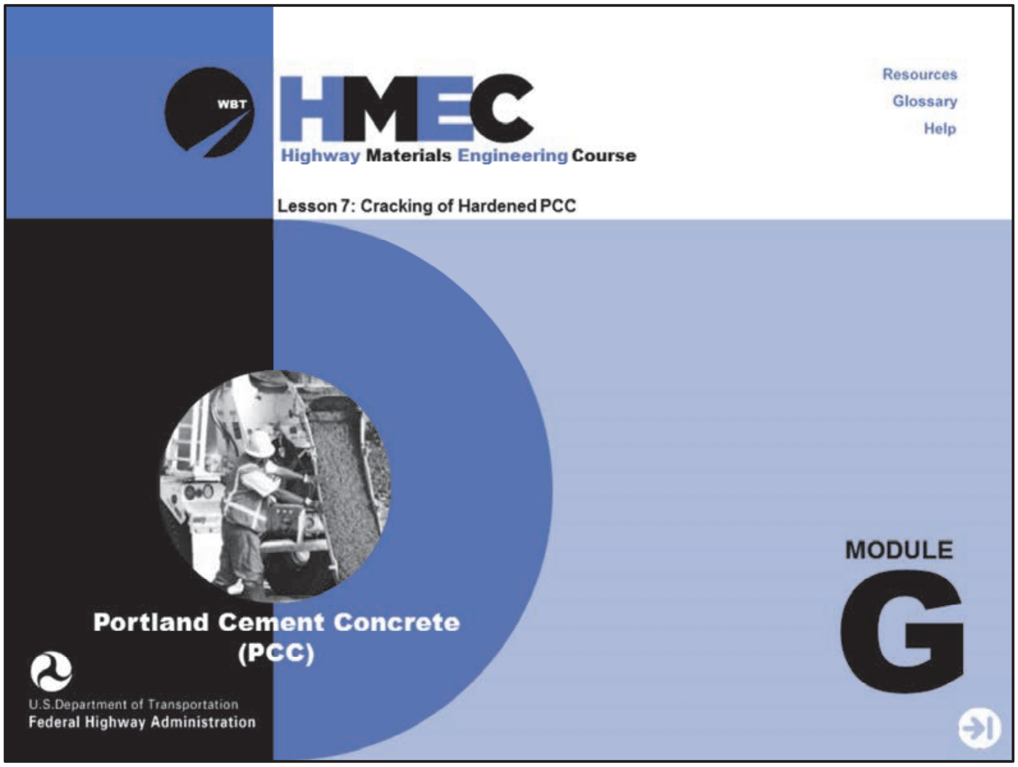
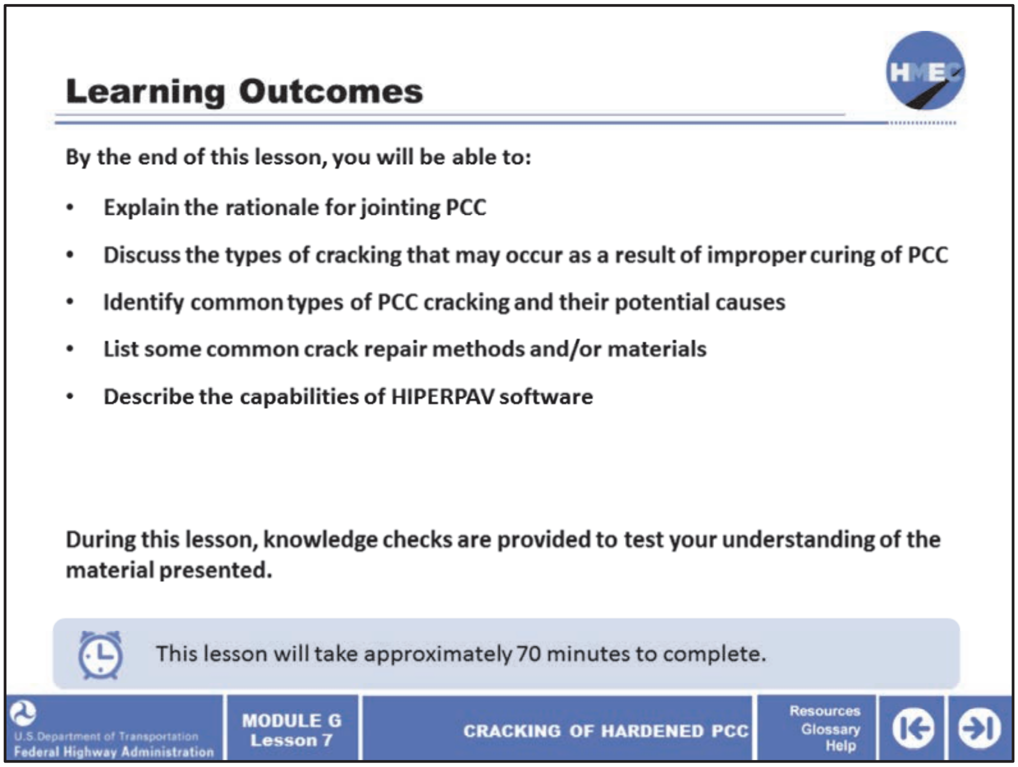


Welcome to the Highway Materials Engineering Course Module G, Lesson 7: Cracking of Hardened PCC. In this lesson, we will look at some ways to avoid and repair cracking of PCC.

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

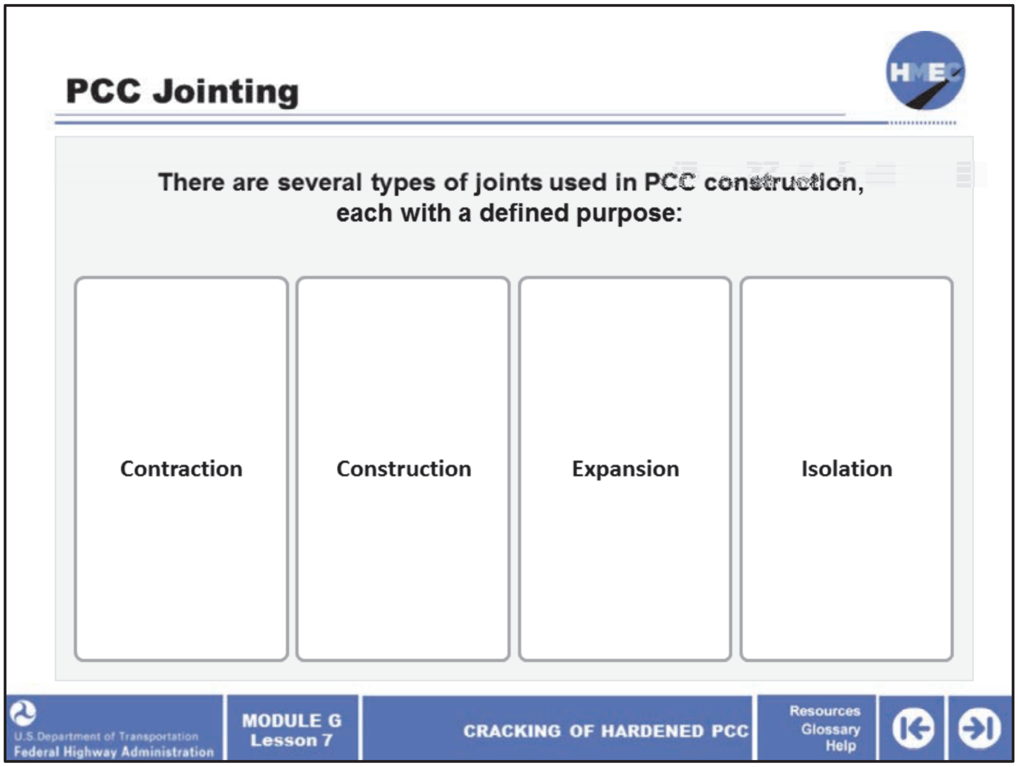


By the end of this lesson, you will be able to:

- Explain the rationale for jointing Portland cement concrete (PCC);
- Discuss the types of cracking that may occur as a result of improper curing of PCC;
- Identify common types of PCC cracking and their potential causes;
- List some common crack repair methods and/or materials; and
- Describe the capabilities of HIPERPAV software.

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

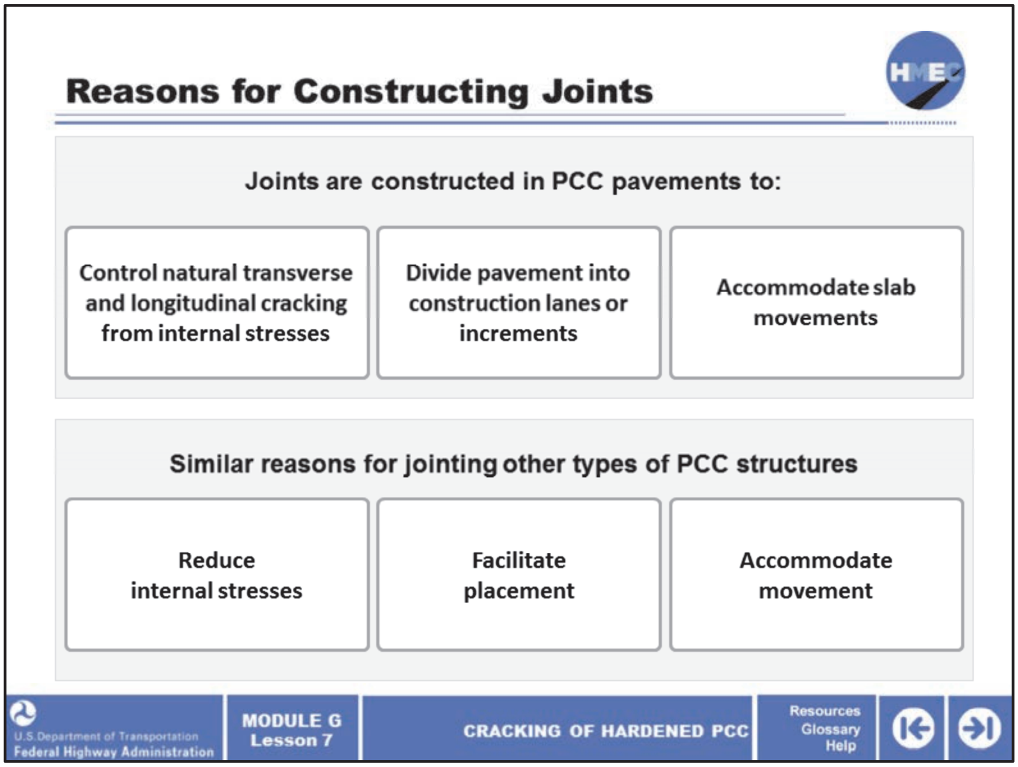
This lesson will take approximately 70 minutes to complete.



Let's get started with PCC jointing. There are several types of joints used in PCC construction, each with a defined purpose.

- Contraction;
- Construction;
- Expansion; and
- Isolation.

PCC pavements feature all of these joint types and will be the focus of this section for that reason. Since PCC pavements use all of the common joint types, we will show pavement related examples for simplicity, keeping in mind the same factors are generally found in all PCC structures.

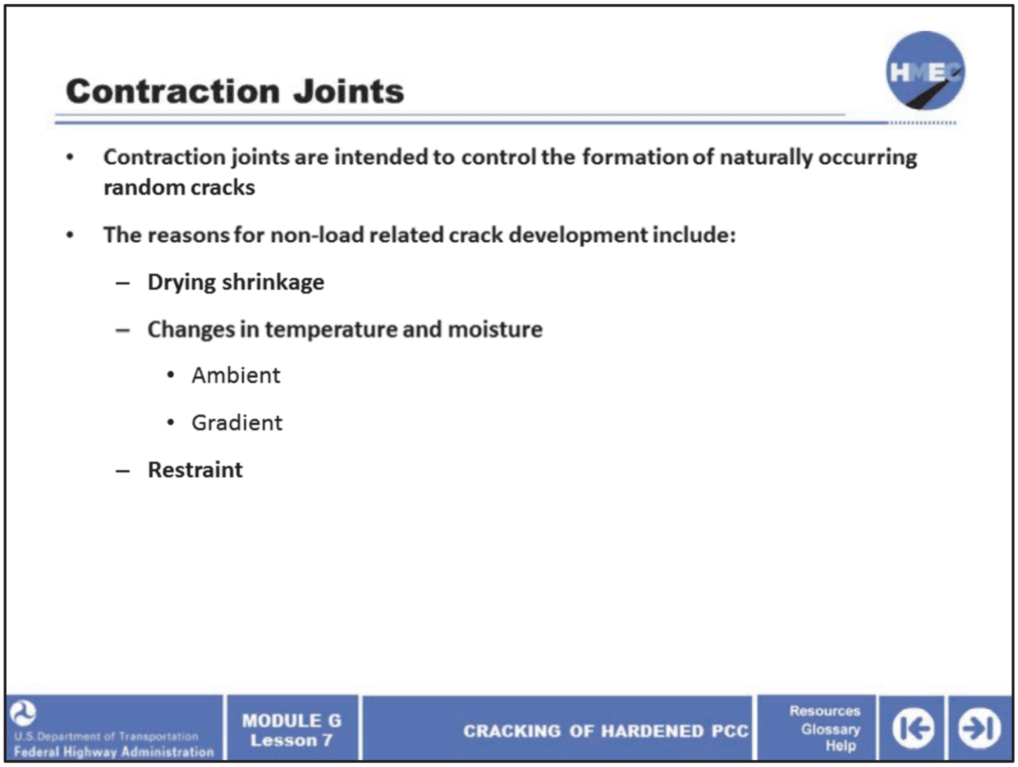


Joints are constructed in PCC pavements for the following reasons:

- Control natural transverse and longitudinal cracking from internal stresses;
- Divide pavement into construction lanes or increments; and
- Accommodate slab movements.

Some similar reasons for jointing other types of PCC structures are:

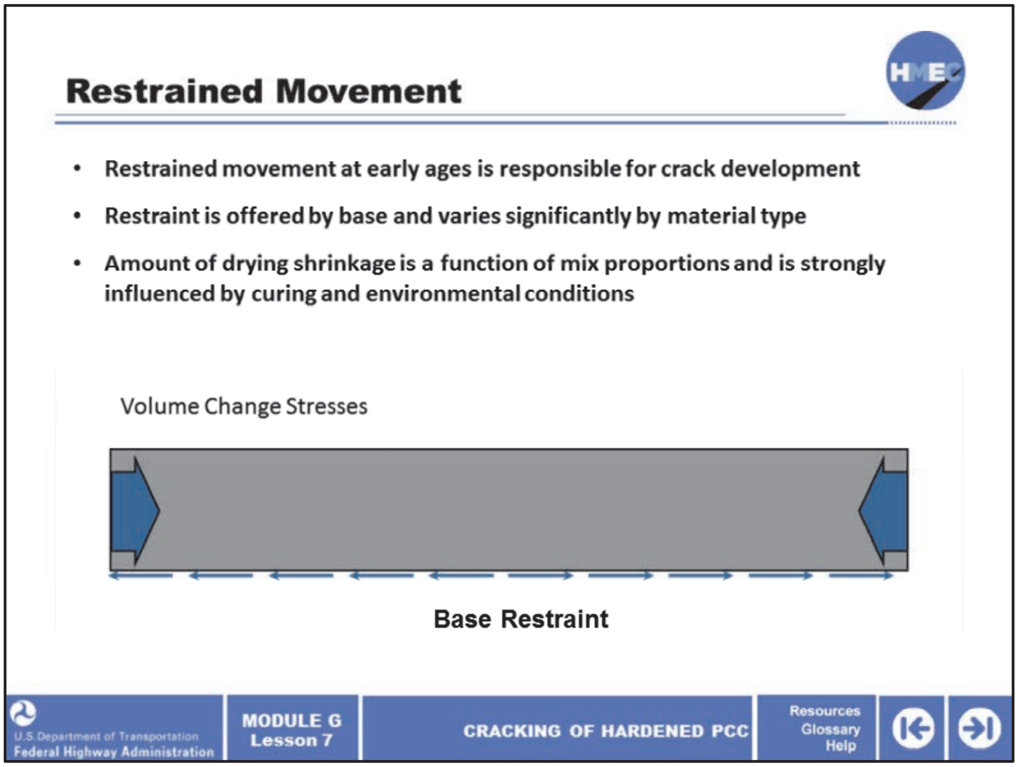
- Reduce internal stresses;
- Facilitate placement; and
- Accommodate movement (primarily drying shrinkage and thermal).



Contraction joints are used to control the location of random cracks developing at an early age due to restrained drying shrinkage (and later, due to thermal movement).

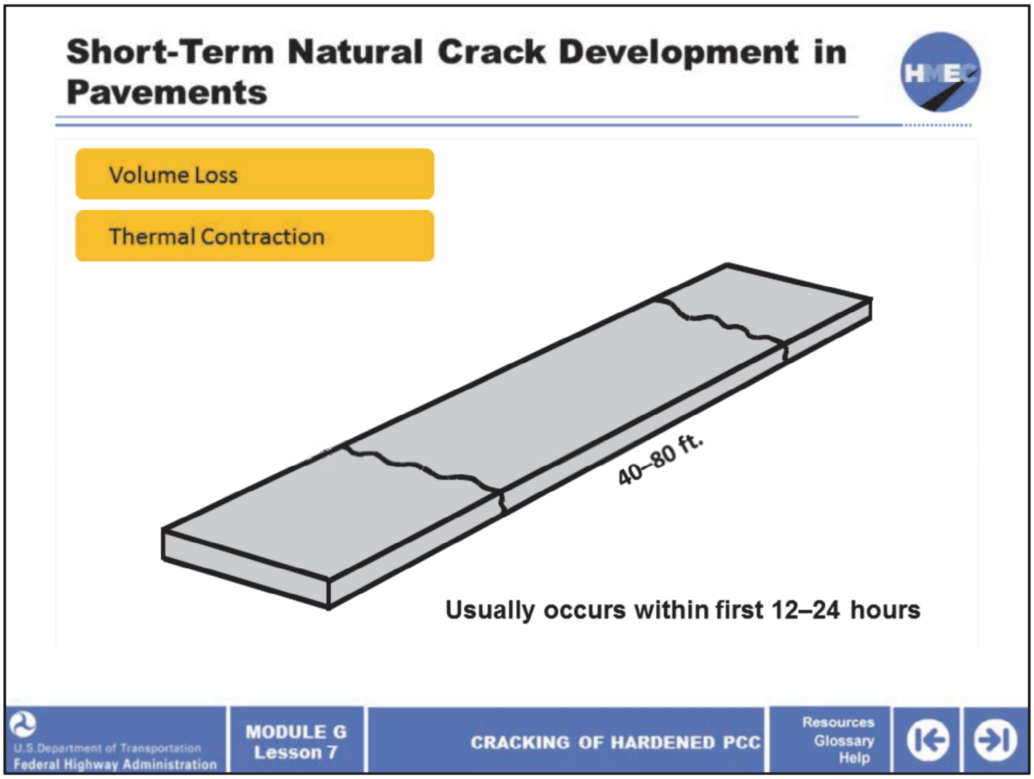
The reasons for non-load related crack development include drying shrinkage, changes in temperature and moisture—ambient (contraction) and gradient (curling)—and restraint (friction or bond).

Note that cracking will occur due to internal stresses. The joints are placed to control their location and orientation.



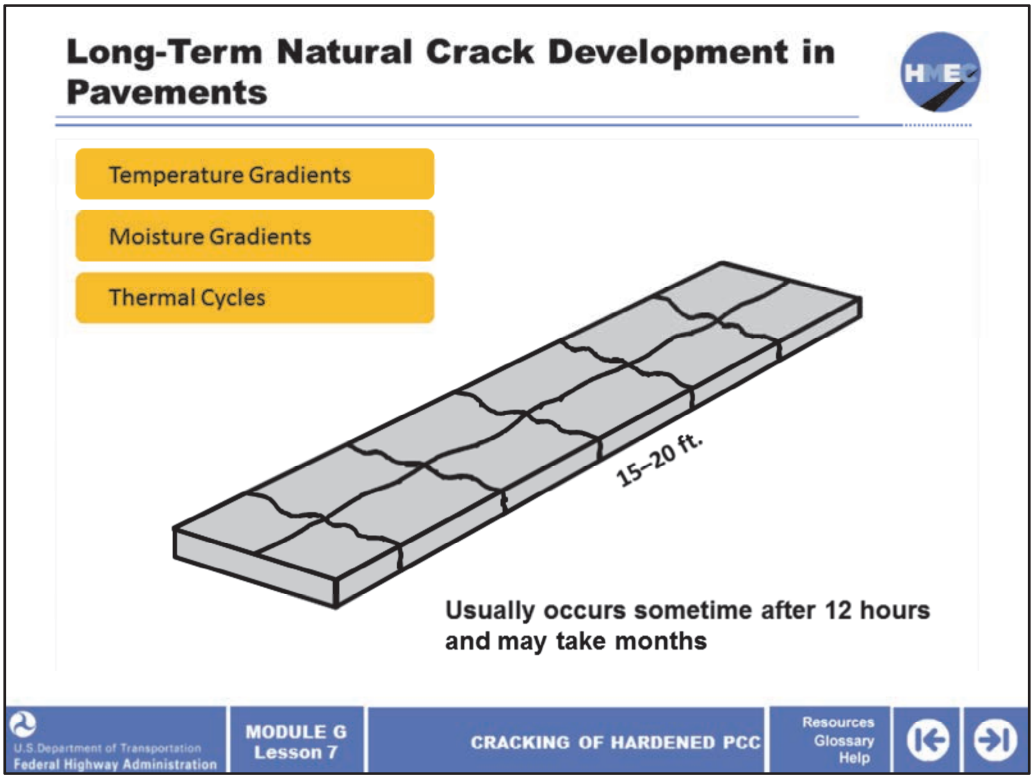
Restrained movement at early ages is responsible for crack development. The restraint is offered by the base and varies significantly by material type. The amount of drying shrinkage is a function of the mix proportions and is strongly influenced by curing and environmental conditions. In theory, if there were no restraint, drying shrinkage and thermal movement would not result in crack formation. Attempts to substantially reduce the level of friction have not proven effective. Therefore, we place contraction joints to account for the restrained movement. The base restraint (friction) is a function of the material type and is relatively low for unbound aggregates and high for cement treated or asphalt treated bases.

Image description: Diagram showing base restraint and volume change stresses.



The initial crack development is to accommodate the high level of drying shrinkage that happens in the first 12 to 24 hours (for normal PCC mixes in a moderate environment).

Image description: Diagram showing cracks across a slab of pavement.

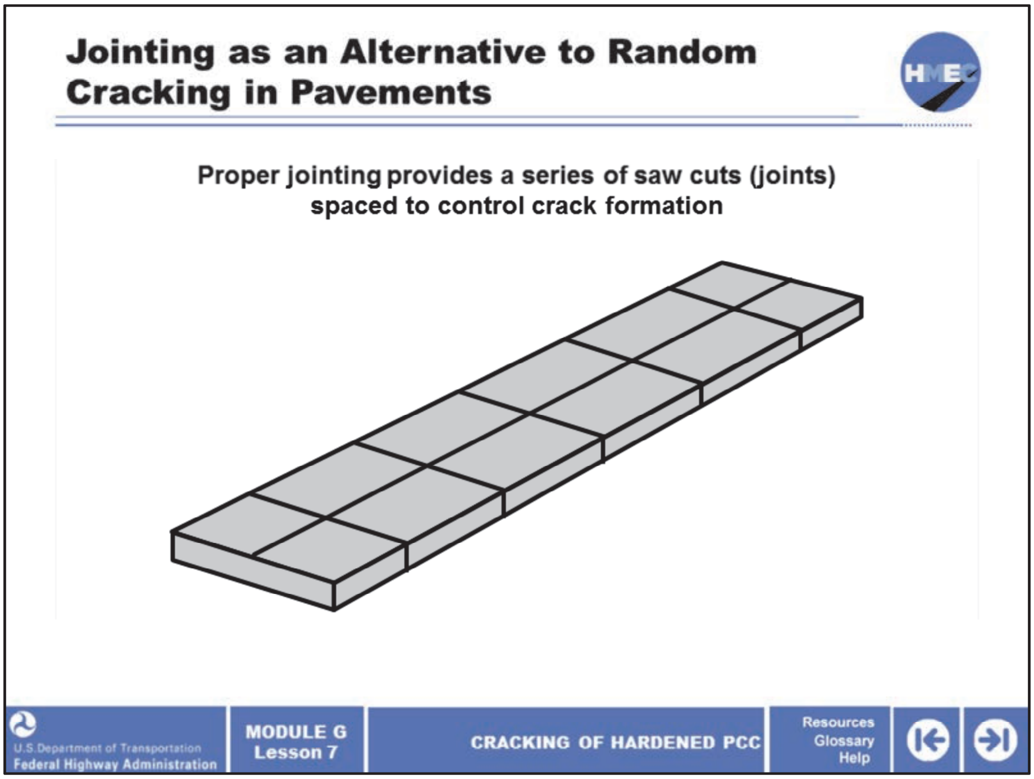


Cracking will continue to develop over a much longer period of time in order to relieve internal stresses. The reasons for continued crack development are:

- Temperature gradients;
- Moisture gradients; and
- Thermal cycles.

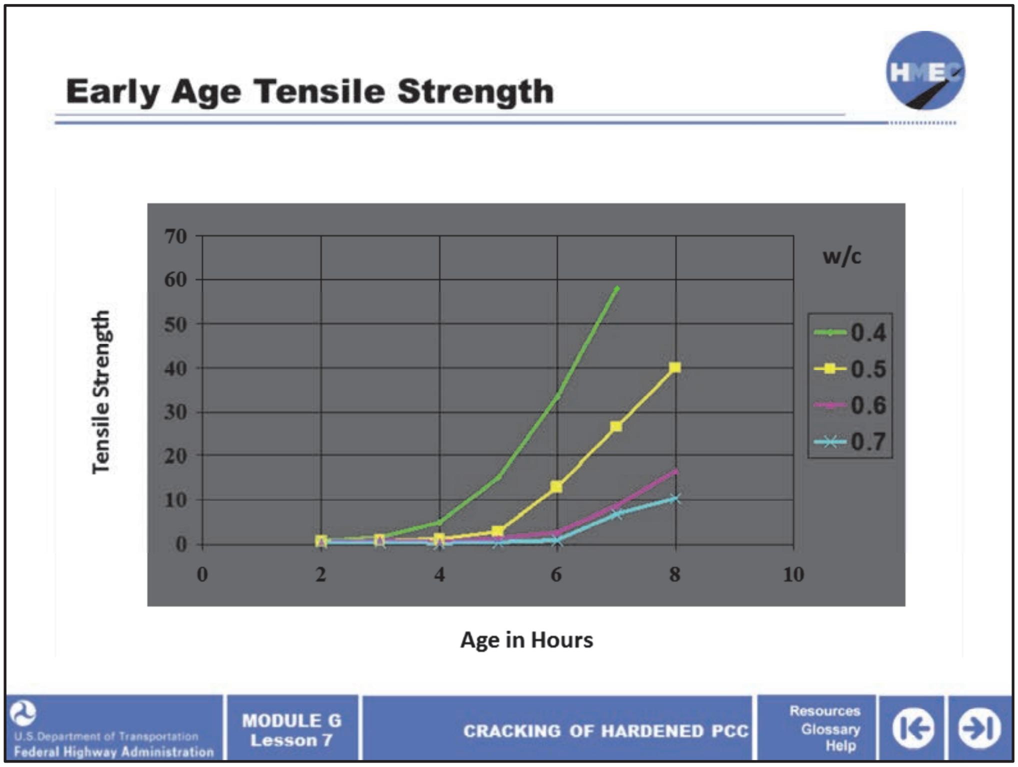
Loading is not included as part of the restrained movement crack development, but it can play a role.

Image description: Diagram showing cracks across a slab of pavement.



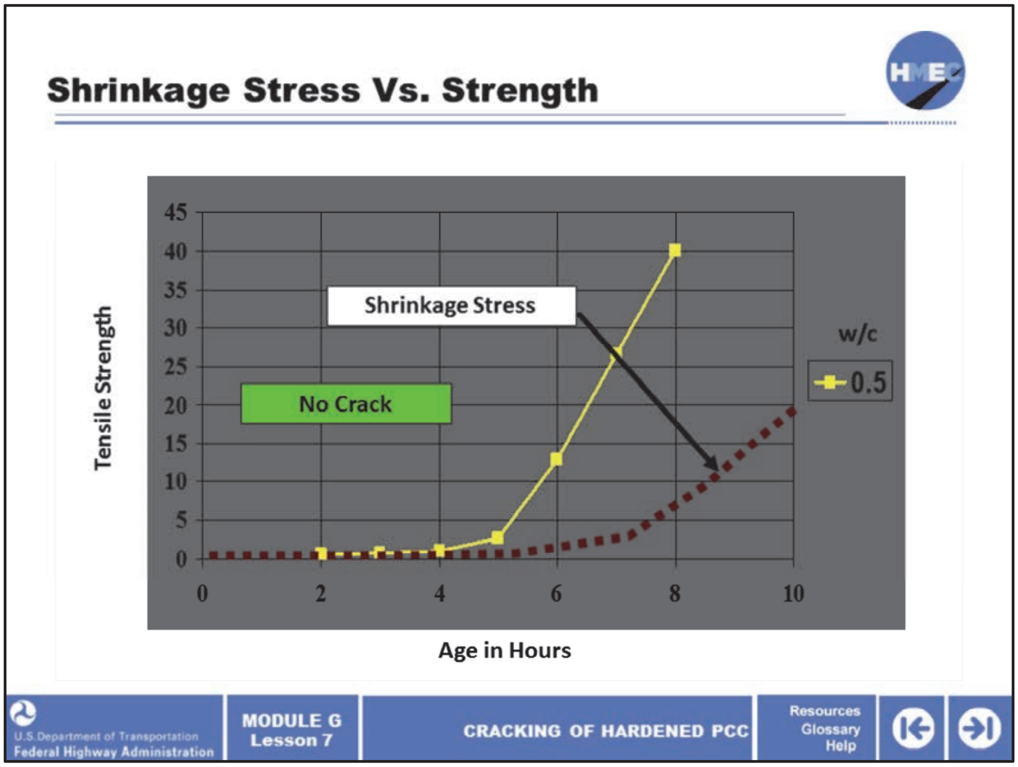
Proper jointing provides a series of saw cuts (joints) spaced to control where cracks will occur and facilitate maintenance. Contraction joints also allow us to use appropriate load transfer (dowels or aggregate interlock) based on the level of traffic.

Image description: Diagram showing joints across a slab of pavement.



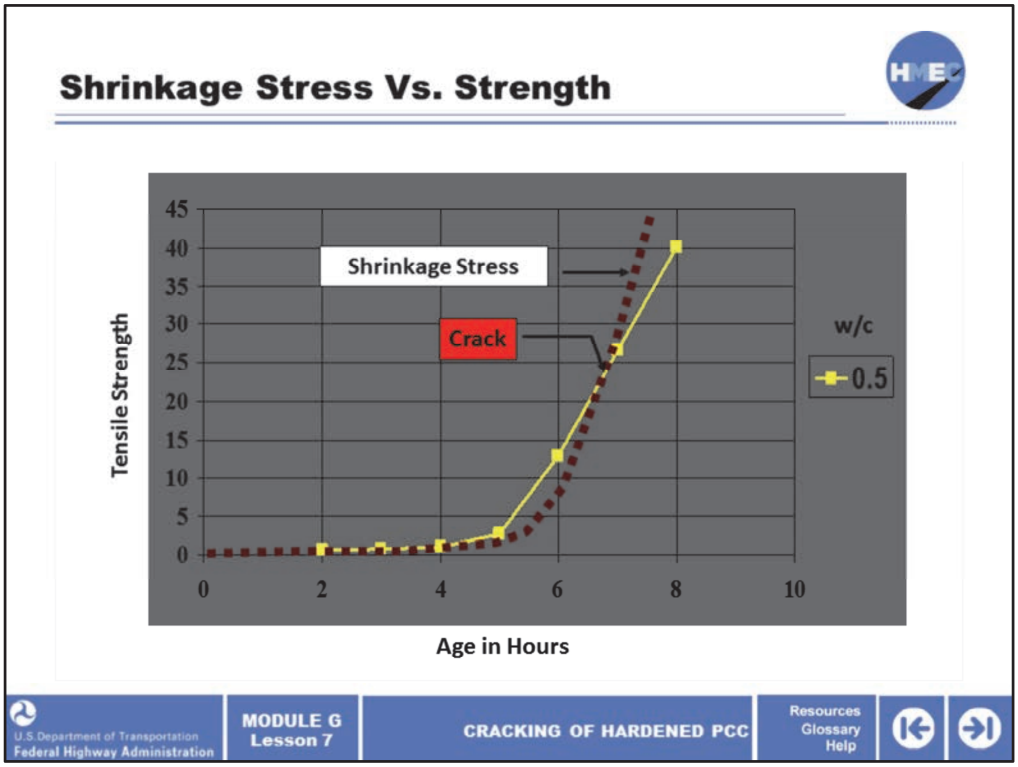
Although PCC is very strong in compression, it is relatively weak in tension. When the internal stresses in the slab (or member), resulting from restrained drying shrinkage, exceed the tensile strength of the PCC, a crack will occur. As a side note, the effect of water-cement (w/c) ratio on tensile strength development is very pronounced as shown in this slide. In addition, the overall mix characteristics, ambient conditions, and curing are very important as well.

Image description: Graph showing that the effect of water-cement (w/c) ratio on tensile strength development is very pronounced.



As long as the internal stresses do not exceed the tensile strength of the PCC, cracking will not occur.

Image description: Graph showing shrinkage stress vs. strength.

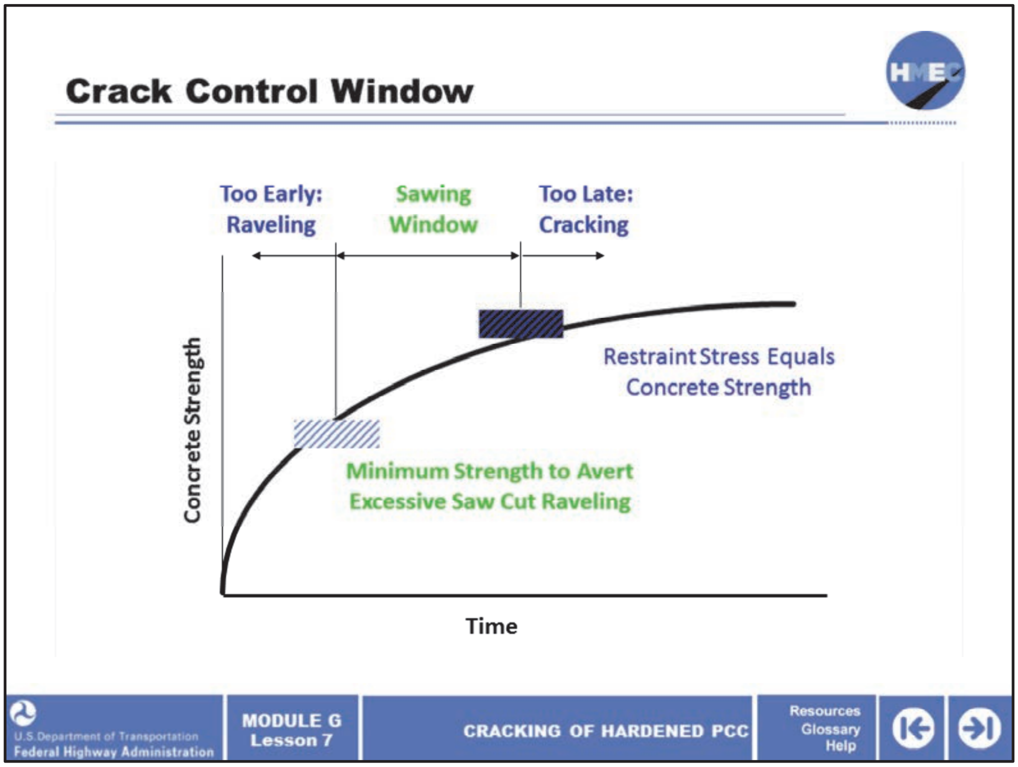


When the stress within the slab exceeds the tensile strength a crack will develop.

The shrinkage stress is primarily a function of the amount of restraint and the drying shrinkage in the PCC.

It is clear from the figure that a crack will form at about 7 hours. Saw cutting a weakened plane contraction joint prior to this time is required or a random crack will develop.

Image description: Graph showing shrinkage stress vs. strength.

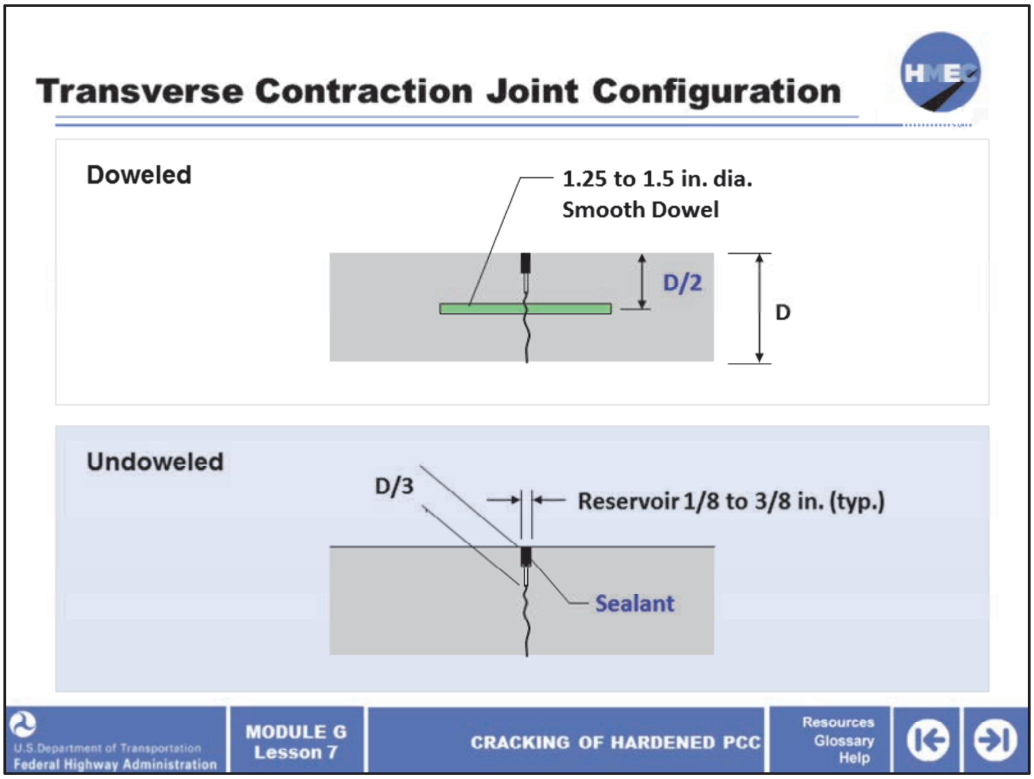


This figure shows the window of opportunity for sawing contraction joints. If the saw cuts are made too early, the surface of the pavement is damaged; if it is sawed too late, random cracks will already have developed.

The following factors have a strong influence on the sawing window:

- PCC mix characteristics;
- Weather and ambient conditions;
- Curing protection;
- Base conditions;
- Sawing operations; and
- Joint spacing and design.

Image description: Graph showing the window of opportunity for sawing contraction joints.



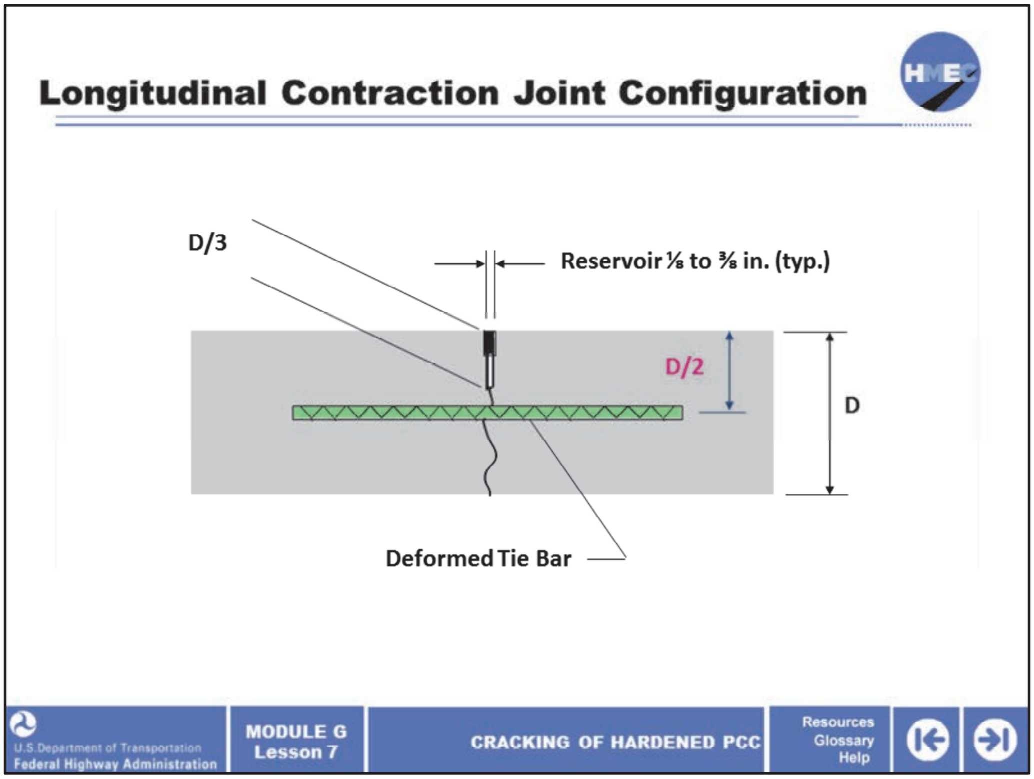
Jointed plain concrete pavements (JPCP) use one of the options shown in this slide to facilitate load transfer across the transverse joints. The need for dowel bars is based on the level of truck traffic and the bar size is dependent on slab thickness. These joints are designed to accommodate unrestrained longitudinal movement while eliminating differential vertical movement across the joint.

Transverse joints are sawed to a depth of ⅓ of the slab thickness to create a weakened plane that will force a crack to occur due to restrained drying shrinkage and thermal movement of the PCC. The saw cuts are made as soon as possible after final set to ensure cracks develop only at these locations (joints).

The joint reservoirs (if used) are sawed at a later time and are designed to accommodate the specific type of sealant used (silicone, preformed neoprene, bituminous, etc.). Reservoirs of ⅛ in. are typically used for bituminous sealants while ⅜-in. reservoir widths are used for silicone sealants. The depth of the reservoir is also dictated by the sealant type. Check your agency's specifications or manufacturer's literature for the appropriate reservoir dimensions.

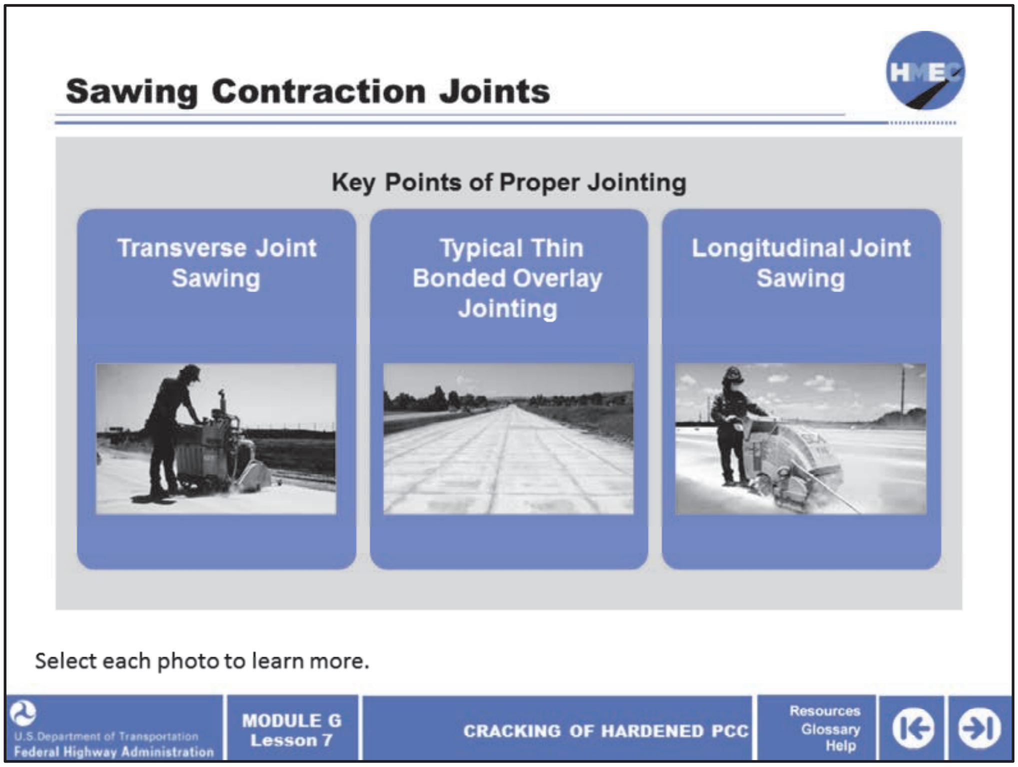
Image description: Diagram of jointed plain concrete pavements (JPCP) doweled to facilitate load transfer across the transverse joints.

Image description: Diagram of jointed plain concrete pavements (JPCP) undoweled to facilitate load transfer across the transverse joints.



These joints are designed to tie the lanes together and not allow movement in any direction. Note the use of a deformed tie bar rather than a smooth dowel bar as is required for transverse contraction joints.

Image description: Diagram of longitudinal contraction joint configuration.



There are many aspects of proper jointing that we will not have time to cover.

The key points are:

- Saw the joints as soon as possible without raveling the surface;
- The joint spacing is a function of thickness; and
- The depth of the saw cut, which will be discussed further.

The American Concrete Pavement Association (ACPA) recommends that the joint spacing not exceed 24 times slab thickness (in inches) for unbound aggregate bases and 21 times thickness for stabilized bases.

A long-standing rule of thumb is that the joint spacing in feet should not exceed 1.5 times the slab thickness in inches. For instance, a 10-in. slab would have a joint spacing of 15 ft.

Select each photo to learn more.

Image description: Photo of a conventional middle weight saw being used to saw transverse contraction joints.

Image description: Photo of a thin bonded PCC overlay of an asphalt pavement.

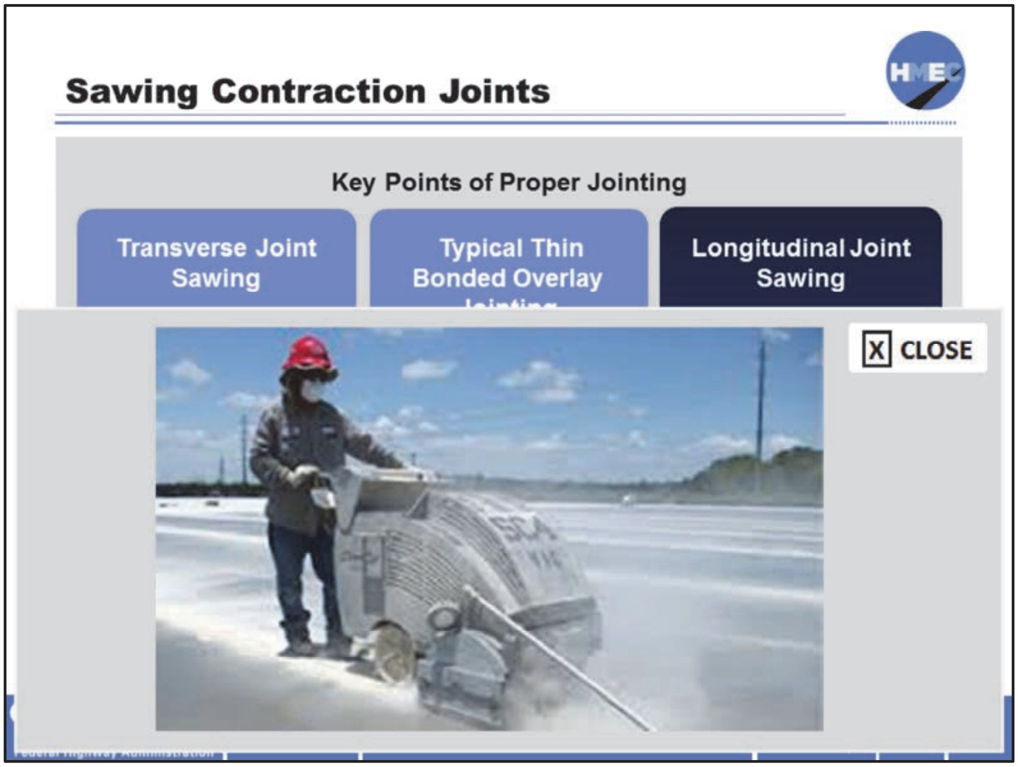
Image description: Photo of an early entry saw being used to saw a longitudinal contraction joint.

This photo shows a conventional middle weight saw being used to saw transverse contraction joints.

Image description: Photo of a conventional middle weight saw being used to saw transverse contraction joints.

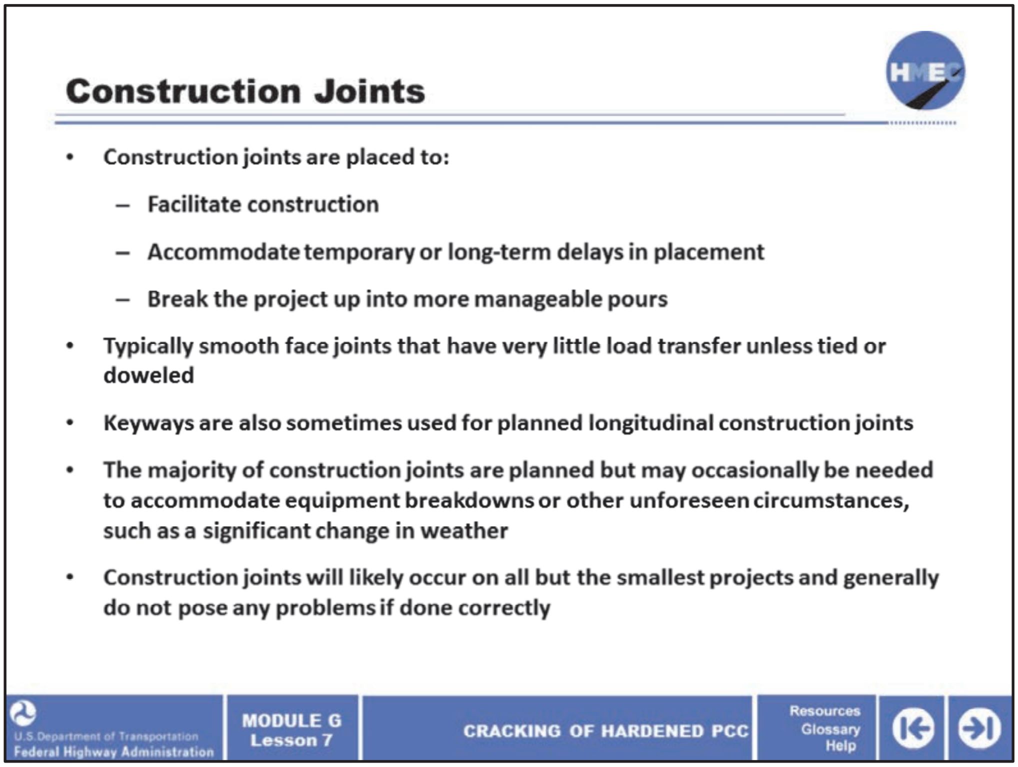
This photo shows a thin bonded PCC overlay of an asphalt pavement. Note the close joint spacing that corresponds to the thickness of the overlay.

Image description: Photo of a thin bonded PCC overlay of an asphalt pavement.



This photo shows an early entry saw being used to saw a longitudinal contraction joint.

Image description: Photo of an early entry saw being used to saw a longitudinal contraction joint.



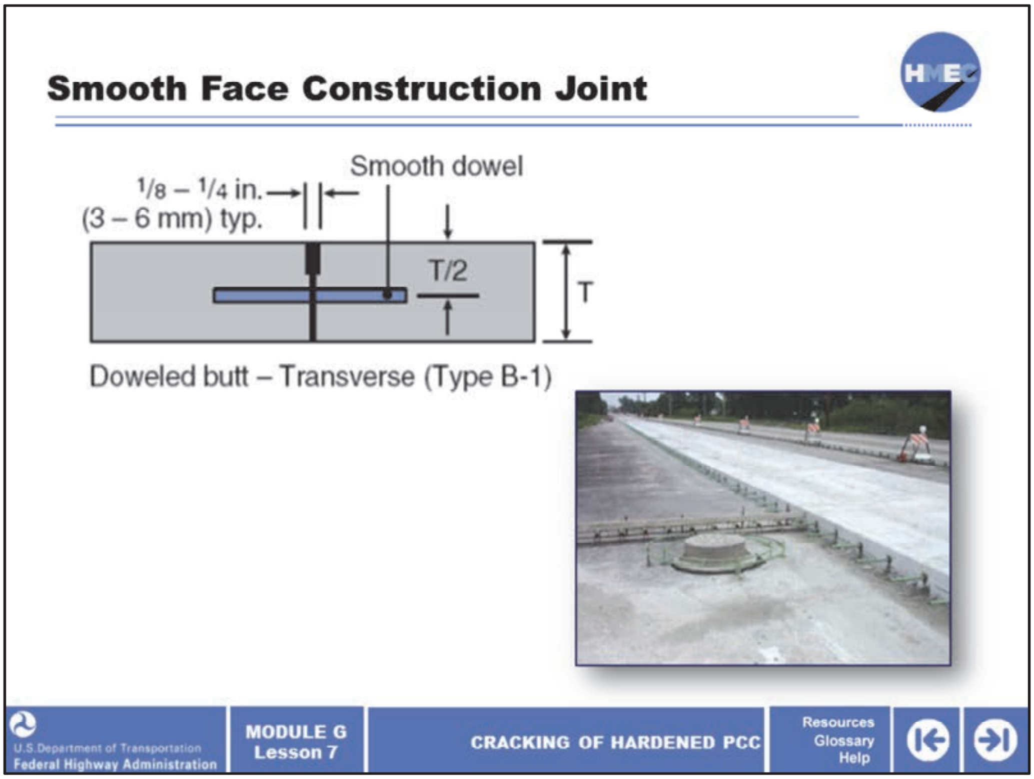
Construction joints are placed to:

- Facilitate construction;
- Accommodate temporary or long-term delays in placement; and
- Break the project up into more manageable pours.

Construction joints are typically smooth-faced joints that have very little load transfer unless tied or doweled. Keyways are also sometimes used for planned longitudinal construction joints.

The majority of construction joints are planned but may occasionally be needed to accommodate equipment breakdowns or other unforeseen circumstances, such as a significant change in weather.

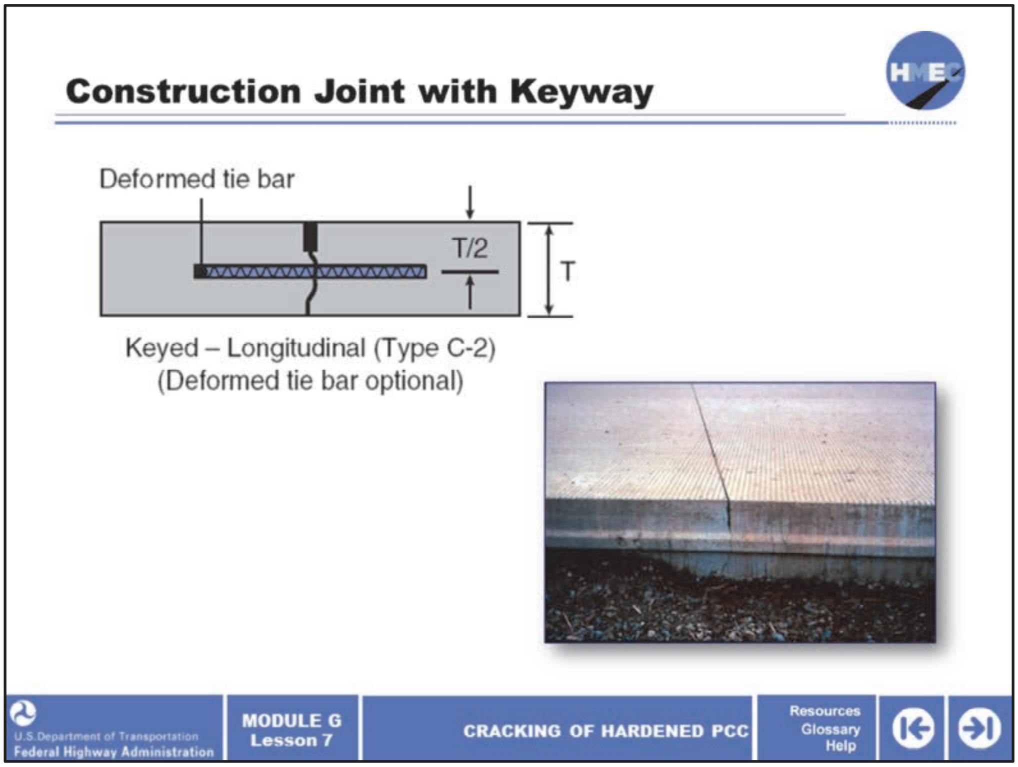
Construction joints will likely occur on all but the smallest projects and generally do not pose any problems if done correctly.



Transverse construction joints in pavements are constructed with smooth dowel bars to permit longitudinal but not vertical movement.

Image description: Diagram of smooth face construction joint.

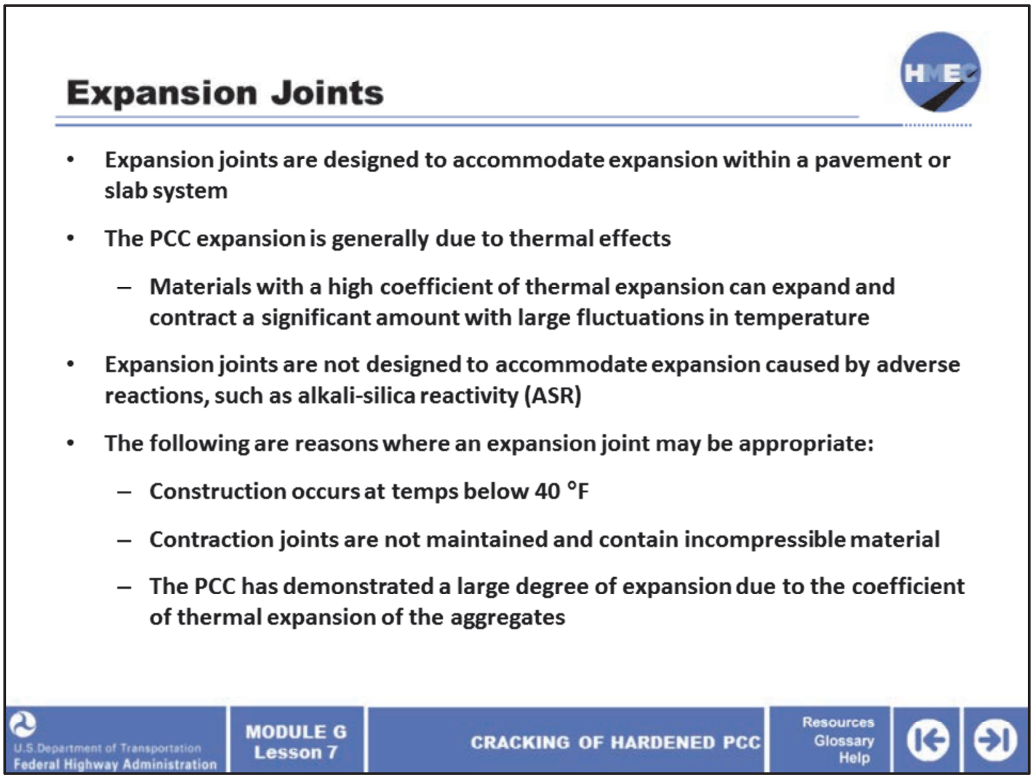
Image description: Photo of a stretch of pavement with smooth dowel bars.



Keyways are sometimes used for longitudinal contraction joints on thicker pavement sections, although they facilitate some level of load transfer if tie bars are used to limit joint openings. The risk with keyways is the possibility of breaking one of the “ears” on the top or bottom of the slab.

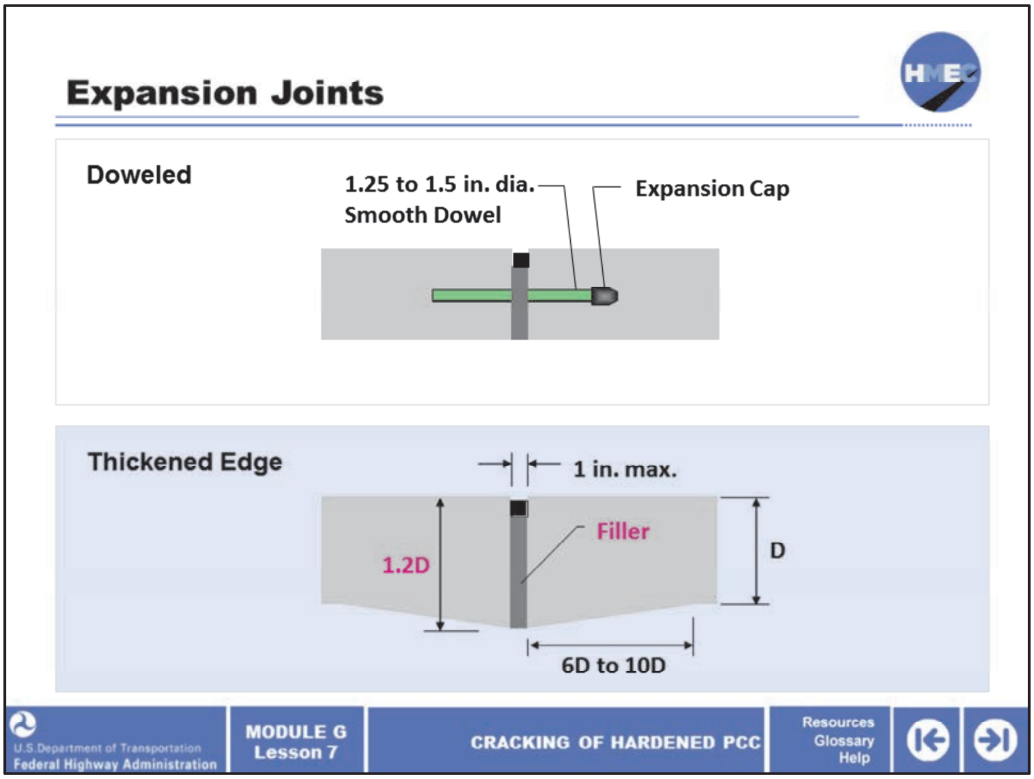
Image description: Diagram of a construction joint with keyway.

Image description: Photo of pavement with keyway.



Expansion joints are rarely needed if the pavement is well designed and constructed. For the majority of PCC mixes, the initial drying shrinkage is more than the potential thermal expansion. In other words, the slab length is at its maximum when placed. Expansion joints have traditionally been difficult to maintain and are actually detrimental to jointed pavement performance because they allow the pavement to “grow” into the expansion space. The times when expansion joints are required are listed on the slide.

When PCC is placed at low temperatures, the thermal expansion may be larger than the drying shrinkage. This is a function of the coefficient of thermal expansion (CTE) and mix characteristics. If contraction joints are not maintained, incompressible material may fill the joint at lower temperatures (joint opening is at the maximum). When the temperature increases, the joint cannot close. The issue is the pavement expands into the expansion joint and leaves the contraction joints permanently open.



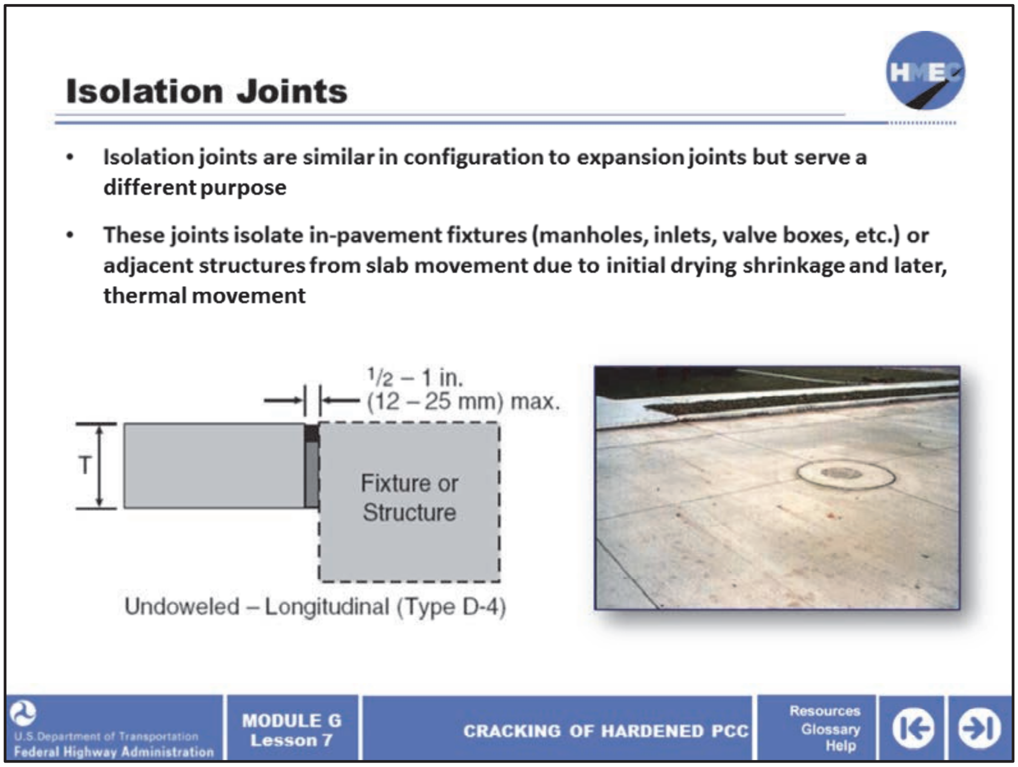
Note that the joint details presented here are typical but many other configurations are also used.

When a dowel bar is used in an expansion joint, an expansion cap is placed on one or both ends of the dowel to allow the joint to close without the restraint of the end of the dowel. In other words, without the caps, as the expansion joint began to close, the ends of the dowels would offer restraint (point bearing) until a crack developed or spalling occurred to relieve the internal stress in the PCC.

If dowels are not used, it is common practice to increase the thickness of the pavement (thickened edge) to reduce stress in the slab due to edge loading. This is common for thinner pavements where dowels are not typically used.

Image description: Diagram of expansion joint doweled with expansion cap.

Image description: Diagram of expansion joint with a thickened edge.



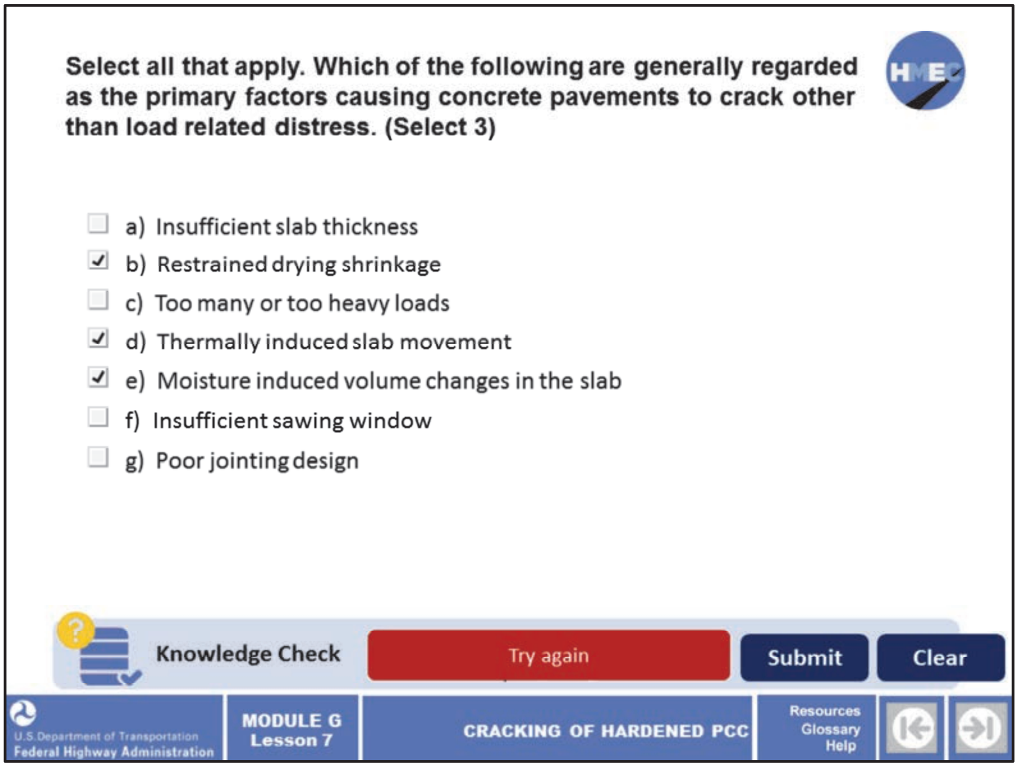
Isolation joints are not to be confused with expansion joints, although their configuration is similar. Isolation is potentially required early on due to PCC drying shrinkage and later due to thermal movements. As the name implies, isolation joints are intended to isolate adjacent structures or in-pavement fixtures (manholes, inlets, valve boxes, etc.) from movement of the PCC pavement. For instance, isolation joints are used at tee intersections to isolate manholes as well as at storm inlets and where pavements are placed adjacent to buildings and so on.

A typical isolation joint configuration is shown on the left. There are numerous joint details depending on the type of isolation joint and its intended function. For instance, thickened edge details, as shown on the previous slide, are also appropriate and widely used for isolation joints.

The photo on the right illustrates an isolation joint surrounding the perimeter of a manhole. The combination of the circular isolation joint and proper jointing pattern will ensure the manhole cover remains stationary as the pavement expands and contracts.

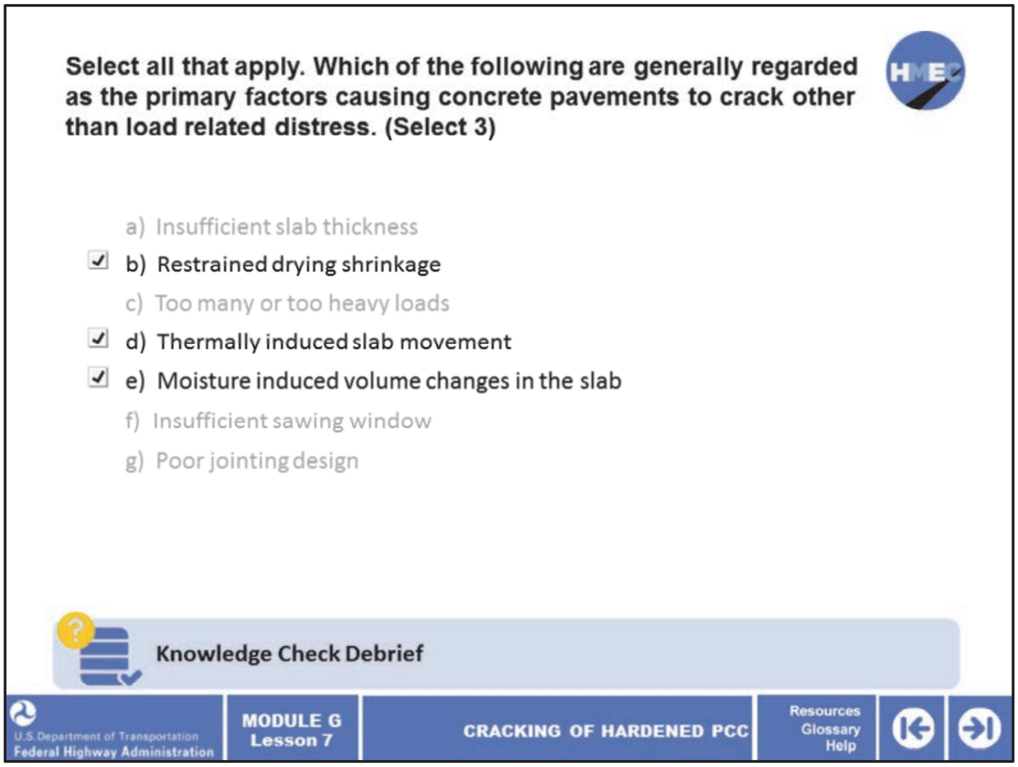
Image description: Diagram of an isolation joint.

Image description: Photo of an isolation joint surrounding the perimeter of a manhole.

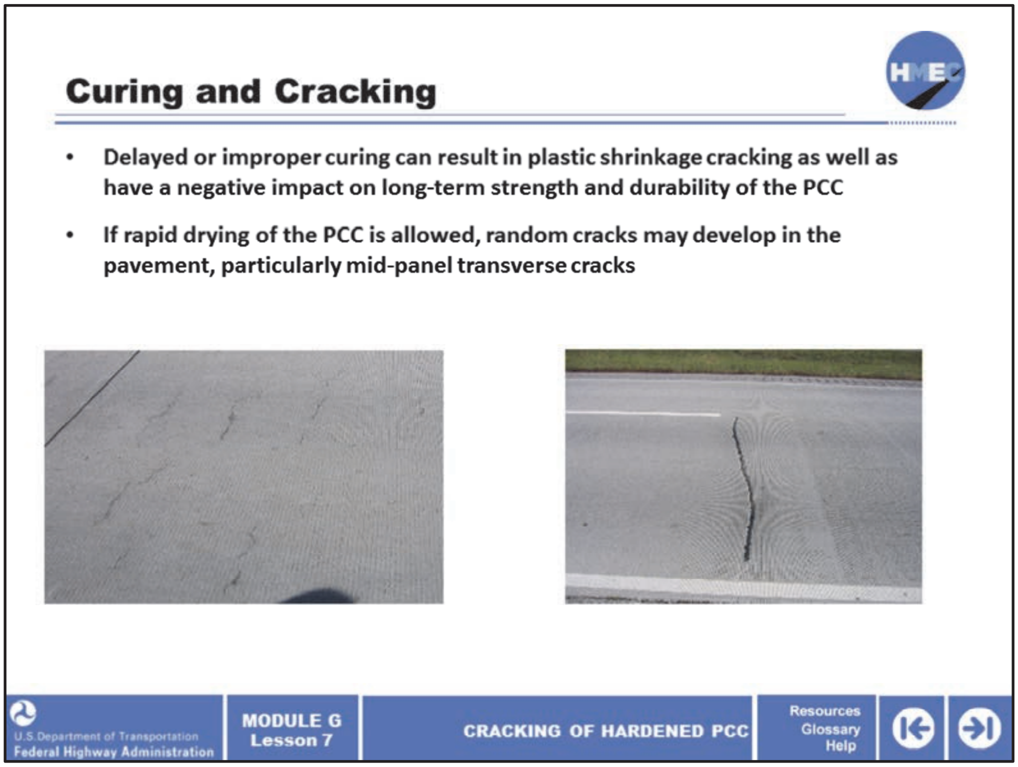


Select all that apply. Which of the following are generally regarded as the primary factors causing concrete pavements to crack other than load related distress. (Select 3)

a) Insufficient slab thickness;
b) Restrained drying shrinkage;
c) Too many or too heavy loads;
d) Thermally induced slab movement;
e) Moisture induced volume changes in the slab;
f) Insufficient sawing window; and/or
g) Poor jointing design.



The correct answers are b) Restrained drying shrinkage; d) Thermally induced slab movement; and e) Moisture induced volume changes in the slab.



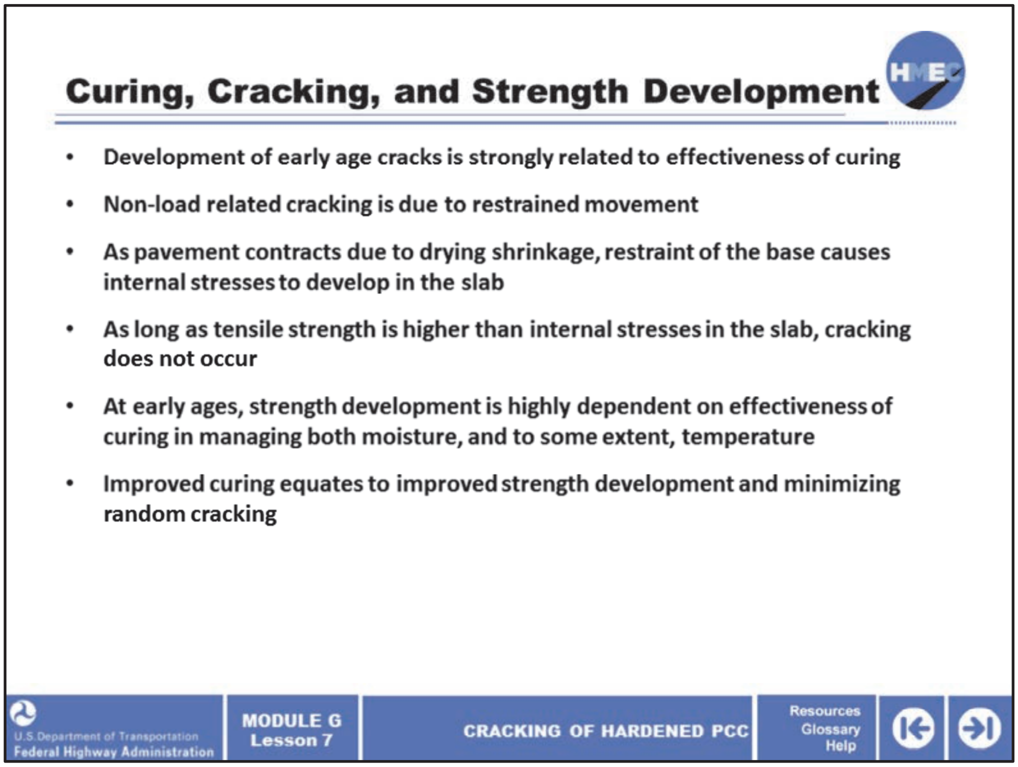
In Lesson 6, we discussed the need for adequate and timely curing. The effects of adequate curing are improved performance in every regard encompassing both strength and durability. If rapid drying of the PCC is allowed (lack of or poorly executed curing), random cracks may develop in the pavement, particularly mid-panel transverse cracks. The effects of poor curing are shown in the photos.

The photo on the left is plastic shrinkage cracking likely due to late or inadequate curing.

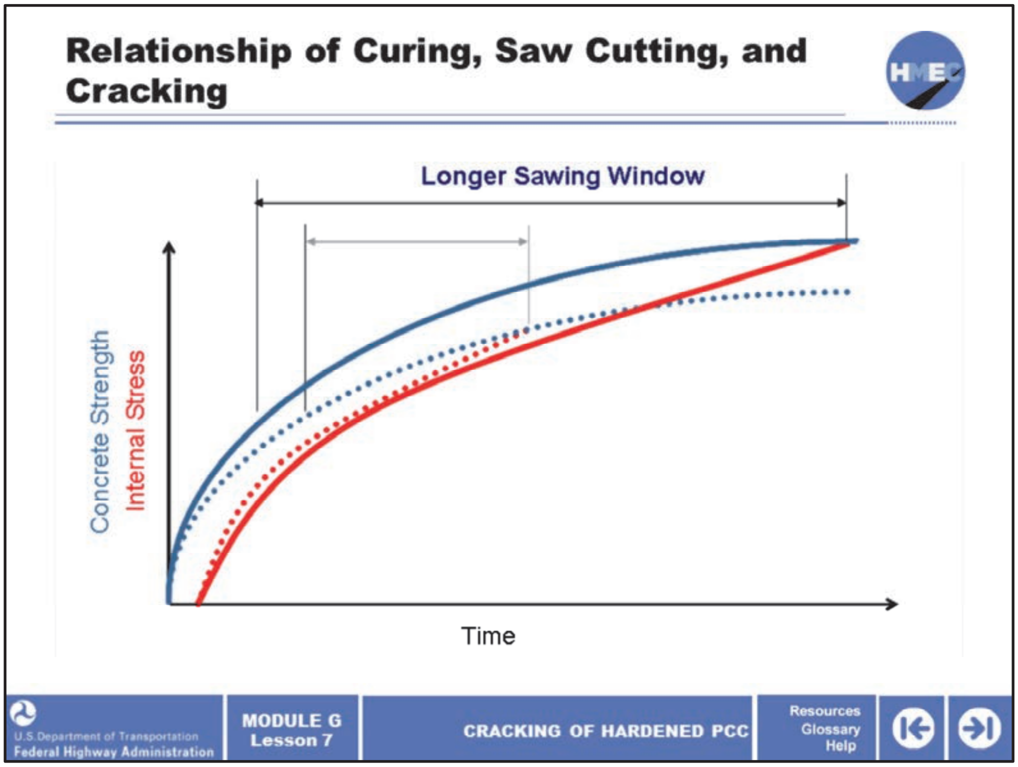
The photo on the right is of a mid-panel crack that may have developed due to excessive drying shrinkage or perhaps developed later due to fatigue induced by lower strength PCC.

Image description: Photo of plastic shrinkage cracking likely due to late or inadequate curing.

Image description: Photo of crack in the pavement.

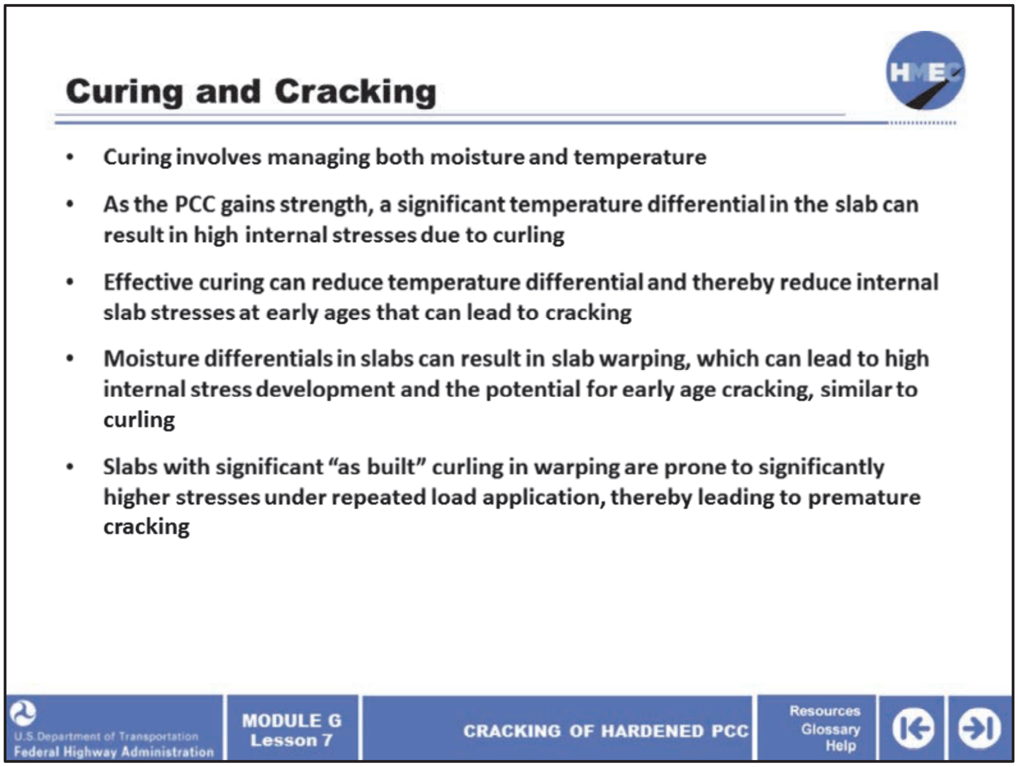


Development of early age cracks is strongly related to the effectiveness of curing. As was previously discussed, non-load related cracking is generally due to restrained movement. As the pavement contracts due to drying shrinkage, the restraint of the base causes internal stresses to develop in the slab. As long as the tensile strength of the PCC is higher than the internal stresses in the slab, cracking does not occur. At early ages, the strength development of PCC is highly dependent on the effectiveness of the curing in managing both moisture, and to some extent, temperature. Improved curing equates to improved strength development and minimizing random cracking.



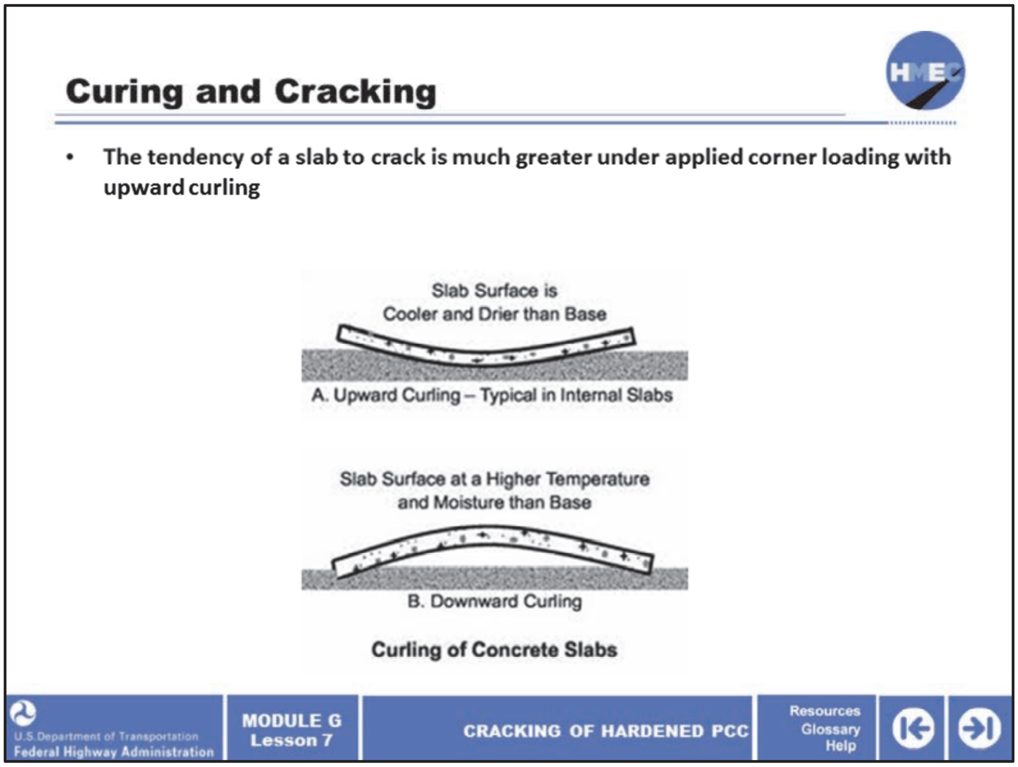
One of the key elements in eliminating early age transverse cracking is the timely sawing of joints. The sawing window shown in the figure is strongly influenced by the timing and effectiveness of curing. One way to envision this is that effective curing offsets the start of drying shrinkage. This can help reduce internal stresses until the PCC has achieved a high enough strength to resist cracking until the saw cutting operations are completed.

Image description: Graph showing the relationship of curing, saw cutting, and cracking.



Curing involves managing both moisture and temperature. As the PCC gains strength, a significant temperature differential in the slab can result in high internal stresses due to curling. Effective curing can reduce temperature differential and thereby reduce internal slab stresses at early ages that can lead to cracking.

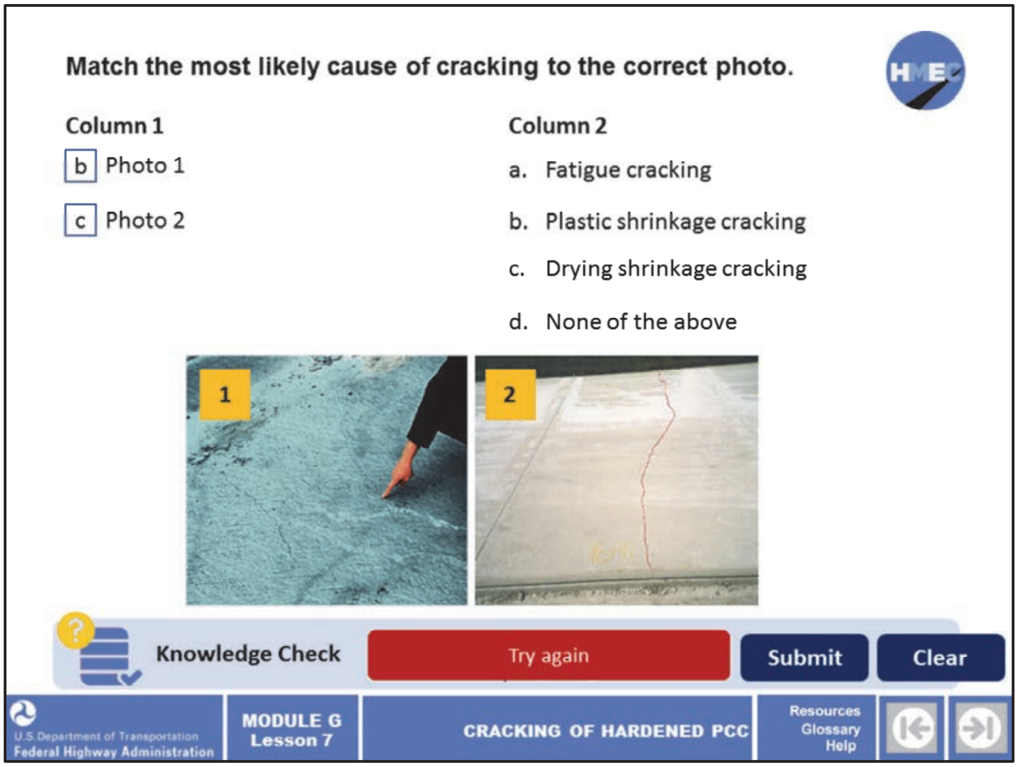
Moisture differentials in slabs can result in slab warping, which can lead to high internal stress development and the potential for early age cracking, similar to curling. Slabs with significant "as built" curling in warping are prone to significantly higher stresses under repeated load application, thereby leading to premature cracking.



Thick slabs can have fairly substantial temperature and moisture differential; however, this can be reduced by adequate curing. The goal of curing in this case is to reduce the moisture differential by sealing in the water needed for uniform hydration. If curing is not done correctly, moisture evaporates from the surface, thereby reducing or stopping hydration while sufficient moisture is still present at the bottom of the slab.

As the coefficient of thermal expansion increases, differential temperatures within the slab lead to higher curling. Built-in curling can occur if the temperature differential in the slab is significant as final set takes place. Upward curling, as shown in the figure, is an important factor in pavement design as corner loads are essentially unsupported and are additive to the weight of the slab also tending to deflect the slab. These high corner stresses can result in top-down cracking. Effective and timely curing can significantly improve the early age behavior and limit both curling and warping.

Image description: Diagram showing curling of concrete slabs.

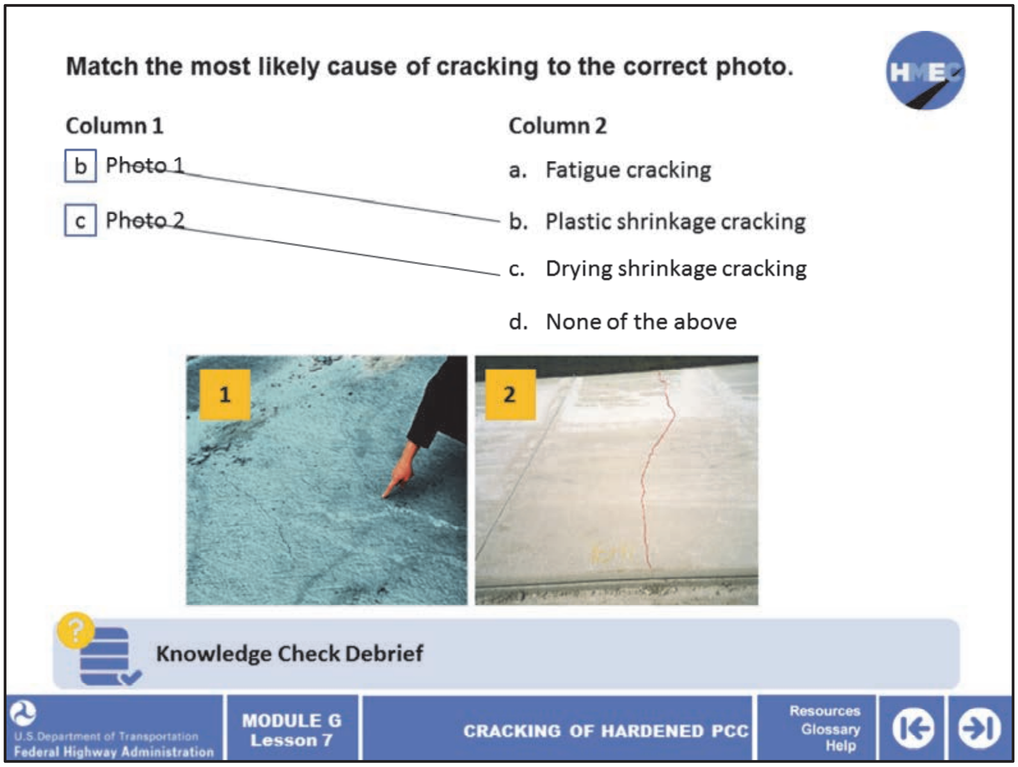


Match the most likely cause of cracking to the correct photo.

a) Fatigue cracking;
b) Plastic shrinkage cracking;
c) Drying shrinkage cracking; and
d) None of the above.

Image description: Photo of cracked pavement.

Image description: Photo of cracked pavement.



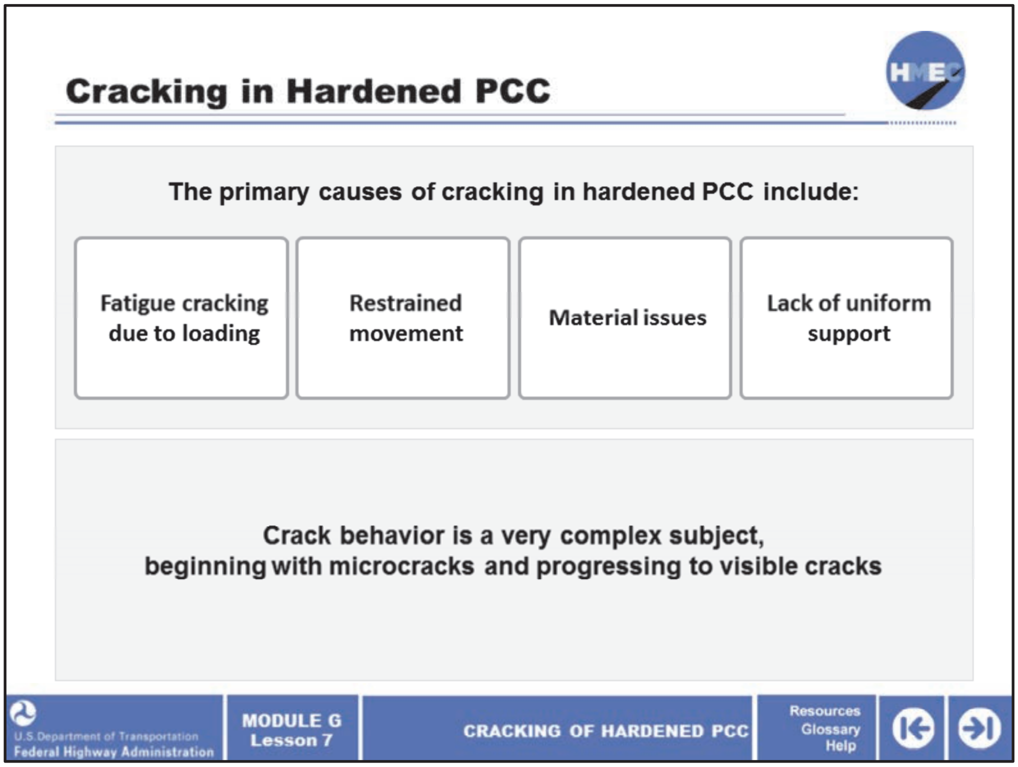
The correct answers are photo 1 is b) Plastic shrinkage cracking and photo 2 is c) Drying shrinkage cracking.

Plastic shrinkage cracking consists of very narrow cracks that do not penetrate deeper than approximately ¼ in. These cracks develop perpendicular to the direction the wind was blowing across the surface of the PCC.

Drying shrinkage cracking is due to the restraint of the base course as the pavement contracts due to drying shrinkage. In this case, late joint sawing may have contributed to the development of this random crack, which likely developed prior to the sawing.

Image description: Photo of cracked pavement.

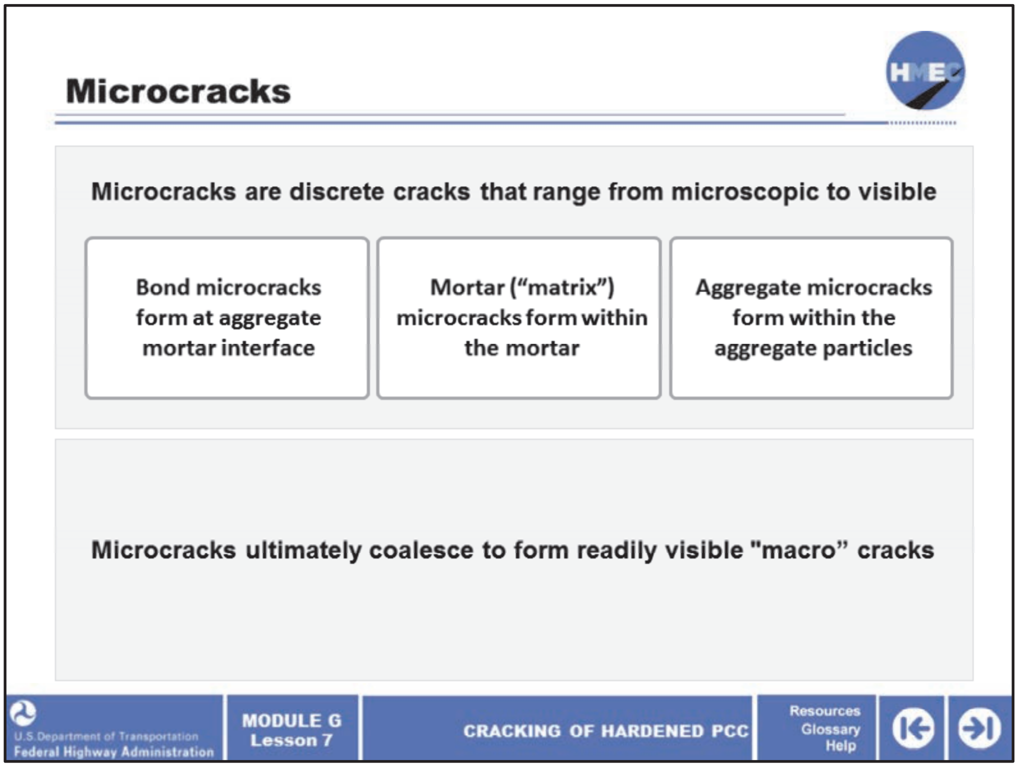
Image description: Photo of cracked pavement.



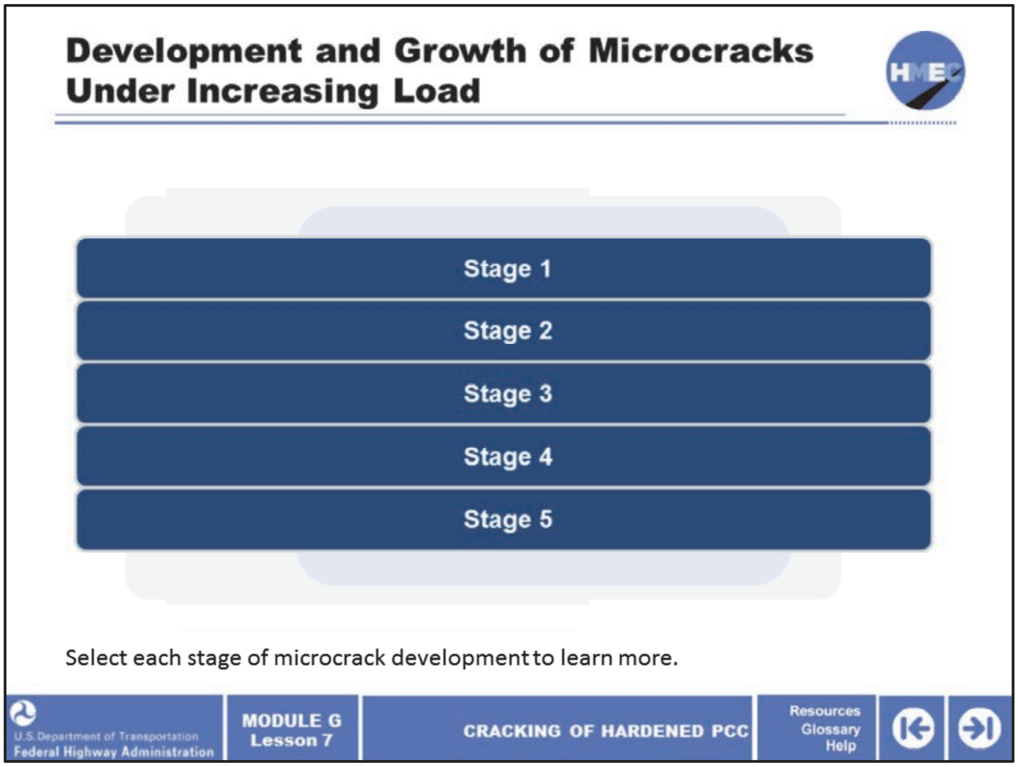
The subject of crack behavior is very complex and is somewhat outside the realm of this course. We will however briefly look at the origins of cracks, crack propagation and the various types of visible cracks. The primary causes of cracking in hardened PCC include:

- Fatigue cracking due to loading;
- Restrained movement (generally thermally induced);
- Material issues (D-cracking, ASR); and
- Lack of uniform support.

Crack behavior is a very complex subject, beginning with microcracks and progressing to visible cracks.



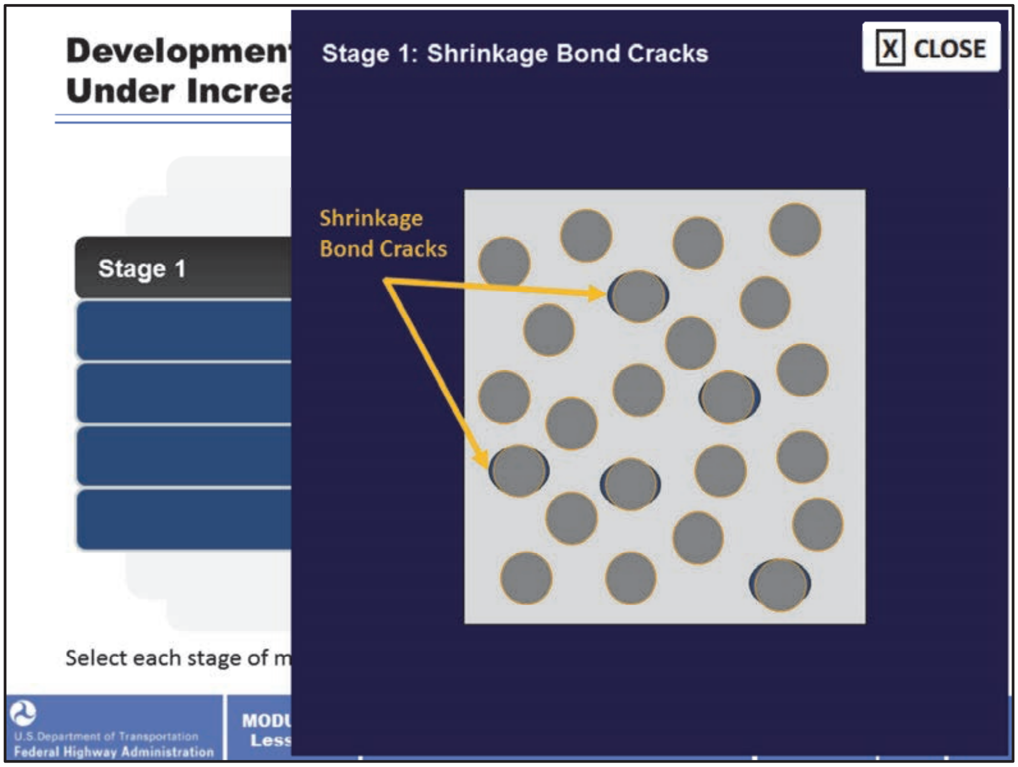
Microcracks are discrete cracks that range from microscopic to just visible. Bond microcracks form at the aggregate mortar interface. Mortar (or “matrix”) microcracks form within the mortar. Aggregate microcracks form within the aggregate particles. Microcracks ultimately coalesce to form readily visible "macro” cracks.



Microcrack development can be slow as in accumulated fatigue damage, or fast as when a PCC cylinder is tested in the lab. Microcrack development and growth (propagation) is a multistep process ultimately resulting in failure if the imposed load is sufficiently high. There are typically five stages of microcrack development:

- Stage 1: Shrinkage bond cracks at the aggregate/paste interface can occur without applied loads due to drying shrinkage;
- Stage 2: As a load is applied, load-induced bond cracks develop;
- Stage 3: Stable mortar cracks develop (these are discontinuous);
- Stage 4: Unstable mortar cracks develop (interconnected); and
- Stage 5: Aggregate cracks develop.

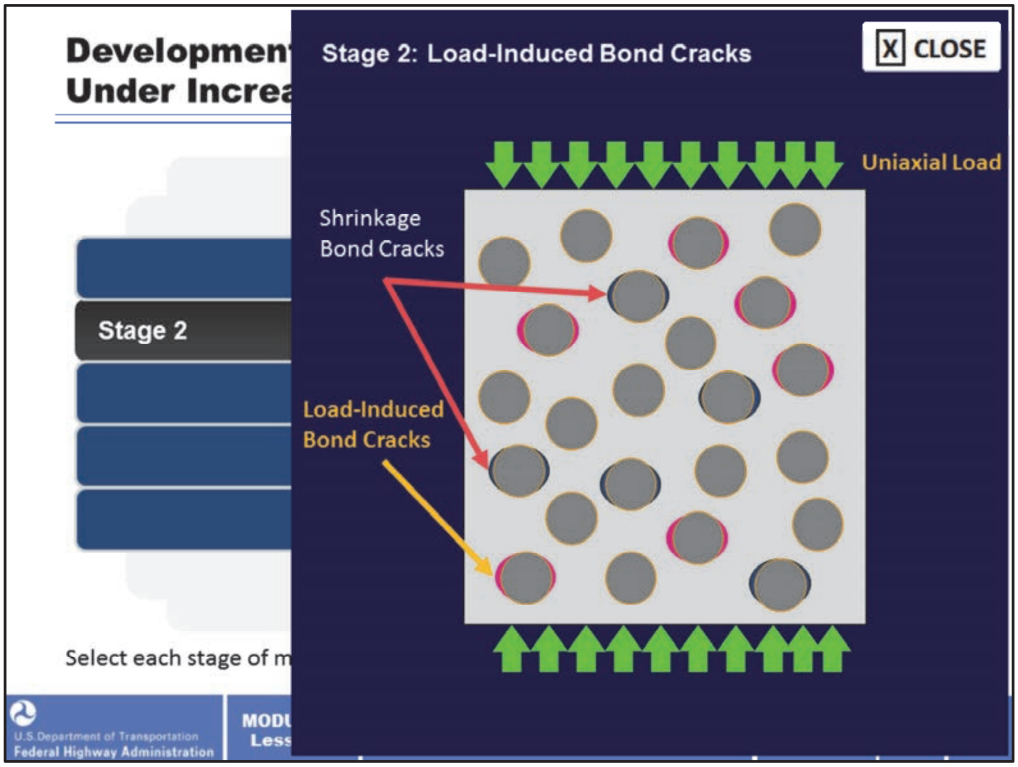
The rate at which these occur is controlled by the material characteristics and the type and magnitude of loading. Select each stage of microcrack development to see what occurs in the various stages of crack development.



Shrinkage bond cracks can develop in the very early stages of hydration. The mechanical bond between the paste and aggregates is very important as was discussed earlier in desirable aggregate properties.

Shrinkage bond cracks are influenced by the aggregate properties and the paste characteristics. Normal hydration reactions result in paste shrinkage, which is most easily controlled by the w/c ratio and total water content. Note that this cracking is not load induced.

Image description: Illustration of shrinkage bond cracks.

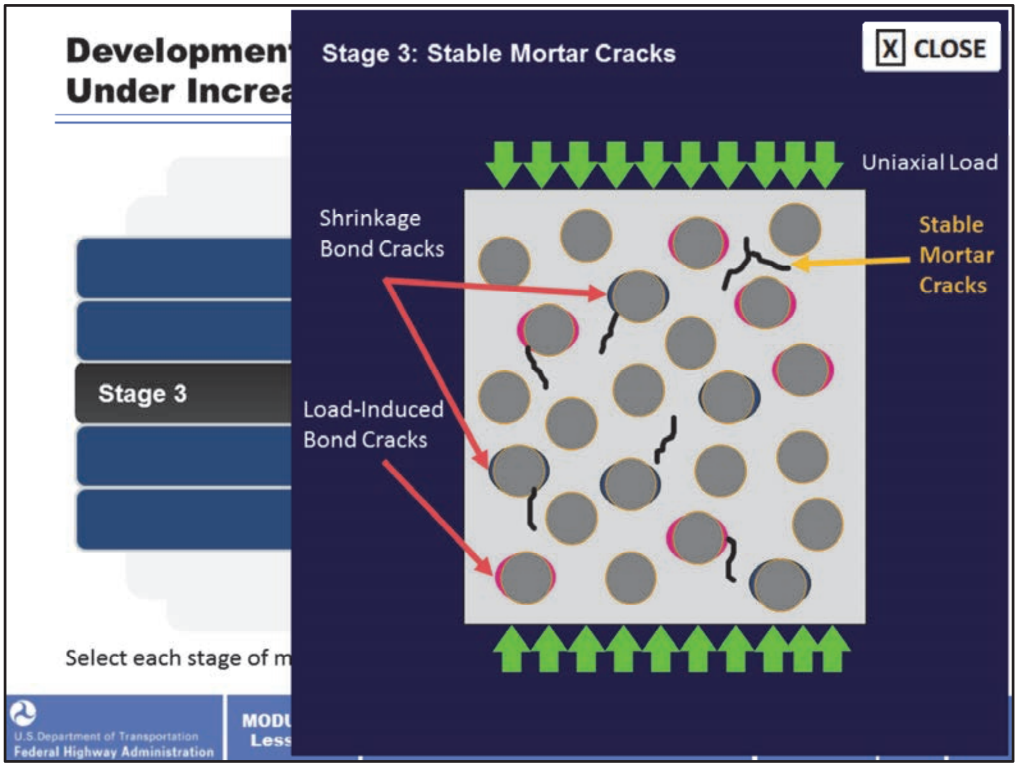


Load-induced bond cracks can form early and at low stress levels. These cracks have the following influences on PCC behavior:

- Of marginal importance in compressive strength behavior;
- Of critical importance in flexure and direct tension; and
- "Stable" cracks—growth stops when stress increase stops.

As relatively low levels of applied loads (low relative to failure), cracks begin to form at the paste/aggregate interface. These cracks are once again controlled by the aggregate properties and paste characteristics. The paste strength is most effected by the w/c ratio, while the surface texture, mineralogy, cleanliness, and strength/deformation properties of the aggregate are of importance.

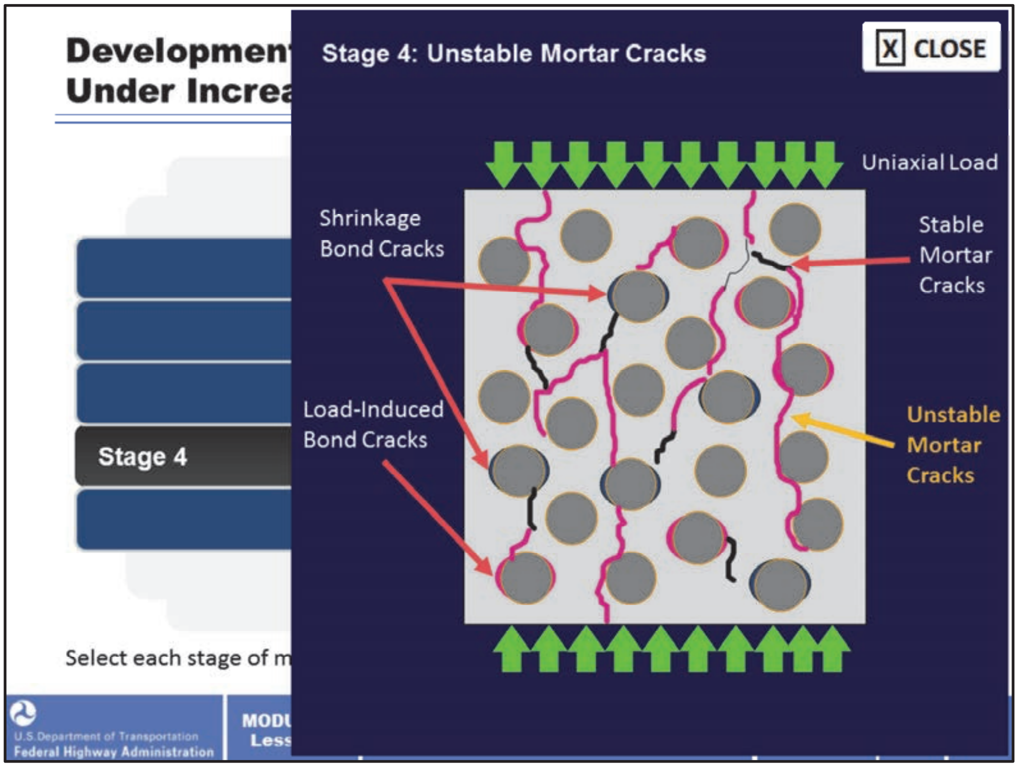
Image description: Illustration of load induced bond cracks.



As the load is increased, stable mortar cracks develop. These cracks remain stable as long as the load intensity is not increased.

The stable mortar cracks develop primarily as a function of the paste characteristics and fine aggregate properties. As the mortar strength increases (lower w/c), the load required to cause the initiation of cracking is also increased and those that do are more easily arrested. The higher the mortar strength, the more load the PCC can carry without crack propagation.

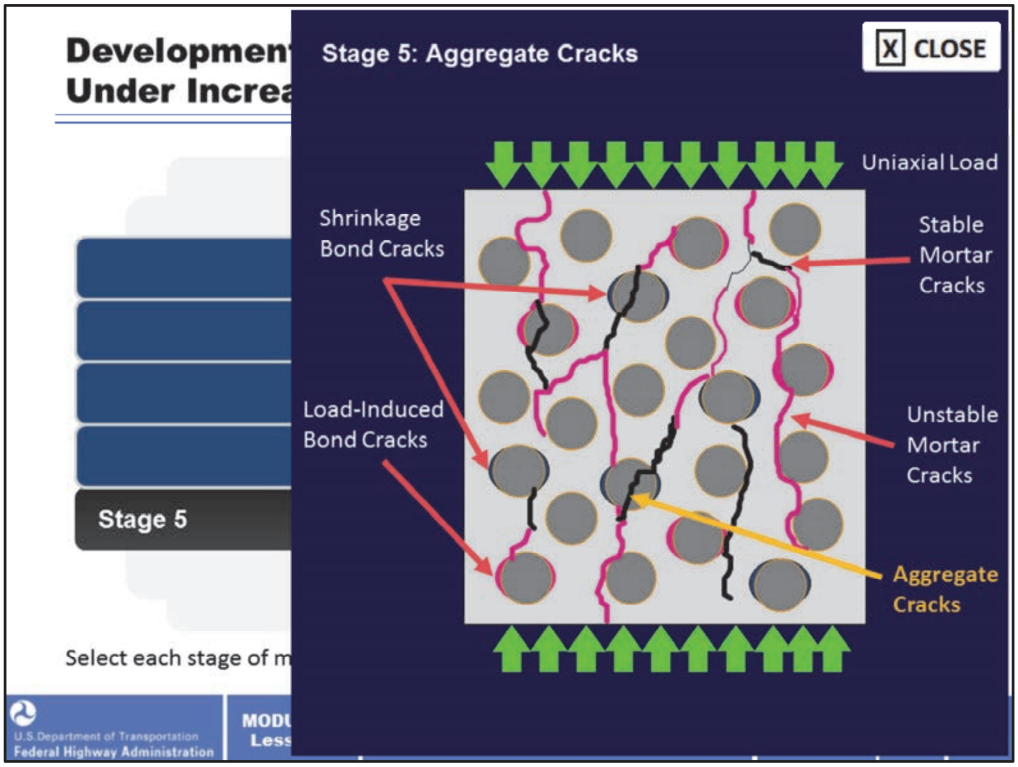
Image description: Illustration of stable mortar cracks.



Mortar cracks become unstable with increasing load. The point at which they become unstable is near what is termed the "discontinuity point." The volume of the concrete begins to increase at the discontinuity point due to the formation of these continuous cracks. Unstable mortar cracks can continue to grow after the applied load stabilizes or is removed.

As the load is increased, the stable mortar cracks begin to propagate through the mortar and ultimately become interconnected. Again, increasing the paste and mortar strength (lower w/c) will result in a higher load required to cause the crack propagation.

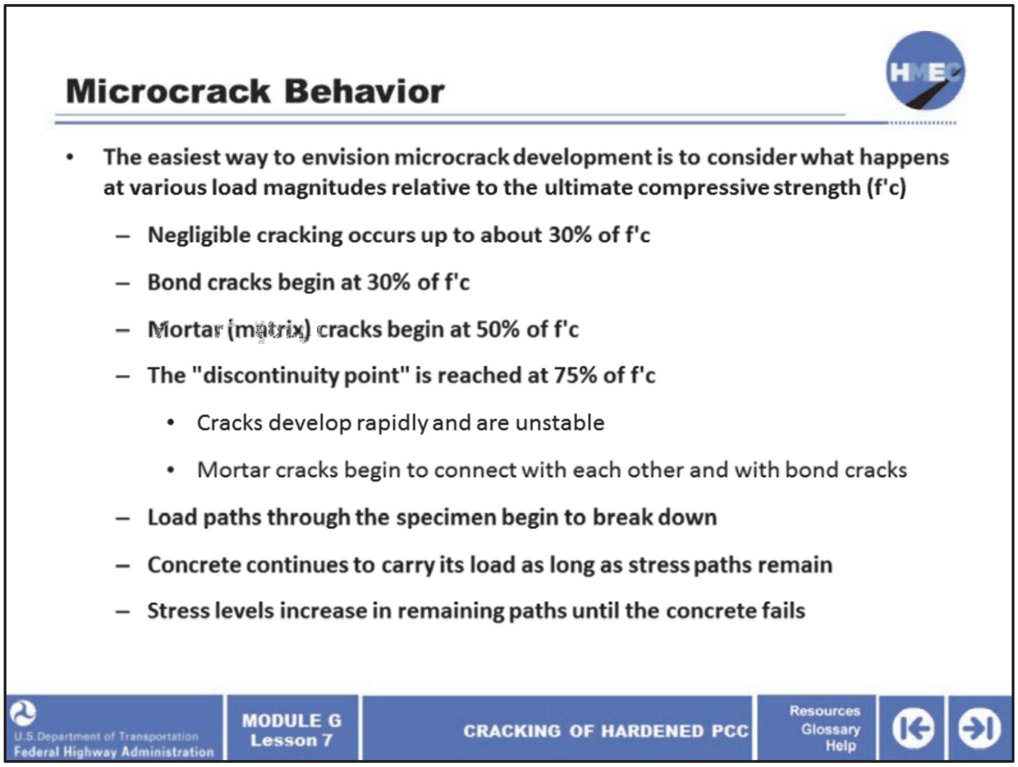
Image description: Illustration of unstable mortar cracks.



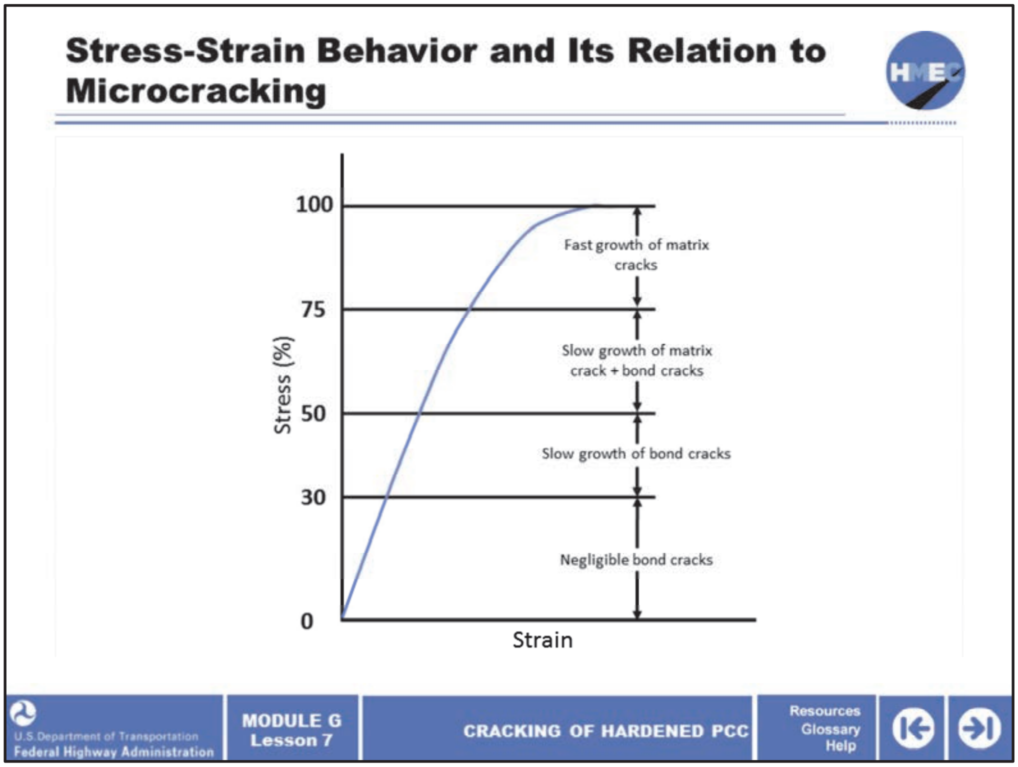
The final stage of microcrack development is cracking in the aggregate particles. At this stage, failure is imminent and removing the load will not reverse continued crack growth.

As the load is increased to the point of failure, the paste strength as well as the aggregate properties are of critical importance. The paste strength is most easily controlled by the w/c ratio while the aggregate strength is now an increasingly important property. Assuming the paste/aggregate bond is sound, the ultimate failure will be through the large aggregate particles with minimal bond failure.

Image description: Illustration of aggregate cracks.



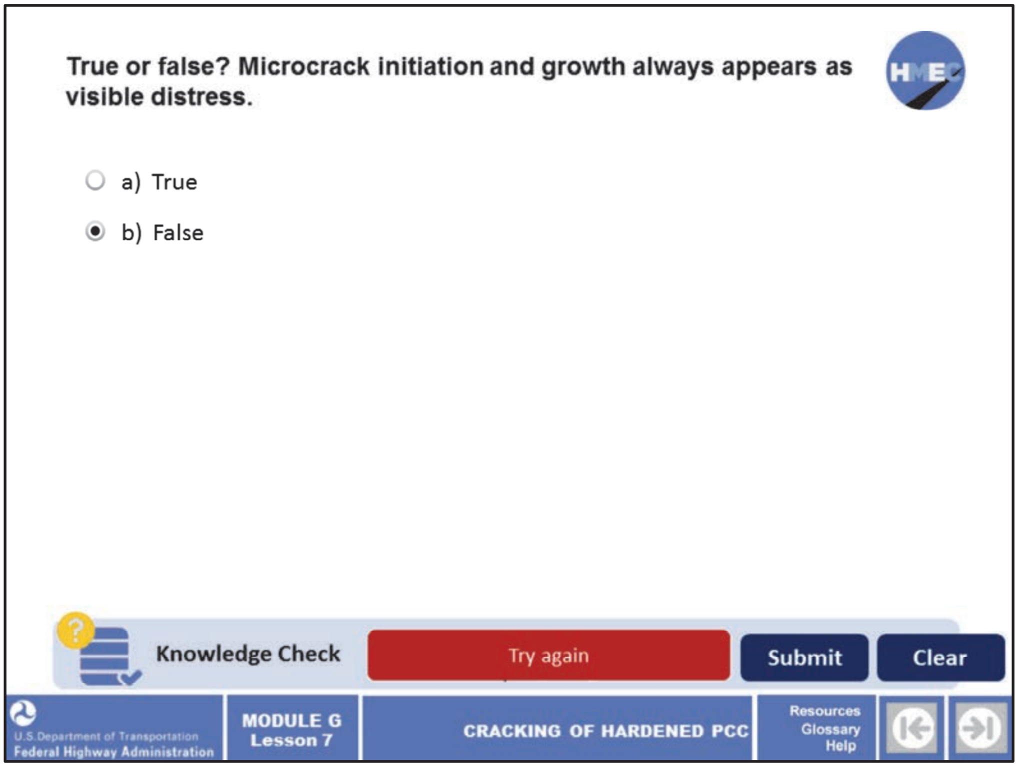
Microcrack behavior is dependent on a number of factors including PCC strength and modulus, magnitude of the applied load, and the speed at which the load is applied. The crack types corresponding to various load levels are shown here. Please take a moment to read this slide.



This slide illustrates the development and growth of microcracks in terms of the stress-strain behavior of the PCC. The stress-strain relationship is defined by the modulus. If we assume that the graph depicts a “normal strength“ PCC with a modulus of approximately 4,000,000 psi, what would be the implication of using a significantly higher modulus value?

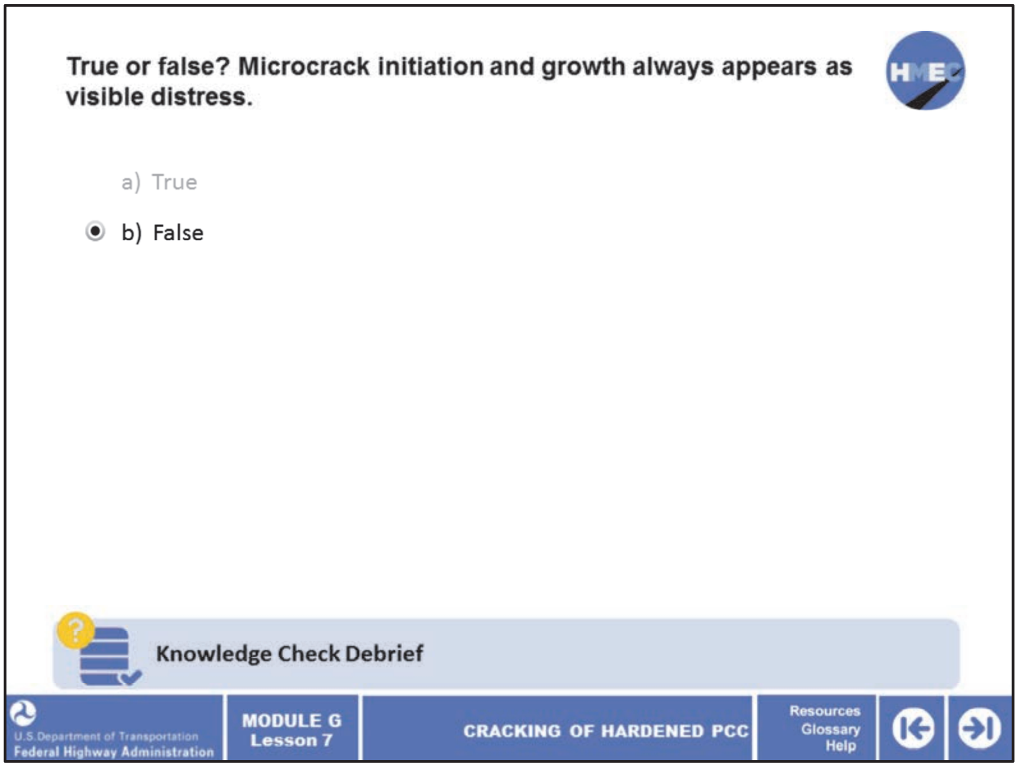
If you assume a modulus of 4,000,000 and a stress level of 2,000 psi, the resulting strain is .0005. If we increase the modulus to 6,000,000 psi, for the same level of applied stress, the strain is .00033. The result is the curve is steeper, meaning that microcrack growth will actually be faster for the higher strength material. However, remember that there is much more to consider, such as the relationship we saw on the previous slide. Although crack growth would be more rapid, the onset of cracking would be significantly delayed due to the increased f'c.

Image description: Graph showing the development and growth of microcracks in terms of the stress-strain behavior of the PCC.



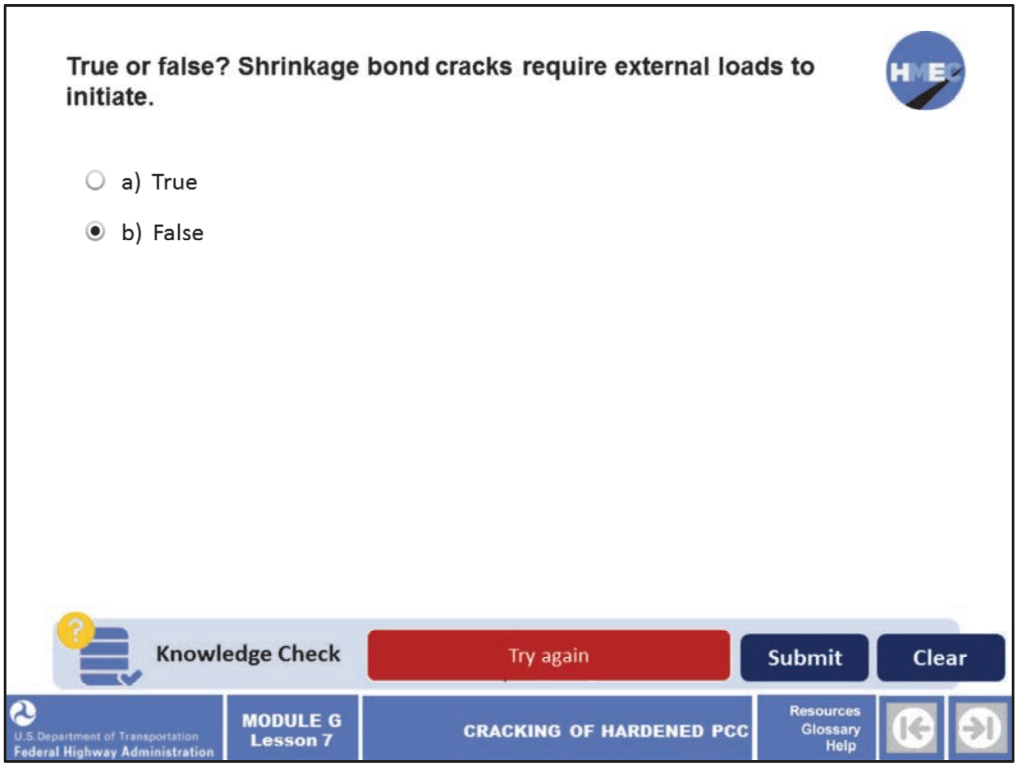
True or false? Microcrack initiation and growth always appears as visible distress.

a) True; or
b) False.



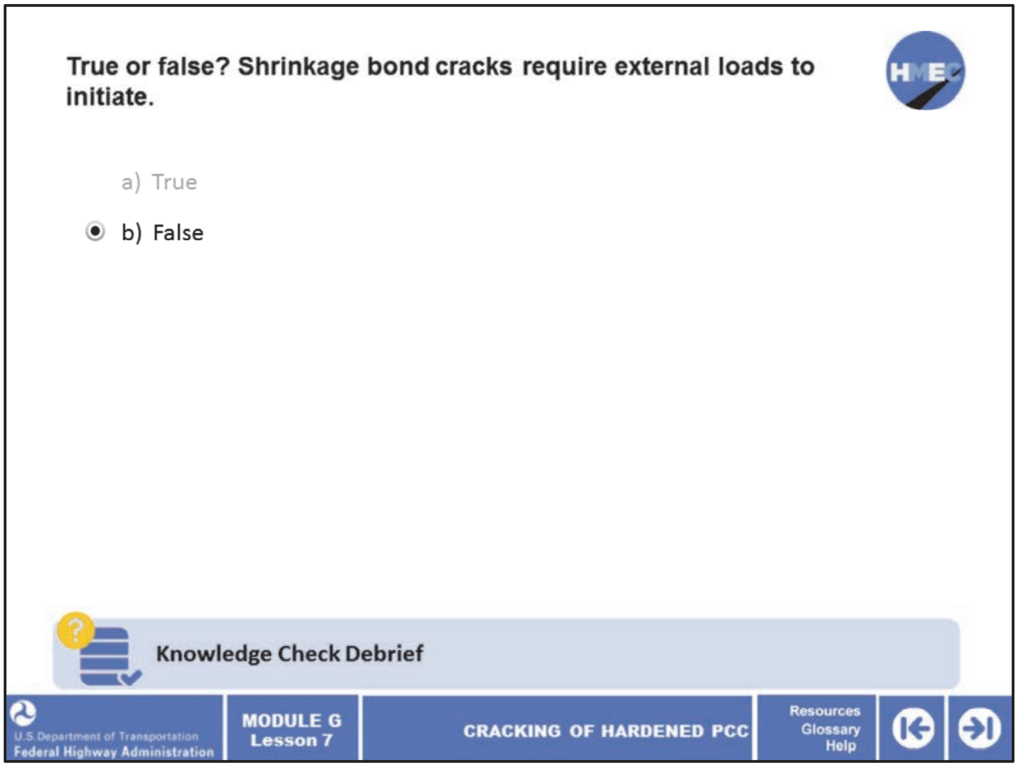
The correct answer is b) False.

Microcrack growth is invisible until Stage 4 of the development when the PCC begins to show external cracks and dilate.



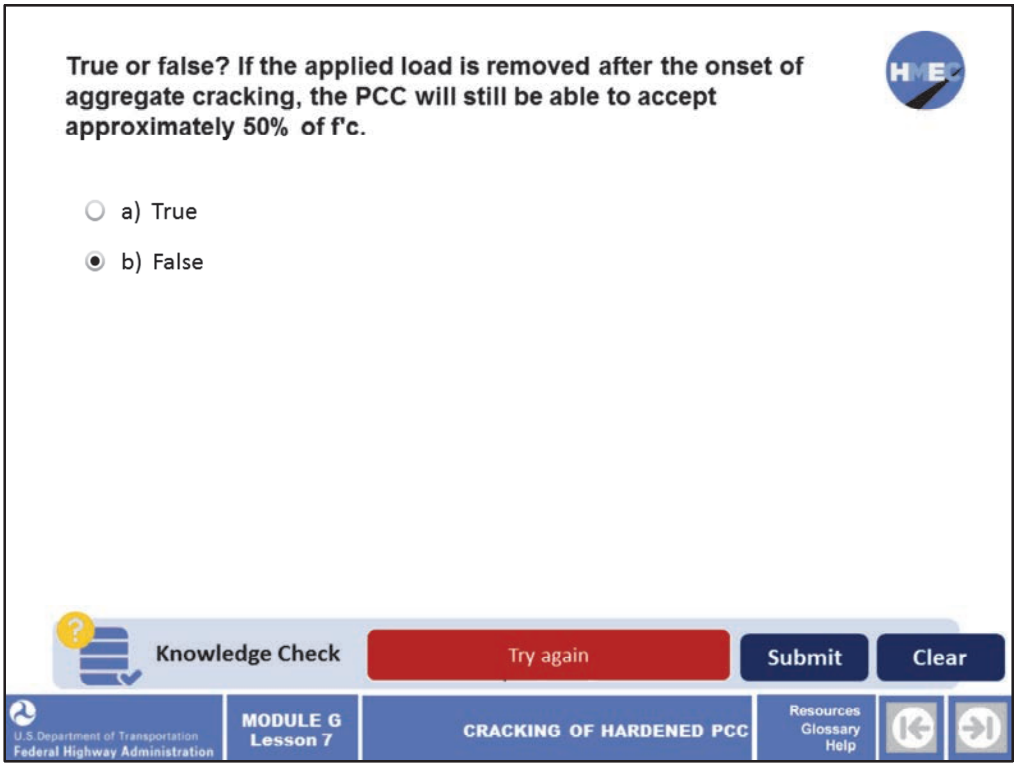
True or false? Shrinkage bond cracks require external loads to initiate.

a) True; or
b) False.



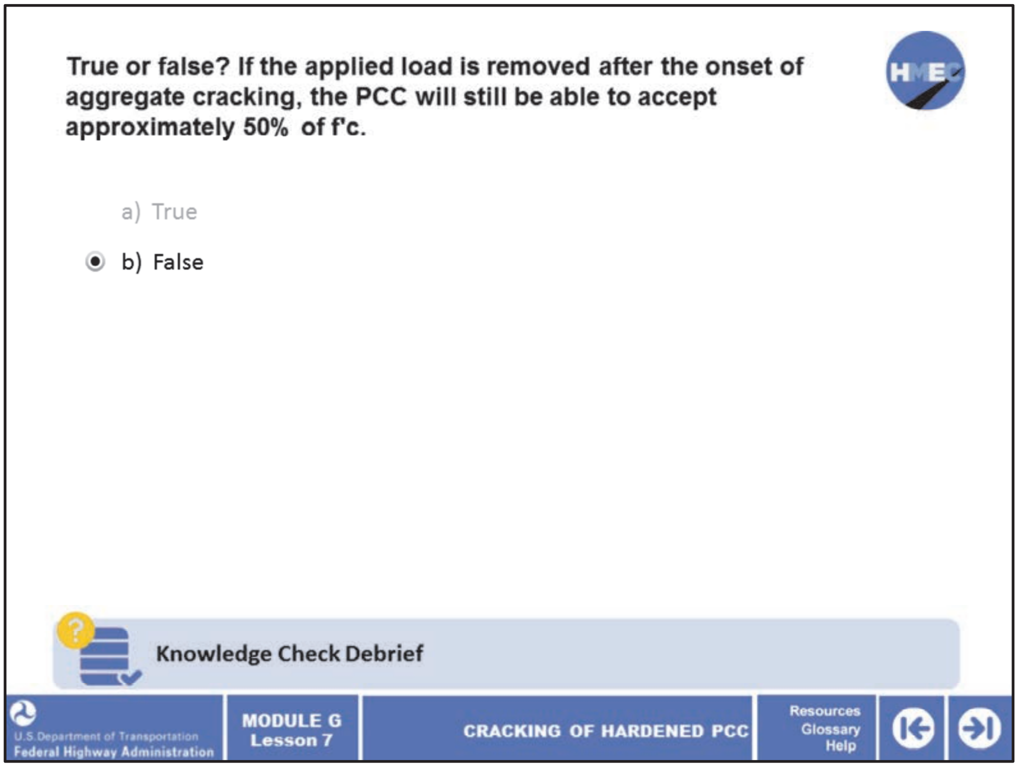
The correct answer is b) False.

Shrinkage bond cracks are the result of the paste shrinkage and do not require external loads to initiate (Stage 1 of microcrack development).



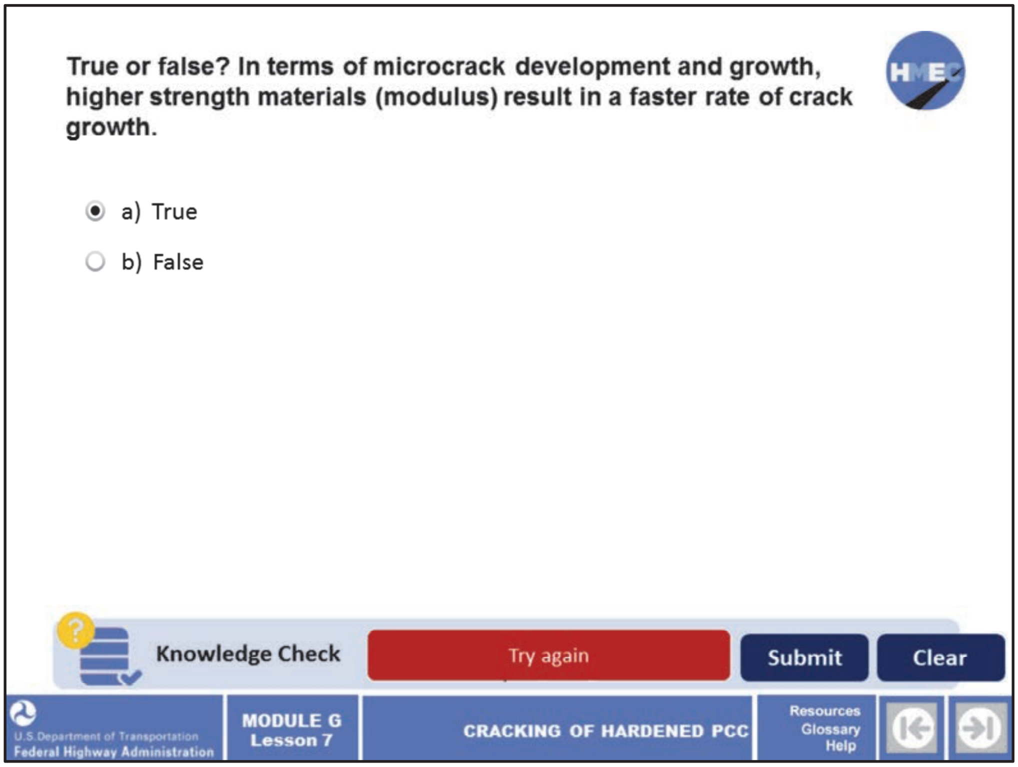
True or false? If the applied load is removed after the onset of aggregate cracking, the PCC will still be able to accept approximately 50% of f'c.

a) True; or
b) False.



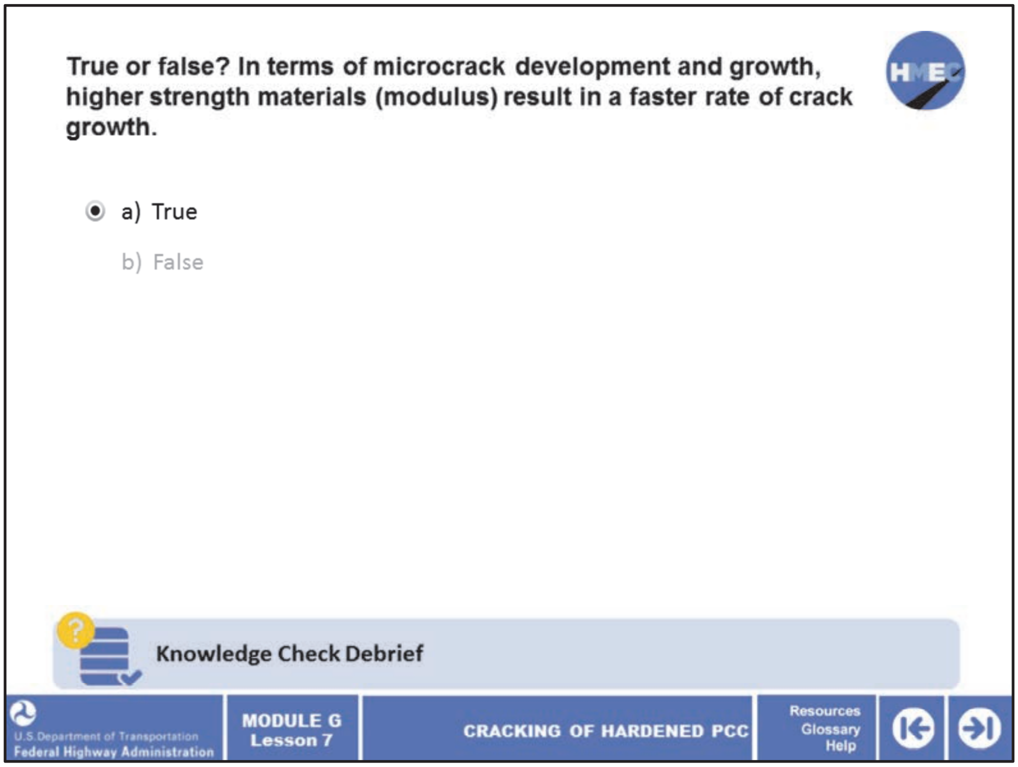
The correct answer is b) False.

When aggregates begin to fracture (Stage 5 of crack development), failure is imminent and even removal of the load is not sufficient enough to stop the complete loss of structural integrity and ultimate failure.



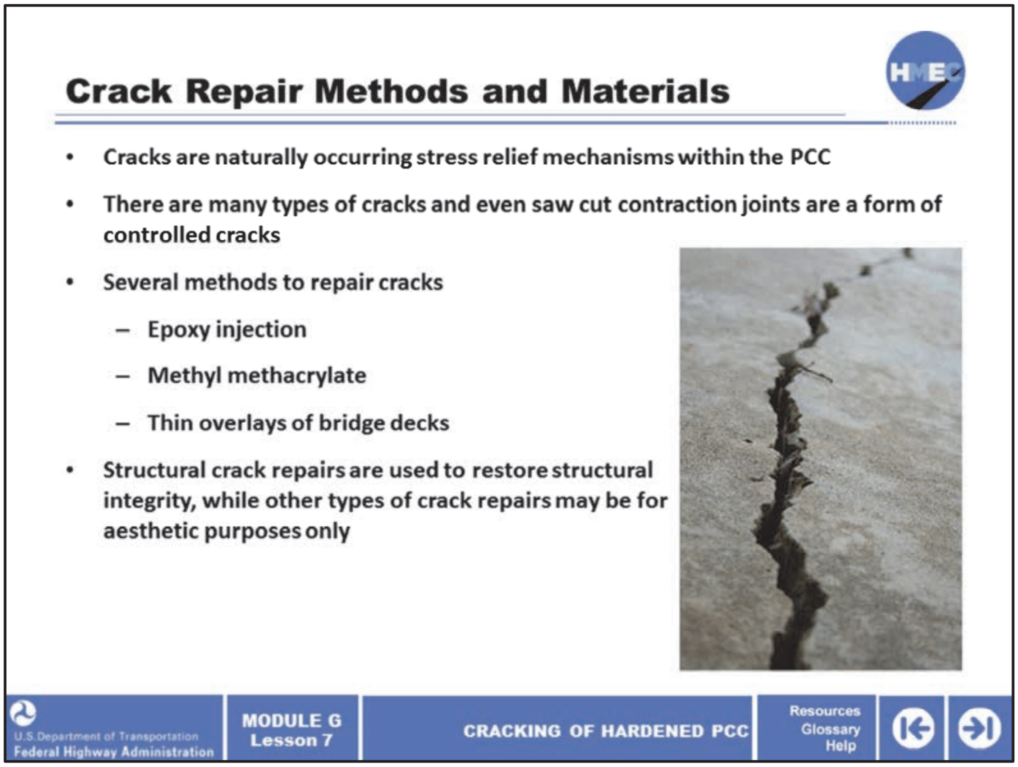
True or false? In terms of microcrack development and growth, higher strength materials (modulus) result in a faster rate of crack growth.

a) True; or
b) False.



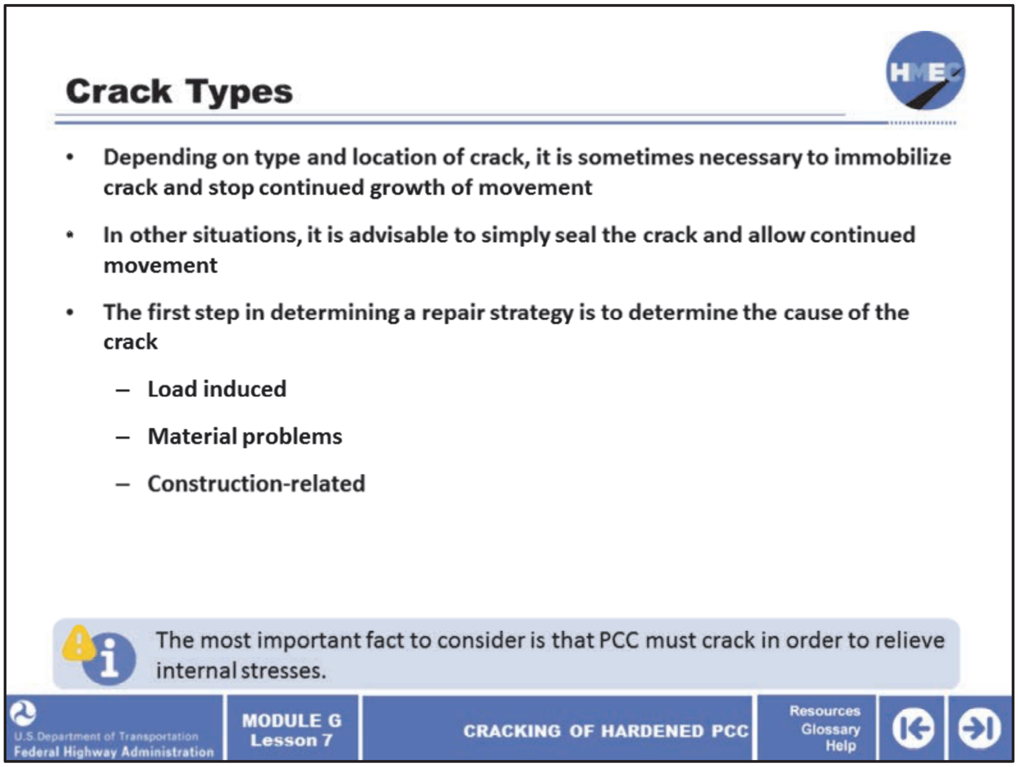
The correct answer is a) True.

High strength usually implies high modulus of elasticity. Higher modulus materials are essentially more brittle and therefore cracks in the later stages of development (Stages 4 and 5) propagate more quickly.



Cracks are naturally occurring stress relief mechanisms within the PCC. In this section, we are going to briefly look at common crack repair techniques. Some repair techniques are epoxy injection, methyl methacrylate, and thin overlays of bridge decks. This list is not meant to be all inclusive as new materials and procedures are frequently developed. Crack repair can either be on an individual crack basis (such as epoxy injection) or a global repair, such as an overlay.

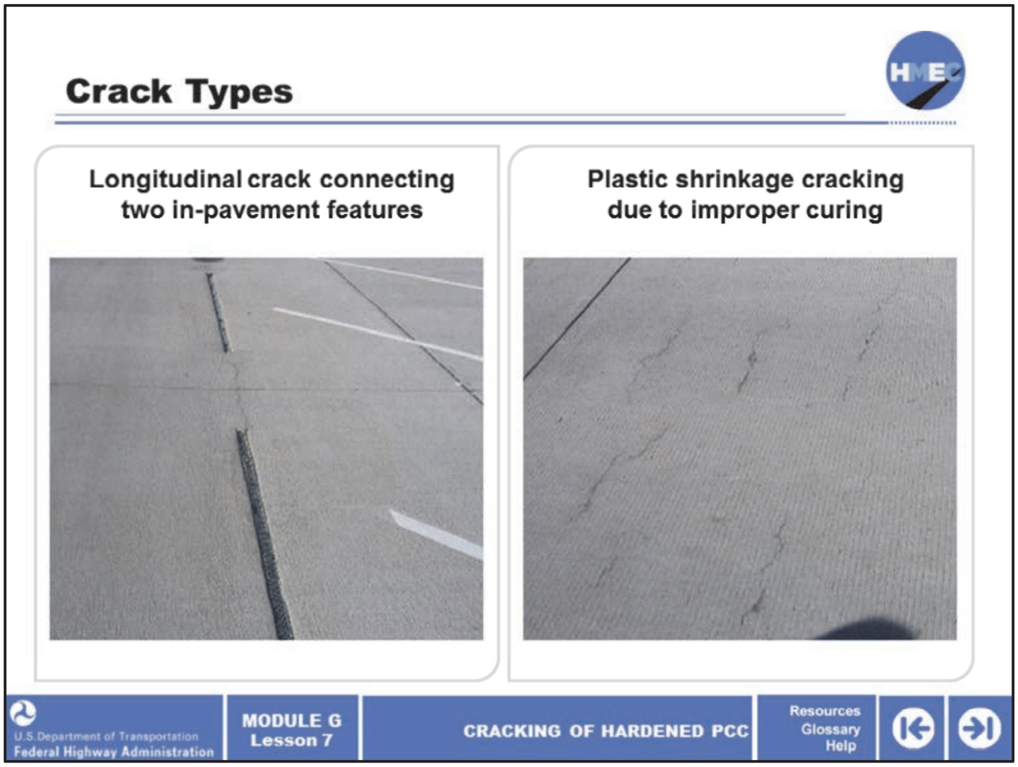
Image description: Photo of cracked concrete.



The most important fact to consider is that PCC must crack in order to relieve internal stresses. These types of cracks are normal and hopefully well controlled by jointing. There are two crack types: those that are detrimental to performance and must be fixed and those that are naturally occurring and do not negatively impact performance. Depending on the type and location of the crack, it is sometimes necessary to immobilize the crack and stop continued growth of movement. In other situations, it is advisable to simply seal the crack and allow continued movement. The first step in determining a repair strategy is to determine the cause of the crack. Some causes might be:

- Load induced (such as fatigue);
- Material problems (such as ASR, D-cracking); and
- Construction-related (such as late sawing, improper curing, etc.).

Remember that if you immobilize a crack that was due to internal stress relief, there is a high probability that it will crack adjacent to your repair.

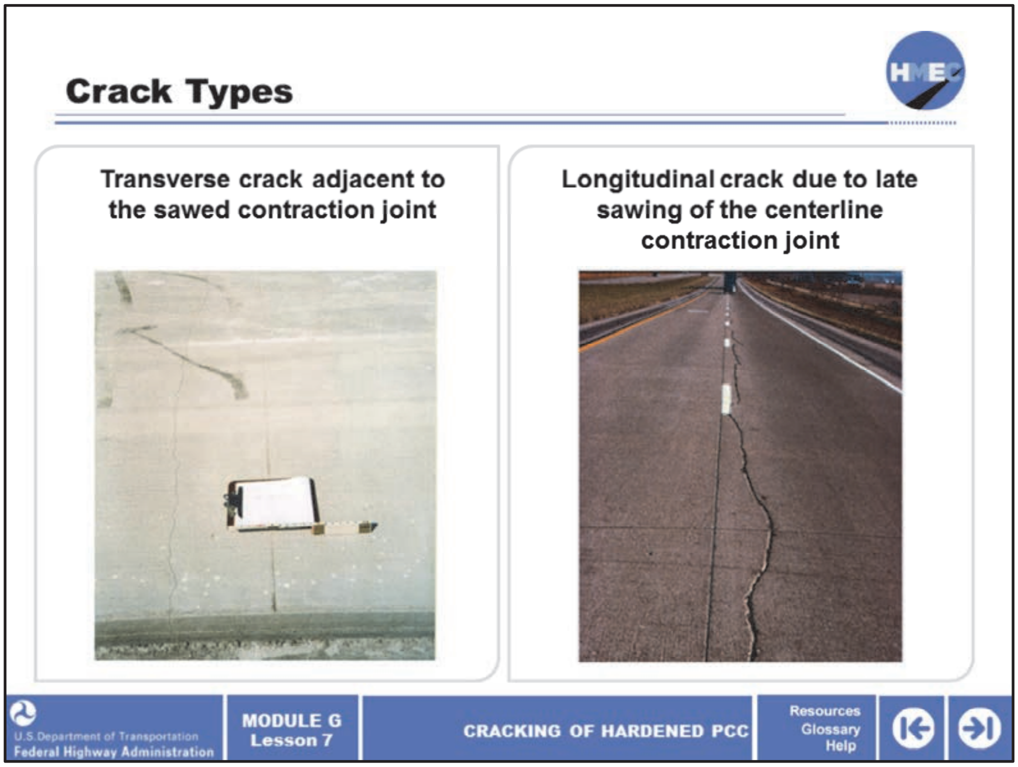


The photo on the left shows a longitudinal crack connecting two in-pavement features. This crack doesn't have the opportunity to propagate beyond its current boundaries and should remain in this condition for many years. Repairing this crack with epoxy injection is a likely solution but is very likely not worth the effort or expense. An alternative might be to simply seal the crack to prevent moisture and chloride intrusion.

The photo on the right shows plastic shrinkage cracking due to improper curing. These cracks typically extend only ¼ to ½ in. into the slab and have very little tendency to propagate. Since these cracks do not pose a problem in terms of structural capacity, they are oftentimes left unrepaired. If there is a concern that moisture or deicing salts may pose a problem in the future, ultra low viscosity epoxy or methyl methacrylate can be used for repair.

Image description: Photo of a longitudinal crack connecting two in-pavement features.

Image description: Photo of plastic shrinkage cracking due to improper curing.



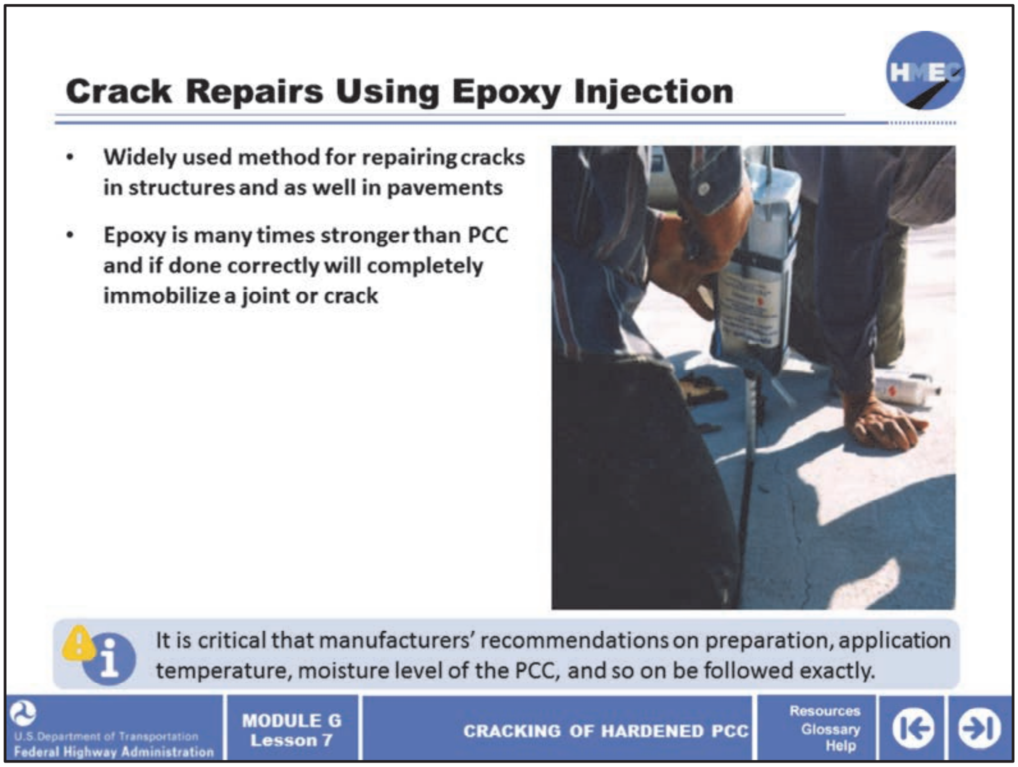
The photo on the left shows a transverse crack adjacent to the sawed contraction joint. There are a number of possible causes that should be investigated prior to the decision to repair. Was the crack due to late sawing (in which case the joint did not crack) or misaligned dowels, which effectively immobilized the joint?

If the crack is immobilized at this point by epoxy injection, there is a reasonable chance that another crack will develop adjacent to the repair and not necessarily at the saw joint. In this case, the most appropriate repair might be the dowel bar retrofit, to provide load transfer and epoxy injecting the saw joint if desired. For details of the dowel bar retrofit procedure or on crack repair, consult the American Concrete Pavement Association Web site at www.pavement.com.

The photo on the right is a longitudinal crack due to late sawing of the centerline contraction joint. This is another case where immobilizing the crack may not be the best choice unless there is evidence that the crack is moving horizontally, vertically, or both. In this case, routing and sealing the crack to prevent moisture intrusion might be the best strategy as was done here. If the crack is opening and beginning to move vertically, crack stitching or slot stitching may be a good alternative.

Image description: Photo of a transverse crack adjacent to the sawed contraction joint.

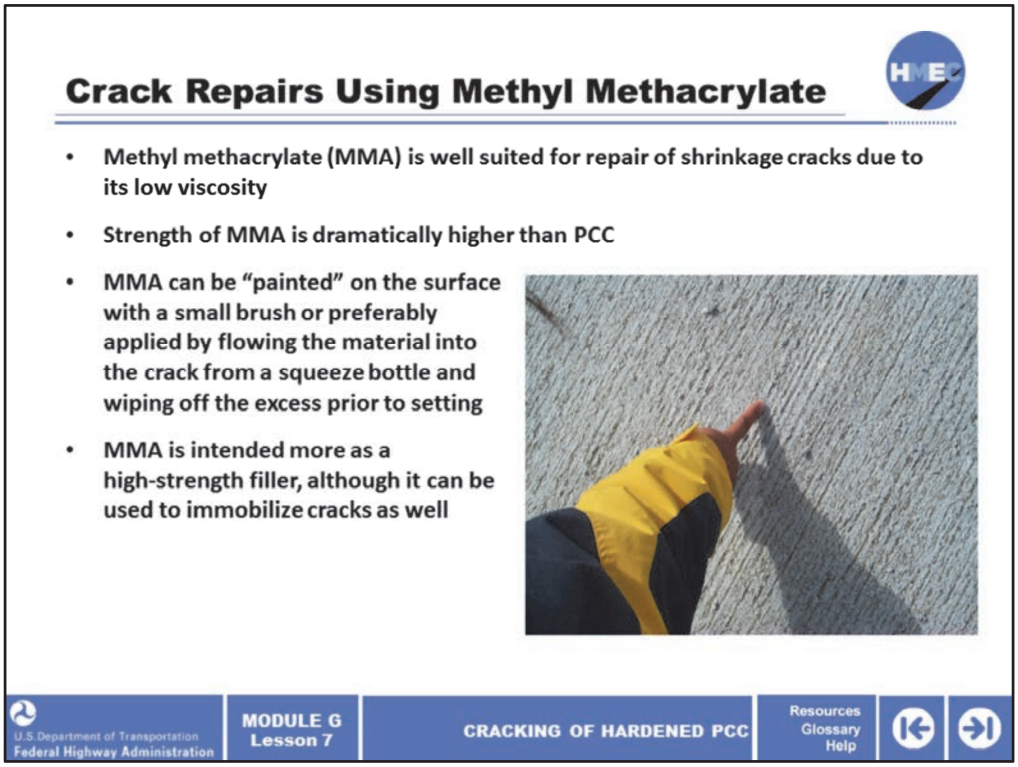
Image description: Photo of a longitudinal crack due to late sawing of the centerline contraction joint.



Epoxy injection is a widely used method for repairing cracks in structures and as well in pavements. Epoxies are two-part polymeric materials that when thoroughly mixed react to form a repair material that is much stronger than the PCC. There are many formulations of epoxy developed specifically for crack repair in PCC. It is critical that the manufacturers' recommendations on preparation, application temperature, moisture level of the PCC, and so on be followed exactly. Remember that the epoxy is many times stronger than the PCC and if done correctly will completely immobilize a joint or crack.

The photo shows epoxy being injected into a transverse joint that failed to mobilize (crack below the saw cut). Note that the crack is now going to provide movement at this location rather than the saw cut contraction joint.

Image description: Photo of epoxy being injected into a transverse joint that failed to mobilize (crack below the saw cut).

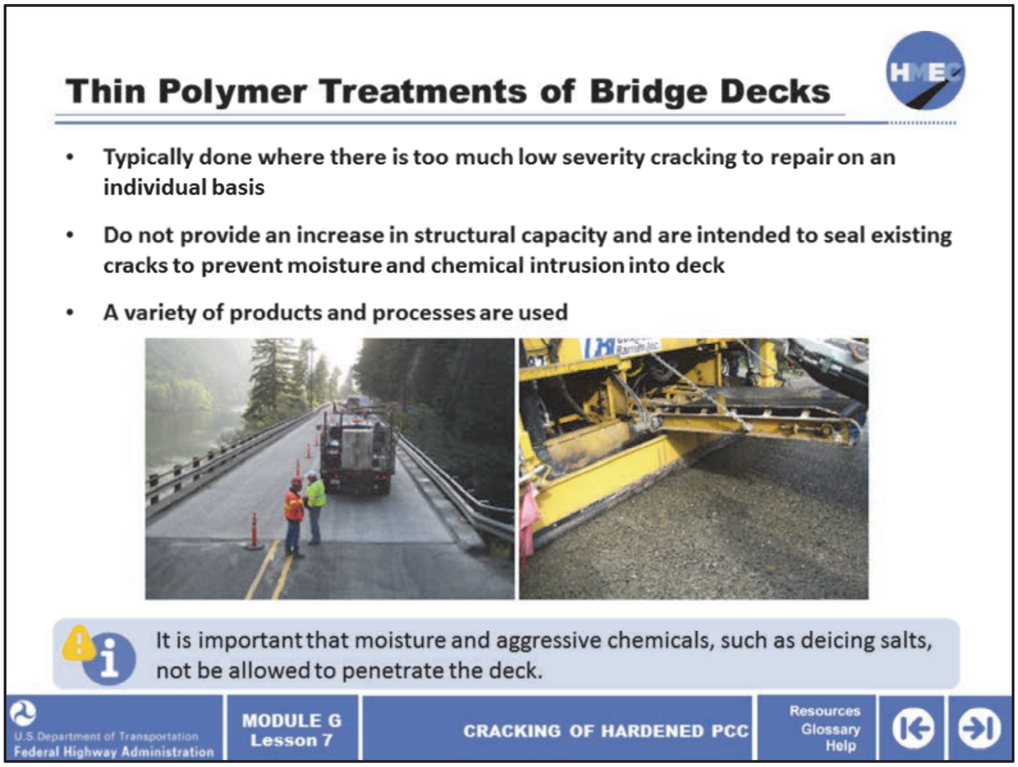


Methyl methacrylate (MMA) is a two-component system consisting of a monomer and catalyst similar to epoxy. MMA has extremely low viscosity and will penetrate cracks as narrow as 0.003 in. This product is well suited for repair of shrinkage cracks due to its low viscosity. The strength of MMA also is dramatically higher than PCC.

The photo shows a very narrow thermal shrinkage crack that is an ideal candidate for MMA repair, if corrective measures are deemed necessary.

Due to the ultralow viscosity of this material, application is very easy. The MMA can be "painted" on the surface with a small brush or preferably applied by flowing the material into the crack from a squeeze bottle and wiping off the excess prior to setting. Unlike epoxy, which is generally used to "glue" the PCC together, MMA is intended more as a high-strength filler, although it can be used to immobilize cracks as well.

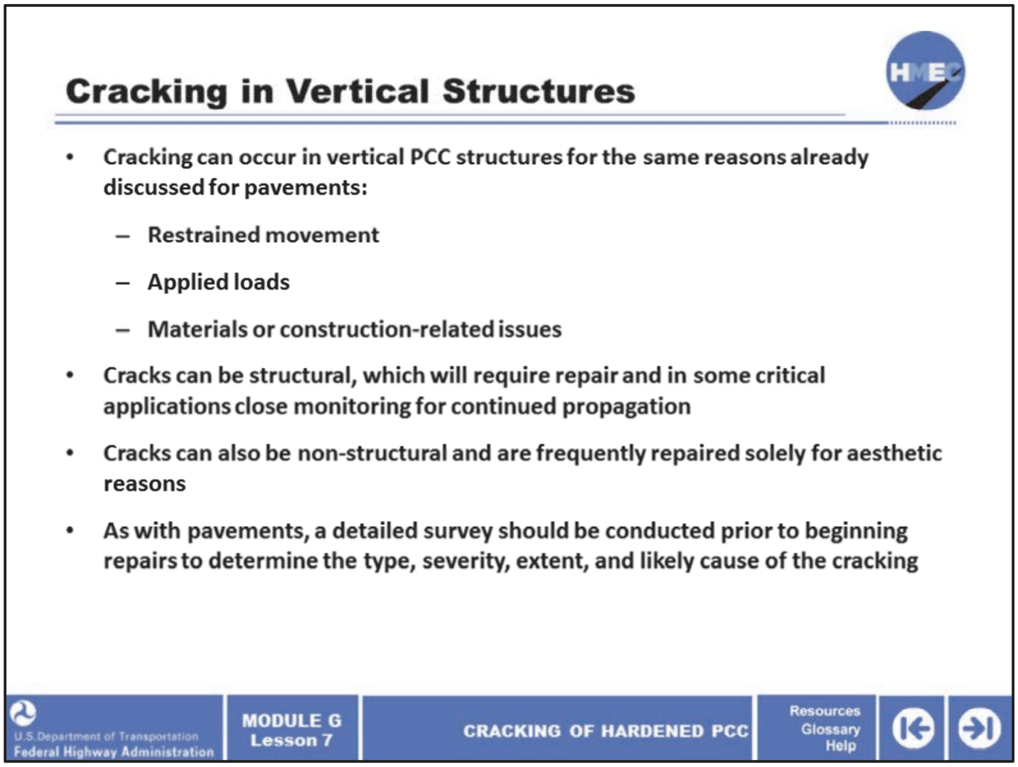
Image description: Photo of a very narrow thermal shrinkage crack that is an ideal candidate for MMA repair.



Polymer treatment of bridge decks is common practice in many parts of the US. These treatments are typically done where there is too much low severity cracking to repair on an individual basis. They do not provide an increase in structural capacity and are intended to seal existing cracks to prevent moisture and chemical intrusion into the deck. There are a variety of products and processes that are used. It is important that moisture and aggressive chemicals, such as deicing salts not be allowed to penetrate the deck. Where low levels of cracking are present, these treatments are very effective as sealers.

Image description: A piece of equipment on a bridge with two construction workers and traffic cones.

Image description: Photo of a piece of equipment spreading polymer.



Cracking can occur in vertical PCC structures for the same reasons already discussed for pavements:

• Restrained movement;
• Applied loads; and
• Materials or construction-related issues.

Cracks can be structural, which will require repair and in some critical applications close monitoring for continued propagation. Cracks can also be non-structural and are frequently repaired solely for aesthetic reasons.

As with pavements, a detailed survey should be conducted prior to beginning repairs to determine the type, severity, extent, and likely cause of the cracking.

Crack Repair in Vertical Structures

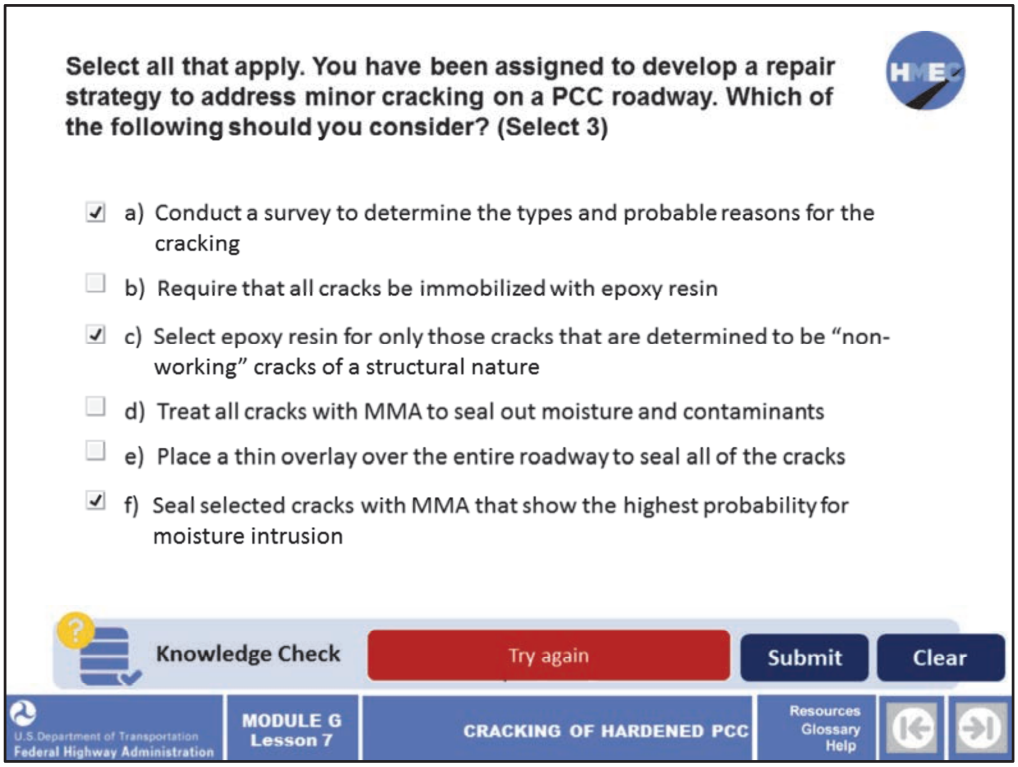
- Crack repair techniques for vertical structures are very similar to pavements, and they frequently make use of epoxy and MMA injection.
- Cracks of a structural nature need to be thoroughly evaluated to determine if they pose a safety issue

Crack repair techniques for vertical structures are very similar to pavements, and they frequently make use of epoxy and MMA injection. Cracks of a structural nature need to be thoroughly evaluated to determine if they pose a safety issue.

The photo on the left shows a high pressure epoxy injection system being used on a bridge support. The photo on the right shows the underside of a bridge deck following epoxy injection.

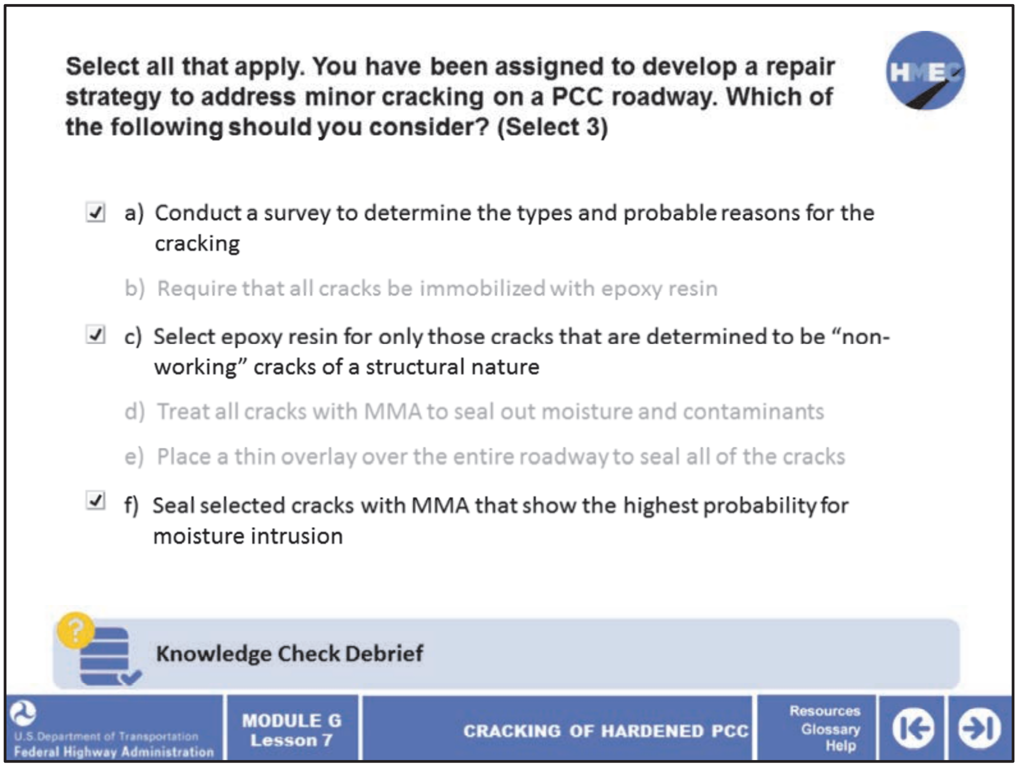
Image description: Photo of a high pressure epoxy injection system being used on a bridge support.

Image description: Photo of the underside of a bridge deck following epoxy injection.



Select all that apply. You have been assigned to develop a repair strategy to address minor cracking on a PCC roadway. Which of the following should you consider? (Select 3)

a) Conduct a survey to determine the types and probable reasons for the cracking;
b) Require that all cracks be immobilized with epoxy resin;
c) Select epoxy resin for only those cracks that are determined to be “non-working” cracks of a structural nature;
d) Treat all cracks with MMA to seal out moisture and contaminants;
e) Place a thin overlay over the entire roadway to seal all of the cracks; and/or
f) Seal selected cracks with MMA that show the highest probability for moisture intrusion.

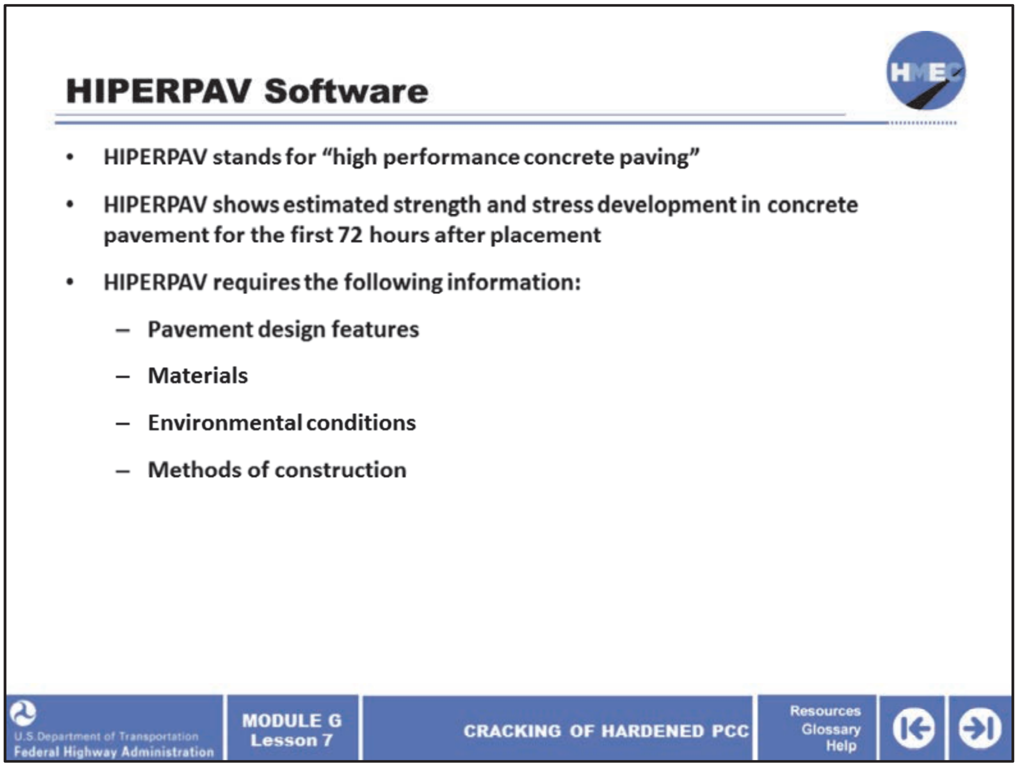


The correct answers are a) Conduct a survey to determine the types and probable reasons for the cracking; c) Select epoxy resin for only those cracks that are determined to be “working” cracks; and f) Seal selected cracks with MMA that show the highest probability for moisture intrusion.

In order to determine the appropriate crack repair technique, a survey should be conducted to determine the types and probable causes of the cracks.

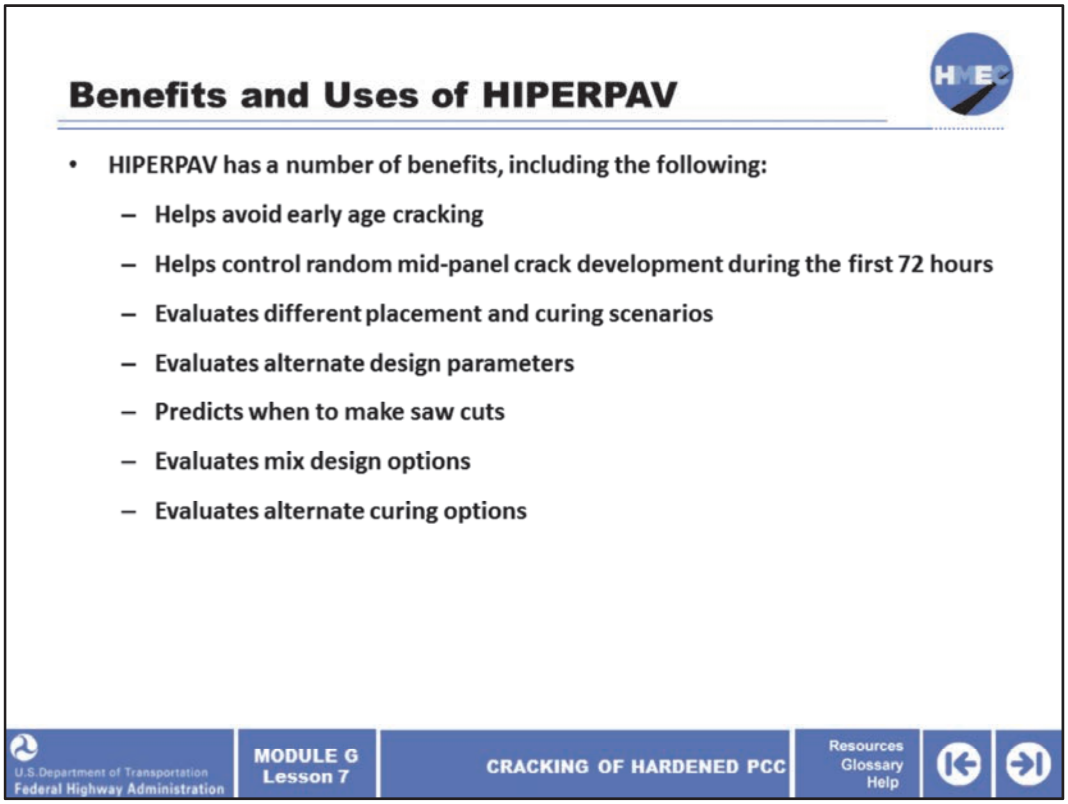
Epoxy can be used to repair non-working cracks of a structural nature. If a working crack (showing movement), is repaired with epoxy, it is likely that another crack will develop to relieve the stress.

Cracks that are of a non-structural nature that show no movement may be repaired with MMA to seal out moisture and possible chloride intrusion.

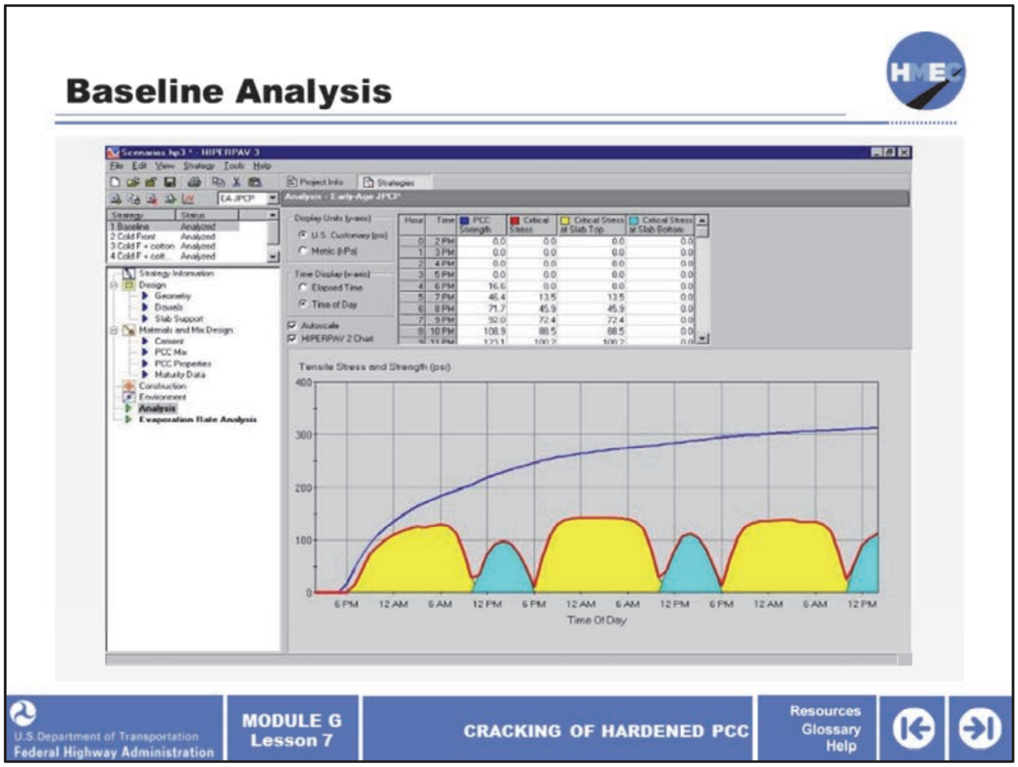


HIPERPAV stands for "high performance concrete paving." HIPERPAV was the result of developing guidelines for the temperature control of fast-track mixes. It is free software developed for FHWA by the Transtec Group. HIPERPAV shows the estimated strength and stress development in concrete pavement for the first 72 hours after placement. The first version of the program was released in 1996 and it has undergone continuous updates. To achieve good control, we need to understand the relationships between:

- Pavement design features;
- Materials;
- Environmental conditions; and
- Methods of construction.



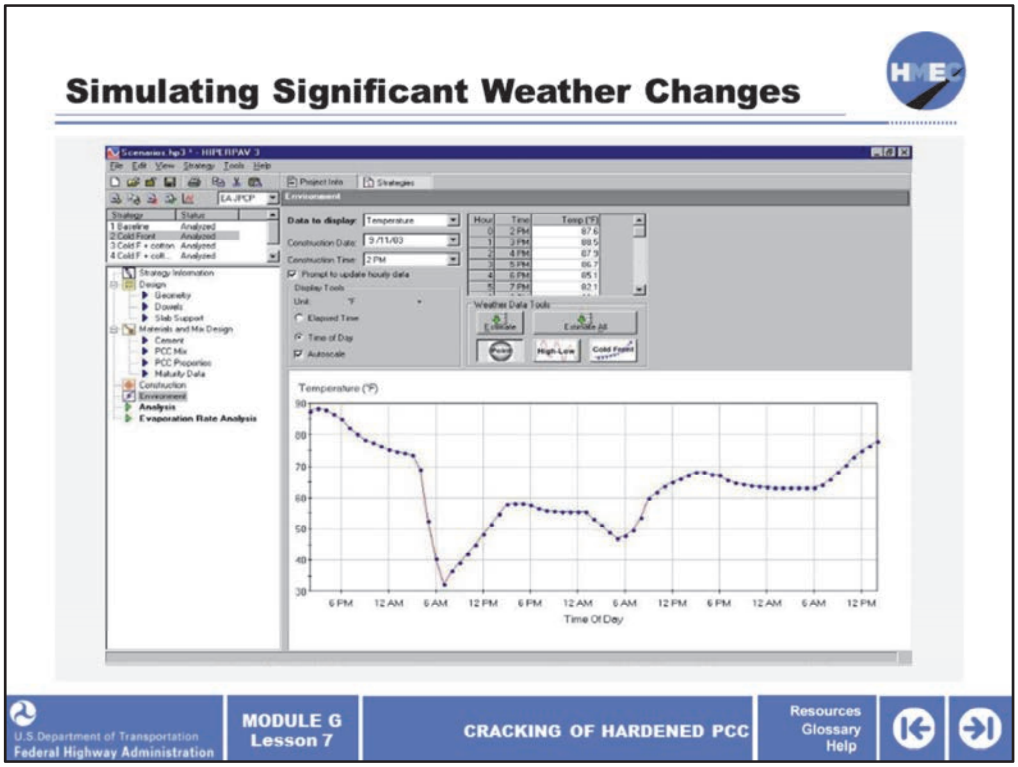
HIPERPAV is a powerful construction tool that has been validated through projects all over the US. The program is used by agencies and contractors for the reasons stated here. Please take a moment to read this slide.



This series of slides represent a small portion of the capabilities of the program but are intended to give you an idea of the user interface.

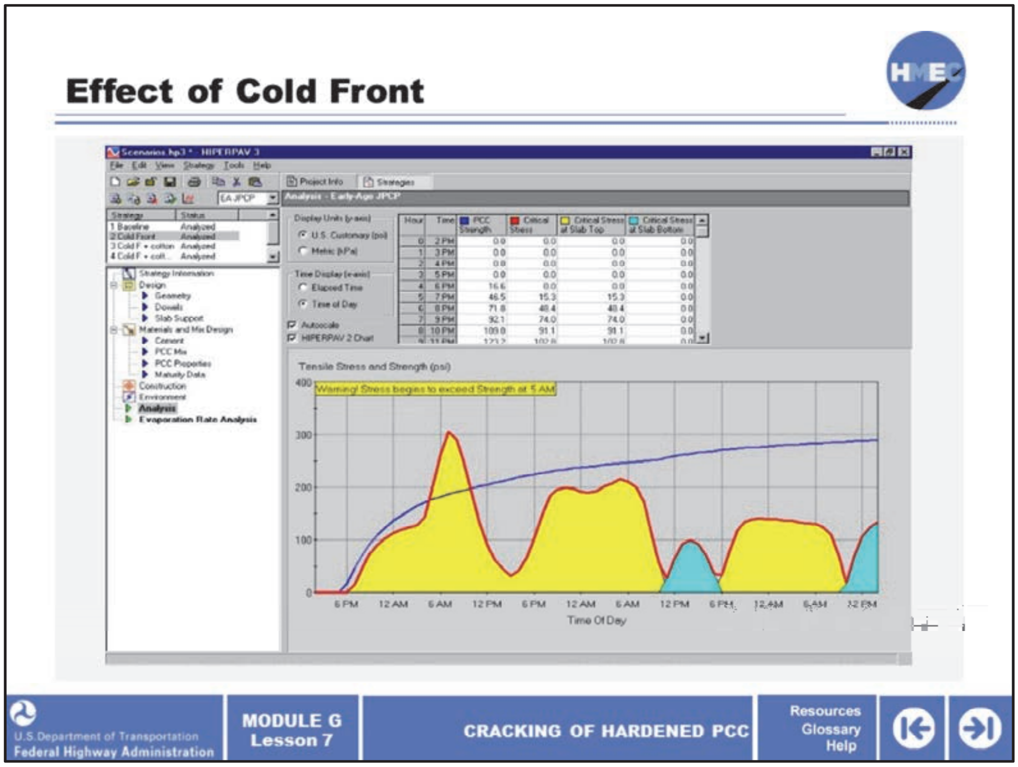
This screen is the basic input screen. There are many drop-down menus for entering detailed information regarding design, materials, environment, and so on. The red line on the graph represents the stress development in the slab while the blue line is the estimated PCC strength as a function of time. Consider this as a baseline analysis if things go as planned.

Image description: Screenshot of the baseline analysis basic input screen.



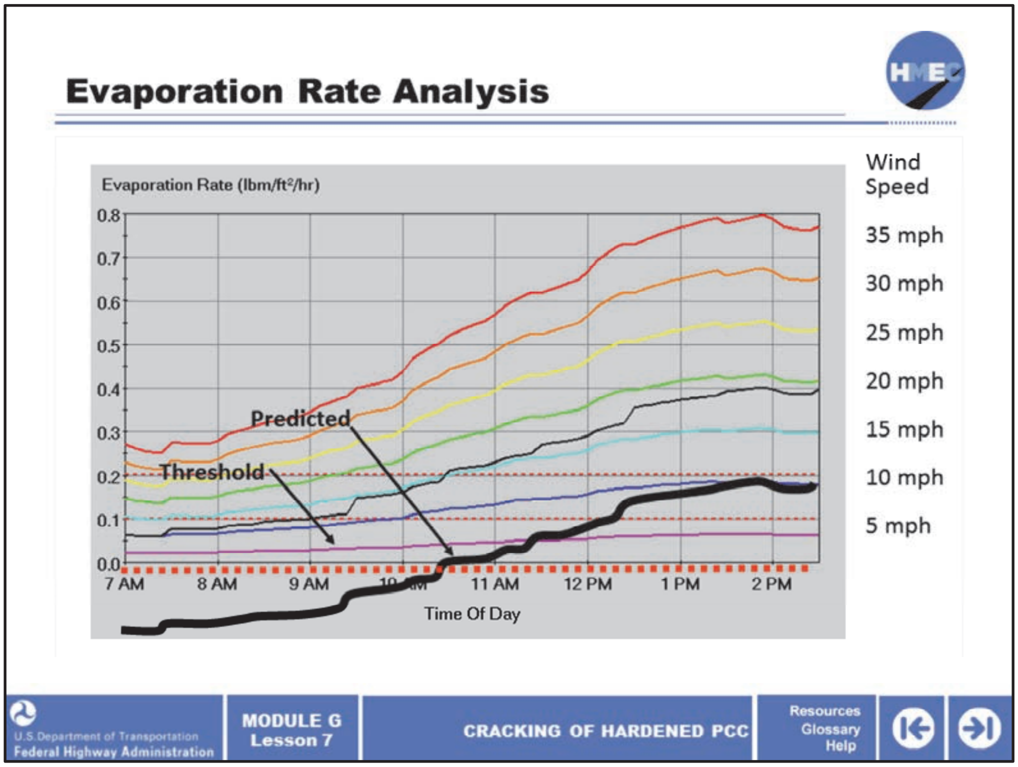
You can modify the climatic inputs in HIPERPAV to simulate the effect that a cold front will have on the stress development in the slab. In this case, the temperature dropped to near freezing at about 0700 hours after reaching nearly 90 °F at 1400 hours the preceding afternoon.

Image description: Screenshot simulating weather changes.



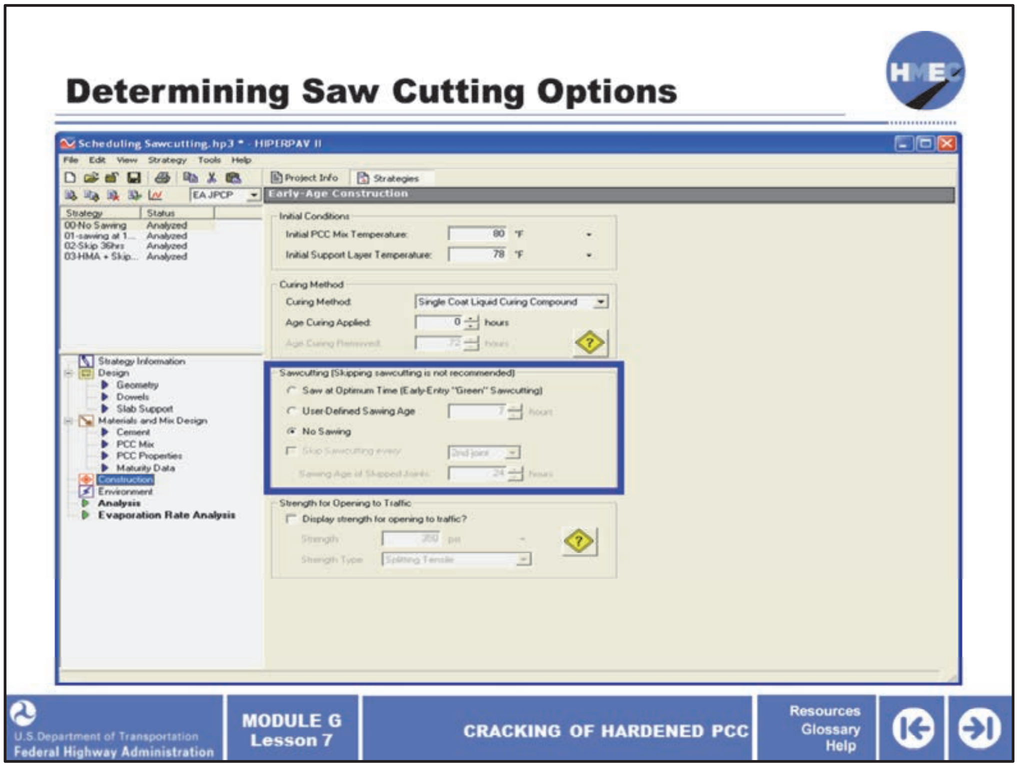
The strategy with the cold front indicates that stresses are likely to exceed the strength and cracking of the slab may occur.

Image description: Screenshot of cold front analysis.



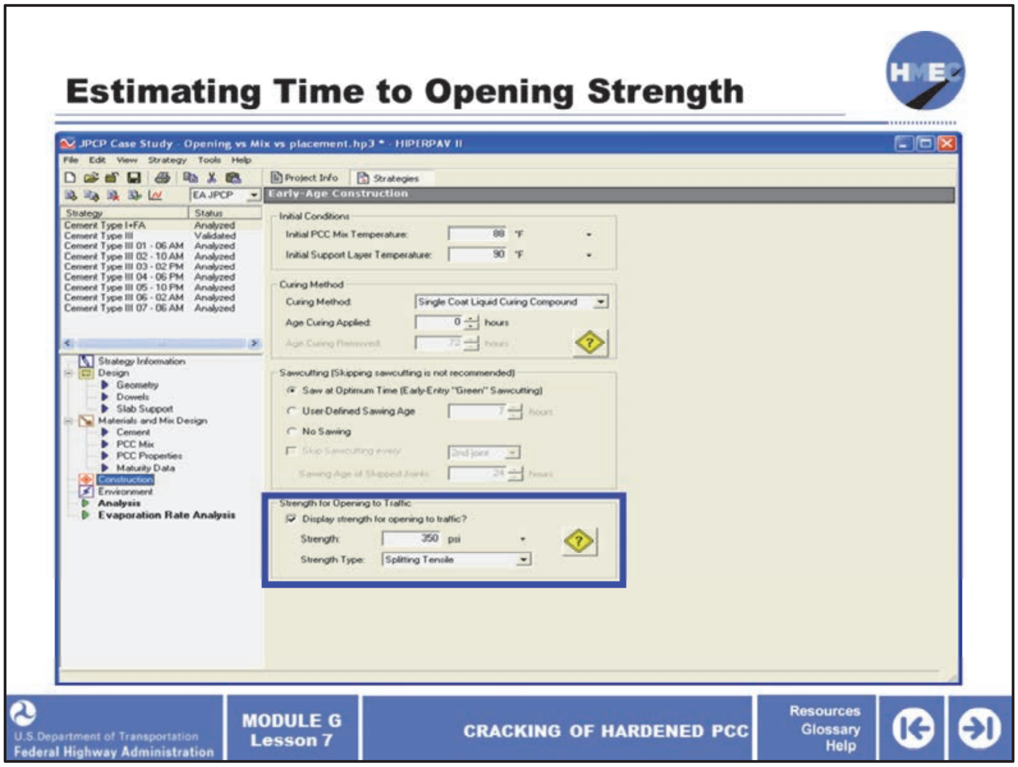
Another capability of the program is to estimate the evaporation rate for different scenarios. Under the conditions analyzed, the evaporation rate at 1130 hours exceeds the allowable limit. Without remediation, this would likely result in plastic shrinkage crack development.

Image description: Screenshot of evaporation rate analysis.



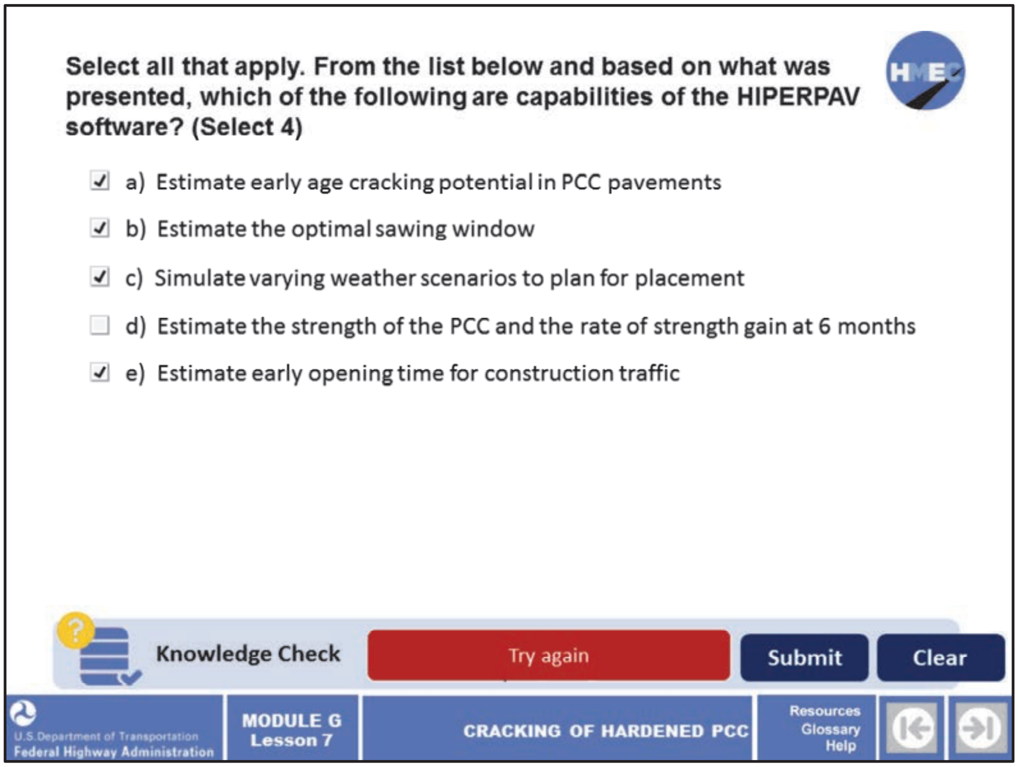
The program estimates the effect of modifying the saw cutting operation.

Image description: Screenshot of program estimates of the effect of modifying the saw cutting operation.



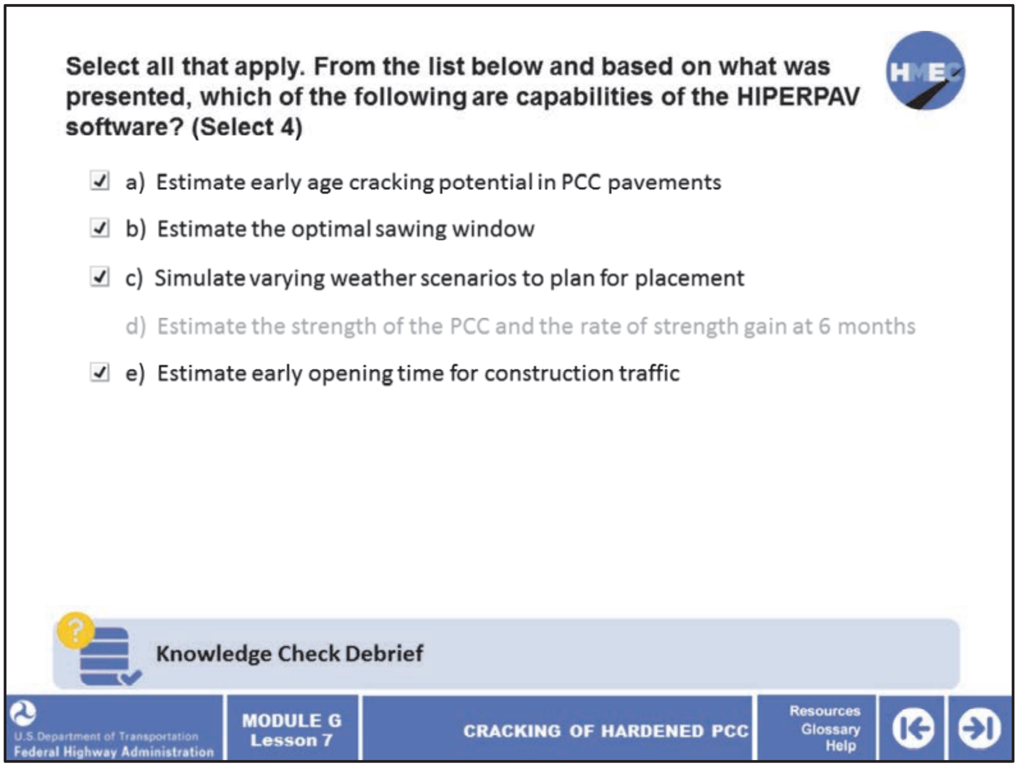
The program estimates the time to opening to construction traffic by inputting the mix parameters, temperature, curing conditions, and threshold strength.

Image description: Screenshot of estimating time to opening strength.



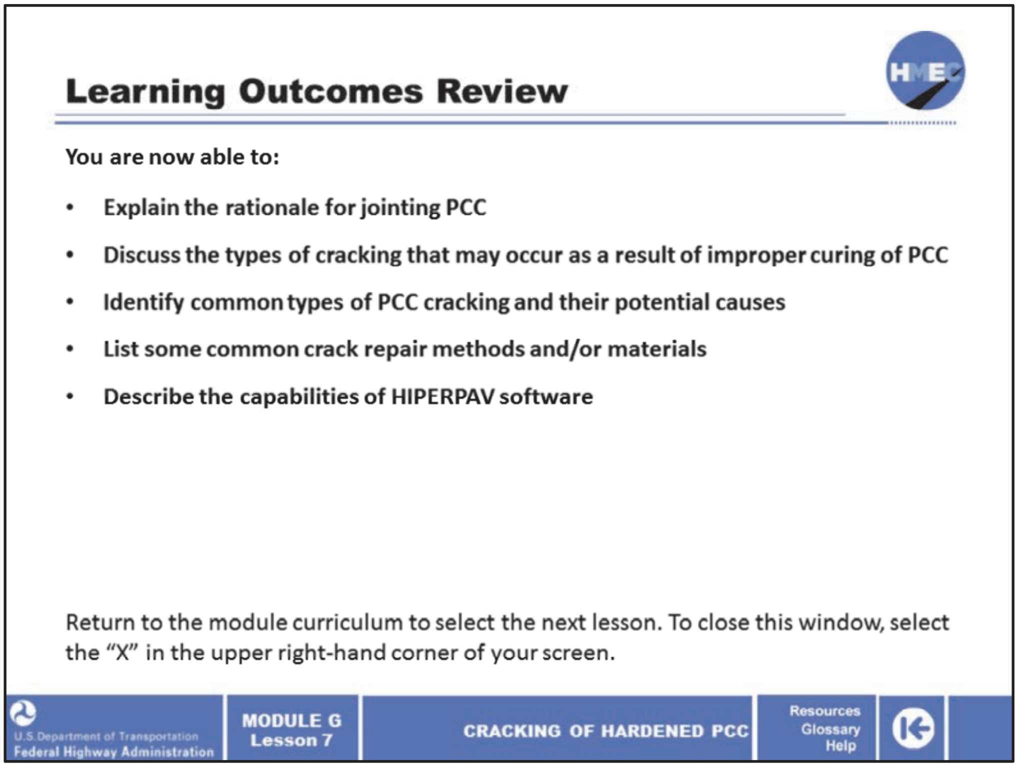
Select all that apply. From the list below and based on what was presented, which of the following are capabilities of the HIPERPAV software? (Select 4)

a) Estimate early age cracking potential in PCC pavements;
b) Estimate the optimal sawing window;
c) Simulate varying weather scenarios to plan for placement;
d) Estimate the strength of the PCC and the rate of strength gain at 6 months; and/or
e) Estimate early opening time for construction traffic.



The correct answers are a) Estimate early age cracking potential in PCC pavements; b) Estimate the optimal sawing window; c) Simulate varying weather scenarios to plan for placement; and e) Estimate early opening time for construction traffic.

HIPERPAV is designed to model early age behavior of PCC. All of the topics listed are included in the capabilities of HIPERPAV with the exception of strength estimates at 6 months, which is well beyond the range of application.



You have completed Module G, Lesson 7: Cracking of Hardened PCC.

You are now able to:

- Explain the rationale for jointing PCC;
- Discuss the types of cracking that may occur as a result of improper curing of PCC;
- Identify common types of PCC cracking and their potential causes;
- List some common crack repair methods and/or materials; and
- Describe the capabilities of HIPERPAV software.

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.