TEXAS TECH UNIVERSITY
Multidisciplinary Research in Transportation

PROJECT SUMMARY

Texas Department of Transportation

0-7026: Optimizing Reinforcing Steel in 12-inch and 13-inch Continuously Reinforced Concrete Pavement (CRCP)

Background

Over the years, slab thicknesses of CRCP in Texas have increased – from 6 to 8 inches until the early 1970s, 6 to 10 inches until the middle of the 1980s, 8 to 15 inches until 2008, and 6 to 13 or 15 inches since then to address the increase in truck traffic. This increase in slab thickness resulted in better CRCP performance; however, certain aspects of longitudinal steel designs, such as steel depth from the surface of the slab, were not adjusted and the required steel depth remained at the mid-depth of the slab. This large steel depth provides less restraints on concrete volume changes above the steel, resulting in less concrete stresses and larger crack spacing. Since the amount of longitudinal steel required is normally fixed at a certain ratio of the concrete cross-sectional area, the larger the slab thickness, the more steel, resulting in smaller spaces between longitudinal bars. The use of thicker slabs in Texas with one-mat steel without adjusting steel depth resulted in larger crack spacing, with unexpected distresses.

What the Researchers Did

Researchers analyzed the structural responses of CRCP using three-dimensional finite element modeling (3D-FEM) in Ansys at the depth of the longitudinal steel at transverse crack areas with various steel designs which, if excessive, could cause horizontal cracks. The output was used in selecting the steel designs that will be employed at the experimental sections. Subsequently, the researchers investigated the CRCP behaviors affected by various steel designs in the field. Four (4) test sites were identified, namely: IH35 in Waxahachie, US62/180 in El Paso, IH10 in Converse and IH35 in Hillsboro. Mid-depth, upper-depth and upper-depth low CoTE test sections were investigated in El Paso while only the first two sections were investigated in Waxahachie, Converse, and Hillsboro. Sensors were installed accordingly such as steel strain gages (SSG), 2- and 6-inch vibrating wires strain gages (VWSG), and thermocouples along the induced crack location of the slab. In addition, researchers also installed REBEL sensors, which are gages that provide real-time information of the elastic modulus development of concrete, in IH35 in Hillsboro. Early-age and long-term strain analysis in relation to environmental conditions were conducted along with the investigation of the crack patterns. Researchers also performed another 3D-FEM to simulate and compare the actual pavement behavior (i.e., concrete and steel strains). The input values used in the model such as material properties and concrete temperatures have been obtained from the field experiments. When the predicted values of the FEM models were close to the measured values, the output is used to simulate multiple steel depth conditions to be able to support the analysis of optimum steel designs.

What They Found

The findings from the numerical simulations, extensive field investigations and data analysis are summarized as follows:

- Drying shrinkage has substantial effects on concrete stresses around reinforcement at transverse crack locations. Higher drying shrinkage will result in higher stress at the top surface of the concrete and around reinforcement in the transverse crack plane. As a result, the chance of horizontal cracking increases.
- Reinforcement configurations in CRCP have substantial effects on cracking, both transverse and horizontal. In all two-mat designs considered in the simulation, concrete stresses at the top surface of the concrete are greater than those in the one-mat with mid-depth reinforcement. Therefore, it could be assumed that the two-mat design would develop shorter transverse crack spacing than the one-mat design.

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Project Completed:
08-30-2022

- The daily temperature range at the surface of the slab is more than twice the range at the bottom of the slab. In addition, the temperature at the surface of the slab is higher compared to the bottom of the slab from 12 noon until 6PM and vice versa for the rest of the hours in a day.
- The transverse crack movement is higher at the mid-depth section which indicates that, when the concrete begins to contract due to cold weather, the transverse cracks begin to widen. However, when the longitudinal steel is located at the upper-depth section, the movement is restrained generating lower crack movements compared to the mid-depth section.
- Transverse crack data showed that the crack interval at the mid-depth is higher compared to the upper-depth section during the early-age. However, it was observed in El Paso test section that, in the long-term, additional cracks propagate more at the upper-depth sections thereby reducing the crack intervals of the upper-depth section compared to the mid-depth section.
- The steel strain variation at the mid-depth is lower than the upper-depth due to the lower temperature variation.
- For vertical strains, it was observed that the mid-depth section produces higher vertical strains than the upper depth sections. The restraint provided by the longitudinal steel located at the upper depth of the slab minimizes the vertical movement of the slab. Hence, the longitudinal steel located at the upper depth provides restraint at the location where volume changes in the slab is significant, thereby reducing the stress that may initiate horizontal cracking.
- The FEM results have shown that the among the variables investigated, the transverse crack spacing has the most significant effects on concrete stress near longitudinal reinforcement at crack location: the larger the crack spacing, the greater these vertical concrete stresses.
- Coefficient of thermal expansion has a significant effect concrete stresses around the reinforcement at transverse crack plane and horizontal cracking. As the coefficient of thermal expansion increases, the concrete stress around the reinforcement increases.
- Reinforcement configurations in CRCP have substantial effects on horizontal cracking. In the two-mat designs considered, the concrete vertical stresses are smaller than those in the one-mat CRCPs. Therefore, it could be assumed that the two-mat design would develop lower possibility of horizontal cracking that the one-mat design.
- The recommended optimal reinforcement depths for one-mat CRCPs based on the simulations are as follows:
    - 11-in CRCP: 4-inch
    - 12-in CRCP: 4.5-inch
    - 13-in CRCP: 5-inch

What This Means

As the slab thickness increases, the amount of concrete above the location of the steel increases when it is kept at mid-depth. It was observed that the temperature variation at the upper half of the slab is high compared to the bottom half of the slab where it was observed to be mild in all weather conditions. When the amount of concrete is large in locations where the volume changes are high, which is the location close to the surface of the slab, the steel stress as well as crack width increases due to the absence of restraint. In addition, the vertical strains are found to be high which may increase the potential of horizontal cracking propagation. However, when the location of the longitudinal steel is shifted above the mid-depth of the slab, numerical and field test results show that the vertical strains of concrete at the location of the cracks are lower which implies that horizontal cracking is less likely to occur. Since the current design is to place the longitudinal steel at mid-depth, there is a need to reconsider elevating the location of the steel above mid-depth.

Meanwhile, the REBEL sensors installation have demonstrated its capability to provide the elastic modulus information of concrete. When successful, this new technology will be useful in determining the early-age in-situ strength of concrete without the need for destructive testing in concrete samples.