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Causes and Repair Techniques for Distresses in Concrete Pavements

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ABSTRACT

Concrete pavements are designed on the basis of fatigue of concrete, taking traffic and environmental factors into considerations. It is expected that if designed properly, concrete pavements should not suffer from any major form of distress and cracking. Global and limited Indian experience on design, construction and performance of concrete pavements have shown widely different performance of such pavements. Some have performed extremely well and have served beyond their design service life. Some have shown severe signs of distress and premature failure. Some distresses especially related to joints are bound to occur during the service life of the pavements but sometimes it may happen that concrete pavements crack even before its opening to traffic. An engineer who is concerned with the design, construction and maintenance of rigid pavement, must be able not only to evaluate fully the factors that affect the design of pavement but it is also necessary to have an understanding of types of pavement distresses and their causes. In particular, it is important to ascertain whether certain types of distress are progressive, leading to eventual failure of the road, or whether they are non-progressive. Timely repair of distressed pavements with proper technique and material may arrest further deterioration. The paper will discuss different types and causes of distresses of concrete pavements. Repair techniques such as full depth repair, slab replacement, crack sealing, joint resealing etc, which have recently been adopted at some of the project sites will also be discussed in detail.

Keywords: Shrinkage Cracks, Settlement Cracks, Dowel Misalignment, Locked Joints, Full Depth Repair

1. INTRODUCTION

Concrete pavements may face deterioration during its service life as well as just after construction. Distress of rigid pavement which mainly occur during its service life can be due to two basic causes. The first is deterioration or deficiency of the pavement itself. The deterioration may be due to freezing and thawing, use of non-durable materials, alkali aggregate reaction, scaling resulting from the use of deicing salts, and a variety of other reasons. Uncontrolled cracking of concrete slabs may happen just after construction. Contraction joints usually control the formation of cracks in newly constructed concrete pavement but sometimes various design and construction factors influence the ability of contraction joints to control cracking. Substantial changes in weather during and after construction also can induce uncontrolled cracking.

2. RANDOM SHRINKAGE CRACKING OF CONCRETE PAVEMENTS

Early cracking is a complex interaction of a variety of seemingly unrelated factors. When all goes well on a project, cracks form at planned locations where contraction joints are placed in the slab. For most projects, transverse and longitudinal contraction joints are made by sawing the concrete with a single-blade joint cutting machine. In a new concrete pavement cracks develop whenever tensile stresses which build up within the concrete becomes more than the tensile strength of the concrete. The tensile stresses develop from restraint of the concrete's volume change at early ages, and restraint of bending from temperature and moisture gradients through the concrete. Early volume changes are associated with the concrete's drying shrinkage and temperature contraction.

Sometimes, cracks do not develop at the saw cuts and instead crack at some other location within the slabs. The reasons for such uncontrolled cracking of concrete pavements are discussed below.

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Vol. 9 Issue 06
June 2022

2.1 Saw Timing

There is an optimum time to saw contraction joints in new concrete pavements, which is defined as the sawing window. It represents a short period after the placement of concrete within which concrete can be cut successfully before it cracks in an uncontrolled manner. If the sawing of the joints is started too early then it may lead to raveling along the cut. If sawing of joints is delayed beyond a certain period when significant concrete shrinkage occurs then it may induce random cracks at an interval of generally more than 8-10 m within the pavement (photo 1).

2.2 Saw Cut Depth

Sawing of concrete at the location of joint is intended to weaken the concrete at that location so that when concrete shrinks it may induce crack under the saw cut. Required saw cut depth depends upon the time of the sawing. Early sawing of the joints may require lesser saw-cut depth for preventing random cracking. Generally the saw-cut depth is kept as one-third to one-fourth of the depth of the slab. If the depth of the saw-cut is less than the required depth then it may not sufficiently weaken the concrete at that location and it may ultimately lead to cracking of concrete elsewhere.

2.3 Joint Spacing

Pavement with long transverse joint spacing may crack at locations other than the saw cuts due to tensile stresses from temperature curling (fig. 1). Theoretical and practical studies of concrete pavement have determined that the optimal spacing between joints depends on the slab thickness, subbase stiffness, and concrete strength. Most of the time the spacing of transverse contraction joints in plain pavement is kept 4.5 m to 6.0 m. It is also important to check the transverse and longitudinal contraction joint spacing to see if it is within the limits as described in various codes and specifications. For unreinforced concrete slabs, IRC:15-2002, recommends maximum contraction joint spacing of 4.5 m up to 25 cm thick slabs and 5.0 m for 30 and 35 cm thick slabs.

Photo 1. Transverse Crack due to Late Sawing

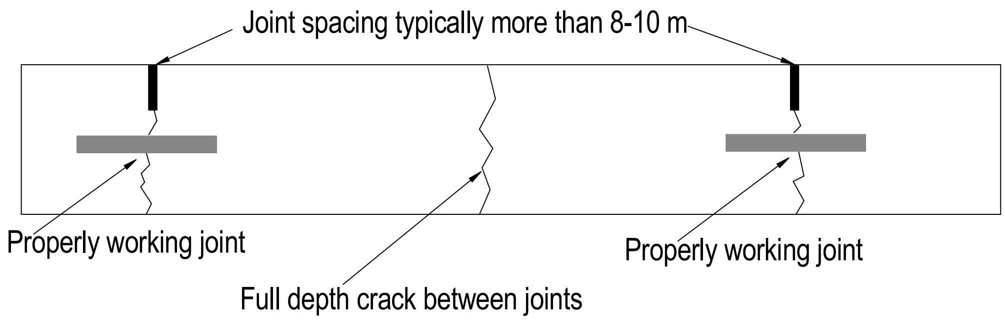

Fig. 1 Mechanism Necessary for Cracking due to Long Joint Spacing

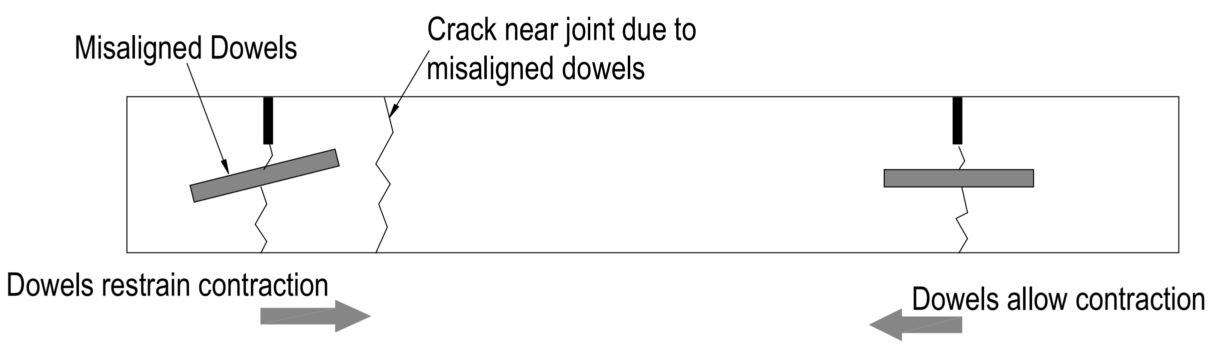

Fig. 2 Mechanism Necessary for Cracking by Misaligned Dowel Bars

2.4 Misaligned Dowels

Sometimes, misalignment of dowel bars at a transverse joint can induce a crack away from the location of saw cut joint if the dowels physically lock two slabs together and restrain their contraction. This can happen even if saw timing and saw cut depth are adequate (fig. 2).

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Vol. 9 Issue 06
June 2022

3. JOINT RELATED DISTRESSES

If joints are properly designed, carefully constructed and adequately maintained, distresses are unlikely to occur. Most joint related problems are preventable. The common distress is described below.

3.1 Joint Faulting

Faulting is differential vertical displacement of joints caused by repetitive axle loads. Faulted joints result in imperfect riding qualities and thus may be considered to be major functional distress. It mainly occurs in concrete pavements where no load transfer devices are provided at contraction joints and pavement slab is directly placed over subgrade. Other causes of faulting include foundation weakness, overloading of the pavement, inadequate pavement thickness, and poor sub-surface drainage. Avoiding these deficiencies generally will make the pavement more resistant to joint pumping and faulting. However, the current practice is to provide a strong sub-base in the form of dry lean concrete under the pavement slabs, hence, there are absolutely no chance for any kind of joint pumping or faulting across the doweled joints.

3.2 Joint Raveling

Joint raveling is a fairly minor distress generally caused by tearing along early saw cuts or where joint-forming inserts are removed early in the pavement's life. The distress is of little consequence, except in cases where preformed seals are to be installed and raveling may prevent full contact of the seal with the upper portions of joint walls and result in a leaking joint. Raveling can be prevented by waiting until the sawcut goes through coarse aggregate particles rather than tearing them from the surface. If raveling is to be repaired at all, the best approach seems to be through the use of a sand-epoxy mortar mixture applied to the clean raveled surface.

3.3 Joint Spalling

Spalling is general deterioration of joints caused by excessive compressive stresses, which may be related to joint infiltration or pavement growth caused by reactive aggregates. Other causes may be related to poor quality of concrete or poor construction practices. Spalls range from very small edge spalls to very large spalls reaching several inches back into the slab or down into the joint.

While spalling may be an advanced stage of raveling, it is more often a manifestation of compressive failure of concrete in the upper regions of the joint. Other causes of spalling have been related to the use of various inserts or joint-forming devices and to overworking of the concrete during joint forming. In the latter case, high quality concrete with an appropriate air content will help eliminate the problem.

Most compressive failures relate to the infiltration of incompressible materials such as sand, grit, and metal particles into joints under the action of traffic and opening and closing of joints because of change in thermal and moisture gradients. Infiltration is much more severe when joint seals have failed or are missing because infiltrated materials accumulate in the joint and resist normal joint closure. The resulting horizontal shear stresses eventually reach the point where the concrete is ruptured. The problem occurs more frequently and is generally more severe for pavements with longer slabs and, therefore, greater joint movement.

Joint spalls can be prevented by the use of high quality concrete and other materials, the use of good construction practices, and by keeping joints well sealed. From a construction standpoint, one of the most effective ways to prevent spalling is to use sawed rather than formed joints. In that way, many problems associated with workmanship and with the use of various inserts are avoided completely.

e-ISSN: 2348-6848
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Vol. 9 Issue 06
June 2022

Joint spalls often are temporarily repaired by filling the spalled areas with asphalt concrete to restore the riding quality and reduce user complaints. However, permanent repairs need to be made with concrete, epoxies, or other compatible materials.

3.4 Blowups of Concrete Slabs

Blowups are compressive joint failures brought about by excessive expansion related to high temperatures, high moisture contents, or a combination of the two. Blowups may occur gradually or may be sudden and dramatic. Failures are full depth and full lane width and can present serious hazards to traffic.

Blowups become likely when normal joint movement is restricted by infiltration. Increase in concrete volume brought about by elevated temperatures and moisture contents create longitudinal thrust that may overcome the compressive strength of the weakest joint in the section. Blowup tendency is more pronounced on pavements with long slabs where individual joint movements are greatest. Joints typically fail in the lower portions first. This failure provides an inclined plane for the slabs to slide upward when further expansion occurs. A sudden and dramatic blowup can occur when the upper portion shears off with little or no warning. Most blowups occur during a significant hot spell and usually in the afternoon. Blowups seldom occur where joint spacing is less than 6 m, with no intermediate expansion joints, even where joints are not sealed. Blowups almost never occur in new pavements. If the pavement is susceptible to blowups, they begin to occur after 3 to 5 years of age. The blowups usually occur at joints or cracks in the pavement and the concrete at the blowup appears to be weak or deteriorated at that point.

If blowups occur in concrete pavement then a major repairing is required. The whole joint assembly is to be removed up to the limits of deterioration. Then, full depth repair is done to restore the joint. In some cases of larger blowups it may be necessary to replace one or more full slabs.

3.5 Locked Transverse Joints

Transverse joints in concrete pavements may sometimes be damaged due to malfunctioning of dowels that are locked or frozen in place. The locking may be caused by either corrosion of the dowel bars or improper alignment or improper lubrication of dowels. The corrosion products occupy more volume than the clean steel, and prevent smooth movement of dowel. Joint locking is more often caused by dowel misalignment during construction. If dowels are not placed in the proper horizontal or vertical plane, the whole assembly can not function as a unit and restraint stresses will develop causing spalling and cracking of the concrete at the joint face on one side of the slab. The cracks are due to shear stresses which result during the expansion cycles.

Photo 2. Blow-up of Concrete Slabs at Joint **Photo 3. Transverse crack due to locked joint**

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The damage caused by locked joints may be relatively minor, especially if adjoining joints are functioning properly. At times, however, a failure plane develops just outside the dowel assembly. Then a full-depth, full-width crack will occur which begins to function as the joint. Because there is no load transfer device at this crack, faulting, pumping and general joint failure soon follow. Photo 2 shows a full width transverse crack that occurred in the vicinity and parallel to the locked joint.

In modern construction, dowel locking is largely avoided by the use of epoxy-coated dowels with effective bond breakers and by the use of new installation technologies, like automatic dowel bar inserter attached to the paver, which eliminates the possibility of misalignment to great extent.

The repair of a joint where the dowels are misaligned or frozen is almost always a major undertaking and involves the removal and replacement of the joint area and the dowel assembly. Typically, such repairs are full depth, full lane width, and 1.5 to 2.5 m long. The length should be to accommodate the new dowel assembly.

4. SETTLEMENT CRACKS

Settlement of the subgrade and subbase can cause the cracking of the concrete pavement (Photo 4). Cracks resulting from settlement of subgrade are normally variable in direction but most commonly they appear diagonally and extend continuously to many slabs. Repeated heavy truck loads may further cause breaking of slabs into several pieces due to loss of support beneath the slab.

5. CORNER CRACKS

Corner cracking is normally prevalent only in thin slabs and slabs with acute-angled corners (Photo 5). In both the cases the stress is very high in the corner region as compared to elsewhere. If the pavement thickness has been designed adequately, such corner cracks will not occur.

Photo 4, Settlement Cracking

Photo 5. Corner Cracking

Pavement pumping can also cause corner breaks. Pumping is the expulsion of water from under a pavement through joints because of the action of repetitive wheel loads. This problem occurs only if concrete pavement is constructed directly on subgrade especially of fine grained soils. Fine material is expelled along with water. Cyclical pavement deflection gradually produce small voids under the pavement and water and suspended solids in these small voids may be ejected upward through joints. The result is a progressively larger void under the pavement and thus removal of support from under the slab so that wheel loads can no longer be carried and the concrete is overstressed resulting in corner break. Pumping is best avoided by providing load transfer and by the provision of strong, well constructed sub-bases. These sub-bases should have drainage characteristics sufficient to remove

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Vol. 9 Issue 06
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infiltrated water in a short time to avoid saturation of the underlying pavement layers. Modern designs make provision of special drainage layer to accomplish this objective. However, all modern concrete pavements are constructed over an erosion resistant dry lean concrete sub-base, so, possibility of mud pumping is completely removed. Either slab replacement or full depth repair technique are needed to correct corner breaks.

6. PLASTIC SHRINKAGE CRACKS

The weather almost always play an important role in the occurrence of uncontrolled cracking of concrete pavement. Air temperature, wind velocity, relative humidity and sunlight influence the hydration and shrinkage of concrete. These factors may heat or cool concrete or draw moisture from exposed concrete surface. Plastic shrinkage cracking is a result of rapid drying of concrete pavement surface due to either high ambient temperature, high wind velocity, low humidity or a combination of these factors. These cracks are generally tight and appear in the form of parallel groups perpendicular to the direction of the wind soon after the placement of concrete (photo 6). Adequate curing measures are necessary to prevent their occurrence.

Photo 6. Plastic Shrinkage Cracks

7. REPAIRING TECHNIQUES

7.1 Partial Depth Repair

Partial-depth repair is a concrete pavement restoration technique that corrects localized distress such as spalls, scaling, and popouts in concrete pavements. Partial-depth repair improves the rideability of jointed concrete pavement. Thus contributing to reduced moisture infiltration and intrusion of incompressibles into joints. It also restores a uniform, well defined joint sealant reservoir prior to joint resealing.

In brief, partial-depth repair involves removing an area of deteriorated concrete that is limited to the top one-third of the slab thickness and replacing it with appropriate repair materials. Depending on the type of repair material used and the repair location, a new joint sealant system may be placed as well. The repair technique can be applied either transversely or longitudinally on the pavement where distress is observed.

7.2 Full Depth Repair

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Full-depth repair (FDR) is a concrete pavement restoration (CPR) technique which involves making lane-width, full-depth saw cuts to remove the deteriorated concrete down to the base, repairing the disturbed base, installing load-transfer devices, and refilling the excavated area with new concrete. It is an effective, permanent treatment to repair pavement distresses particularly those that occur at or near joints and cracks. By removing and replacing isolated areas of deterioration, full-depth repairs may delay or stop further deterioration and restore the pavement close to its original condition. The distresses that can be addressed using full-depth repairs include transverse cracking, corner breaks, longitudinal cracking, deteriorated joints, D-Cracking, blowups, and punchouts.

7.3 Slab Replacement

In cases where a slab has full depth and intersecting multiple cracks, slab replacement become necessary. It involves the demolition and replacement of affected slab. Prior to breaking out of the affected slab, a full depth saw cut be made around the perimeter of the repair to minimize the damage to the surrounding slab. This should include the existing transverse joints on both sides. Care should be taken to ensure that the saw cut do not extend into adjacent slabs. It accidentally it happens, then the cut into the adjacent slab should be repaired with epoxy mortar. The concrete of the affected slab may then be sawn into smaller pieces before being broken up and removed from the slab. The concrete that remains in the corner of the patch after saw cutting should be broken out carefully to avoid undercutting the remaining slab. Reinstatement of the sub-base, if required, should be done by taking care of full compaction especially in the corners. A plate vibrator should be used to compact the subbase. Fixing of dowels into drilled holes, placing, compacting, finishing, texturing and curing of fresh concrete into the patch will be as described in full depth repair section.

7.4 Cross-Stitching

Cross-stitching is a repair technique for longitudinal cracks which are in reasonably good condition. The purpose of cross-stitching is to maintain aggregate interlock and provide added reinforcement and strength. The tie bars used in cross-stitching prevent the crack from vertical and horizontal movement or widening. This technique knits the cracked portions of the slab together and reduces the chances of crack to grow further.

Cross-stitching uses deformed tie bars drilled across a crack at angles of 30-45 degrees. Deformed steel bars of 10-12 mm diameter are sufficient to hold the crack tightly closed and enhance aggregate interlock. Full depth holes of 18-20 mm dia are drilled at a pitch distance of 300 mm with the offset of 150 mm from the crack. The holes are drilled alternately from each side of the crack so that one hole passes through the crack from left to right while the next from right to left. After drilling, the holes are flushed with high pressure air to clean out any residual dust. Then a high strength epoxy gel adhesive is injected into the holes. Immediately after injecting epoxy, deformed steel rods are inserted into each hole. The crack is sealed at the top with a silicon sealant.

Do not stitch a transverse crack which has assumed the role of an adjacent joint. Stitching will not allow transverse joint movement (open and closure). A new crack will likely develop near a stitched working crack or the concrete will spall over the reinforcing bars.

8. CONCLUDING REMARKS

Recently many concrete road projects have been completed in the country and many more are coming up. Many problems faced at the concrete road project specially uncontrolled cracking of slabs can be eliminated or at least minimized by making aware the site staff about the precautions to be taken during concrete paving. Due care during construction can reduce the troubles which otherwise would be very difficult and costly to remove after the concrete has set.

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June 2022

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