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EXPERIMENTAL EVALUATION OF MISALIGNED TIE BAR EFFECTS ON PCC PAVEMENT LONGITUDINAL JOINTS

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Jointed Portland cement concrete (PCC) pavements are widely used for roadways construction. Inspection of PCC pavements revealed that it is common for tie bars across pavement longitudinal joints to be misaligned. A misaligned tie bar could inhibit the tie bars ability to provide load transfer across the joint and to prevent excessive joint opening. An experimental research study was performed to determine the effect of misaligned tie bars on the performance of pavement longitudinal joints. The experimental program consisted of testing 35 slab specimens that represented pavement sections with one tie bar placed across a joint. The test matrix included aligned tie bar configuration and four different misalignment configurations. Specimens with aligned tie bar configuration served as control specimens. The misaligned tie bar cases were vertical translation, vertical skew, longitudinal translation, and horizontal translation. For each misalignment configuration, four different misalignment magnitudes were investigated. The experimental results showed that tie bars with vertical translation, vertical skew, and longitudinal translation had negligible effects on the performance of the longitudinal joint. However, tie bars with horizontal skew resulted in reduced joint performance when compared to the aligned tie bar case.

Keywords: PCCP, Concrete pavement, Joint opening, Joint faulting.

1 INTRODUCTION

Jointed plain Portland cement concrete (PCC) pavement is a common type of concrete pavement that consists of unreinforced concrete slabs with longitudinal and transverse joints. Longitudinal joints run parallel to the direction of traffic and are typically reinforced with deformed, epoxy-coated steel tie bars that control joint opening due to thermal strains in the concrete slab. Ideally, a tie bar is placed perpendicular to the joint at the mid-depth of the slab with equal embedment lengths on both sides of the joint.

Inspections made by South Dakota Department of Transportation (SDDOT) of PCC pavements using ground penetrating radar (GPR) revealed a common occurrence of misaligned or missing tie bars. A misaligned tie bar could inhibit the bar's ability to provide load transfer across the joint and to prevent excessive joint opening.

Previous studies (Mallela *et al.* 2011) suggest that misaligned or missing tie bars could be a contributing factor to joint opening, joint faulting, and slab slippage along the joint.

2 CURRENT PROVISIONS FOR TIE BARS

AASHTO prescribes two design procedures for determining the required size and spacing for tie bars: the AASHTO Guide for Design of Pavement Structures (AASHTO 1993) and the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) (AASHTO 2008). The 1993 AASHTO design procedure is based upon the subgrade drag theory (SDT) which determines the size and the spacing of steel tie bars required to “drag” the concrete slab across the base material without yielding or pulling out of the tie bar. Thus, the force in the tie bar is limited to 75% of the yielding force. The MEPDG design guide is based upon engineering mechanics and has been validated through road test performance data. An MEPDG software is used to predict the pavement distresses and smoothness at any given time throughout the pavements lifespan. The user can then adjust the pavement design, including tie bar selection if needed, for better performance.

Many state DOT’s have adopted one or several different standard tie bar designs. SDDOT specifies #5, Grade 40 or 60, epoxy coated, deformed tie bars. The required bar length is 30 inches if installed in fresh concrete and 24 inches if installed in hardened concrete. The required tie bar spacing is 48 inches for sawed or construction joint with keyway, and 30 inches for construction joint without keyway. SDDOT also specifies vertical and transverse placement tolerances for tie bars. For vertical tolerances, all parts of the bar must be within the middle third of the pavement depth. For transverse tolerances, the bar end must be within ± 3 inches from its ideal position. However, no explanation is provided on how the placement tolerances were developed.

3 EXPERIMENTAL WORK

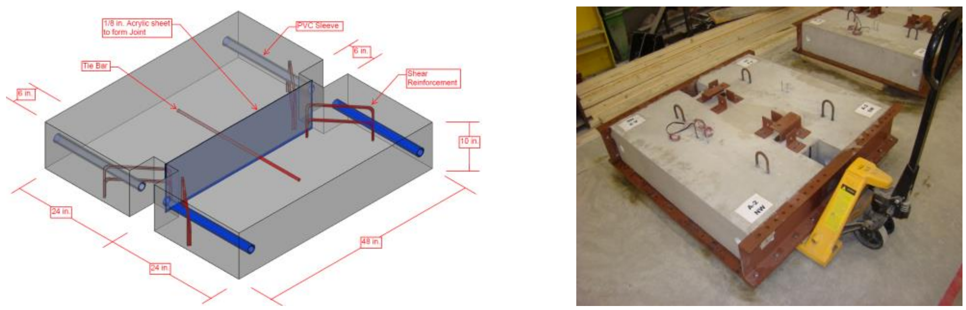
An experimental study was conducted to evaluate the effect of tie bar alignment configuration on the joint behavior and tie bar anchorage strength.

3.1 Test Specimens

A total of 35 test specimens were constructed and tested. Each specimen consisted of two 48 inch wide by 24 inch long by 10 inch thick concrete slabs that were connected with a tie bar across a full depth cold joint. The joint was formed by placing a 1/8 inch acrylic sheet between the two halves of the specimen prior to placing concrete in the mold. The tie bar used was 30 inches long, Grade 60, epoxy coated, #5 deformed bar as specified by SDDOT. The specimens were cast inside steel molds that provided the support needed at the bottom and the sides of the specimen for maintaining joint integrity until the start of testing. Figure 1 shows a schematic of a test specimen and one of the specimens inside its steel mold.

3.2 Test Matrix

The test matrix was developed to investigate the behavior of the tie bars and joint under different tie bar alignment configurations. Three identical specimens with perfectly aligned tie bar configuration were tested and served as control specimens. In addition to the perfectly aligned tie bar configuration, the following four alignment configurations were selected for testing: vertical translation, vertical skew, longitudinal translation, and horizontal skew. For each of these alignment configurations, four different misalignment magnitudes were selected. The misalignment magnitudes were based on current SDDOT tie bar placement tolerances and typical as-built conditions as identified by ground penetrating radar (GPR). Two identical specimens were built and tested for each misalignment magnitude. Table 1 shows the test matrix for the misaligned tie bars considered in this study. For comparison purposes, the SDDOT tolerances limits are also presented.



(a) Schematic of a test specimen. (b) Specimen inside steel form.

Figure 1. Test specimen.

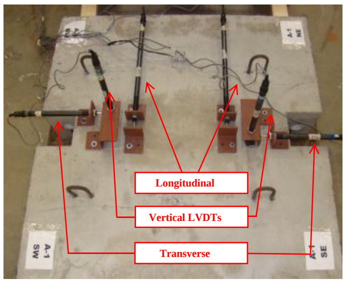
Table 1. Test matrix of misaligned tie bar specimens.

MISALIGNMENT TYPE	MISALIGNMENT MAGNITUDE	SDDOT TOLERANCE
Vertical Translation: (Section View)	X = 1 inches	1.25 inches
	X = 2 inches	
	X = 3 inches	
	X = 4 inches	
Vertical Skew: (Section View)	X = 2 inches	2.50 inches
	X = 4 inches	
	X = 6 inches	
	X = 8 inches	

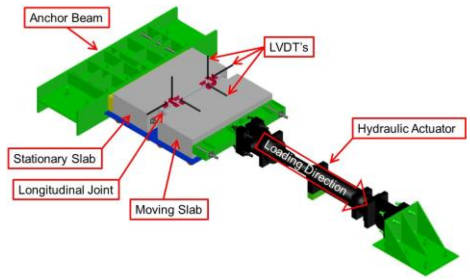
MISALIGNMENT TYPE	MISALIGNMENT MAGNITUDE	SDDOT TOLERANCE
Longitudinal Translation: (Plan View)	X = 3 inches	3.00 inches
	X = 5 inches	
	X = 7 inches	
	X = 9 inches	
Horizontal Skew: (Plan View)	X = 16 inches	18 inches
	X = 20 inches	
	X = 24 inches	
	X = 28 inches	

3.3 Instrumentation and Test Setup

The test specimens were instrumented with strain gauges and linear variable displacement transducers (LVDT) to measure strain in the tie bar and the relative displacement between the two sides of the concrete slab across the joint. Three strain gauges were installed on the tie bar at the location where the tie bar crosses the joint. The strain gauges were attached to the surface of the tie bar 120 degrees apart around the circumference of the tie bar. Six LVDTs were mounted to the top of each specimen to allow for measuring the relative displacement of the two slab segments across the joint in three orthogonal directions and to calculate rotations and twisting about the joint. All of the specimens were tested on the seventh day after concrete pouring. On the day of testing, the specimen was placed on roller supports and tested by securing one end to an anchor steel beam and the other end to a hydraulic actuator. The hydraulic actuator then applied a splitting force normal to the face of the joint until failure occurred. The loading was applied in displacement-control mode to allow for capturing the full spectrum of the response. Figure 3 shows a sketch of the test setup. Figure 2 shows LVDTs installed on a specimen and the test setup.



(a) LVDT Arrangement.



(b) Test setup.

Figure 2. Instrumentation and test setup.

4 EXPERIMENTAL RESULTS AND ANALYSIS

The measured average compressive strengths on the day of testing were 3.97 ksi, 5.36 ksi, 5.26 ksi, 5.24 ksi, and 5.26 ksi for the control, vertical translation, vertical skew, longitudinal translation, and horizontal skew, respectively. The measured yield and ultimate strengths of the tie bar steel were 74 ksi and 124 ksi, respectively, and the measured elastic modulus was 29,000 ksi.

Figure 3. Bond failure in a horizontal skew specimen.

In all of the test specimens, the tie bar yielded before bond failure occurred. Except for one specimen out of the 35 specimens tested in this study, bond failure was manifested by tensile splitting of the concrete along a vertical plane that was aligned with the direction of the tie bar. Bond failure in one of the two specimens with longitudinal translation magnitude of 9 inches (i.e. embedment length of three inches) occurred by bar pull out. Figure 3 shows a typical bond failure in one of the test specimens.

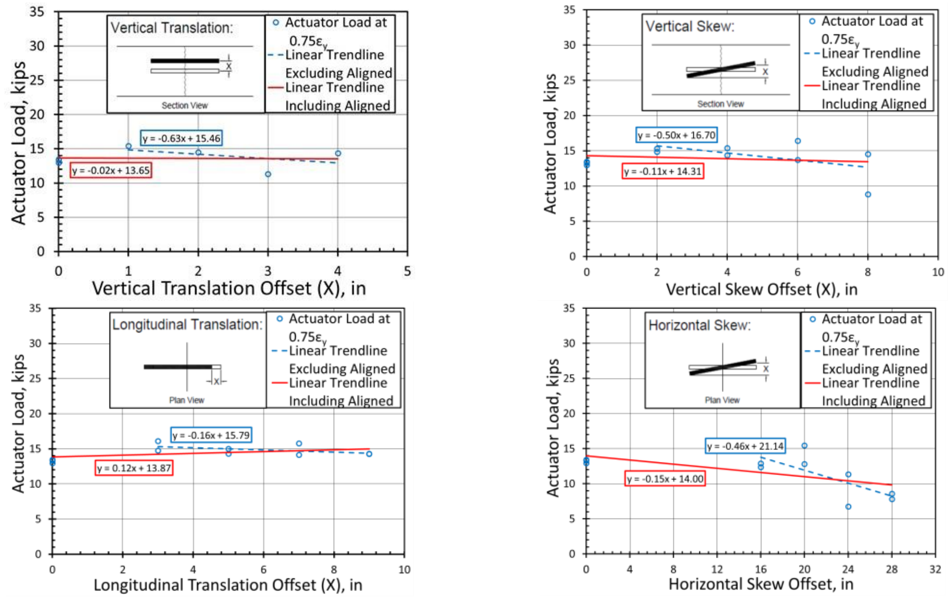


Figure 4. Applied actuator force at tie bar strain of 0.75 ε_y.

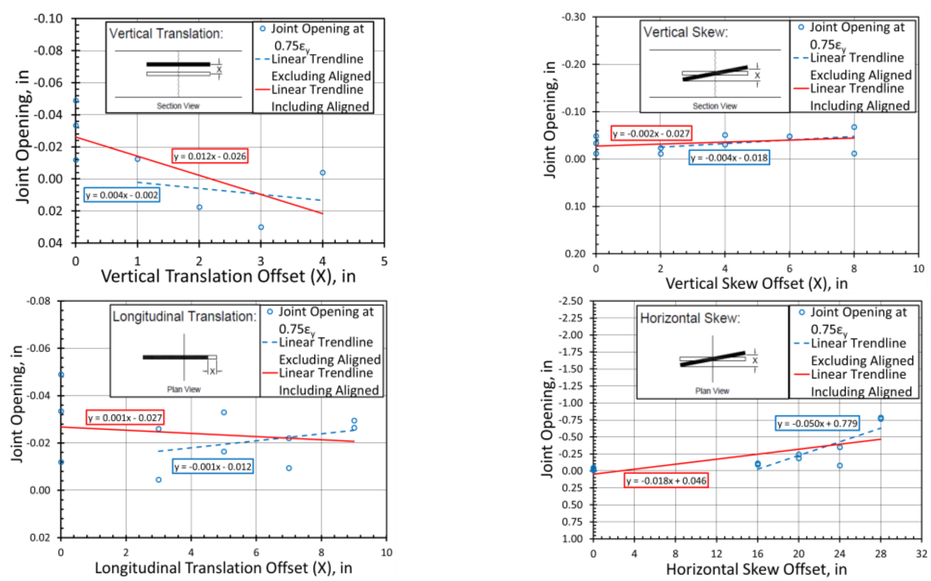


Figure 5. Joint opening at tie bar strain of 0.75 ε_y.

In this study the applied actuator force and the corresponding joint opening for the different specimens were evaluated when the measured strain in the tie bar reached 0.75 ε_y, where ε_y is the yield strain corresponding to the tie bar yield stress, f_y. The 0.75 ε_y threshold was established based on the allowable tie bar design force given in

AASHTO (1993). The allowable tie bar design force, F_{TB}, is calculated as 0.75 f_y A_s, where A_s is the cross sectional area of the tie bar. The joint opening performance limit was based on a hot poured elastic joint sealer elongation limit of 1/8 inch for a 1/4 inch wide sawed joint that is filled with the hot poured sealant. Figures 4 and 5 show the measured actuator force and joint opening, respectively, at measured tie bar strain of 0.75 ε_y.

The experimental results showed that vertical translation, vertical skew, and longitudinal translation alignment configurations did not cause significant change in the applied load and joint opening at 0.75 ε_y compared to the aligned configuration. However, the magnitude of the horizontal skew caused the actuator load at a tie bar strain of 0.75 ε_y to decrease and the joint opening to increase. A horizontal skew of 24 inches caused the average actuator load at 0.75 ε_y to be reduced to 9.1 kips, which is 35% less than that for the aligned specimen. For horizontal misalignment magnitudes of 20 inches and higher the joint opening exceeded the 1/8 inch performance limit. For example, the average joint opening at 0.75 ε_y exhibited by the 20 inches horizontal misalignment specimens was 0.217 inches, 1.7 times the 1/8 inch joint opening performance limit.

5 CONCLUSIONS

The experimental results indicated that vertical translation, vertical skew, and horizontal translation in excess of the tolerances allowed by SDDOT did not cause significant adverse effects on the joint performance when the tie bar reaches a strain of 0.75 ε_y. However, horizontal skew at or in excess of 20 inches resulted in reduced tie bar force and increased joint opening when the tie bar reaches a strain of 0.75 ε_y. The current SDDOT tie bar placement tolerances limit the horizontal skew misalignment to 18 inches when the concrete slab is 10 inches thick. Therefore, the current SD DOT tie bar placement tolerances are adequate for a slab thickness is 10 inches.

Acknowledgments

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