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Repair and rehabilitation of concrete pavements

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Abstract:- This paper provides an overview of the current methods of analysing and repairing cracks in concrete pavements. The Finite element method (FEM) models and non-destructive analysis method, and the repairing methods using electro-deposition, electro chemical, recycled steel fibres are reviewed.

Keywords:- Finite element method, Electro-deposition, Recycled steel fibres, Industrial steel fibres, Non-Destructive analysis

I. INTRODUCTION

Cracking of pavement surfaces is the main cause of deterioration of roadways. The surface water penetration reduces the strength of the sub-base layers, leading to the formation of wide cracks and potholes. Pavement cracks have many different shapes, occasionally with complex morphologies. Nonetheless, crack patterns existing on pavements are generally classified into the following four categories: (1) alligator cracks, (2) block cracks, (3) transverse cracks and (4) longitudinal cracks [1]. In concrete pavements, the repeated application of traffic loads along with temperature variation may lead to initiation of cracks at the highly stressed locations. The cracks propagate through the pavement which may finally lead to failure of pavements due to fatigue. Due to temperature alone, cracks may also be initiated in the newly-constructed pavements. Variation in temperature affects the stresses in concrete slab in two ways. The daily variation in temperature causes quick changes in thermal gradients through the depth of concrete slab, while the seasonal variation results in different average temperatures in concrete slab. The concrete slab will tend to curl upward or downward when it is subjected to an increasing or decreasing temperature variation through its depth. Due to its self-weight, the slab is not allowed to curl, resulting in the development of curling stresses in the pavement [2].

II. METHODS OF ANALYSING CRACKS AND CRITICAL STRESSES

Several researchers have worked in this area, and published their findings on various methods of analysing cracks. A few methods suggested are discussed below in this review.

A numerical study of periodic cracks that appear on surface layer of the pavements is done using finite element method. The FEM model is described by Chang Xu, et al [2]. From the numerical study the evolving process of periodic cracks is generalised in three stages. When the horizontal stress reaches its tensile strength two cracks form at the weaker points initially. The new cracks formed will infill the earlier formed cracks, and hence the crack spacing decreases in the following stage subsequently. No more cracks are formed when the crack spacing reduce to a certain limit even with the increase in external load [3]. From the parametric study conducted by Chang et al. [2] indicate that there is a significant influence of surface layer thickness on crack spacing, while the effect of thickness of the base layer is slight. There is linear increase of crack spacing with increase of surface layer thickness. The properties of the surface layer and base layer that affects the crack spacing layer are tensile strength and elastic modulus. [2]

In an article by Piotr Mackiewicz [3], thermal stresses were analysed in relationship to different diameters of dowel bars. The studies were focused on stresses distributed around the dowel bar and caused by thermal differences. The analyses were carried out using finite element method (FEM). Based on the 3DFE model created stresses were calculated for different diameters of dowels and thermal differences. The calculations indicated that harmful tensile stresses can concentrate in a concrete slab on both sides of dowels with small diameters. They can exceed acceptable values for large thermal differences with the presence of vehicle load. No significant influence of dowel diameter on stresses in the middle of concrete slab was found. The study carried out can be useful in the selection of dowel diameters for concrete pavements in regions with differentiated thermal differences, e.g. in Central Europe (5˚ C to 16˚ C). The 3DFE model is described by Mackiewicz [3].

The common rehabilitation technique for Portland Cement Concrete (PCC) or Asphalt concrete (AC) is placing hot-mix asphalt (HMA) overlay on top of the deteriorated pavements. However there is reflexive cracking problem on HMA surface. The crack formed in HMA reflects the cracks and joints in the old pavements which is a reflexive cracking phenomenon. The cracks in the old pavements act as stress concentrators by increasing overlay stresses and reduce the bending stress of HMA surface. When stress at bottom of HMA overlay exceeds the HMA strength there is a movement at the crack and joint locations. The bending and shearing stresses developed in the HMA overlay due to wheel loads are shown in Fig.1.When the wheel load is directly on top of the crack or joint the underlying pavement structure moves horizontally. A plane strain FE model was constructed including (1) a cyclic pattern of a moving traffic wheel load is applied, (2) a temperature differential simulating typical seasonal pavement temperature distributions, and (3) for simulating the time dependent properties of the HMA overlay a linear viscoelastic constitutive (LVE) model. The LVE model is implemented using Prony series expansion parameters characteristic of typical HMA overlays, (4) the accumulation rate of shear strain increases with overlay thickness for positive pavement temperatures and decreases for negative ones; and (5) the accumulation rate of shear strain at winter temperature conditions is more than the calculated for spring conditions and for low speeds only (8 km/h); the opposite will be true as the speed increases to 48 km/h [4].

A non-destructive method of analysis of cracks is done for massive concrete structure by E. Taillet, J.F. Lat,Riv, A.Den [5]. Here electro resistivity method is used for study of cracks and discontinuities in massive concrete structures by measurements done in pre-existing bore holes. Electrical probe detects damage zones and characterizes centimetre or millimetre cracks with infinite extension. This method is effective to locate, detect and characterize isolated cracks. It also shows that the normal electrical probe detects a set of cracks as a thin conductive layer. For the details of DC current and resistivity parameters, one can refer E. Taillet, J.F. Lat,Riv, A.Den [5].

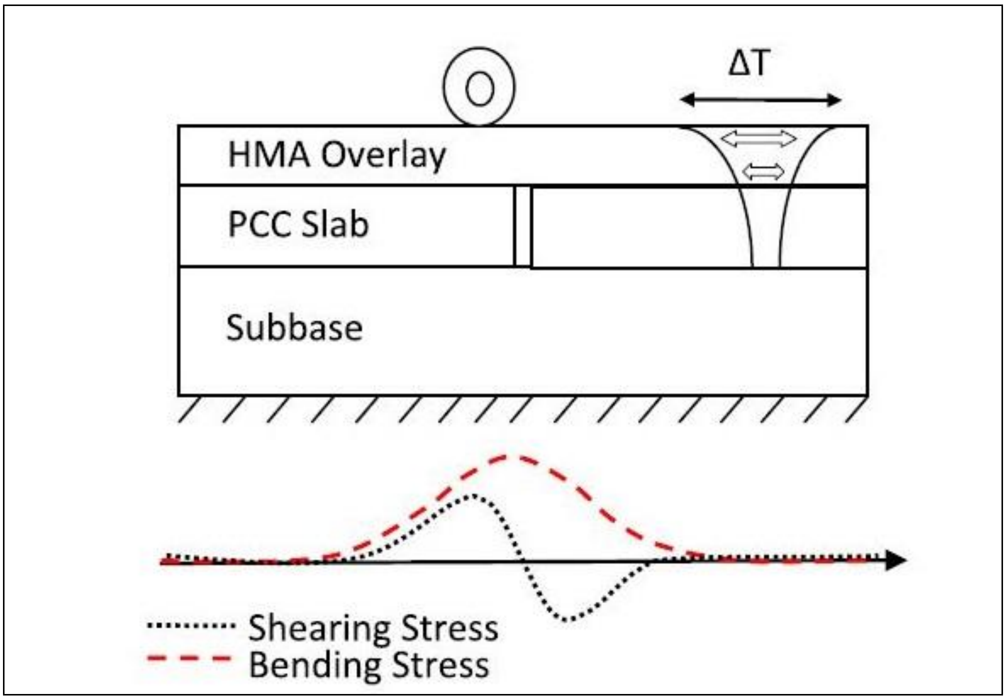

Fig.1. Shearing stress and Idealized bending due to vehicular loading and expansion-contraction movement of the pavement structure due to temperature variation [4]

III. METHODS OF RE REHABILITATION AND REPAIR

A review study is done on various methods of repairing the cracks and their rehabilitation techniques. The key method involved in the research findings are described and discussed below.

Varenyam Achal, et al. made a study on improving the durability, and remediate the cracks in concrete structures by Biogenic treatment. An attempt of repairing cracks is done by bacteria using microbially induced calcium carbonate [6]. Remediation cracks in building materials demonstrate microbially induced calcium carbonate precipitation. The strength and durability of the building structures is improved by crack sealing process. Moreover this method can bring self-healing ability to structures [6].

The electrodeposition method for rehabilitation of cracked reinforced concrete, based on the electrochemical technique, is presented by Jae, Nobuaki [7]. Fig. 2 shows the electrodeposited concrete surface. Based on observation it is seen that electro-deposition occurs uniformly over the concrete surface and along the crack. For examining the water tightness of electro-deposited concrete the modified permeability test is conducted. Fig. 3 shows the relation of coefficient of permeability at the crack of 0.2 and 0.6 mm in width with duration or test period. The results show that the permeability coefficients of electrodeposited specimens are less than that of non-charged specimens, and the values are 3.2×10^{-8} cm/s (the crack of 0.2 mm in width after 8 weeks of charging). This permeability value obtained is much less for cracked specimen and almost equal to non-cracked specimens. The electro-deposition helped in closing of concrete cracks and refinement of concrete surface which intern helped in decreasing the permeability. The results of permeability test indicate that the surface quality of concrete is improved by electro-deposits and permeability coefficient of specimen is decreased [7].

An attempt of repairing of cracks is done by Chu Hongqiang, et al [8] using electro chemical method. This method is made for repairing cracks in concrete for both the marine engineering and the land engineering structures. During the study, rebar in the cracked marine concrete structure was used as cathode, and insoluble electrode was placed in the seawater as anode. After applying weak current between cathode and anode, the cations and anions move toward the two electrodes due to the potential difference. The ions generate a series of reactions and finally form deposits on the surface and in the cracks of marine concrete structure so as to cover the concrete surface and repair the cracks. Those deposits provide a physical protection layer to the concrete and prevent various hazardous substances from corroding concrete to a certain degree [8].

In an article by Angel, et al [9] the concrete pavements are reinforced with recycled steel fibres obtained from post-consumer tyres which are used as fatigue reinforcement. An experimental programme is done in which cyclic flexural loads are applied on concrete prisms. Considering fatigue alone the pavement thickness is reduced up to 26% when the recycled steel fibres are used. The micro-cracks to meso-cracks propagation is restrained by Recycled steel fibres and macro-cracks are efficiently held together when industrially produced steel fibres are used. Hence it can be seen that using a combination of both recycled and industrially produced fibres will enhance the fatigue strength and also increase pavement life by arresting the macro-cracks [9].

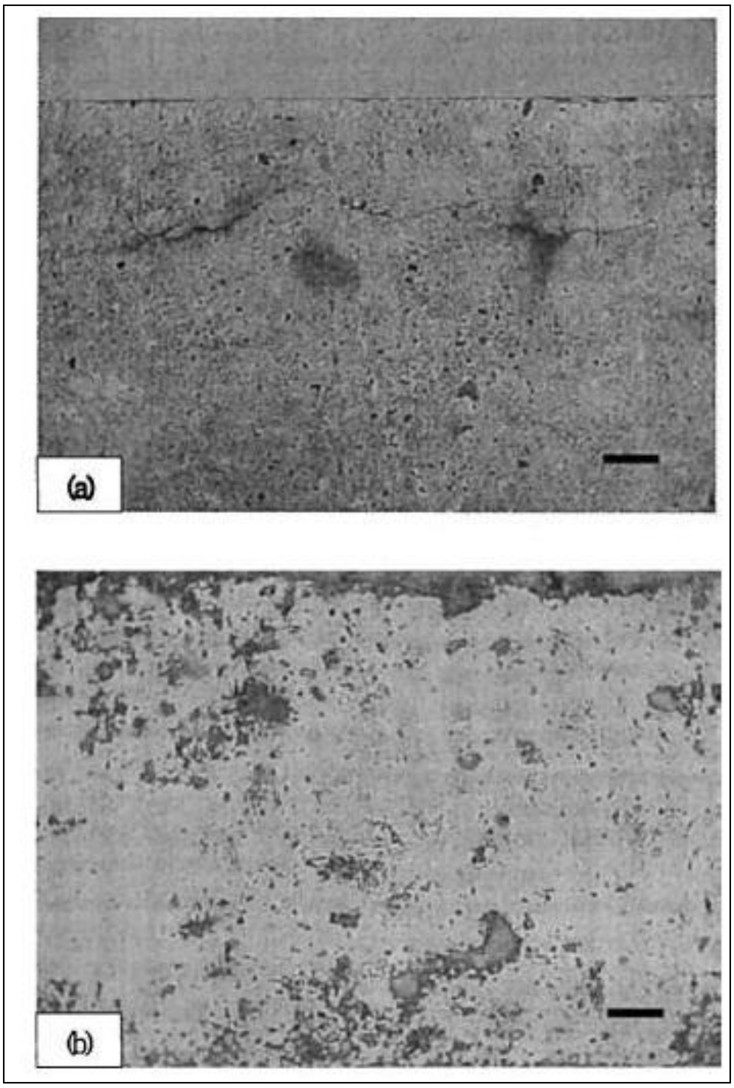

Fig.2 Electro-deposits appearance on the surface:
(a) Before charging, (b) 8 weeks after charging. Bar: 1 cm [7]

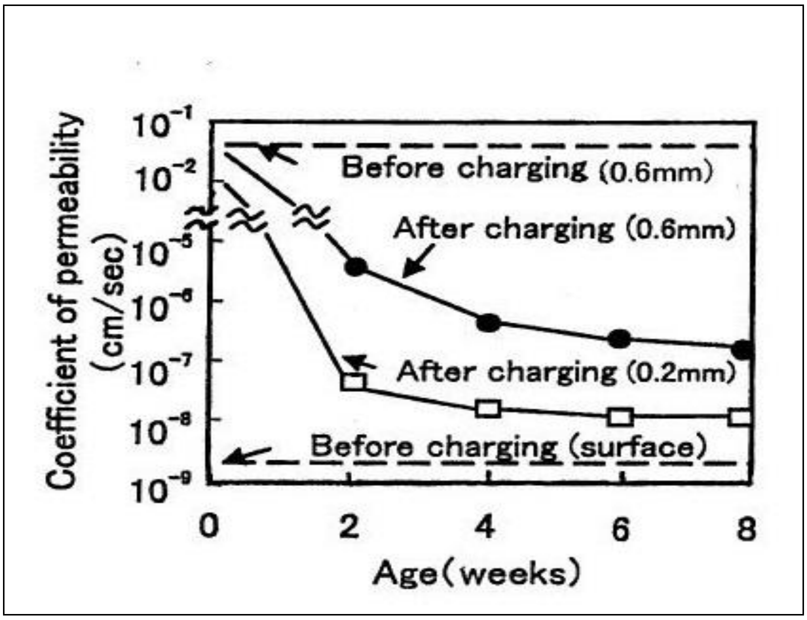

Fig. 3 Coefficient of permeability versus age [7]

IV. CONCLUSIONS

[1]. Using dowels of small diameters increases stresses around the dowels. However, the studies carried out in [4] can be useful in the selection of dowel diameters for concrete pavements in regions with large thermal differences, e.g. in Central Europe.

[2]. While a non-destructive type of analysis is meant for massive concrete structures, it is not economical to use the suggested method [6] for rigid concrete pavements whose thickness is very less compared to massive concrete structure like dams.

[3]. Electro chemical method of repairing cracks [9] is an effective method for marine structures, there is need of for further development in technology to support this method.

[4]. Use of recycled steel fibers obtained from tires as fatigue reinforcement [10] is less effective when compared to industrially produced steel fibers. However, the use of industrially produced steel fibers in pavements will be uneconomical.

[5]. FEM analyses indicate that the surface layers have a significant influence on crack spacing. Using new design constants and values obtained from FEM analysis to design concrete pavements may increase the resistance to cracking.

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