TYPES OF CRACKING IN CONCRETE PAVEMENT, ITS CAUSES AND PREVENTION

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Abstract -Nowadays, Concrete pavements are widely used over flexible pavement due to its heavy load carrying capacity and providing long-lasting solutions in highways, bridges and airports. Even if the pavements are well designed and properly constructed, some distresses occur in concrete pavement such as joint spalling, faulting, cracking, pumping, punch out etc. Among these distresses, cracking commonly occur in concrete pavement. This paper will help to understand the most commonly occurring cracks in concrete pavement. Different types of cracks, causes of cracks, identification of cracks are discussed in this paper. Above all, some preventive measures for each type of crack is also mentioned in this paper.

Key Words:*Concrete pavement, longitudinal cracking, transverse cracking, corner cracking, D- durability cracking, shrinkage cracking.*

1.INTRODUCTION

Transportation has been one of the essential components of the civil engineering profession since its early days. The transportation by road is the only road which could give maximum service to one all. This mode has also the maximum flexibility for travel with reference to route, direction, time and sped of travel. It is possible to provide door to door service only by road transport (Saurabh Jain et.al)[1].

Pavement is the actual travel surface especially made durable and serviceable to withstand the traffic load commuting upon it. A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable lightreflecting characteristics, and low noise pollution. The ultimateaim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub grade (Milind V. Mohod et.al.)[2].

Rigid pavement carries higher flexural strength than flexible pavement i.e. it carries bending and deformation without rupture under wheel axial load. Life span of rigid pavement is more than the flexible pavement with low maintenance cost. Initial cost of rigid pavement is higher but when comparing total cost of pavement through life span rigid pavement is more economical than flexible pavement. Rigid pavement is economical than flexible pavement and there is a need to developed it and used in transportation infrastructure in future (Milind V. Mohod et.al.)[2].

The main distress occur in rigid i.e concrete pavement is cracking and it is need to be controlled. The faults in every step of producing rigid pavement leads to concrete deterioration, micro cracks and wider cracks (ChatarinaNiken et.al ,2017)[3]. There are many types of cracks such as the tearing of concrete through paver, plastic shrinkage cracking at pavement surface, map cracking (craze cracks), transfer and oblique cracks within the panel, random longitudinal cracks within the panel, corner cracks (break at panel corner), random transverse cracks at or near transverse joints, random longitudinal cracks at or near longitudinal joints, and cracks in front of saw during joint cutting (A.M. Mosa, 2015)[4].

This paper provides a perspective on concrete pavement by focusing on types of cracks, its identification causes of cracking and prevention or control of cracking in concrete pavement.

2.TYPES OF CRACKING,ITS CAUSES AND PREVENTION

A.Longitudinal cracking

Longitudinal cracks are individual and run parallel to the centerline. Most of the longitudinal crackings are found to be occur on the roads with the widened slabs and tied concrete shoulders (Danny X. Xiao, 2018)[5]. The longitudinal cracks propagated through cement and did not pass through aggregates. This implies that the cracks occurred in the early age of concrete before the pavement was open to traffic and the primary load was the environmental load. The longitudinal cracks were normally discovered near the central area at the transverse joint and far from the edge of the slab (YoungukSeo et.al, 2012)[6].

This type of cracks are mainly form due to inadequate longitudinal joint forming, inadequate base support. FE analyses indicate that the longitudinal cracking potential would be greatly increased under (1) heavier traffic load; (2) a thin and/or widened slab; (3) less temperature gradient (or a warmer region) (Danny X. Xiao,2018)[5]. Dowel bars provide excellent load transfer at transverse contraction joints, which help prevent faulting distress. Therefore mainly longitudinal cracks are formed due to weak slab support (Dar Hao Chen et.al, 2007)[7]. primary causes of longitudinal cracks at joints were found to be related to the vertical translation of dowel bar and the curling of the JCP slab due to environmental loading.

Other factors affecting those cracks included concrete elastic modulus, concrete thermal expansion coefficient, foundation stiffness, vertical temperature gradient, and bond characteristic between concrete and dowel bar (YoungukSeo et.al ,2012)[6]. Late or Shallow Saw Cutting of Longitudinal Saw Cut Joints and Aggregate Materials with High Coefficient of Thermal Expansion Caused Longitudinal Cracks (Dar Hao Chen et.al, 2007)[7].

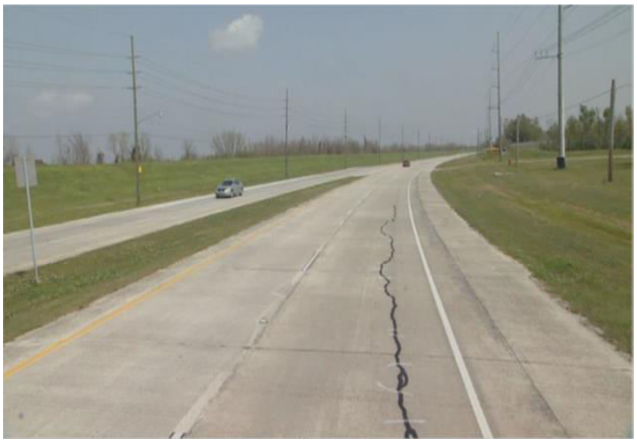

Figure 1.Typical examples of longitudinal cracking of JPCP pavements in Louisiana (Danny X. Xiao,2018)[5]

Besides the effects due to construction, materials, base and subgrade support, the FE analysis results clearly manifest that the longitudinal cracking on JPCP pavements may be better controlled when the geometry of a slab (length, width, and thickness) is appropriately designed (Danny X. Xiao,2018)[5]. To mitigate longitudinal cracking at joints, dowel bars should be installed at the mid-depth of the slab and cares must be taken when installing dowel bars to prevent their vertical translation (YoungukSeoet.al ,2012)[6].

B.Transverse Cracking

Cracks perpendicular to the pavement's centerline or laydown direction. Transverse cracking is an important CRCP design parameter affecting the prediction of crack width, crack load transfer efficiency, and critical stresses leading to longitudinal cracking and punchout development (Olga Selezneva et.al)[8].

Finite element models such as ABAQUS, 3DPAVE, EVERFE, ILLI-SLAB, ISLAB, KENSLAB, and JSLAB are needed for accurate modeling of curling stresses and deflections, as well as for combined loading (i.e., multiaxle vehicle loading in the presence of curling) (Will Hansen et.al)[9].

In JCP, Longer joint spacing leads to a greater number of transverse cracks per slab. This is due to the larger curling stresses associated with longer slabs. Pavements containing slag or recycled concrete coarse aggregate appear to have more transverse cracks than those using natural gravel or carbonate aggregates. Natural gravel pavements having tied concrete shoulders demonstrated significantly fewer transverse cracks than those having asphalt shoulders. High temperatures cause downward curling and thermal expansion of the slab, which result in tighter crack widths and better potential for aggregate interlock load transfer (Michael A.Frabizzio et.al,1999)[10]. Built-in negative temperature gradients from hot weather construction have the effect of shifting the entire temperature gradient distribution such that the slab is predominantly upward curled. This condition in turn greatly increases loss of slab support, which was the major factor promoting premature top-down mid slab transverse cracking for a jointed plain concrete pavement (JPCP) (Will Hansen et.al)[9].

The FE model indicated that two controlling mechanisms may contribute to the initiation of transverse cracking in CRCP: build-up of uniform compressive longitudinal stress at the pavement surface and tensile stress concentration in the vicinity of the transverse steel bars (I. L. AL-QADI†* et.al, 2006)[11].

The use of tied concrete shoulders essentially eliminates the critical midslab free edge load condition and thus reduces slab stresses in JCP. Maintaining adequate aggregate interlock load transfer across these cracks isessential to preserving the functional and structural integrity of these pavements (Michael A. Frabizzio et.al,1999)[10].

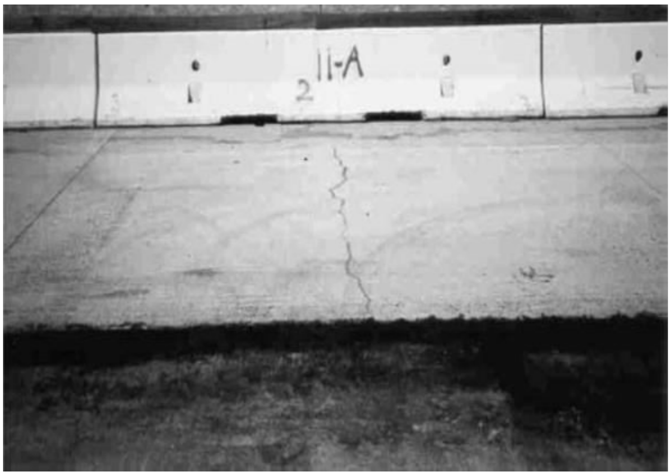

Figure 2. Transverse crack from environmental loading (Andrew C. Heath et.al ,2014)[12]

Mechanistic–empirical design procedures for continuously reinforced concrete pavement (CRCP) require characterization of variations in major design parameters so that a new or rehabilitated pavement can be designed for a desired level of reliability (Olga Selezneva et.al)[8]. Practically widened slab and tied shoulder have been proved to effectively reduce transverse and corner cracking, but the negative effect on longitudinal cracking (Danny X. Xiao,2018)[5].

C.Corner Cracking

Corner cracks may occur either at the edge of the slab or where the transverse joint intersects with the longitudinal joint. A mechanistic analysis of rigid pavements with only linear temperature gradients and a single loaded area used to predict bottom-up transverse cracking under edge loading in almost all situations (Andrew C. Heath et.al ,2014)[12].

Corner cracks are usually caused by heavy traffic over a corner that does not have adequate support. Support may have been lost because the slab curled, because the sub base was not originally compacted properly, or because of the phenomenon of pumping of sloshy sub base material up through the crack by the action of traffic in wet weather. Corner cracks may occur either at the edge of the slab or where the transverse joint intersects with the longitudinal joint. If nothing is done about them they work themselves free and sink. At the edge of the pavement they may move horizontally as well.

Temperature differences between the top and bottom of PCC slabs cause the pavement slabs to curl. The direction (lifting or dropping of the slab corners) and amount of curling depend on the sign and magnitude of the temperature gradient (H. Thomas Yu et.al)[13]. When the tensile stress induced by either traffic or environmental loading or both exceeds the tensile strength of concrete, aconcrete slab would crack in transverse, longitudinal or corner cracking types (Danny X. Xiao,2018)[5].

Loss of slab support aggravated by built-in upward curling or warping, if moisture effects are present, is undesirable since it can lead to premature failure in the middle of short slabs in jointed plain concrete pavement (JPCP) in terms of corner cracking, transverse cracking, and joint faulting if joints are not doweled (Will Hansen et.al)[9].

Figure 3.Corner cracking from HVS loading (Andrew C. Heath et.al ,2014)[12].

Using finite-element analysis, found that residue negative gradients due to built-in temperature curling and differential drying shrinkage together with traffic loading can cause either longitudinal, transverse, or corner fatigue cracks depending on the slab geometry and shoulder type (J. Hiller,2002)[14].

D. Durability Cracking

D-cracking is associated primarily with the use of coarse aggregates in the concrete that disintegrate when they become saturated and are subjected to repeated cycles of freezing and thawing. The cracking originates in the coarse aggregate particles and then propagates through the mortar matrix surrounding the aggregate (Donald R. Schwartz et.al.,1987)[15].

D-cracking is generally found initially at longitudinal and transverse joint intersections and later at transverse cracks. The deterioration starts in the corners and progresses along the joints with transverse joints usually exhibiting the most rapid damage.

A series of slightly inclined cracks develop in the concrete, usually starting at the bottom of the slab and working upward. Signs of D-cracking on the pavement surface include a series of closely spaced cracks that are generally parallel to transverse and longitudinal joints and cracks and to the pavement free edges and may be filledwith a dark deposit at the pavement surface (Donald R. Schwartz et.al.,1987)[15].

It is important to use a high quality durable aggregate; or if use of moderately susceptible sources is necessary, use a suitably small maximum particle size. Some aggregates, such as high quality dolomite and rocks of igneous origin are not so prone to such cracking. The option of full depth concrete pavement removal was the preferred option duringthe pre-design. Full removal would eradicate the D-cracking issues by taking the concrete containing the poor aggregate away from the site. Additionally, the replacement would allow the airport to maintain the current loading levels on the runway (Jason Fuehne et.al, 2014)[16].

The use of vacuum impregnation with nanoparticles was found to only slightly improve the performance of poor freeze-thaw durable aggregates. The use of the silane/siloxane based sealers was found to slightly improve the performance of the aggregates, whereas the use of the potassium methyl siliconate sealer did not (Kyle A. Riding et.al.,2015)[17]. Improvements in resistance of coarse aggregates to freezing and thawing

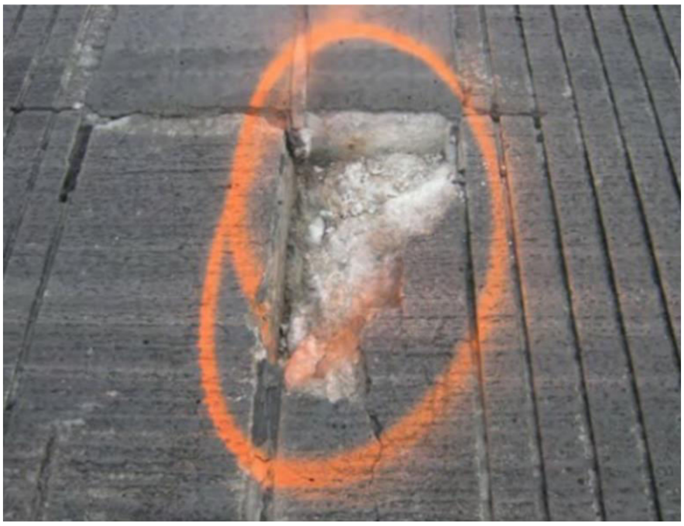

Figure 4. Durability cracking in concrete pavement (Jason Fuehne et.al, 2014)[16].

can sometimes be accomplished through aggregate beneficiation techniques, including reducing the nominal maximum size of coarse aggregate particles, mechanical separation, and blending. Reducing the maximum size of coarse aggregate particles is considered the best technique and aggregate blending is the least desirable (Donald R. Schwartz et.al.,1987)[15].

E.Shrinkage Cracking

Shrinkage cracks in concrete occur due to change in moisture of concrete. Concrete and mortar are porous in their structure in the form of inter-molecular space. They expand when they absorb the moisture and shrink when they dry. This is the main cause of concrete shrinkage cracks on drying. The typical causes of cracks in concrete pavement are the hydration cracking at early hydration state ofconcrete, the plastic shrinkage cracking, the environmental cracking caused by thermal changes at the top of the pavement, the drying shrinkage cracking according to the hardening of concrete, and the cracking caused by the long-term process of alkali-silica reaction (S. Y. Choi et.al,2011)[18].

The cracking pattern varies with the length of the elastic bar (i.e., the spacing between the two possible cracks), from which the minimum and maximum crack spacings can be obtained. Numerical analyses can be made of a model pavement and the results indicate that it is the energy minimization principle that governs the cracking pattern. The practical spacings can be evaluate by numerical analyses fall within the minimum and maximum crack spacings (G. Chen et.al,2004)[19].

Figure 5. Early-age plastic shrinkage cracking (Lei Yu et.al,2011)[21]

Polypropylene fibers are highly effective in controlling plastic shrinkage cracking in concrete. In general, fibers reduce the total crack area, maximum crack width and the number of cracks. As fiber volume fraction increases, effectiveness of fiber reinforcement increases. Longer fibers and low denier fibers were more effective in reducing crack areas and crack widths. Finally, fibrillated fibers were more effective in controlling shrinkage cracking than their comparable monofilament counterparts (NemkumarBanthia et.al, 2006)[20]. Single fiber reinforcement provides the largest reduction of the drying shrinkage while mix with hybrid fiber reinforcement develop the smallest shrinkage (S. Y. Choi et.al, 2011)[18].

In recent years, most of researchers have adopted the evaporation rate as standard for discriminating whether the early-age plastic shrinkage cracking happens or not. Meanwhile, most construction companies have also considered the evaporation rate as the index to assessing whether or not. However, the early-age plastic shrinkage still happens in many constructions by now, which shows that the evaporation rate indexes can't discriminate the cracking appearance situations absolutely and accurately, the more accurate discrimination method is needed (Lei Yu et.al,2011)[21].

3.RECOMMENDATIONS

Based on the findings of the present study and the experience of the authors, the following key recommendations are made:

1. Determine whether the cracks are isolated or widespread and gather information relevant to the possible causes of cracking in concrete.
2. Develop a database to record, analyze, and examine the formation and causes of different cracks in concrete. The type, source, and location of cracks may vary. The database will allow for more accurate prediction and simulation of cracks.
3. Apply an iteration process to identify one or more major causes and verify the major causes one by one with field observations.
4. Collect samples by coring and conducting laboratory testing when more rigorous data evaluation is required.
5. Thoroughly review all materials and design features as well as check the major construction procedures if the cracks are widespread.
6. Coat dry cement powder on the concrete surface in the presence of bleed water to reduce the probability of the formation of cracks in newly placed concrete elements.
7. Investigate how the structural capacity and function of concrete elements are affected due to various type of cracking.
8. Employ one or more nondestructive on-site assessment such as ultrasonic testing and elastic modulus measurement through ambient response method to monitor and assess the early-age concrete properties that are intimately related with the early-age cracking in concrete elements.
9. Improve workers skills by providing necessary training prior to placement in concrete construction jobs.
10. Allow third-party assessment for the analysis of crack-causing factors and the necessary remedial measures.
11. Develop models that can represents the effect of reinforcement, particularly in the case of high-strength concrete (Md. Safiuddinet.al. ,2018)[22].

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