



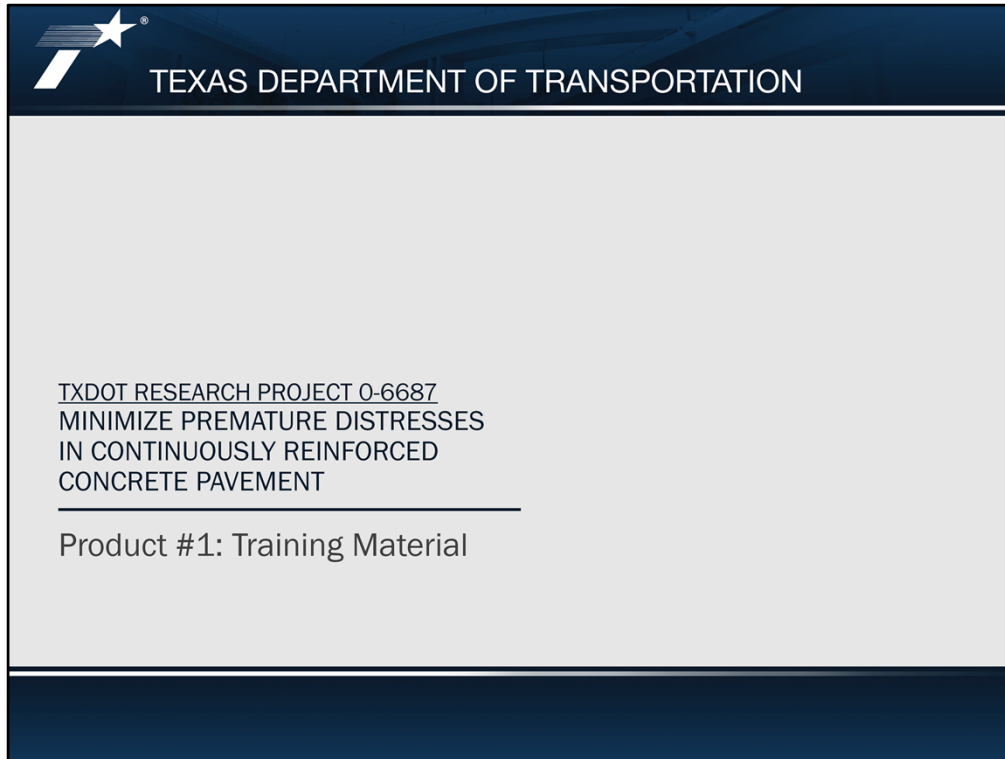
TEXAS DEPARTMENT OF TRANSPORTATION



TXDOT RESEARCH PROJECT 0-6687
MINIMIZE PREMATURE DISTRESSES
IN CONTINUOUSLY REINFORCED
CONCRETE PAVEMENT

Product #1: Training Material

This training material presents research findings on premature distresses in continuously reinforced concrete pavement, including their potential mechanisms and what needs to be done to minimize their occurrence.



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This training material consists of discussions on CRCP distresses in Texas, detailed discussions on premature CRCP distresses, what needs to be done to minimize premature CRCP distresses, and concluding remarks.

Distresses in CRCP

- **Structural Distress**
 - Caused by deficiencies in structural capacity of CRCP system
 - Punchouts
- **Non-Structural Distress**
 - Caused by factors other than structural deficiency
 - Spalling
 - Others? ([Premature Distresses](#))

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In CRCP, there are two types of distresses. One type is distress due to structural deficiencies of the pavement system. The most prominent and only structural distress in CRCP is punchout. The structural deficiencies include inadequate slab and/or base thicknesses and/or stiffness, and inadequate slab support condition. Traditional pavement designs are supposed to eliminate these structural deficiencies in the pavement system.

The other type is the distresses that are not caused by structural deficiencies of the CRCP system, but rather those caused by quality control issues in materials and/or construction, and/or imperfections in design details or intrinsic limitations of CRCP construction. In Texas, spalling has been a primary distress of this type. Spalling in Texas has a lot to do with coarse aggregate type used. Efforts were made by TxDOT to limit the use of the coarse aggregate type responsible for spalling problems to CPCD, and it is expected that spalling will no longer be the problem in new CRCP sections in Texas. Accordingly, spalling was not addressed in this research project.

Distresses in CRCP

- Structural Distress



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This is a typical distress, called punchout, caused by structural deficiencies in CRCP. There is evidence of pumping at a joint between the outside lane and asphalt shoulder, with depression of slab edge and asphalt shoulder at a joint. The “cause” of this distress is insufficient slab support, i.e., deterioration of base/subgrade materials. An argument can be made that deficient slab thickness was the cause of this distress. The fact that this type of distress was not frequent in this section of CRCP indicates that slab thickness might have been adequate. It is noted that asphalt patching materials were placed more than once, and most depression by wheel loading applications was under the wheel path, not at the joint between the outside lane and asphalt shoulder.

Distresses in CRCP

- Structural Distress



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The distress shown in this slide is classified as punchout. The difference between the distress shown in this slide and in the previous slide is that, in the previous slide, the depression of the slab was in the form of a half-moon, while in this slide, the distress is near the transverse construction joint and longitudinal cracks were confined within three transverse cracks. It is believed that the distress shown in this slide could be due to the combined effects of construction operations near a transverse construction joint and potentially design detail (the end of additional tie bars coinciding with the boundary of this distress). From the standpoint of potential distress mechanism, it may not be correct to classify this distress as structural distress. However, in the current distress classification system, it is considered as a structural distress.

Distresses in CRCP

- Structural Distress



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The distress shown in this slide is covered with asphalt and the mechanism of this distress is not easy to identify. However, based on the area and location of the distress, it is considered as a structural distress.

Distresses in CRCP

- Structural Distress



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The distress shown here is also classified as structural distress, since it is not spalling. On the other hand, the slab is 13-in thick, on 4-in asphalt base. Also, at the time this picture was taken, the pavement was less than four years old. Investigation of this distress indicated severe delaminations at the depth of longitudinal steel. Even though this distress is classified as structural distress, it appears that structural deficiency was not the cause of the distress.

Distresses in CRCP

- Structural Distress



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This distress does not meet the traditional definition of punchout. No cantilever action by CRCP segment bordered by two short transverse cracks is observed. No evidence of pumping or other deficiencies in slab support are noted either. Evaluation of WIM (weight in motion) data in this section revealed truck traffic with weights far exceeding legal limits. From that standpoint, it can be stated that this distress was due to the structural deficiency of CRCP system. The use of thicker slabs could have prevented this distress from occurring.

Distresses in CRCP

- Non-Structural Distress



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This distress shows a typical spalling due to the use of a specific coarse aggregate type, whose coefficient of thermal expansion is larger than other aggregate types.

Distresses in CRCP

- Non-Structural Distress



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Another spalling distress in severe condition. Shallow delamination is observed. This section was placed in the winter in Houston when the concrete placement temperature was ideal. This distress indicates “temperature control” during concrete placement is not effective in reducing the spalling potential of concrete containing coarse aggregates prone to spalling.

Distresses in CRCP

- Non-Structural Distress



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Spalling with longitudinal cracking. It appears that wheel loading applications at locations with transverse and longitudinal cracks resulted in spalling. Spalling in this project was quite rare, and it is considered that the quality of construction was a cause for this distress.

Distresses in CRCP

- Non-Structural Distress



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Typical shape of a distress at a transverse construction joint (TCJ). A transverse crack next to the TCJ coincides with the end of additional longitudinal tie bars. This distress is not structural capacity related; rather, it appears to have to do with TCJ.

Distresses in CRCP

- Non-Structural Distress



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Repair of distresses at transverse construction joint between CRCP sections built at different times. TCJs connecting old CRCP with new sections are prone to distresses. This type of distress is not due to structural deficiency of the pavement system. Rather, it has a lot to do with slab movements due to temperature variations, and the inability to provide continuity of slab movements at TCJ. Slab movements in old CRCP at the end of the section due to temperature variations are usually large, primarily due to the free end of the pavement. Depending on the coefficient of thermal expansion of concrete and base friction, the longitudinal movements of the CRCP could be large, and when new CRCP is placed, new CRCP should be capable of restraining the slab movements of old CRCP. The forces, primarily axial forces, in the longitudinal steel at TCJ must be quite large, and if bond stress between steel and surrounding concrete along longitudinal tie bars exceeds bond strength, debonding could occur. In that case, slab movements in both old and new CRCPs could be excessive, potentially resulting in distresses at TCJs.

Distresses in CRCP

- Non-Structural Distress



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This shows a repair of distress at a TCJ. It is reported that additional longitudinal tie bars at TCJs in southbound lanes were placed at every spacing between longitudinal bars, i.e., double the required amount. Additional tie bars for the construction of northbound lanes were in accordance with the requirements in the design standards, and no distresses were observed. This case illustrates that doubling additional tie bars at TCJs is not a good practice.

Distresses in CRCP

- Non-Structural Distress



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This slide shows a distress caused by slab expansion. The distressed area was previously repaired with full depth repair. The bent bar is epoxy grouted tie bar. When the slab was cut for a full depth repair and new concrete was poured for a repair, slab restraint was removed and the existing slab slowly expanded, pushing epoxy grouted tie bars and causing delaminations. In the picture, a comparison of the saw cut mark made in a lane without repair and the repair boundary indicates that the concrete slab cut full-depth expanded. In other words, CRCP has been in compression, and when the restraint was removed, the concrete expanded. Theories accepted in CRCP research state that concrete in CRCP is normally in tension, while in this project, the concrete was in compression. The discrepancy between theories and actual behavior is not fully understood; however, it appears that concrete setting temperature and creep of concrete are responsible for the discrepancy. There are evidences of CRCP expansions, even though the expansion quantity is quite small, which also explains the high level of crack stiffness and load transfer at transverse cracks observed in CRCP sections investigated in the TxDOT rigid pavement research project.

Distresses in CRCP

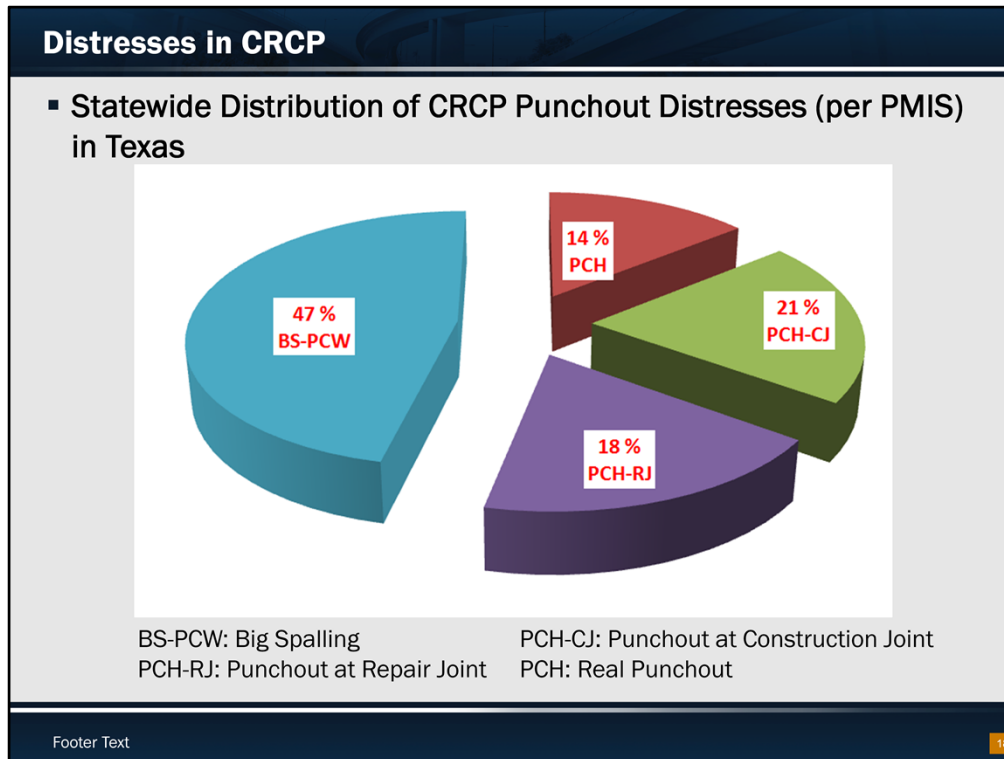
- Non-Structural Distress



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The distress shown here is at a gore area. In a gore area where the outside shoulder is asphalt pavement as shown in this picture, there is a discontinuity between gore concrete and asphalt shoulder. As a result, when there are temperature variations, the concrete in the gore near the asphalt shoulder is trying to move more than the concrete in the outside lane. The gore concrete and outside lane are connected with tie bars along the longitudinal joint. The potential for these differential movements resulted in the distress in the outside lane near the end of the gore area. To prevent this type of distress, tie bars should be omitted for some distance from the end of the gore area.



This graph shows classification of CRCP distresses recorded as punchout in TxDOT PMIS. The research team for the TxDOT rigid pavement database project tried to identify the mechanisms of all the punchouts in the Amarillo, Childress, Dallas, Fort Worth, Houston, and Wichita Falls Districts. Based on the field observations, the distresses were classified as shown in this graph. About half of all the distresses classified as punchout were actually large spalling, most of which were in the Houston District. About one-fifth of the distresses were at transverse construction joints. Eighteen percent of punchouts in TxDOT PMIS were actually at repair joints. The remaining 14 percent of the total distresses were real punchouts that could be attributed to structural deficiency of the pavement system. In other words, 86 percent of distresses recorded as punchouts in TxDOT PMIS are not directly related to structural deficiency of the pavement system. Rather, they are more related to materials and construction quality issues. The information in this graph indicates that increasing slab thickness only is not the most cost-effective way of improving CRCP performance in Texas. Rather, identifying the mechanisms of the remaining 86 percent of the distresses and improving materials selection and the quality of construction operations might be a more cost-effective way of improving CRCP performance in Texas.

Distresses in CRCP

- **Statewide Distribution of CRCP Punchout Distresses (per PMIS) in Texas**
 - Big Spalling – CoTE requirement
 - PCH at Repair Joint – New Spec Item 361
 - Real PCH – Continued requirement for tied concrete shoulder or widened lanes & stabilized base
 - [PCH at Transverse Construction Joints](#)

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For the distress types shown in the previous slide, TxDOT developed a new policy or improved existing specifications. To address severe spalling problems, based on the findings from the TxDOT research project 0-6681, a new CoTE requirement was developed and implemented. With the implementation of a new CoTE requirement, it is expected that severe spalling problems will be no longer an issue in new CRCP. Specification Item 361 for full-depth repairs has been improved, and improved specification requirements will be incorporated in the 2014 version of the specification. Proper implementation of Item 361 is expected to minimize distresses at repair joints. Continued use of tied concrete shoulder or widened lanes and non-erodible base will keep the distresses due to structural deficiencies of the pavement system quite rare. Distresses in transverse construction joints (TCJs) need to be minimized, which requires the identification of their mechanisms and the development of specifications or design details, which is the focus of this research project.

Premature Distresses (PMDs) in CRCP

- PMDs at Transverse Construction Joints (TCJs)
- Y-cracks
- Narrow Transverse Cracks
- PMDs due to Slab Expansions
- PMDs at Gore Areas
- PMDs at Longitudinal Construction/Warping Joints

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All the distresses discussed so far, except for real punchout due to structural deficiencies, take place well before the end of design life of CRCP, primarily due to the fact that these distresses are not caused by classical fatigue damage of concrete. In that sense, these distresses can be termed premature distresses, or PMDs, in this manual. In addition to the distress types discussed so far, there are other manifestations in CRCP that are not typical CRCP behavior. They include Y-cracks, narrow transverse cracks, and distresses at longitudinal warping or construction joints, which will be discussed in the next few slides.

Premature Distresses (PMDs) in CRCP

- **PMDs at Transverse Construction Joints (TCJs)**
 - Not related to structural capacity of CRCP system
 - Caused by construction quality issues and/or imperfections in design details

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As discussed earlier, distresses at TCJs appear to be related to construction quality issues and/or imperfections in the design details, not necessarily to structural deficiency of the pavement system.

Premature Distresses (PMDs) in CRCP

- PMDs at Transverse Construction Joints (TCJs)



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This shows a distress at TCJ in a relatively new CRCP. This CRCP has all the right features, including tied concrete shoulder and stabilized base. Still, this distress occurred, which indicates that this distress has nothing to do with structural capacity of the CRCP system.

Premature Distresses (PMDs) in CRCP

▪ Y-Cracks

✓ Tow Types

- Load related
- Non-load related

✓ Load-related

- Excessive loading & deficient slab thickness
- Usually results in distresses

✓ Non-load related

- Occurs on top of transverse steel
- Not necessarily results in distress

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There are different opinions regarding whether Y-cracks are distresses or not. Extensive field evaluations conducted under TxDOT's rigid pavement database project indicate that there are two different Y-crack types – one related to wheel loading applications and the other related to transverse steel. If Y-cracks occur due to heavy wheel loading applications in CRCP with deficient slab thickness for the given wheel loading, they normally result in partial-depth distress. On the other hand, some Y-cracks develop along transverse steel and these cracks do not necessarily result in distresses.

Premature Distresses (PMDs) in CRCP

- Y-Cracks (Load-Related)



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The transverse crack on the left is a normal crack in CRCP caused by temperature and moisture variations, while that on the right is a crack caused by wheel loading applications that occurred at a later age. Note that the crack on the right did not propagate into the outside shoulder.

Premature Distresses (PMDs) in CRCP

- Y-Cracks (Load-Related)



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This shows a Y-crack-turned to distress. The water on the concrete surface indicates the distress here may not be a full-depth distress; rather, there may be delaminations at the depth of the steel, which prevented the water from draining.

Premature Distresses (PMDs) in CRCP

- Y-Cracks (Load-Related)



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The condition of the concrete in this area was evaluated with MIRA, followed by coring. The evaluations showed horizontal cracking at the depth of the longitudinal steel. It should be noted that the crack on the right of the Y-crack stopped at the longitudinal joint between the outside lane and shoulder, which indicates the crack was caused by wheel loading applications.

Premature Distresses (PMDs) in CRCP

- Y-Cracks (Non-Load-Related)



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This shows Y-cracks caused by materials and potentially unusual temperature conditions during concrete curing. However, they did not develop into distresses.

Premature Distresses (PMDs) in CRCP

- Y-Cracks (Non-Load-Related)



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The Y-crack in this slide is not related to wheel loading applications. Rather, the crack appears to have occurred at early ages due to environmental loading (temperature and moisture variations). This pavement was constructed in 1972, and the Y-crack survived 40 years of traffic applications.

Premature Distresses (PMDs) in CRCP

- **Narrow Transverse Cracks**

- ✓ **Tow Types**

- Concrete material related
- Load related

- ✓ **Concrete material related**

- High CoTE/modulus
- Doesn't appear to result in distress

- ✓ **Load related**

- Normally results in distress

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In the past, it was assumed that narrow cracks have higher probability of punchouts, and efforts were made to minimize narrow cracks, including the use of lower longitudinal steel amount. TxDOT built several test sections in the 1980s and 1990s to investigate the effects of steel percentages and crack spacing on long-term performance. The findings so far indicate no good correlations between crack spacing and punchout development. However, there are narrow transverse cracks that easily develop into distress. The difference is that, if narrow crack spacing was due to “natural” causes – high CoTE, modulus, larger amount of longitudinal steel – narrow crack spacing is not causing any problems. However, heavy wheel loading applications could cause transverse cracks right next to existing transverse cracks, eventually causing distresses.

Premature Distresses (PMDs) in CRCP

- Narrow Transverse Cracks (Concrete Material Related)



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This section was built in 1960, so it is more than 50 years old. Transverse crack spacing is quite small; still, the pavement survived more than 50 years of heavy traffic on US 290 in Houston. This section shows that narrow transverse crack spacing does not necessarily represent weak elements in CRCP.

Premature Distresses (PMDs) in CRCP

- Narrow Transverse Cracks (Load-Related)



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This slide shows narrow transverse crack spacing caused by wheel loading applications with weights exceeding legal limits. The slab segments bounded by transverse cracks will develop into distresses.

Premature Distresses (PMDs) in CRCP

- PMDs due to Slab Expansion

- ✓ Exact cause unknown

- Could be due to temperature differential between concrete setting temperature and temperature at any time
- Could be due to concrete expansion resulting from chemical reactions such as ASR

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Sometimes, it has been observed that CRCP slabs actually expanded, which is quite contradictory to established theories on CRCP behavior. Slab expansions could cause distresses in CRCP. The exact mechanism of slab expansions is not known. It is postulated that temperature differential between setting temperature and a temperature at any time (setting temperature is lower) could cause slab expansions. Another cause could be the expansion of concrete due to chemical reactions such as alkali silica reaction.

Premature Distresses (PMDs) in CRCP

- Slab Expansion



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This shows slab expansion as large as 3.5 inches when the portion of the concrete in one lane was removed for pavement repair, which caused deformations in the stitching bar. The exact cause of this slab expansion is not known.

Premature Distresses (PMDs) in CRCP

- PMDs at Gore Areas

- ✓ Due to differential slab movements & edge support condition
- ✓ TxDOT does not use asphalt shoulder any more.
- ✓ Not an issue at newly constructed CRCP

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As discussed in Slide #17, distresses have been observed at gore areas where asphalt pavement was used as an outside shoulder. The mechanism of the distress was described in Slide #17. Since TxDOT does not use asphalt as outside shoulder, the distresses at gore areas are no longer an issue at TxDOT.

Premature Distresses (PMDs) in CRCP

- Gore Area



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Distress at gore area, followed by asphalt patch

Premature Distresses (PMDs) in CRCP

- Gore Area



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Repair of a distress at gore area

Premature Distresses (PMDs) in CRCP

- PMDs at Longitudinal Construction or Warping Joints (LCJs or LWJs)
 - ✓ Due to differential slab movements along longitudinal joints
 - ✓ Exact mechanisms of differential longitudinal slab movements unknown, other than volume changes in base/subgrade

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A distress type that has not gained due attention is distresses at longitudinal warping or construction joints (LWJ or LCJ). There have been few papers on this issue, if any, and not much has been known. What is known, though, is that slabs can move longitudinally at different rates, causing problems at longitudinal warping or construction joints.

Premature Distresses (PMDs) in CRCP

- PMD at LWJ



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This shows a distress at LWJ. It is noted that the distress is not only near the LWJ, but under the wheel path as well. In other words, it could be that slight damage to concrete from differential movements transmitted by transverse steel and tie bars at LWJ occurred first, and subsequent wheel loading applications could have caused the distress.

Premature Distresses (PMDs) in CRCP

- PMD at LCJ



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This is a distress at LCJ. It is noted that the transverse crack on the right of the distress is a normal crack in CRCP from temperature and moisture variations. On the other hand, the crack on the left has characteristics of a transverse crack due to heavy wheel loading applications. Or, it could be that there were differential displacements between the two lanes, which could have caused minor damage to the concrete in the outside lane.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs)
- Y-cracks
- Narrow Transverse Cracks
- PMDs due to Slab Expansions
- PMDs at Gore Areas
- PMDs at Longitudinal Construction/Warping Joints

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So far, discussions have been made on six types of PMDs in CRCP in Texas.

Prevention of PMDs in CRCP

■ PMDs at Transverse Construction Joints (TCJs)

✓ Construction Issues

- Placing and finishing operations different from other areas
- Concrete materials may be a little different from those at other areas.

✓ Design Detail Issue

- Too much steel hindering proper consolidation of concrete ?

✓ Pavement Behavior Issue

- Excessive slab movements prior to the placement of concrete on the other side of TCJ

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As discussed in Slide #18, about 20 percent of all the distresses recorded as punchouts in TxDOT PMIS are actually distresses at transverse construction joints (TCJs). Accordingly, the focus of this research study was on the identification of distress mechanisms at TCJs and what needs to be done. There are three operational differences in CRCP design and construction between TCJs and at other areas. One is construction operation. Concrete placing and finishing operations are quite different at TCJs. Also, the concrete placed at TCJs is either the first batch or the last batch of the day. In addition, at the end of the day of the construction, placing the header at the right place so that there will be a minimum concrete left is not always easy, resulting in the use of extra paste to fill the space between a TCJ and concrete. There is evidence that placing excessive additional longitudinal tie bars at TCJs causes distresses, possibly due to the difficulty in the proper consolidation of the concrete. Another issue is that concrete slab movements at TCJs before concrete is placed at the other side of TCJs are quite large, which should be restrained by the newly placed concrete, potentially increasing the chances of distresses at TCJs.

Prevention of PMDs in CRCP

▪ PMDs at Transverse Construction Joints (TCJs)

✓ Construction Issues

- Placing and finishing operations may be different from other areas.
 - Consolidate and finish concrete near TCJs as closely as in other areas.
 - Finish the concrete near TCJs as soon as possible.
 - Make sure that good curing in accordance with Spec 360 requirements near TCJs.
- Concrete materials may be a little different from those at other areas.
 - Do not bring in excess mortar from other areas and place near TCJs.

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As discussed in the previous slide, placing and finishing operations at TCJs are different from other areas. Also, due to the additional longitudinal tie bars at TCJs and the inability of a paver to start or end paving operations right at TCJs, consolidation of the concrete is primarily by hand vibration, with the construction quality at TCJs potentially varying from normal paving operations. At the same time, the finishing operations at TCJs are usually delayed, sometimes as long as several hours after concrete placement, leaving the concrete exposed to moisture loss for an extended period of time. Curing operations at TCJs normally do not follow the requirements for curing in Item 360. As discussed in the previous slide, at TCJs concrete materials may be a little different from those at other areas. It is important that excess mortar from other areas is not used at TCJs.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs) – Construction Issues



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This shows the auto-float operation at a TCJ. Note the surface condition of the concrete. The rough surface condition is due to the hand operations of concrete placement near a TCJ. This rough surface will be smoothed by excessive floating, which may not be able to remove all the voids in concrete.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs) – Construction Issues



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This shows finishing operations at a TCJ. Note that a slip form paver placed the concrete, but with no surface finishing operation, which is done by hand operations. Hand operations are not effective in removing all the voids from concrete. Field evaluations of concrete near TCJs indicate voids in concrete near the surface, degrading the durability of the concrete.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs) – Construction Issues



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This illustrates consolidation of concrete at a TCJ by a hand vibrator, which is again different from consolidation operations in the other areas where a paver with mechanical vibrators consolidates the concrete.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs) – Construction Issues



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This shows the result of different concrete placement operations near a TCJ. A paver is not able to start a concrete placing operation right at a TCJ. The concrete placement operations start near a TCJ, only part of which was done by a paver and the rest must be done by hand operations.

Prevention of PMDs in CRCP

▪ PMDs at Transverse Construction Joints (TCJs)

✓ Design Detail Issue

- Currently, 50 % additional tie bars are placed at TCJs.
 - Research shows that the behavior of those tie bars is different from that of longitudinal steel.
 - Test sections were placed where no additional tie bars were placed. The behavior and performance of those sections will be monitored and, design details will be modified if warranted.

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Review of design standards in the early use of CRCP in Texas revealed that the current requirements of 50 % additional tie bars at TCJs existed as early as in 1960. There is no written document that explains the logic behind the use of 50 % additional tie bars at TCJs. During the research, steel strain gages were installed at additional tie bars and longitudinal steel at TCJs. The results show that the behavior of additional tie bars and longitudinal steel in terms of stresses and strains is quite different, which questions the value of the additional tie bars. A test section was constructed with and without additional steel, and the performance will be monitored. At the same time, another section was constructed without additional tie bars, but with transverse saw cuts. Its performance and mechanistic behavior is currently evaluated.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs) – Design Detail Issue



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This shows the steel placed at a TCJ. It is observed that steel is somewhat crowded and extra effort should be made to ensure good concrete consolidation.

Prevention of PMDs in CRCP

▪ PMDs at Transverse Construction Joints (TCJs)

✓ Pavement Behavior Issue

- Excessive slab movements prior to the placement of concrete on the other side of TCJ
 - There is not much that can be done, except that the surface of the base near a TCJ is cleaned so that base friction is provided, and that proper curing is provided in accordance with Item 360 requirements.

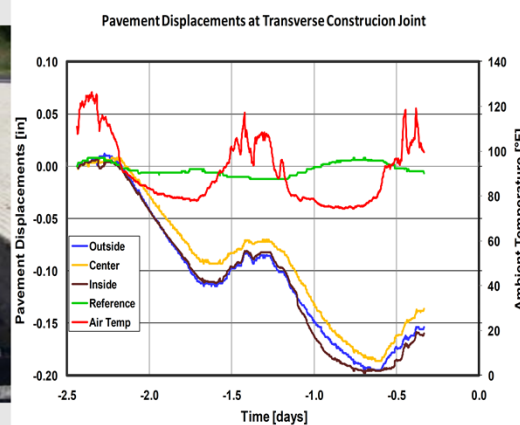
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Measurements of concrete slab displacements in a longitudinal direction at a TCJ revealed excessive slab movements prior to the placement of concrete on the other side of a TCJ, primarily due to drying shrinkage of concrete, as will be shown in the next slide. As long as the concrete on the other side of a TCJ is not placed, the concrete displacements – primarily slab contractions due to drying shrinkage – are not necessarily bad. However, once the concrete on the other side of a TCJ is placed, potential concrete slab displacements near TCJ should be minimized, thus inducing less stresses in longitudinal steel and tie bars, and increasing the potential for good bond between concrete at a TCJ. The best way to achieve this is to clean the base surface prior to concrete placement and to provide quality curing in accordance with Item 360 requirements.

Prevention of PMDs in CRCP

- PMDs at Transverse Construction Joints (TCJs)
- ✓ Pavement Behavior Issue



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This shows the measurements of slab displacements at a TCJ for just over two days. LVDTs were installed against concrete at a TCJ as well as against an invar. The data shows that there was a slab contraction of about 0.2 inches, even though maximum air temperatures were practically the same, which illustrates the effect of drying shrinkage. In this experiment, LVDTs were installed at the mid-depth of the slab. If they were installed at the upper portion of the slab, the displacements could have been larger. When new concrete is placed on the other side of a TCJ, new concrete would pull the previously placed concrete from drying shrinkage of the new concrete. If the contraction is excessive by poor curing, there could be bond slips between newly placed concrete and longitudinal steel/additional tie bars, resulting in larger joint width in a TCJ and eventual distress. Again, quality curing as well as cleaning the base surface before concrete placement near a TCJ is the best that can be done to minimize the potential for distresses at TCJs.

Prevention of PMDs in CRCP

- **Y-Cracks & Narrow Transverse Cracks**

- ✓ The implementation of CoTE requirement is expected to minimize the occurrence of benign Y-cracks and narrow transverse cracks.
- ✓ Proper construction of base and appropriate structural design of CRCP, along with the enforcement of legal weight limits, is expected to minimize the distresses associated with Y-cracks and narrow transverse cracks.

Prevention of PMDs in CRCP

- PMDs due to Slab Expansions

- ✓ The exact cause for slab expansions has not been fully understood. However, differences in concrete setting temperature and temperature at any time are considered to have effects on slab expansions.
 - There is not much that can be done.
- ✓ Observations of concrete strains for up to 600 days reveal no evidence of slab expansion.

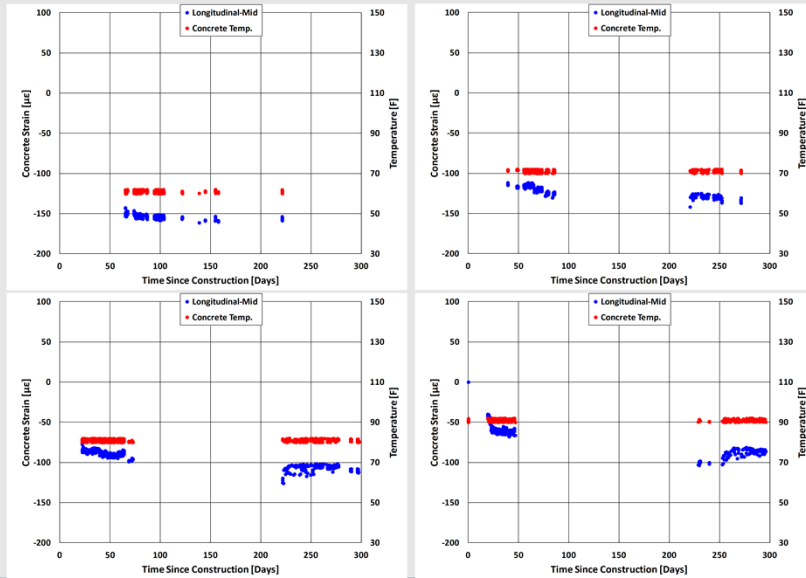
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Minimization of distresses due to Y-cracks and narrow transverse cracks, even though, as explained earlier, not all Y-cracks and narrow transverse cracks are detrimental, can be achieved by (1) the implementation of CoTE requirements for CRCP, and (2) proper construction of base and appropriate structural design of CRCP, along with the enforcement of legal weight limits. Better quality control of concrete materials is expected to minimize the occurrence of Y-cracks.

Prevention of PMDs in CRCP

■ PMDs due to Slab Expansions – Summer Construction Section



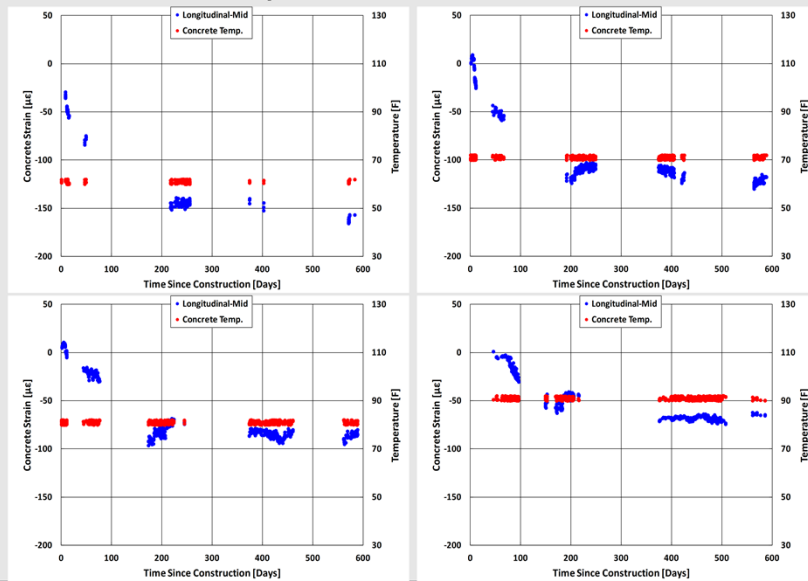
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Even though distresses due to slab expansions have been observed, as discussed in Slides #16 and #33, the exact mechanism of slab expansions is not fully understood. However, differences in concrete setting temperature and temperature at any time (concrete setting temperature lower than temperature at a point of interest) and potential concrete volume expansions due to chemical reactions such as ASR are considered to have effects on slab expansions.

Prevention of PMDs in CRCP

■ PMDs due to Slab Expansions – Winter Construction Section



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Vibrating wire strain gages (VWSGs) were embedded in the longitudinal direction in an actual CRCP project, and long-term monitoring was made. The graphs in this slide show long-term concrete strains in the longitudinal direction from those VWSGs in the section constructed in the summer. Since concrete strains depend on concrete temperatures, a specific concrete temperature has to be selected to evaluate whether the concrete is expanding or contracting from VWSG data. In this slide, four concrete temperatures (60, 70, 80, and 90°C) were selected and the variations in concrete strains were evaluated. As can be seen, there is no systematic trend in concrete strains over time.

Prevention of PMDs in CRCP

- PMDs at LCJs or LWJs

- ✓ It appears that the instability of the base or subgrade causes slabs move differentially at LCJs or LWJs.

- Provide stable support (solid base layer) for concrete slabs.
- Stabilize subgrade material with proper material (lime or cement depending on PI of soil) at sufficient depth.

Footer Text

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As discussed earlier, distresses have been observed along LWJs or LCJs. As is the case for the slab expansions, the exact mechanisms are not completely known; however, it appears that (1) the instability of the base or subgrade or (2) differential slab movements in the longitudinal direction causes slabs to move differentially at LCJs or LWJs. Accordingly, this distress mechanism is a long-term phenomenon, and to minimize this distress type, sound and stable slab support needs to be provided or differential slab movements in the longitudinal direction need to be minimized. Anecdotal evidence shows that the quantity of stabilizing materials for subgrade (lime or cement) and the depth of subgrade stabilization have substantial effects on volume changes in the subgrade.

Prevention of PMDs in CRCP

- PMDs at LCJs or LWJs



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This slide shows a differential slab movement in the longitudinal direction as large as 1 in at LWJ between two lanes. Since the same concrete materials were used in this project, the large differential slab movements appear to be due to the instability in the base/subgrade layers. In this slide, lane separation is also noted, which further indicates volume changes in the layers below the concrete slab.

Prevention of PMDs in CRCP

- PMDs at LCJs or LWJs
- ✓ The CoTE requirement is expected to minimize PMDs at LCJs or LWJs.
 - Place tie bars and transverse steel in accordance with the requirements in CRCP Design Standards.
- ✓ Further research is needed in this area.

Footer Text

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As discussed in Slides #38 and #39, there is evidence that differential slab movements in the longitudinal direction between lanes could cause distresses at LWJ or LCJ. It is expected that the CoTE requirement TxDOT implemented lately for CRCP will minimize PMDs at LCJs or LWJs. To minimize this distress type, tie bars and transverse steel need to be placed in accordance with the requirements in CRCP Design Standards. Also, as discussed earlier, not much work has been done in this area, and further research needs to be conducted.

Concluding Remarks

- Most of the premature distresses in CRCP could be minimized by improving the quality of construction practices.
- The implementation of the suggested practices in this training material is expected to reduce the frequency of premature distresses in CRCP.

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Based on the research work, it appears that most of the premature distresses in CRCP could be minimized by improving the quality of construction practices. The implementation of the suggested practices in this training material is expected to reduce the frequency of premature distresses in CRCP.