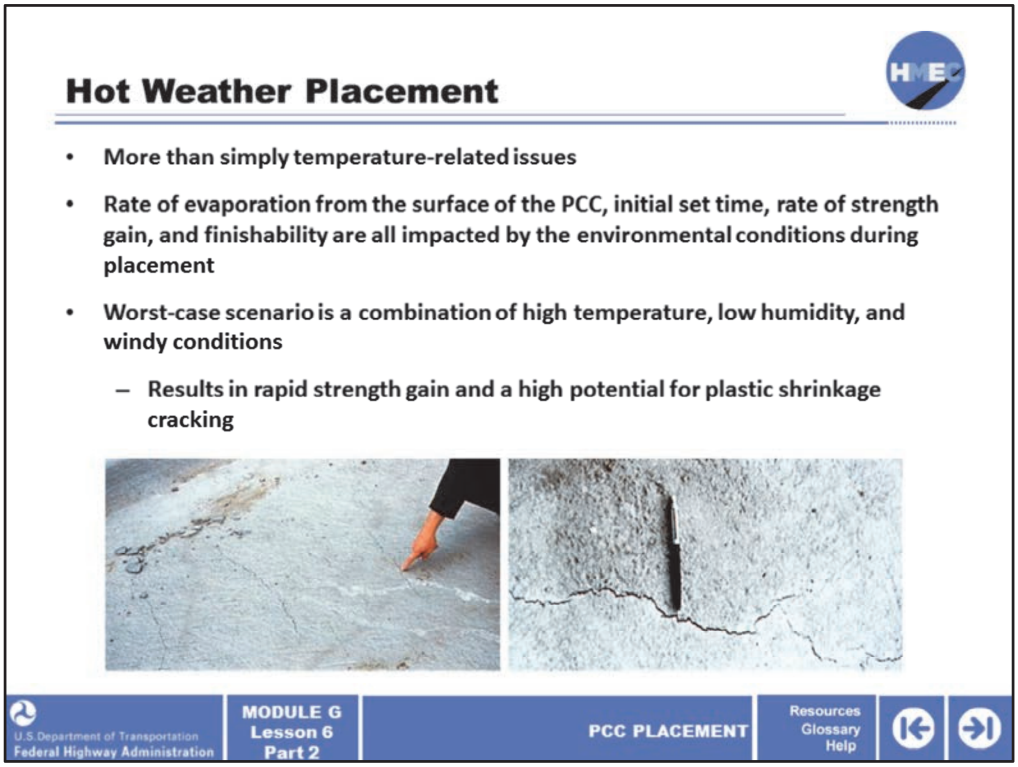
- Hot and cold weather placement present some unique challenges, such as workability, strength, and long-term durability
- We have previously discussed the potential changes in hydration products, rate of reaction, initial set times, and so on resulting from high and low temperatures

Hot and cold weather placement present some unique challenges, such as workability, strength, and long-term durability. While hot and cold weather placement is challenging, it can be done with minimal impact through proper construction techniques.

We have previously discussed the potential changes in hydration products, rate of reaction, initial set times, and so on resulting from high and low temperatures. In this section, we are going to discuss construction implications during and after placement.

Image description: Photo of thermometer registering high heat.

Image description: Photo of thermometer registering cold temperature.

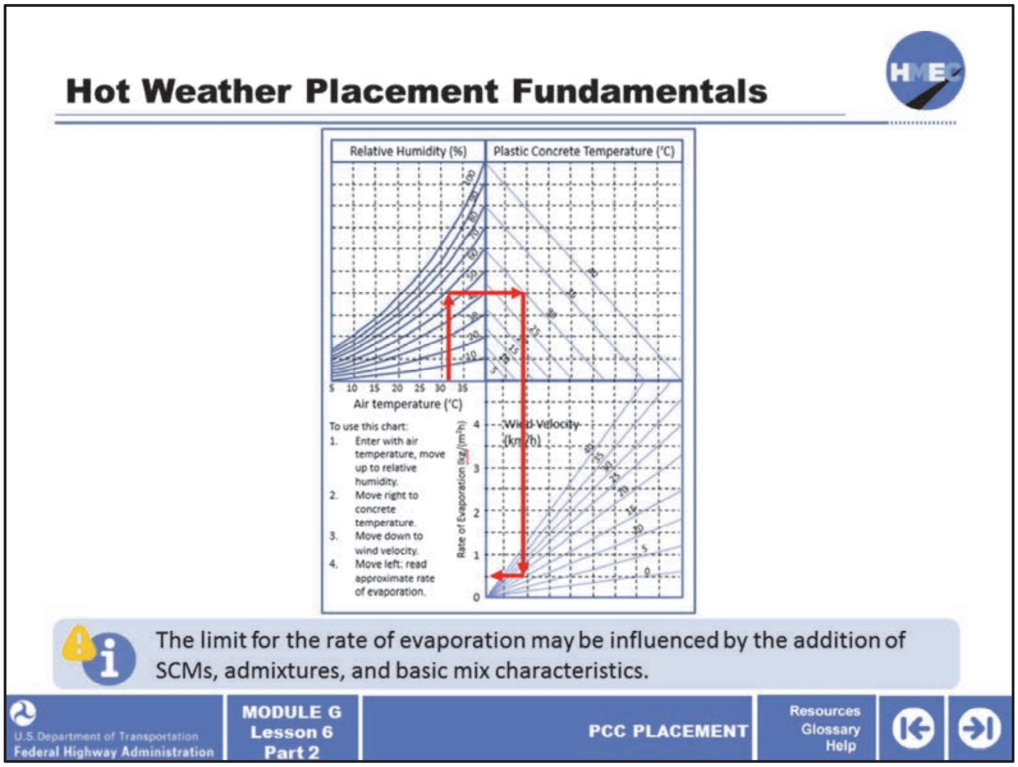


Hot weather placement is more than simply temperature-related issues; it is a combination of factors, as shown here. The rate of evaporation from the surface of the PCC, initial set time, rate of strength gain, and finishability are all impacted by the environmental conditions during placement. The worst-case scenario for hot weather placement is a combination of high temperature, low humidity, and windy conditions. These result in rapid strength gain and a high potential for plastic shrinkage cracking. Fortunately, remedial measures are relatively easy to implement.

The photos here illustrate early age cracking due to adverse conditions at placement and lack of proper precautions during placement, finishing, and curing.

Image description: Photo of early age cracking due to adverse conditions at placement and lack of proper precautions during placement, finishing, and curing.

Image description: Photo of early age cracking due to adverse conditions at placement and lack of proper precautions during placement, finishing, and curing.

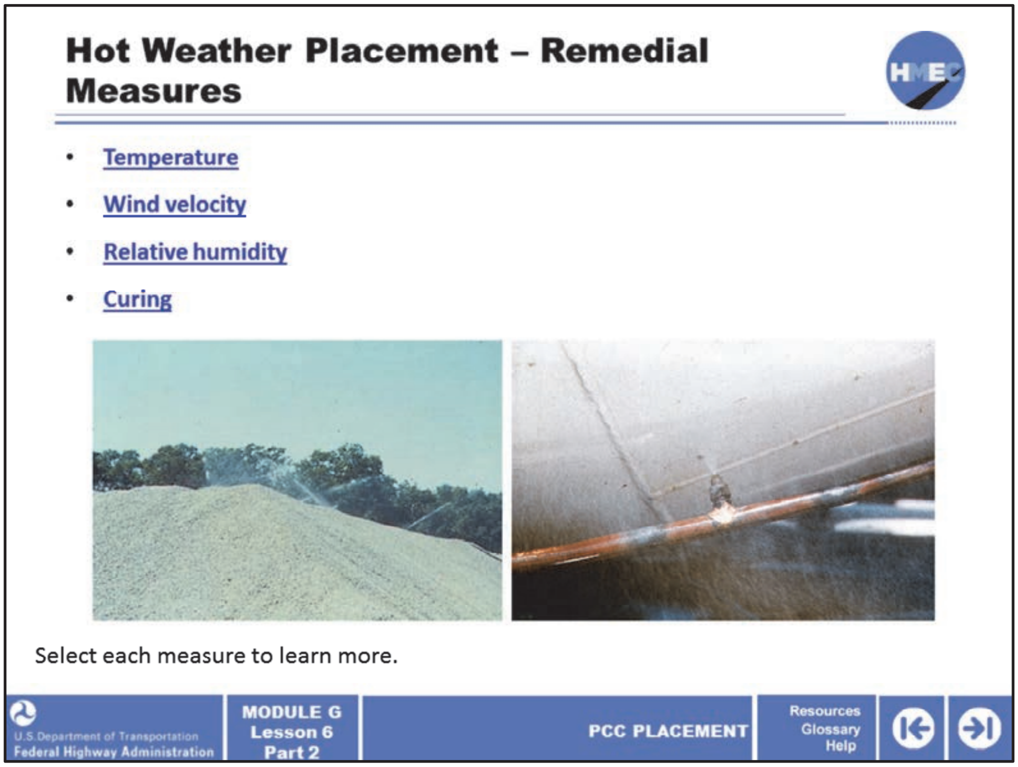


A high rate of surface evaporation will almost always result in early age cracking, as shown on the previous slide. The key elements that must be addressed include PCC temperature, relative humidity, and wind velocity.

As a general rule, when the rate of evaporation exceeds 0.2 lb./sf, remedial measures should be implemented. Note that this limit may be influenced by the addition of supplementary cementitious materials (SCMs), admixtures, and basic mix characteristics.

Here's an example: Assume the air temperature is 32 °C (90 °F), the relative humidity is 50%, the PCC is 29.5 °C (85 °F) and the wind is steady at 16 km/hr (10 mph). Following the arrows beginning with the air temperature, the rate of evaporation is approximately 0.5 $kg/m^2/hr$ (0.14 $lb./ft^2/hr$). Based on this calculation, no remedial action is required.

Image description: Graph displaying effects of hot weather placement.



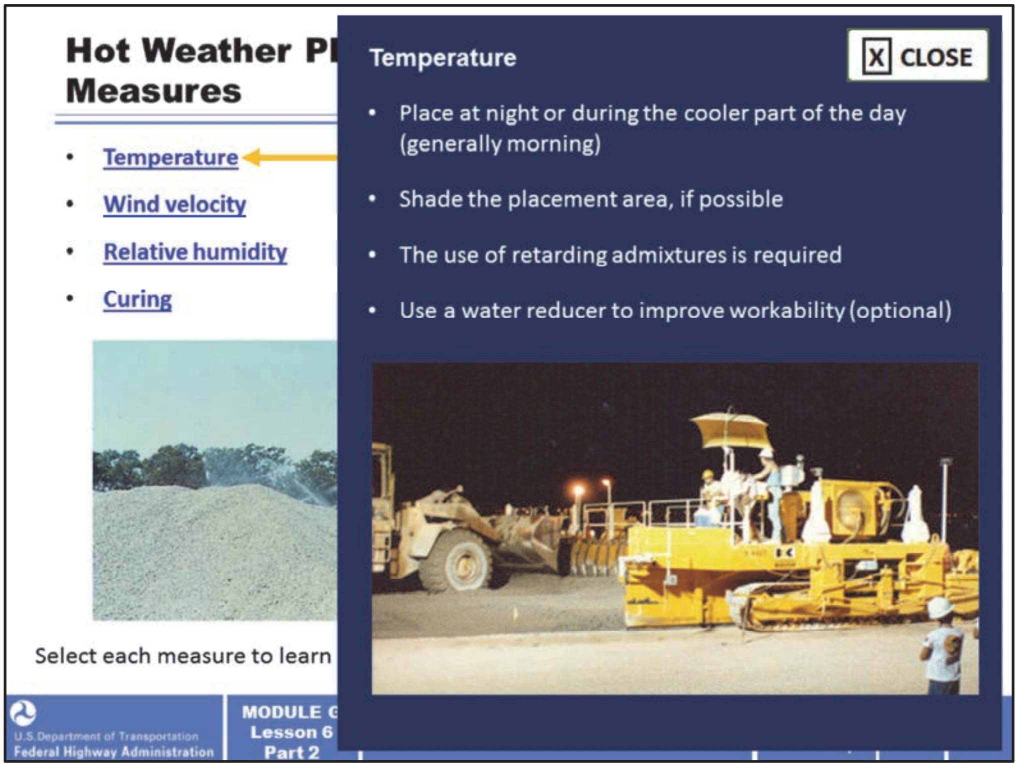
The following practices will aid in hot weather placement. Note that these measures are not always 100% effective and more than one measure may be required. Lowering the PCC temperature is typically the first step in managing hot weather placement.

Evaporative cooling, done through misting, can be very effective, particularly when the relative humidity is low and the wind velocity is high. The photo on the left shows the misting of a large aggregate stockpile and the photo on the right shows the misting of the mixing drum on a transit mix truck.

Select each measure to learn more.

Image description: Photo of the misting of a large aggregate stockpile.

Image description: Photo of the misting of the mixing drum on a transit mix truck.



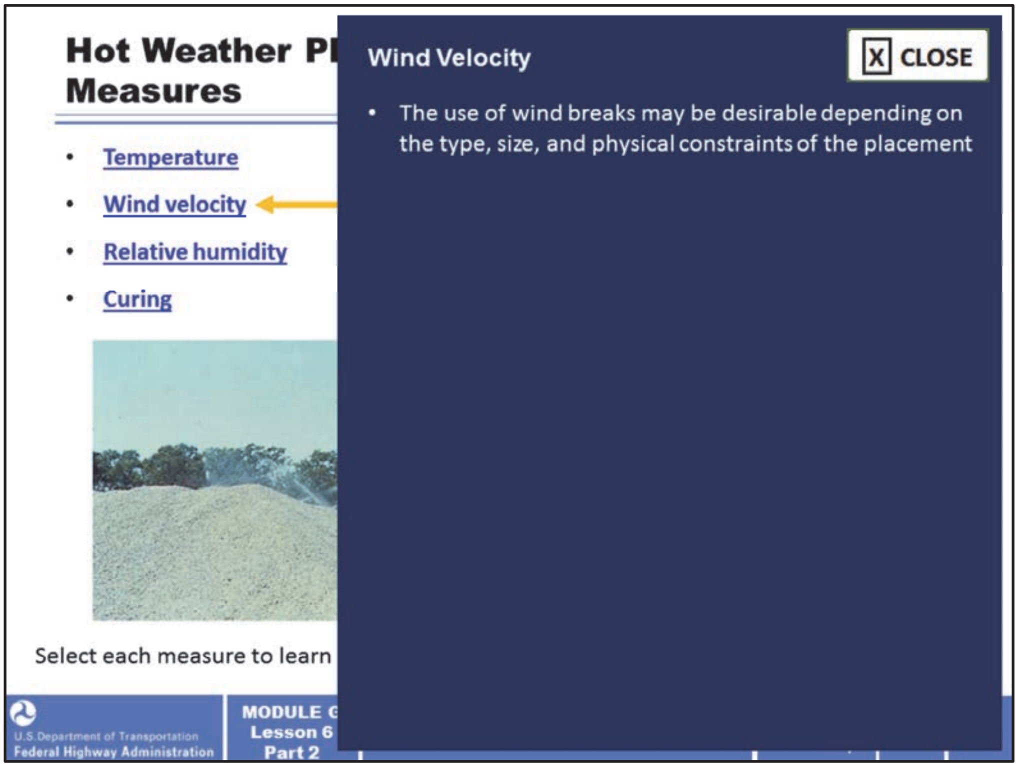
Although the PCC temperature is shown in the evaporation graph, ambient temperature is also important. While we mention night and morning placement, it is desirable that the peak hydration temperature does not coincide with the hottest part of the day to minimize the differential thermal stresses in the slab. Night placement presents a number of challenges but in some cases it may be the only viable option. Night placement does have one benefit, however, which is that wind velocities tend to diminish at night, helping to lower the evaporation rate.

This photo shows night placement for a highway project.

We have discussed temperature in terms of evaporation rate, but it is also very important to note that higher temperatures result in a faster initial set and rate of hardening. The use of a retarder is necessary to allow time to place, consolidate, and finish the PCC.

Image description: Photo of the misting of a large aggregate stockpile.

Image description: Photo of night placement for a highway project.



Wind velocity is also a factor in hot weather placement.

Temporary fencing placed adjacent to hot weather placements can be effective at reducing wind velocity at the PCC surface provided they can be placed in close proximity. However, wind breaks are generally not practical for transportation-related projects, particularly for paving, due to the amount typically placed in a single day's operation.

Care must be taken if using wind breaks for bridge deck pours as they can make matters worse due to wind vortices developing and increasing the wind speed at the deck level.

Image description: Photo of the misting of a large aggregate stockpile.

For relative humidity, fogging is a very effective means to raise the relative humidity at the surface of the PCC. It is important that the proper fogging equipment be used to produce very finely divided water droplets. Spraying the surface with water is not equivalent and can damage the surface of the PCC.

Image description: Photo of the misting of a large aggregate stockpile.

Image description: Photo of fogging.

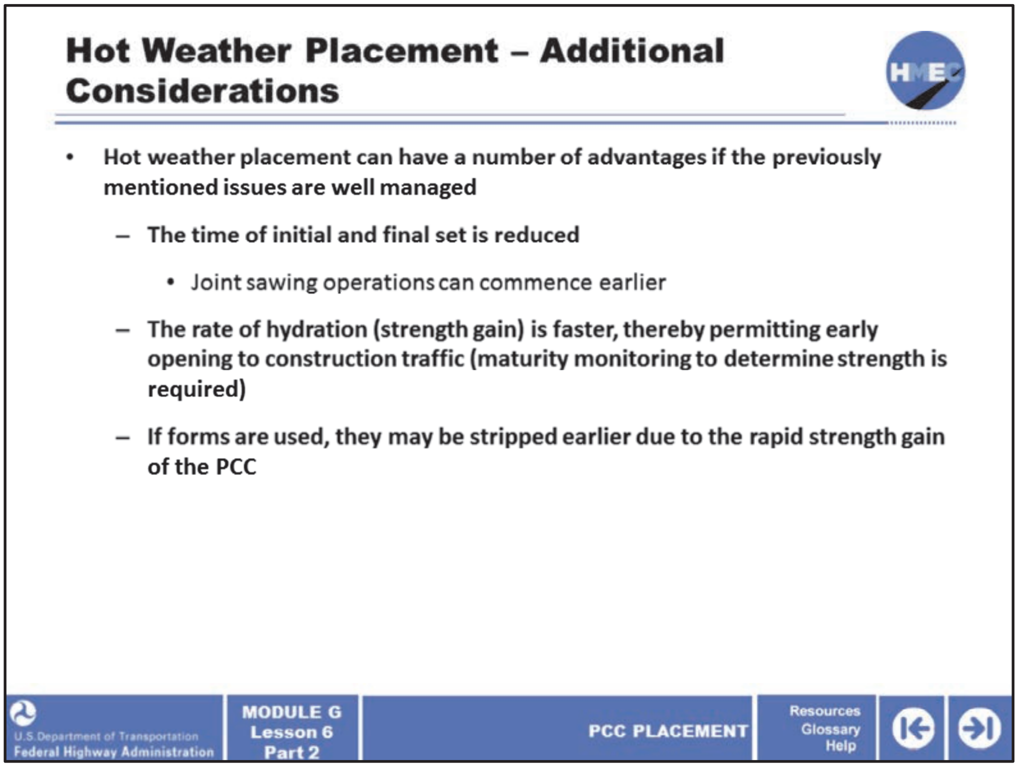
Curing is always important but timely application of the curing compound or other curing method is critical for hot weather placement. The most widely used alternatives to curing compound include wet burlap, plastic sheeting, or ponding water—or a combination of these techniques.

Evaporation retarders are to be used after all finishing operations are completed. These products are water-based and should not be worked into the surface of the fresh PCC for the same reasons as were discussed with overworking the surface. Evaporation retarders are not a substitute for adequate and timely application of curing (compound, sheeting, burlap, etc.) but can provide additional working time in cases where curing is delayed.

White pigmented curing compounds, as shown in the photo, are intended to encapsulate the PCC on all exposed surfaces, forming a close to impermeable barrier to prevent moisture loss due to evaporation.

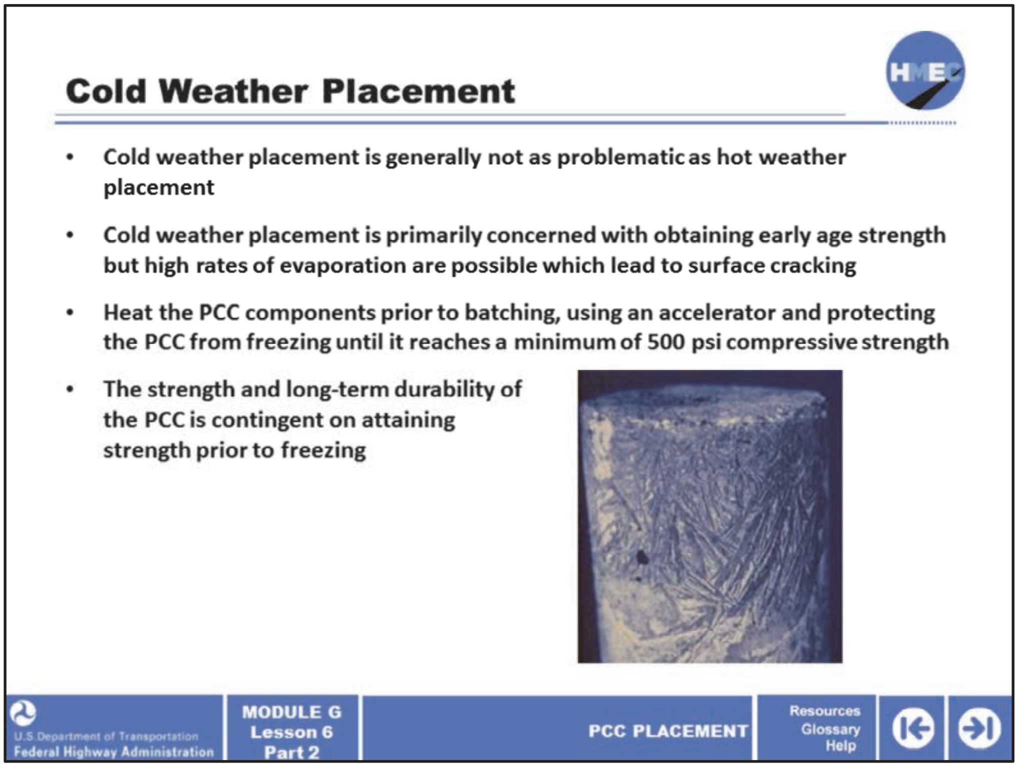
Image description: Photo of the misting of a large aggregate stockpile.

Image description: Photo of adding white pigmented curing compounds.



Hot weather placement can have a number of advantages if the previously mentioned issues are well managed. As a general rule of thumb, an increase of 20 °F will reduce the setting time of a PCC mixture by as much as 50%. As an example, a PCC mixture that reaches final set in three hours at 60 °F may reach final set in as little 1½ hours at 80 °F.

Maturity monitoring will be discussed in more detail in Lesson 6.3. Maturity is simply a relationship that relates curing time and temperature to either compressive or flexural strength of the PCC. As previously discussed, PCC gains strength more rapidly at higher temperatures and more slowly at lower temperatures. By monitoring the time the PCC is cured at various temperatures, and by use of a mix-specific, laboratory-based “maturity curve,” the strength at early ages can be estimated.



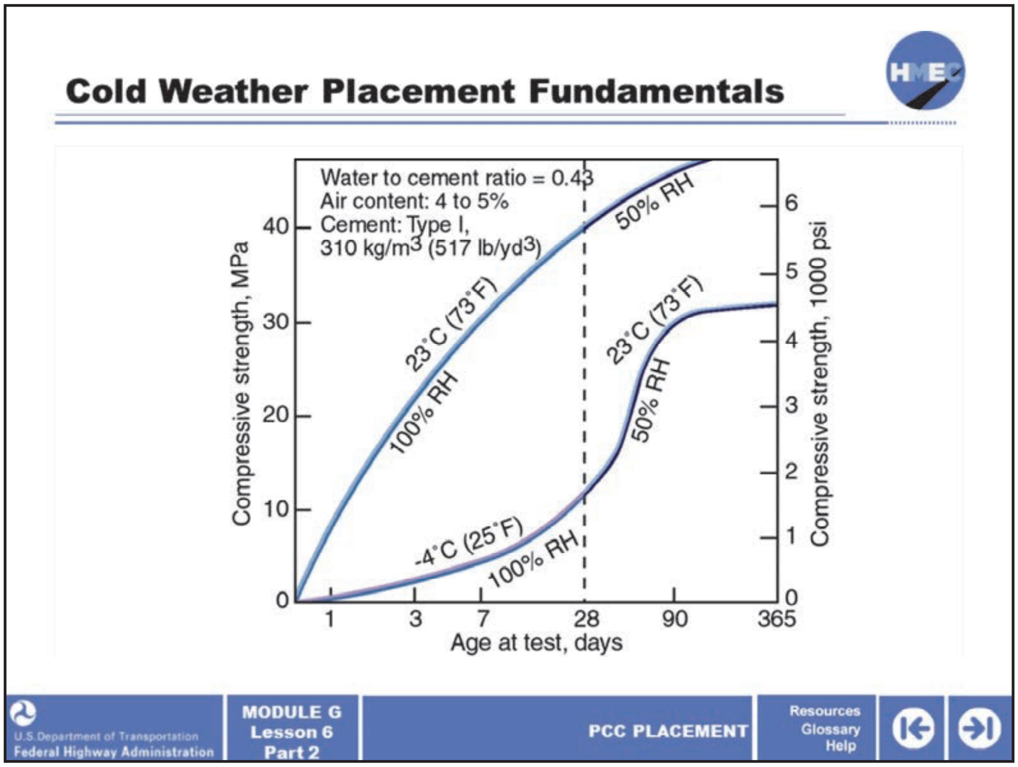
Cold weather placement is common practice and is less challenging than hot weather placement. The key to placing in cold weather is to heat the PCC components prior to batching, which is done by using an accelerator and protecting the PCC from freezing until it reaches a minimum of 500 psi compressive strength. As discussed earlier, the degree of saturation in the PCC due to mix water is reduced sufficiently at 500 psi to allow for freezing without damage. Recall that the damage is due to the expansion of water within the PCC as it freezes. This irreversible damage is shown in the photo.

Because of the heated components and the low relative humidity typically encountered during cold weather, a high rate of evaporation is possible. Refer back to the example on the hot weather placement fundamentals slide to estimate these effects. For example, if you assume an air temperature of 35 °F, a concrete temperature of 80 °F, a relative humidity of 10%, and a wind velocity of 10 mph, the estimated evaporation rate is 0.28 lb./sf/hr. This value greatly exceeds the recommended limit of 0.20, thereby necessitating additional means of protection (early application of curing, for instance).

It is important to note that if the PCC is allowed to freeze prior to reaching this value, the strength and long-term durability will be reduced. This reduction is dependent on many factors, including the mix characteristics, batching, mixing and placement conditions, and curing.

The photo shows a crow's foot pattern.

Image description: Photo of a crow's foot pattern in a core sample.

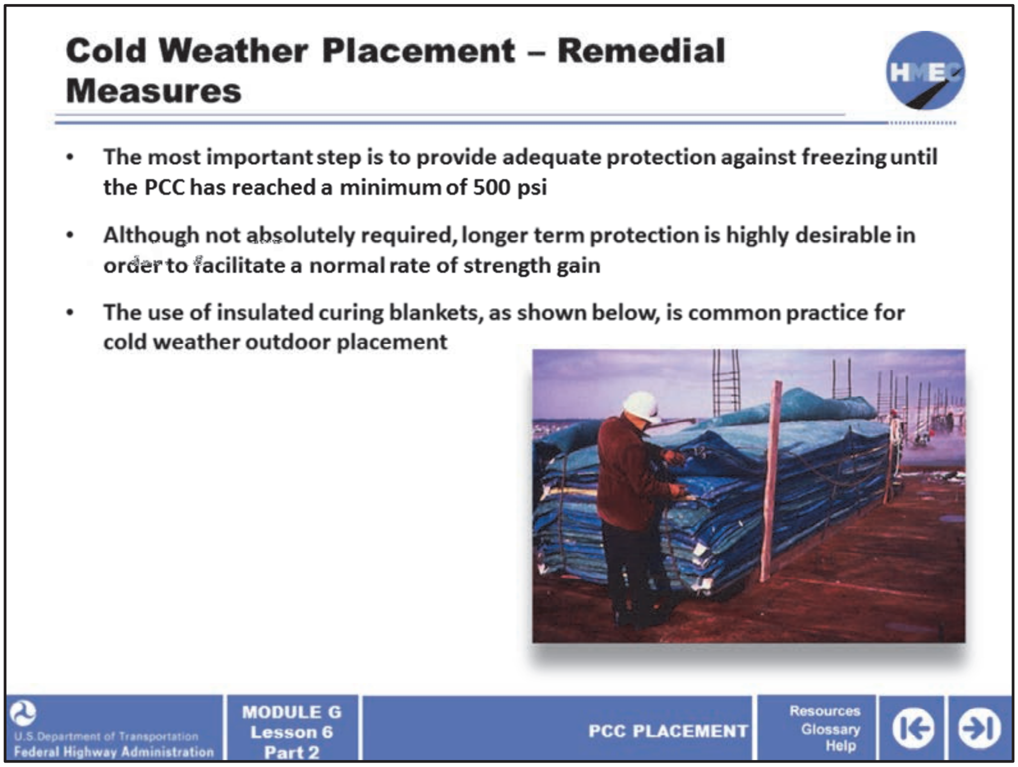


The effects of low temperature at early age (in this case, temperature below freezing) leads to a substantial reduction in ultimate strength. Note that the PCC cured at 73 °F and achieved a 28-day strength of approximately 6,000 psi, while PCC cured at 25 °F reached 1,700 psi.

It should be noted that damage incurred by freezing prior to reaching 500 psi is irreversible. Regardless of the curing regimen following low strength freezing, the PCC will never reach the same ultimate strength.

Both specimens were cured at 100% relative humidity after casting. This relationship is indicative of PCC behavior under these conditions, but may differ in your case based on mix characteristics and field placement conditions.

Image description: Graph showing cold weather placement fundamentals.

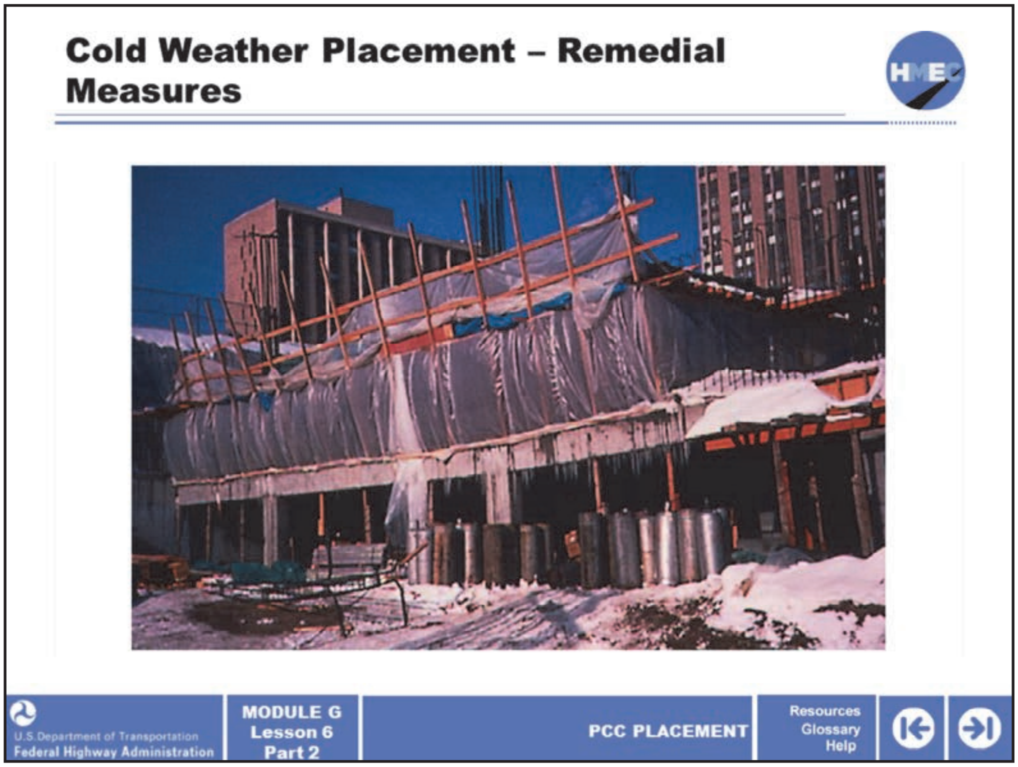


The most important step is to provide adequate protection against freezing until the PCC has reached a minimum of 500 psi. Note that recurring freeze/thaw cycles continue to damage the PCC as long as the degree of saturation remains high (corresponding to 500 psi).

Although not absolutely required, longer term protection is highly desirable in order to facilitate a normal rate of strength gain.

The use of insulated curing blankets, as shown in the photo, is common practice for cold weather outdoor placement. Curing blankets are commonly used on flatwork to retain the heat of hydration and minimize temperature differentials in the slab. These blankets are also an effective moisture barrier, acting similarly to conventional curing techniques. Note that in order to minimize “thermal shock” to the slab, the blankets should be left in place until the temperature of the slab approximates the ambient temperature.

Image description: Photo of the use of insulated curing blankets.

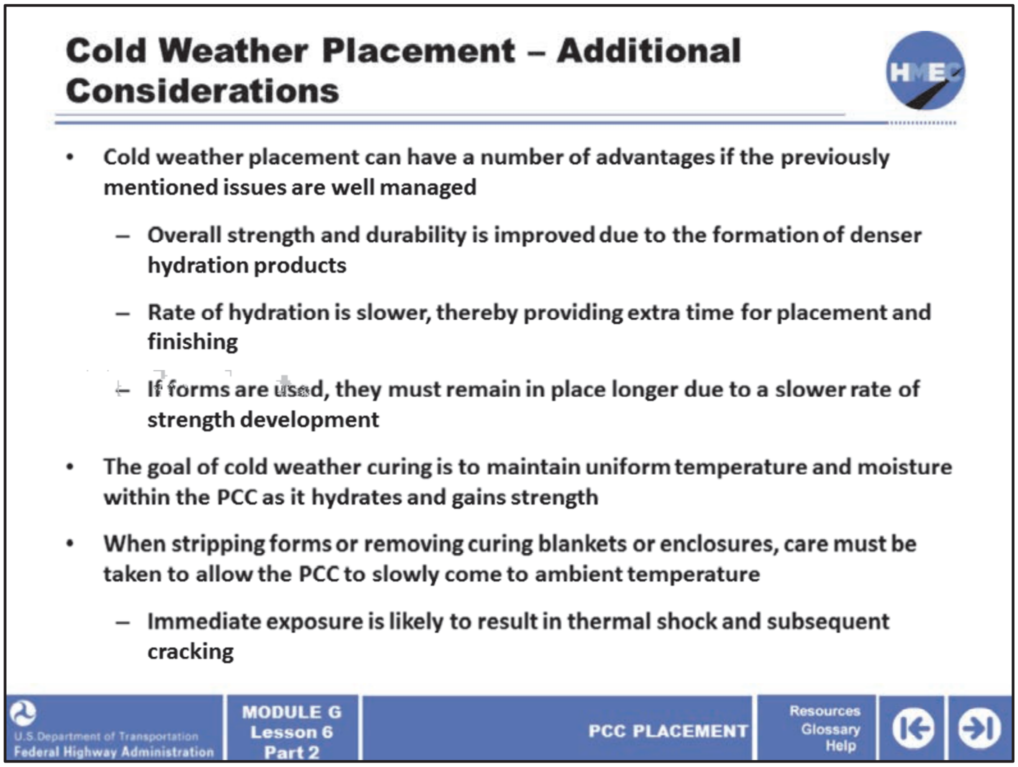


In the case of structures, constructing an enclosure to protect the fresh PCC is good practice. This technique may be applicable to bridge elements depending on site conditions. The primary advantage of an enclosure is that the curing environment can be regulated for a longer period of time than simply using curing blankets.

With a sufficient number of heaters, the curing conditions can be made to approximate normal curing. Remember that adequate curing involves not only temperature but moisture control, which may require curing compound or other curing methods.

When using fossil-fueled heaters (kerosene, for example) to maintain temperature during curing, the heaters must be adequately vented to prevent carbonation on the surface of the PCC.

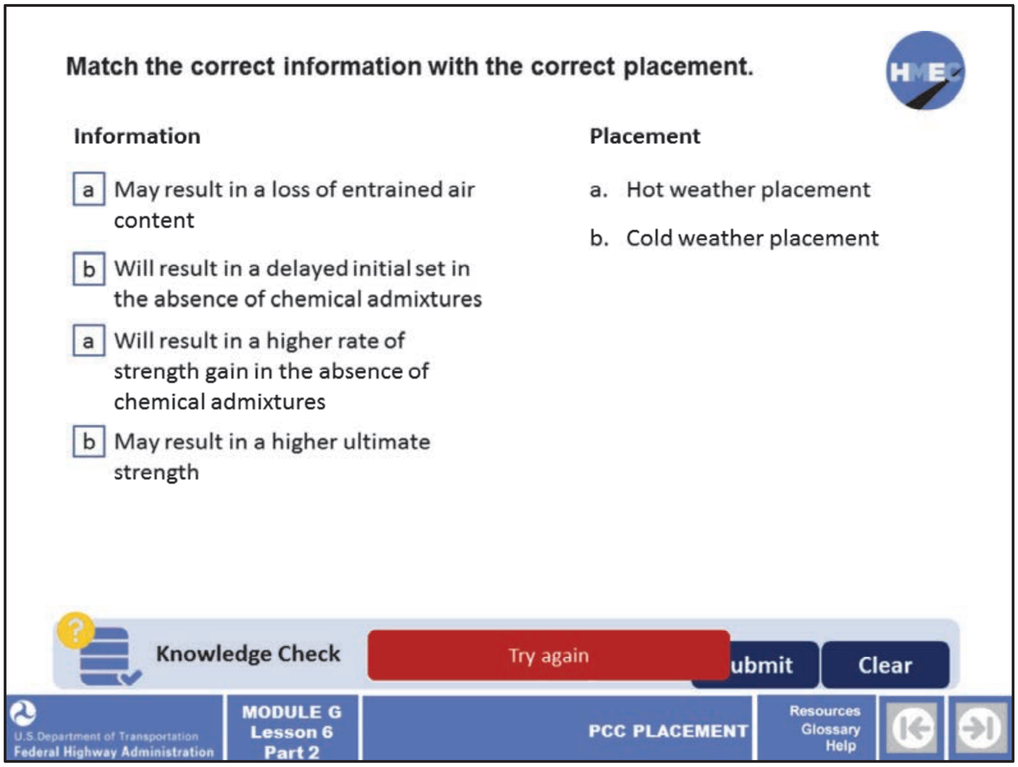
Image description: Photo of an enclosed structure.



Cold weather placement can have a number of advantages if the previously mentioned issues are well managed. The rate of hydration (strength gain) is slower, thereby providing extra time for placement and finishing. As we discussed in the lesson on hydration, the slower rate of reaction leads to higher ultimate strength, lower permeability, and improved long-term durability. Note that the rate of hydration is subject to the mix characteristics, particularly admixtures and cement type and content. Note also that if forms are used, they must remain in place longer due to the slower rate of strength development.

The goal of cold weather curing is to maintain uniform temperature and moisture within the PCC as it hydrates and gains strength.

When stripping forms or removing curing blankets or enclosures, care must be taken to allow the PCC to slowly come to ambient temperature. Immediate exposure is likely to result in thermal shock and subsequent cracking.



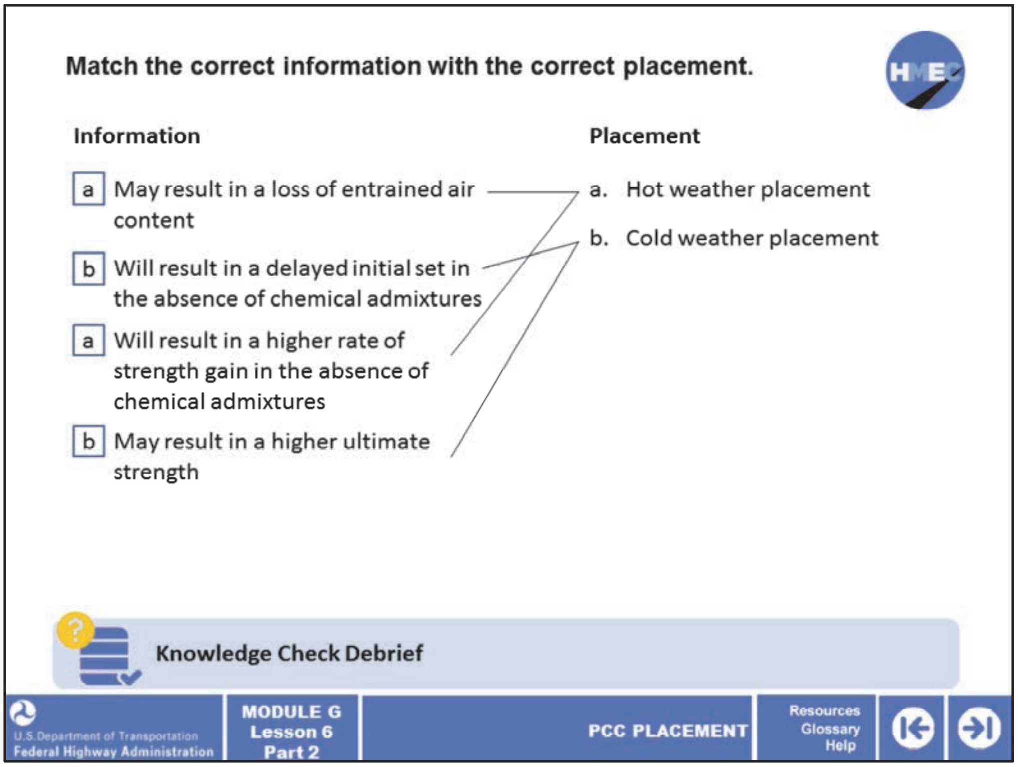
Match the correct information with the correct placement:

Information:

- May result in a loss of entrained air content;
- Will result in a delayed initial set in the absence of chemical admixtures;
- Will result in a higher rate of strength gain in the absence of chemical admixtures; and
- May result in a higher ultimate strength.

Placements:

a) Hot weather placement; and
b) Cold weather placement.



The correct answers are:

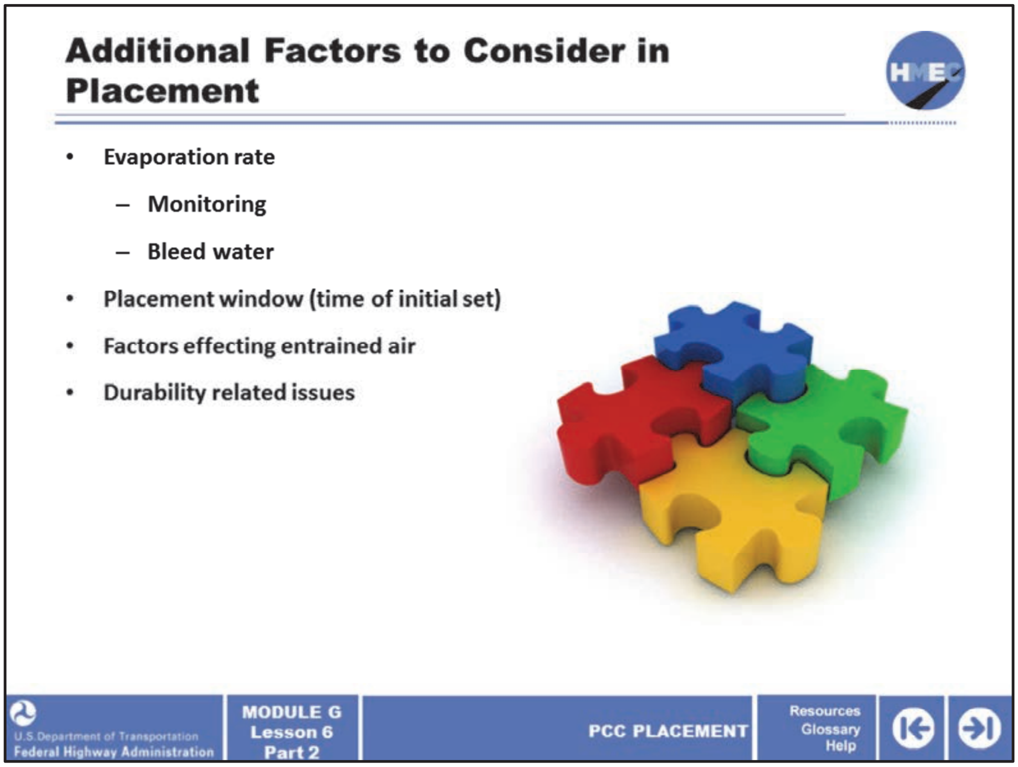
• May result in a loss of entrained air content is a) Hot weather placement;
• Will result in a delayed initial set in the absence of chemical admixtures is b) Cold weather placement;
• Will result in a higher rate of strength gain in the absence of chemical admixtures is a) Hot weather placement; and
• May result in a higher ultimate strength is b) Cold weather placement.

Higher temperatures result in a lower entrained air content unless additional admixtures are used to compensate for the anticipated loss.

Cold weather slows the hydration (chemical) reactions and can result in a delayed initial set.

Higher temperatures result in an increase in the rate of reaction and therefore a higher rate of strength gain.

Colder temperatures slow the rate of reaction and allow for the formation of denser hydration products leading to higher ultimate strength.



Now we'll review some additional factors to consider in terms of general construction practices.

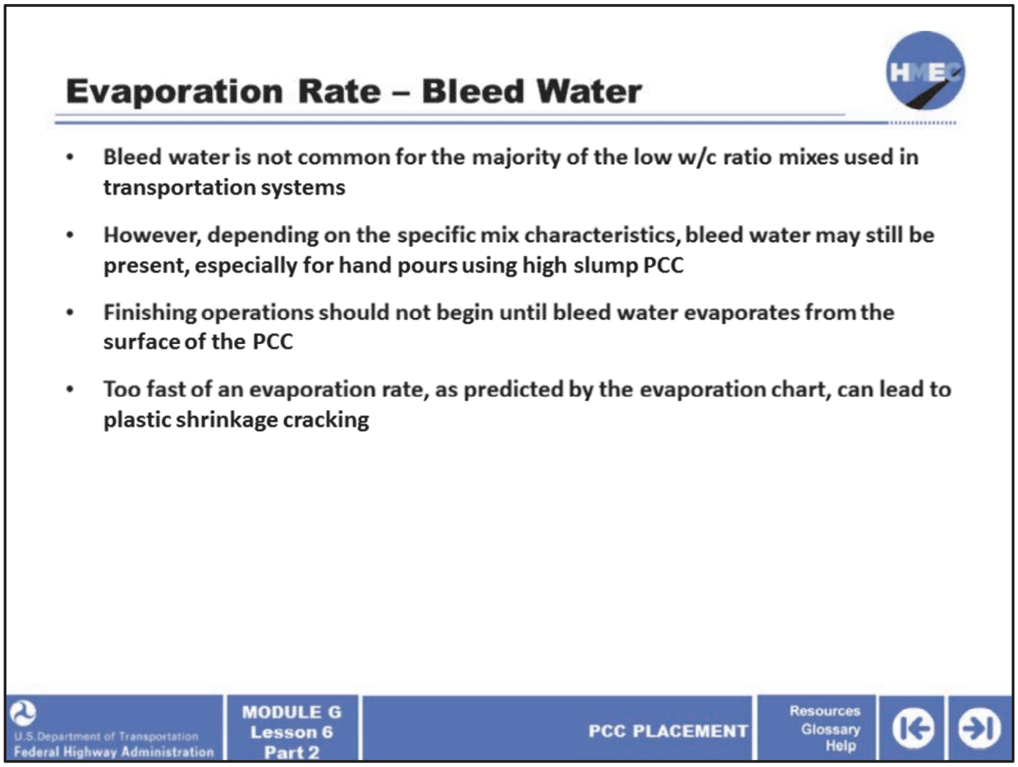
Image description: Image of four puzzle pieces fitting together.

The evaporation rate is important in controlling plastic shrinkage cracking. This may be determined using a thermometer to measure the temperature of the fresh PCC, a wind velocity measuring device, and a hygrometer to determine relative humidity.

Evaporation rate was discussed in terms of hot weather practices but should be considered in all placement conditions. There are also devices that have been specifically developed for this purpose, as shown in the photos. The device shown in the photo on the left calculates evaporation rate directly. The photo on the right provides another option for determining the evaporation rate. Note that the measurements should be taken as close to the surface of the PCC as possible.

Image description: Photo of the device that calculates evaporation rate directly.

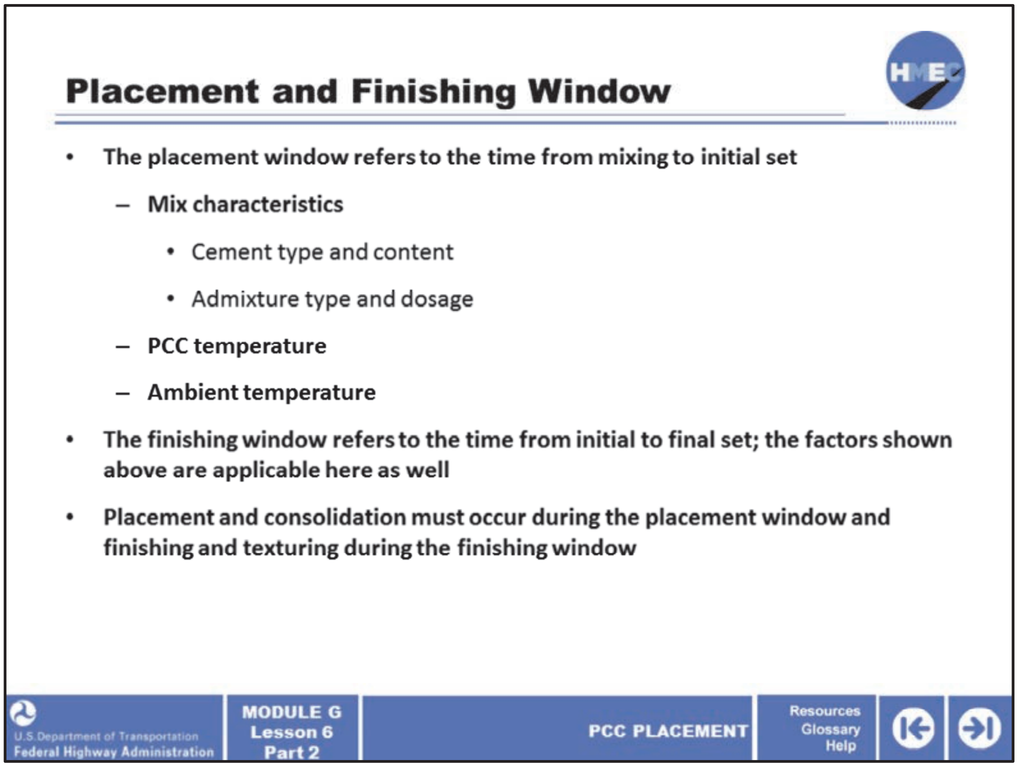
Image description: Photo of a number of other devices for determining the evaporation rate.



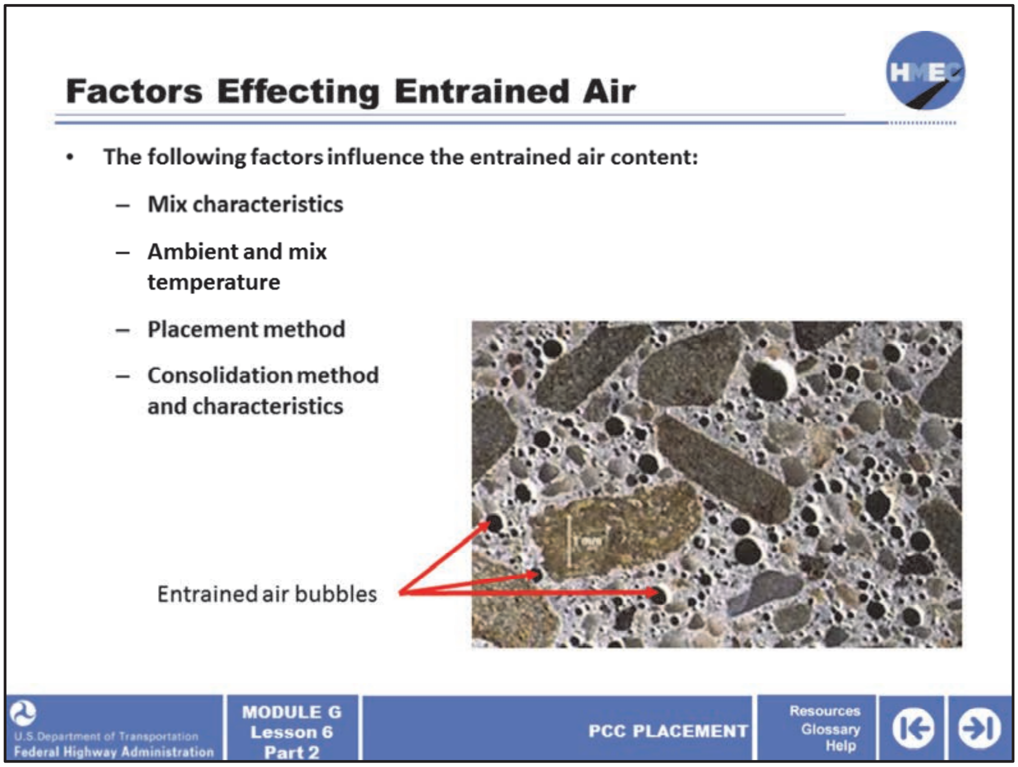
Bleed water is not common for the majority of the low w/c ratio mixes used in transportation systems. However, depending on the specific mix characteristics, bleed water may still be present, especially for hand pours using high slump PCC.

Finishing operations should not begin until bleed water evaporates from the surface of the PCC. If finishing is allowed prior to the evaporation of the bleed water, there is a strong possibility that the water will be worked into the surface, thereby raising the w/c ratio and compromising surface durability.

However, too fast of an evaporation rate, as predicted by the evaporation chart, can lead to plastic shrinkage cracking. In this case, a “crust” will develop at the surface while the remaining PCC remains plastic. This differential in strength development and shrinkage can lead to the formation of plastic shrinkage cracks.



The placement window refers to the time from mixing to initial set. The placement and finishing windows are highly variable and depend on the factors shown on the slide. Take a moment to read this slide.



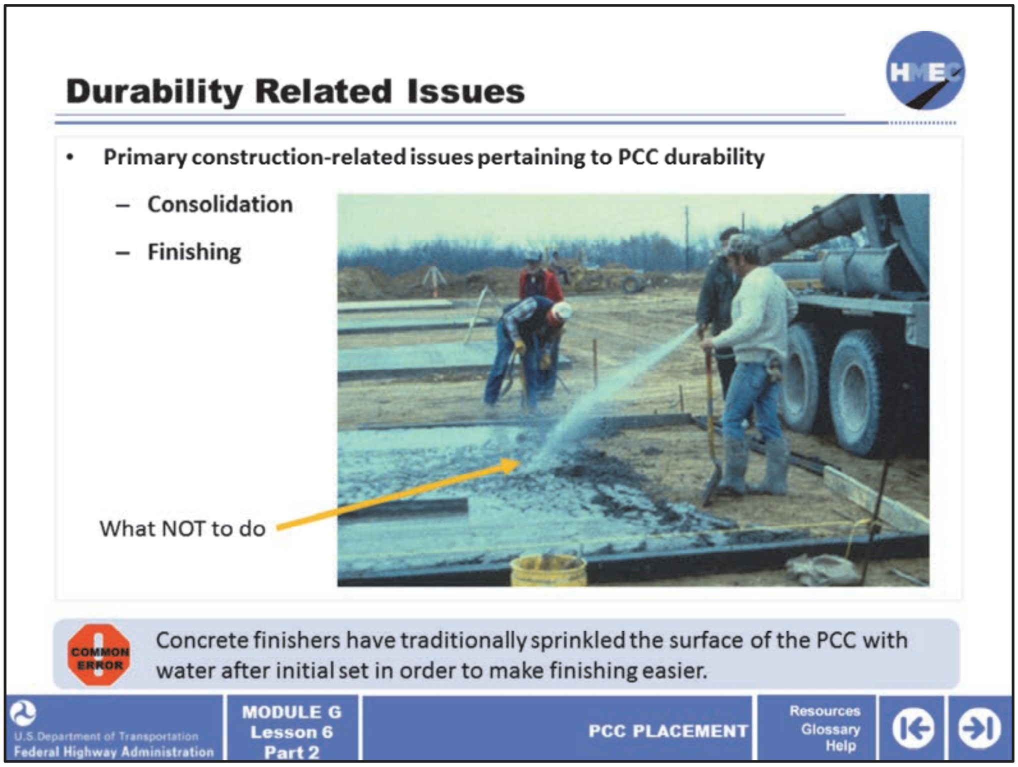
In terms of construction-related issues, the following factors influence the entrained air content.

- Mix characteristics (particularly cement and SCM content, aggregate gradation, w/c, and admixtures);
- Ambient and mix temperature;
- Placement method; and
- Consolidation method and characteristics.

Entrained air content typically fluctuates throughout the day. Remember that entrained air is only found in the paste fraction of a PCC mix so changes to mix proportions can change air content. The aggregate gradation, particularly the fines, can cause fluctuations in air content.

As temperature increases, the air content typically decreases and must be compensated for with increased air entraining admixture dosage. Vibration generally decreases air content so it is desirable to limit consolidation to only what is required.

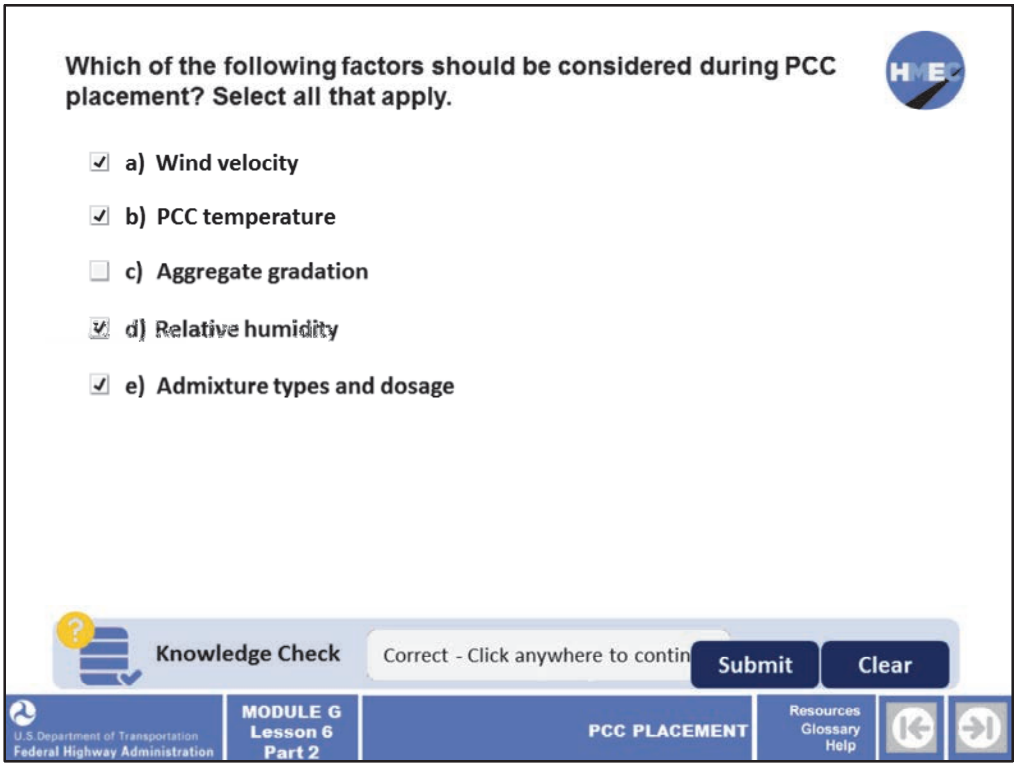
Image description: Photo of entrained air bubbles.



The primary construction-related issues pertaining to PCC durability include consolidation and finishing. However, durability can be negatively impacted during construction operations as well. Over-consolidation is not typical but can occur when placing relatively stiff mixes.

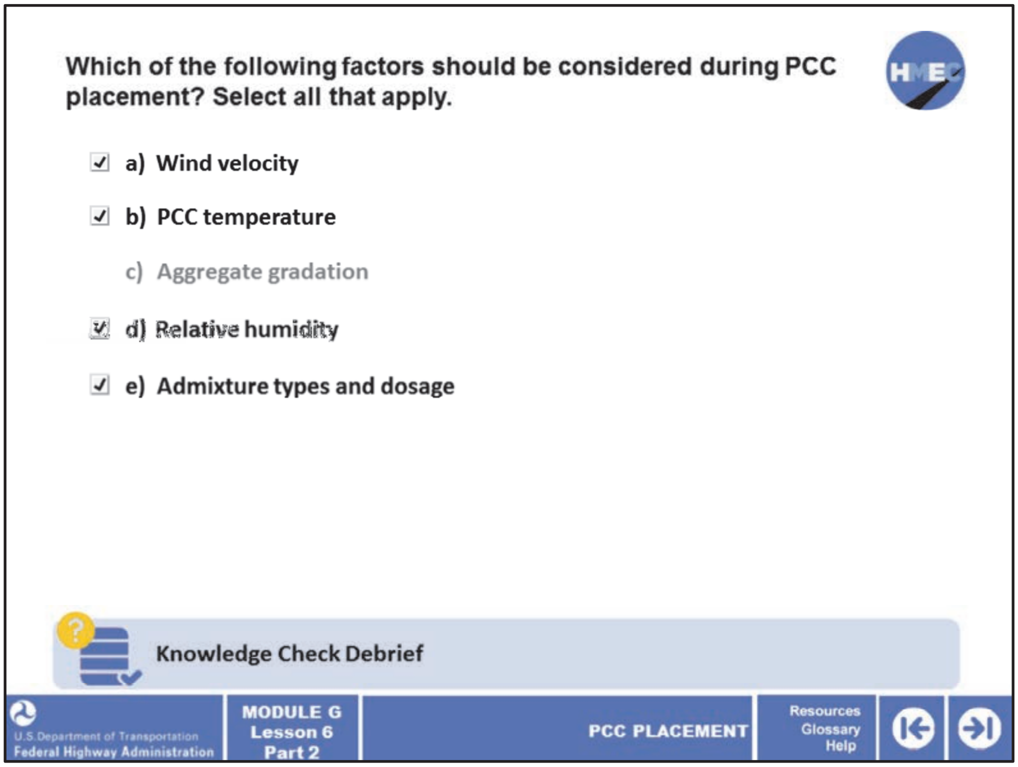
The potential effects include both segregation and a reduction in entrained air content, which reduces freeze/thaw resistance and increases permeability. Finishing operations can also be problematic. Concrete finishers have traditionally sprinkled the surface of the PCC with water after initial set in order to make finishing easier. This practice is very detrimental to the durability of the surface due to the increase in w/c and a reduction in entrained air content.

Image description: Photo of a worker spraying water on the PCC.



Which of the following factors should be considered during PCC placement? Select all that apply.

a) Wind velocity;
b) PCC temperature;
c) Aggregate gradation;
d) Relative humidity; and
e) Admixture types and dosage.



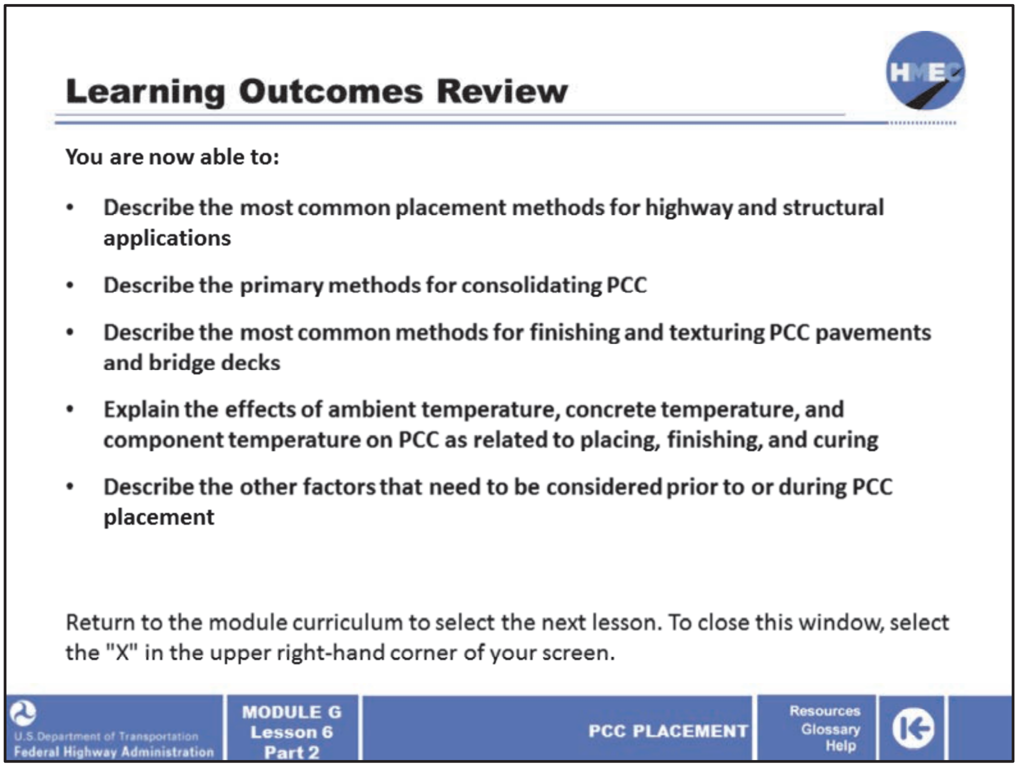
The correct answers are a) Wind velocity; b) PCC temperature; d) Relative humidity; and e) Admixture types and dosage.

The wind velocity is important as it influences the evaporation rate.

The temperature of the PCC influences the evaporation rate but it is also a key factor in the initial set time and the rate of hydration (strength gain).

The humidity is important in predicting the evaporation rate.

Admixture types and dosage are always important in that they can be used to control the workability, water requirement, set time, rate of strength gain, etc.



You have completed Module G, Lesson 6: Construction Practices, Part 2 of 3.

You are now able to:

- Describe the most common placement methods for highway and structural applications;
- Describe the primary methods for consolidating PCC;
- Describe the most common methods for finishing and texturing PCC pavements and bridge decks;
- Explain the effects of ambient temperature, concrete temperature, and component temperature on PCC as related to placing, finishing, and curing; and
- Describe the other factors that need to be considered prior to or during PCC placement.

Close this lesson, and return to the module curriculum to select the next lesson. To close this window, select the “X” in the upper right-hand corner of your screen.