

# Cracks in Pavement Quality Concrete (PQC) - Causes and Remedies

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**Abstract:** The Road construction has become a growth engine for infrastructure development, across the country, consequently, we have experienced a tremendous growth in Infra-structure of India and National Highways specifically, the construction of pavement quality concrete highway has been the preferred option compared to the bituminous highway due to its low maintenance and long life. However, there are various types of cracks which PQC pavements develop post construction and during the service life. This paper describes the repairs of many types of cracks which are most common and develop either during construction, post construction and during the service life. The structural defects are highlighted in the form of various types of cracks in the slab. The settlement at joints may also occur and if the remedial action is not taken it may also lead to development of cracks.

**Keywords:** Road, PQC cracks, Causes, repairs, settlements, remedial actions

## I. INTRODUCTION

Development of Surface Cracks in PQC due to temperature difference, late joint cutting, and defective curing of PQC etc. The cracks will allow water / mud /debris going into the cracks and widens them further. Shrinkage is another common reason for cracking. As concrete hardens and dries it shrinks. The chemical reaction, which causes concrete to go from the liquid or plastic state (or a solid state), requires water. This chemical reaction, or hydration, continues to occur for days and weeks after you pour the concrete.

**1.1** Regardless of quality of pavement material and design, increase in the vehicular traffic and changing environmental conditions will reduce the service life of pavement which ultimately results in its failure. The causes and types of failure of pavements, particularly of rigid pavements should be understood in order to initiate proper repair and rehabilitation programme to increase their service life. The repair and restoration of rigid pavement depends on the type of distress. Cracking is the most common feature of the rigid pavement. Fatigue cracking is considered as the major cause for the failure of rigid pavements. The stress ratio between flexural tensile stress and modulus of rupture of concrete is the primary factor which decides the number of load repetitions to cause fatigue cracking. Pumping, faulting, spalling, shrinkage, polished aggregates, punch out, deterioration of joint load transfer system, linear cracking, durability cracking, corner break, alkali-aggregate reaction, pop-outs and blow-ups are some the other causes of failure of rigid pavements.

Crack filling, Crack sealing, Stitching, Diamond grinding, Dowel bar retrofitting, Joint repair, Partial-depth repair and Full-depth repairs are the most common techniques used for restoration of rigid pavements.

**1.2** The structural cracks are classified according to their severity which is defined in terms of width of the cracks

- **Narrow Cracks** – If the width of crack is 0.5mm it is considered as narrow crack. It is assumed that there is full aggregates interlock and full load transfer is taking place within the slab at the crack.
- **Medium Crack** – If the width of crack is 0.5 -1.5mm it is considered as medium crack. It is assumed that there is partial aggregates interlock and partial load transfer is taking place within the slab at the crack. These types of cracks permit ingress of water.
- **Wide Crack** – If the width of the crack is greater than 1.5 mm it is considered as wide crack. It is assumed that there is no aggregates interlock and no load transfer is taking place within the slab at the crack. These types of cracks permit ingress of water and fine detritus.

### **1.3 Settlement of the sub-base**

- **Initial settlement:** Caused by the settlement of sub-base, as soon as the sub- base reach a certain depth and boulders in soil getting crushed (slowly/rapidly) sufficiently compacted soil
- **Continuing settlement:** Load bearing element of sub-base is still being subjected to continuous stress and the

cracks appeared will develop further and may reach a point where the stability of the whole sub-base is undermined.

- **Uniform settlement:** In some cases, the whole sub-base is settled uniformly. In such cases cracks may be minimum or, may have not yet started.
- **Deferential settlement:** It means that deferent elements/parts of the sub-base are settling at deferent rates (slow /rapid).

## II. FAILURE TYPES AND CAUSES

Typical rigid pavement failures and their causes are discussed in this section.

### 2.1 Fatigue cracking

Fatigue failure of concrete roads is the phenomenon by virtue of which the pavement fails under repetitive loading by a load smaller than the load that can cause failure in single application. Larger the load, smaller will be the number of repetition to cause fatigue damage. According to studies, number of factors contribute to the fatigue damage of the pavement, which include heat of hydration, low thermal conductivity, shrinkage and creep. The micro cracks formed at the early age of concrete and the micro-voids formed due to excess water capillary cavities progressively extend under the effect of repetitive loading when the ratio of tensile stress in the pavement and modulus of rupture of pavement material exceeds 0.45. Fatigue failure initiates by weakening the bond between aggregate cement paste within the tension zone till the first continuous cracks start forming from inwards from the tension face which ultimately results in reduction of effective slab thickness and progressive shift in the neutral axis, after which full depth cracks appear, dividing the pavement slab into discrete smaller segments, as shown in fig.-1.



Figure -1 Flexural fatigue cracks

Proper and uniform thickness throughout the length of pavement and high modulus of rupture can assure fatigue adequacy of concrete pavements. Further, the micro cracks which have potential to develop into full depth fatigue cracks can be controlled by low heat of hydration for which the use of blended cements is a viable option. But once the fatigue cracks develop the rehabilitation is inevitable which may go to the extent of full-depth repair.

### 2.2 Pumping

Pumping is the phenomenon of ejection of water and subgrade (or base) material through the joints and cracks or at the pavement edge due to deflection of pavement slab, when the free water accumulates underneath the slab.



Figure 2 Pumping in rigid pavement



Figure 3 Faulting in rigid pavement

Pumping is the feature of rigid pavements only because flexible pavements do not create void space under them, as their rebound capability is not sufficient to do so. Hence flexible pavements fail by rutting, shoving and so on when they are overloaded. Pavement at fills and cut areas are more prone to pumping after rainfall. Pumping takes place after certain duration of time when the pavement is incessantly subjected to heavy vehicular loads. Creation of void space under the pavement where free water accumulates is the primary cause of pumping of subgrade soil. Plastic deformation of soil and warping of the slab due to temperature gradient within slab are factors that promote the creation of void space. The entry of the water in the void space may be due to surface infiltration at the joints and edges of the pavement. The ground water is also a potential source. If the soil is not free draining the water comes out of the pavement when it deflects. The ejection of water is more pronounced at the pavement edge just ahead of joint or crack. After continuous pumping of water and soil, the structural support to the slab reduces which can lead to corner breaking, linear cracking and faulting.

The repair of the pavement which is affected by pumping starts with full depth repair of the affected slab, followed by use of load transfer device (dowel bar) for effective load transfer across transverse joints created after repair. Stabilizing of slabs adjacent to the pumping area is equally important as loss of subgrade base or subbase material would have taken place after pumping. The problems of permeability of pavement and poor drainage of soil should also be addressed.

### 2.3 Faulting

Vertical differential movement of slab adjacent to joint or crack is called faulting. Faulting may be longitudinal or transverse. It is usually seen in case of pavements without load transfer devices. The primary cause of faulting is slab pumping. The other possible causes are thermal and moisture stresses. In the most common faulting mechanism, the approach slab is higher than the leave slab due to pumping.

Faulting becomes noticeable if its average value reaches 2.5 mm. The major problem of the faulting is roughness and unevenness in the pavement which affect the riding quality. Diamond grinding is usually done to restore the pavement if the average faulting reaches 4 mm. Diamond grinding is nothing but removal of thin top layer of hardened PQC (4 to 6 mm) by means of closely spaced diamond saw blades so as to improve the pavement rideability. Dowel bar retrofitting is usually required if the faulting is between 4 and 12.5 mm and if the faulting exceeds 12.5 mm complete reconstruction of the slab (full-depth repair) is necessary.

### 2.4 Spalling

Cracking, breaking or chipping of the edges of cracks, joints and edges of the pavement, is termed as spalling. Joint spalling is usually noticed within 300 mm from the face of longitudinal or transverse joints. Corner spalling is the breakdown of the corners of the slab which is noticed within about 300 mm from the corner. Loose debris on the pavement and roughness are the problems associated with spalling. If spalling is left unattended it may severely impair the serviceability of the pavement.



Figure 4 Spalling



Figure 5 Shrinkage cracks

Possible causes of spalling are excessive stresses at joints, cracks and edges, caused by infiltration of incompressible materials and consequent expansion. "D" cracking (durability cracking) or freeze-thaw damage, weakness of pavement concrete at joints or edges due to poor workmanship, improper insertion, misalignment and corrosion of dowel bar and heavy traffic are other causes that promote spalling. Spalling is basically categorized as shallow spalling (occurs within  $\frac{1}{3}^{\text{rd}}$  of slab thickness) and deep spalling (extends at least up to half slab thickness). Partial-depth and full-depth repairs are the remedies for shallow and deep spalling respectively.

### 2.5 Shrinkage cracking

Formation of hairline cracks during setting and hardening of pavement concrete at places away from the joints are called shrinkage cracks. Shrinkage cracks are not found to extend throughout the slab thickness. Formation of plastic shrinkage cracks is seen in pavements as early as 3 to 4 hours after the pavement slab is laid, they can have width of 0.1 to 3 mm and length of up to 1000 mm. Shrinkage cracks exhibit the uncontrolled nature of slab shrinkage. These cracks allow moisture and chemical movement in the pavement that the pavement surface experience, which is detrimental to the pavement concrete if left unchecked. Severity of damage depends on the width and orientation of crack. The possible causes of shrinkage cracks are, late sawing of contraction joint, poor design of reinforcement, improper curing where the surface of the slab is allowed to dry quickly and use of high early-strength cement or admixtures that give high heat of hydration. Shrinkage cracks can be treated by means of crack sealants if they are of moderate size. Crack sealing procedure is nothing but placement of specialized material into cracks to prevent movement of water into the body of pavement. Synthetic resin is generally used as crack sealant. Entire slab replacement (full-depth repair) is warranted in severe situations.

### 2.6 Aggregates with polished surfaces

Aggregates which protrude out of cement paste with less angularity and roughness are said to be polished aggregates. In due course of time when the pavement ages due to repeated traffic loads, the protruding rough and angular particles get polished and this can occur if the abrasion value of particles is low. Excessive studded tyre wear also contributes to polishing of aggregates. The obvious problem of polished aggregates in pavement is the reduction of skid resistance, which may lead to riding discomfort and if the severity increases it may lead to road accidents.



Figure 6 Polished aggregates



Figure 7 Punch-out

Diamond grinding or an overlay is the solution to the problem of polished aggregates in rigid pavements.

### 2.7 Punch-out

Punch-out is nothing but breaking of small portion of concrete slab into several pieces. It is localized behaviour in concrete slab. Punch-out causes roughness of the pavement surface and creates ingress to moisture into pavement and later in base and subgrade, leading to erosion of base or subgrade. Punching makes cracks to spall and disintegrates them.



Figure 8 Failure of Joint load Transfer system



Figure 9 Linear cracking



Localized construction defect such as improper compaction is the primary cause of punch-out in plan cement concrete pavements. Corrosion and inadequacy of steel are the key factors for the punch-out failure in continuously reinforced pavements. Excessive width and closeness of shrinkage cracks too promote punch-out. Punch-out problems are addressed by full-depth patch.

### **2.8 Failure of Joint Load Transfer System**

Failure of load transfer system at joints is characterized by transverse crack or corner break. The possible reasons for this type of failure are corrosion and misalignment of dowel bars. The products of corrosion which occupy certain volume will induce tensile stresses around the dowel bar and the excess corrosion weakens the dowel bar which may prematurely fail due to repeated loading. Bending of dowel bar and their closeness to the slab edge will induce localized stresses which may be high enough to break the pavement.

Usually the pavement is restored by a full-depth patch at the affected area after replacement of the failed joint load transfer system.

### **2.9 Linear cracking**

Linear cracks divide the individual slabs into more than two parts and extend across the entire slab. The phenomenon of linear cracking is also referred to as panel cracking. Linear cracking will affect the riding quality of the pavement. Linear cracking will allow moisture movement in the body of pavement, as a result of which erosion of base or subbase may take place, which may lead to loss of soil support to the pavement. If not sealed the cracks may spall and disintegrate. The possible causes of linear cracking are heavy traffic, temperature gradient, curling of slabs, moisture stresses and loss of soil support. Crack sealant can be used to seal linear cracking. If linear cracking leads to panel cracking, then the pavement is restored by full-depth repair.

### **2.10 Durability cracking**

Durability cracking ("D" cracking) is characterized by sequence of crescent-shaped closely spaced hairline cracking pattern. "D" cracking occurs adjacent to joints, cracks or free edges and it normally starts from slab corners. Cracking pattern is characterized by dark colouring of the affected and surrounded area. Aggregates that are susceptible to freeze-thaw are responsible for "D" cracking and due to which roughness of pavement surface, spalling and eventual disintegration of pavement may take place "D" cracking is the problem of aggregates which are susceptible to freeze-thaw damage. The affected pavement can be refurbished by partial-depth or full-depth repair, depending on the severity of the damage but the problem may persist if the aggregates remain vulnerable to freeze-thaw attack.



Figure 10 "D" cracking

Figure 11 Corner break

### **2.11 Corner break**

A crack that intersects the joint of the pavement near the corner of the slab (within 200 mm) is called corner break or corner crack. It can extend through the entire slab. The causes that are responsible for corner break are high corner stresses, loss of soil support, curling and warping stresses and ineffective load transfer at the joints. Corner break leads to infiltration of moisture, faulting, spalling and disintegration in the pavement slab. Full-depth repair is the solution to refurbish the pavement that suffers corner break.

### **2.12 Alkali-aggregate reaction**

In hardened concrete, aggregates containing reactive silica interact with alkali (sodium oxide and potassium oxide) present in the cement to form expansive alkali silicate gels which disrupt the concrete by forming pattern cracks.

This phenomenon is popularly known as alkali-aggregate reaction. Factors that promote this reaction are reactive aggregates (high silica content), high alkali content in cement (more than 0.6 per cent), moisture and conducive temperature (10 °C to 38°C) conditions.

Factors that promote alkali-aggregate reactions need to be controlled to keep the pavement away from this menace. Hence use of non-reactive aggregates, low alkali cement and pozzolanas can help in this regard. Controlling temperature and moisture conditions is also very helpful. It has been observed that osmotic pressure which develops on the set cement gel due to alkali-aggregate reaction is responsible for disruption in concrete. Use of air-entraining agents is found to be useful in absorbing osmotic pressure. The alkali-aggregate reaction if unchecked may cause other problems like pop-outs, spalling etc. and concrete slab may require partial-depth or full-depth repair depending on severity.



Figure 12 Alkali-aggregate reaction



Figure 13 Pop-outs

### 2.13 Pop-outs

A small piece of concrete that breaks loose from the surface of pavement concrete, either due to expansive nature of aggregate or due to low quality of material and workmanship, is known as pop-out. 25 to 100 mm in diameter and 13 to 50 mm in depth are the usual sizes of pop-outs. Pop-outs cause discomfort to riding and are not repaired unless they pose threat to tyres of vehicles. Pop-outs of greater size need to be repaired by partial-depth repair.

### 2.14 Blow-ups

Localized upward movement or shattering of the pavement slab due to increasing compressive stress at the joints or cracks is called blow-ups. During winter wide joint openings are created due contraction of concrete slabs. These joint openings are usually filled by materials like rocks or soil which are incompressible. During summer the expansion of joints is prevented by non-availability of space (occupied by incompressible material) and hence compressive stresses are induced at the joints, which may cause the slabs to shatter or move upward. Hence the blow-up is the consequence of compressive joint failure.



Figure 14 Blow-up

Spalling of the joints, “D” cracking and freeze-thaw damage will hasten the process of formation of blow-ups. Full-depth repair is the only alternative to rehabilitate the pavements which suffer damage due to blow-ups.

**III. REPAIR AND RESTORATION OF RIGID PAVEMENTS**

Most common methods of rigid pavement repair are discussed in this section

**3.1 Crack filling**

It is the process of filling crack filler into 'non-working cracks' to substantially reduce the intrusion of incompressible material and the infiltration of moisture in the pavement. Usually cracks less than 2 mm and are 'non-working' require crack filling. Low viscosity epoxy and polymer- modified asphalt are used as crack filler.

**3.2 Crack sealing**

Placement of a specialized material into 'working cracks' using unique configurations to reduce the intrusion of incompressible material and the infiltration of moisture in the pavement is known as crack sealing. Working crack is a crack in the pavement that undergoes significant deflection as well as thermal opening and closing movements greater than 2 mm. These cracks are oriented transverse of the pavement centreline. All unsound material near the crack should be chiselled out to form a trapezoidal notch of 30 to 40 mm deep with width at the bottom of the notch slightly more than at top for better interlocking. After thoroughly cleaning, the notch is given a tack coat and then sealed using epoxy resin mortar.

**3.3 Stitching**

It is a repair technique to maintain aggregate interlock at the point of cracking and to provide added reinforcement and strength to the pavement. Stitching is carried out for strengthening longitudinal cracks in slabs. Stitching is also adopted to alleviate the problems of omission of tie bars during construction, to tie roadway lanes and centreline longitudinal joints of pavements. There are three types of stitching used; cross-stitching, slot-stitching, and U-bar stitching. Cross-stitching is the most widely used method. In cross-stitching, holes are drilled at an angle so that they intersect the longitudinal cracks or joints at about mid-depth of the slab. Dusts are removed by compressed air and epoxy is injected into the holes. Tie bars are inserted and excess epoxy is removed. In slot-stitching, slots with lengths no smaller than 600 mm are cut approximately perpendicular to the longitudinal joints or cracks using a slot cutting machine or walk- behind saw. Slots are prepared by removing the concrete and cleaning the slot. Deformed bars are placed and backfill material is applied, finished, and cured. In slot- stitching, the concrete slabs are held together by the shear stress of deformed bars. It is important to provide high strength backfill material and good consolidation around the bars and concrete surface.



Figure 15 Slots and U-bars

In U-bar stitching, slots are cut using a slot cutting machine and concrete is broken and removed by pneumatic hammer. In this method, anchoring action by the U-bars provides most of the restraining force. Proper backfilling around the ends of the U- bars is important.

**3.4 Partial depth repair**

This method is used to correct several distresses which are mentioned in section. Identification of deteriorated concrete, demarcation of repair boundaries, removal of distressed concrete, cleaning, joint preparation, application of bonding agent, placing the patching material, texturing, curing and joint sealing are the sequential operations before the pavement is opened to traffic. Cementitious grout is usually used as bonding agent. The patch mixture should have strength of the concrete of the existing pavement. The repaired patch is often cured by a curing compound which should be applied as soon as possible to avoid occurrence of shrinkage cracks. If properly done the partial depth repairs can perform well for 3 to 10 years [11].





Figure 16 Patch repair

### 3.5 Full depth repair

Structural integrity and functioning of rigid pavements can be restored by full depth repairs. Here full depth of part of the slab is removed and replaced by new concrete patch. The reasons for full depth repair are already mentioned in section 4.2. The sequence of operations in case of full depth repair are similar to that of partial depth repair but with an addition of provision of load transfer devices, as for most jointed pavement dowel bars are essential for load transfer. 32 mm dia. dowel bars at 300 mm spacing are usually inserted by means of automatic dowel drilling rigs. The holes of the dowel bars are grouted after insertion of dowel bars. The opening time of the full depth repair patch depends on the attainment of required strength. As conventional concrete is slow to gain strength, it is required to modify its property to allow early opening.

### 3.6 Dowel bar retrofit

This rehabilitation technique is applicable to only jointed concrete pavements. Low load transfer efficiency (less than 60 per cent), greater faulting and differential deflection of pavement slab are the reasons for dowel bar retrofitting. Slots of required size are cut using diamond saw slot cutters. Dowel bars are then placed in the prepared slots and then the slots are back filled. Backfill materials should have similar thermal properties to the concrete, provide strong bond to the existing concrete, be fast setting, have little shrinkage, and develop enough strength to allow traffic in a short time. High early strength concrete is used for this purpose. High early strength concrete usually contains ASTM Type III cement, accelerators, and aluminium powder. Accelerators and aluminium powder improve set times and reduce shrinkage. Aggregates in the mix should be small enough to allow the concrete to flow around the bar and consolidate properly. Consolidation of backfill material is done with a small spud vibrator. Care should be taken not to hit the dowels with the vibrator, since touching dowels with a vibrator will knock it out of alignment. Once the backfill material is applied, the surface is finished flush with the surrounding surface. Curing compound should be applied as soon as practical.



Figure 17 Dowel bar retrofitting



### 3.7 Diamond grinding

Diamond grinding removes a thin layer at the surface of hardened concrete pavement using closely spaced diamond blades. It is often used to restore or improve ride-ability of pavement. It is also used for removing bumps in the newly placed concrete pavement, especially at the transverse construction joints. The level surface is achieved by running the blade assembly at a predetermined level across the pavement surface, which produces saw-cut grooves. The uncut concrete between each saw-cut breaks off more or less at a constant level above the saw-cut grooves, leaving a level surface with longitudinal texture.

## IV. CONCLUSION AND RECOMMENDATION

❖ Many type of cracks such as uncontrolled transverse full depth cracks, plastic shrinkage cracks, full depth cracks near slab culverts, cracks over dowel bars etc. have been observed on the concrete road projects that have been completed recently. All such cracks can be prevented or 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.

❖ These types of repairs are carried out within the panel. If the crack wider than 1.5 mm is experienced within 1 -1.5 metre at the transverse or longitudinal joint it is always necessary to carry out full depth repair i.e. to cut the panel to the full depth and redo the concreting after removing the old concrete.

❖ Staple pin and cross bar stitching helps in arresting the cracks and avoid further deterioration of the panel and the sub-base. The reason for carrying out stitched crack repair is to convert the crack into a tied warping joint which will allow the slab to “hinge “at that point whilst preventing the crack from becoming wide thereby enhancing the life of slab.

❖ The presence of boulders in subgrade material should not be more than 75mm or 1/3 of layer thickness, to avoid the chances of settlements.

The presence of any foreign/organic materials in subgrade should not be allowed. The compaction for formation, subgrade and sub-base should be strictly as per specifications.

❖ The sealing of all kind of cracks in PQC must be done instantly with approved material to avoid/arrest the further development; however final repair and rectification may be taken up subsequently. Wherever full panel replacement is required, it should be done along with sub-base, to avoid the chances of re-occurrence of cracks. Following are some product for instant sealing of cracks:

- Delpatch-Elastomeric concrete or equivalent
- Fosroc-Nitofill LV, Rendroc CS crack filler, Rendroc Plug or equivalent

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