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Implications of zero-stress temperature for the long-term behavior and performance of continuously reinforced concrete pavement

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HIGHLIGHTS

- Implications of ZST for the behavior and performance of CRCP are investigated based on field evaluations.
- ZST has non-significant effects on the long-term transverse crack spacing and crack width of CRCP.
- The CRCP distresses, namely punchout and spalling, occur due to construction and material quality issues.
- The current MEPDG needs to be technically revised to include realistic long-term CRCP behavior.

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ABSTRACT

The excellent performance of continuously reinforced concrete pavement (CRCP) has been well known. Over the years, various efforts are underway to further improve the long-term performance of CRCP in terms of material, design, construction, and quality control. According to the national mechanistic-empirical pavement design guide (MEPDG) developed as part of NCHRP 1-37A, one of the material factors with a substantial effect on the long-term performance of CRCP is zero-stress temperature (ZST) of early-age concrete. However, there is no documented evidence that the long-term performance of CRCP depends on ZST. In this paper, implications of ZST for the long-term behavior and performance of CRCP are investigated. To accomplish this objective, a series of field evaluations was made in seven experimental CRCP sections with known material properties, design details, and early-age temperature histories, all of which are as old as 7–22 years after construction. Performance indicators such as transverse crack spacing, crack width, and typical CRCP distresses, namely punchout and spalling, were evaluated and then compared with the ZST to find a possible correlation between ZST and resulting CRCP performance. Results revealed that there is no strong correlation between them, which suggests needed improvements to the current MEPDG considering more realistic CRCP behavior.

1. Introduction

Continuously reinforced concrete pavement (CRCP) is a representative type of Portland cement concrete (PCC) pavement with a continuous longitudinal steel layout. CRCP is forming a major portion of the PCC roadway systems in several states in the US as well as in Europe due to its low life cycle cost, ease of maintenance, and durable nature. In such type of PCC pavement, no artificial transverse joints are cut, but it rather allows random non-structural transverse cracks, most of which typically initiated within a couple of days after construction to relieve the stresses arising from environmental interactions, such as temperature and moisture variations [1–3]. These transverse cracks are kept tight by proper longitudinal reinforcement normally placed at the mid-depth of slab, providing continuous load transfer across the transverse cracks.

Although decades of research has shown that the overall performance of CRCP is quite excellent, some performance issues are still found as the form of distresses such as punchout and spalling [4–6] as shown in Fig. 1. Especially, the latest mechanistic-empirical pavement design guide (MEPDG) developed as part of NCHRP 1-37A postulates that punchout, one of the major structural distresses in CRCP, is closely associated with zero-stress temperature (ZST) of early-age concrete, a reference temperature where tensile stresses begin to develop in concrete shortly after final setting [7–10]. Fig. 2 presents the result of sensitivity analysis obtained from the MEPDG software, indicating that the number of punchouts (per lane mile) noticeably increases as the ZST increases. This is because the punchout mechanism described by the MEPDG is based

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(a) (b)

Fig. 1. Major CRCP distresses: (a) punchout; (b) spalling.

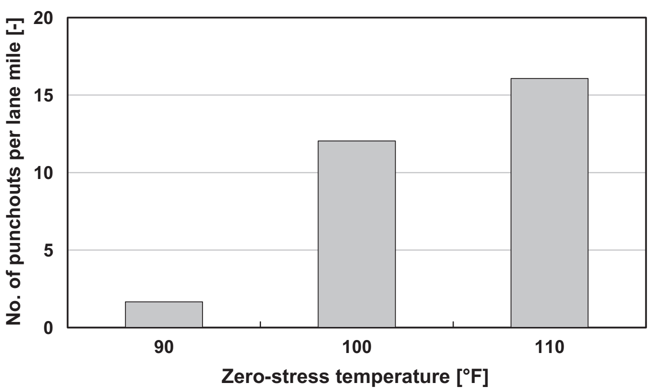

Fig. 2. Effect of ZST on the number of punchouts (°F = 1.8 × °C + 32).

on the premise that ZST affects the post-cracking behavior of CRCP, such as later-age transverse crack width and crack spacing, and in turn, ultimate load transfer efficiency (LTE) across transverse cracks. In other words, the MEPDG crack width model assumes that concrete is completely elastic, and crack width and spacing at any point depends primarily on the concrete temperature difference from ZST. The punchout development model in the MEPDG is based on the assumption that crack stiffness deteriorates as a result of increased crack width over time, resulting in a loss of LTE at transverse cracks and eventual punchouts. Accordingly, it is not surprising that the basic framework of CRCP performance in the MEPDG is substantially rooted in ZST. Eqs. (1) and (2) represent the crack spacing and crack width models used in the MEPDG [8].

$$\bar{L} = \frac{\left\{f_t - C\sigma_0\left(1 - \frac{2\zeta}{H}\right)\right\}}{\frac{f}{2} + \frac{U_m P_b}{c_1 d_b}} \quad (1)$$

where $\bar{L}$ is the mean crack spacing [in.], f_t is the concrete tensile strength [psi], f is the subbase friction stiffness [psi/in.], U_m is the peak bond stress [psi], P_b is the ratio of steel reinforcement area to concrete area [–], d_b is the steel bar diameter [in.], c_1 is the first bond stress coefficient [–], H is the slab thickness [in.], ζ is the depth to steel layer [in.], C is the Bradbury's curling/warping stress coefficient [–], and $\sigma_0 = \frac{E_{PCC}\Delta\varepsilon_{tot}}{2(1-\mu_{PCC})}$ is the Westergaard's nominal stress factor [psi]; where, E_{PCC} is the PCC elastic modulus [psi], $\Delta\varepsilon_{tot}$ is the unrestrained curling and warping strain due to thermal and moisture changes [–], and μ_{PCC} is the Poisson's ratio of PCC [–].

$$cw = Max\left(\bar{L} \cdot \left(\varepsilon_{sh} + \alpha_{PCC}\Delta T\zeta - \frac{c_2 f_\sigma}{E_{PCC}}\right) \cdot CC, 0.001\right) \quad (2)$$

where cw is the average crack width at the depth of the steel [in.]; ε_{sh} is the unrestrained concrete drying shrinkage at the depth of steel [–]; α_{PCC} is the PCC coefficient of thermal expansion [/°F]; ΔT_ζ is the drop in PCC temperature from the concrete ZST at the steel depth for each season [°F]; c_2 is the second bond stress coefficient [–]; f_σ is the maximum longitudinal tensile stress [psi]; and CC is the local calibration constant [–].

If the above crack width and crack spacing models are valid (and all other variables except ZST are fixed), CRCP placed during summer would have far wider crack opening and shorter crack spacing than that placed during winter because the summer section would have much greater ZST and subsequent temperature drop from the ZST as illustrated in Fig. 3. As a result, the aggregate interlock and resulting LTE at transverse cracks would be considerably worsened especially during winter seasons, which is more prone to suffer from punchout distress under repetitive wheel loading applications as per the conventional punchout mechanism depicted in Fig. 4. By the converse logic, when CRCP is placed during winter, it would be less sensitive to punchout distress, resulting in better-performing CRCP.

While ZST is considered such an important factor for the long-term performance of CRCP, only limited research efforts have been made to verify its actual influences. In recognition of the importance of ZST, this paper attempts to examine its implications for the long-term performance of CRCP based on a series of visual field evaluations, with a particular focus on identifying the relationship between ZST and various CRCP performance indicators, such as crack spacing, crack width, and distresses and/or repairs. The results presented in this paper would provide pavement engineers, practitioners, and researchers with better understanding of CRCP long-term behavior and open a new direction to develop a reliable design and analysis framework for CRCP.

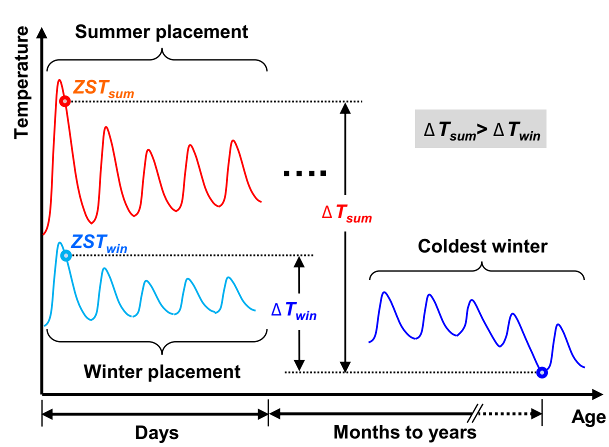

Fig. 3. Conceptual diagram showing possible effect of ZST.