

Field and numerical study of transverse crack in JPCP with misalignment and non-greased dowels

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ABSTRACT: This study investigates the effects of dowel lubrication and positioning on the performance of Jointed Plain Concrete Pavements (JPCPs) through field evaluations, laboratory experiments, and numerical modeling. Field observations of a JPCP section revealed transverse cracking near a bridge transition zone, attributed to the absence of dowel lubrication and misalignment. Laboratory pull-out tests demonstrated that unlubricated dowels exhibited significantly higher friction, restricting movement within the joint, which inhibited natural slab expansion and contraction. In contrast, lubricated dowels allowed smoother movement, reducing pull-out forces and enhancing joint performance. The findings emphasize that dowel lubrication has a more substantial impact on joint functionality than misalignment, especially during the early stages of pavement life when concrete is less stiff and more prone to cracking.

1 INTRODUCTION

1.1 Background

A characteristic feature of Jointed Plain Concrete Pavements (JPCPs) is the division of the pavement into slabs by transverse and longitudinal contraction joints. This design minimizes the formation of randomly located shrinkage cracks by creating a series of interconnected slabs. However, jointed concrete pavements are often susceptible to distresses that either originate at the joints or result from improper joint design, construction, or maintenance. Common joint-related distresses include faulting, pumping, spalling (caused by various mechanisms), corner breaks, blowups, and mid-panel cracking, which can occur due to excessive joint spacing or inadequate joint construction (FHWA 2019).

The use of dowels enhances load transfer capacity between the loaded and unloaded slabs during vehicle traffic while allowing horizontal slab movement due to daily and seasonal variations in temperature and moisture conditions (Huang 2004).

To minimize the risk of premature deterioration during the pavement's service life, several measures should be implemented from the construction stage. These include making contraction cuts promptly and ensuring that dowels are correctly positioned and properly lubricated before installation (Lazarowicz et al. 2023). Improper joint construction can lead to premature pavement failures and significantly compromise long-term pavement performance.

1.2 Objective and Scope

This study aims to examine the effects of dowel lubrication and positioning within contraction joints on the performance of concrete pavements, as observed during field evaluations.

2 MATERIALS

2.1 Field Observations

The evaluated JPCP was constructed using slip-form paving technology in March 2019. It consists of two lanes and an emergency lane. Transverse joints were spaced at 5-meter intervals, while the longitudinal spacings were 3.9, 3.9, and 2.2 meters. Polymer-coated steel dowels $\phi = 0.025$ m were embedded in the transverse joints at 0.25 m intervals, and steel tie bars $\phi = 0.02$ m were placed in the longitudinal joints at 1.0 m intervals. The dowels were not lubricated before installation using the dowel bar inserter.

After several months, transverse cracking was observed across the entire width of the road, splitting the 5-meter-long concrete slabs into fragments approximately 1.5 and 3.5 meters in length. At the time of observation (June 7, 2019), the crack measured 0.5 to 0.8 mm wide and ran parallel to the contraction joints in which the dowels were embedded. The cracked slab was the transition slab where the JPCP connects to the asphalt pavement, located near the access to the bridge. Due to the design of the technological connection between the two pavement types,

the concrete slab exhibited varying thickness in the region where the crack occurred.

During the field investigations, local excavations were conducted to assess the extent of the cracks and the condition of the contraction joints. Diagrams illustrating this case are shown in Figures 1 and 2.

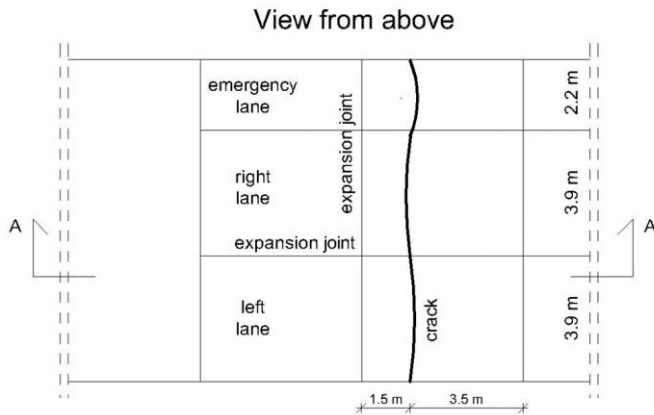


Fig. 1. Diagram of the analysed pavement.

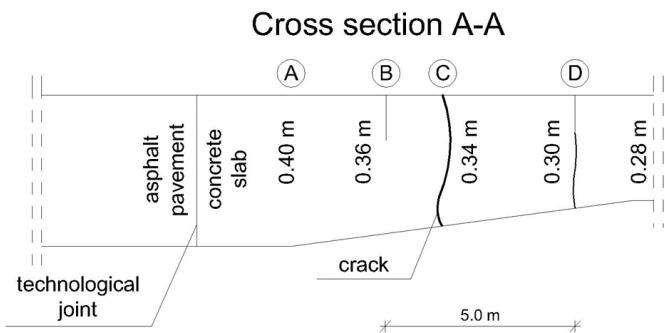


Fig. 2. Cross-section of the analysed pavement.

The excavation revealed that while joint D was properly formed, propagating through the entire thickness of the concrete slab, joint B did not propagate as intended. Additionally, a random crack, labeled as crack C, was found to have propagated through the full thickness of the slab.

The positions of the dowels in joints B and D were examined using the MIT-Scan2-BT device. A statistical summary of the results is presented in Tables 1 and 2.

Tab. 1. Positions of the dowels at point B.

Parameter	Min. value [mm]	Max. value [mm]	Mean value [mm]
Vertical translation	-2	100	42
Transverse translation	177	283	251
Longitudinal translation	-45	0	-13
Horizontal skew	-18	16	3
Vertical tilt	-11	12	2

Tab. 2. Positions of the dowels at point D.

Parameter	Min. value [mm]	Max. value [mm]	Mean value [mm]
Vertical translation	-23	32	-1
Transverse translation	221	273	250
Longitudinal translation	-26	48	-4
Horizontal skew	-24	9	-7
Vertical tilt	-19	17	2

2.2 Documentation analysis

Based on the analysis of the execution documentation, the layout of the pavement structure in the area of the transverse cracking (point C) was determined. Due to the variable thickness of the concrete slab, two sections within the contraction joints, representing the extremities of the cracked slab, were identified. Details of both sections are provided in Table 3.

Tab. 3. Road surface properties at points B and D.

Material	Young's Modulus [MPa]	Poisson ratio	Thickness [cm]	
			Point B	Point D
Cement Concrete C 35/45	35 000	0.16	36	30
Geotextile	-	-	0.2	
Cement Bound Base C 8/10	3 000	0.3	10	16
Cement Bound Base C 5/6	2 000	0.3	15	
Cement Bound Subbase C 1.5/2	200	0.3	20	
Subgrade G1	80	0.35	30	

The analyzed pavement section was constructed on March 20, 2019. Archived weather reports from the nearest weather station to the assessed section were used to compile Table 4, which summarizes the daily minimum and maximum air temperatures for one week following the pavement's construction. Using this data, the positive and negative temperature gradients in the concrete slab during this period were calculated, as described by (Szydło et al. 2013).

Tab. 4. Air temperatures and temperature gradients in the concrete slab during the first week after construction of the test section.

Date	Min. Air Temp. [°C]	Max. Air Temp. [°C]	Negative concrete gradient [°C]	Positive concrete gradient [°C]
20.03.2019	-6,0	9,0	-5,1	11,2
21.03.2019	4,0	11,2	-4,5	7,9
22.03.2019	-2,0	14,0	-5,1	11,6
23.03.2019	-5,0	14,1	-5,3	12,9
24.03.2019	1,0	12,0	-4,8	9,5
25.03.2019	-2,0	9,0	-4,8	9,5
26.03.2019	-1,0	7,0	-4,6	8,2

3 LABORATORY TESTS

3.1 Specimen preparation

The pull-out test of the dowels was conducted on short samples, defined as those with an adhesion length between three and five diameters of the dowel. This configuration allows for necessary simplifications, ensuring linear strain changes along the dowel's axis during measurement. Additionally, adhesion stresses remain constant, corresponding to the smooth surface of the dowels (Burdziński et al., 2024).

The tests were performed on polyethylene-coated steel dowels produced by the same manufacturer as those used in the pavement section under study. Two sets of samples were prepared: dowels lubricated with SAE 30 oil, as recommended by (Snyder 2011), and unlubricated dowels. Each set consisted of three samples.

The dowels tested were 500 mm long and embedded in cubic concrete specimens measuring $150 \times 150 \times 150$ mm. The contact length between the dowel and the concrete was set to four times the dowel diameter (100 mm). The remaining length of the dowel was isolated from the concrete using a protective sponge, which was removed after the concrete hardened.

The concrete used for the specimens was class C35/45, meeting the requirements for concrete slabs subjected to the heaviest traffic loads, as specified in national guidelines. No spiral transverse reinforcement was included in the specimens to avoid additional restraint on the dowels and reduce the likelihood of concrete splitting.

The objective of the test was to replicate, as closely as possible, the working conditions of dowels in concrete slabs, where spiral reinforcement is typically absent.

3.2 Test procedure

The test procedure followed the provisions of ISO 1040-1, Clause 7, and the methodology described by (Burdziński et al. 2024). After the concrete had cured for at least 28 days, the specimen was placed in the testing machine with the free end of the dowel fixed securely. The concrete cube was positioned in a specially designed steel cage, which allowed a vertical force to be applied, causing upward movement. The displacement rate of the specimen was set at 1 mm/min, as recommended by (Khazanovich et al. 2009). A schematic of the test setup is shown in Fig. 3.

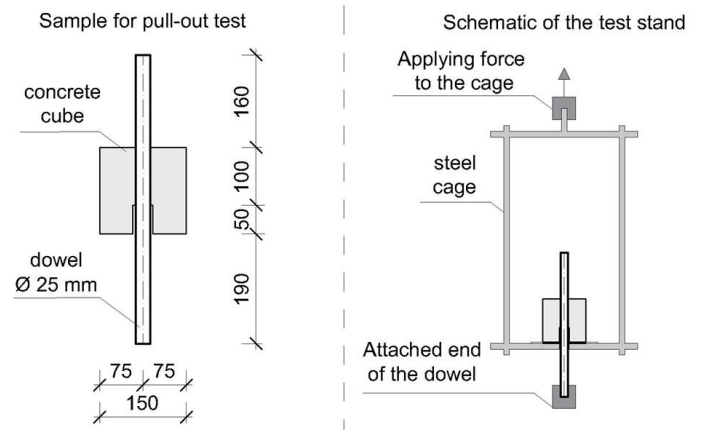


Fig. 3. View of the sample and schematic of the pull-out test apparatus.

3.3 Results of pull-out tests

The maximum pull-out forces for the dowels from the concrete specimens are shown in Fig. 4. The average force required to pull out the lubricated dowels was 8.9 kN, approximately half the pulling force of the unlubricated dowels (17.5 kN). These results align well with findings from other studies; for instance, (Saxena et al. 2009) reported that the absence of lubrication can increase pull-out forces by more than 2.5 times. This indicates that high friction between the concrete slab and the unlubricated dowels restricts their free movement within the joint, hindering the natural expansion and contraction of the concrete slabs.

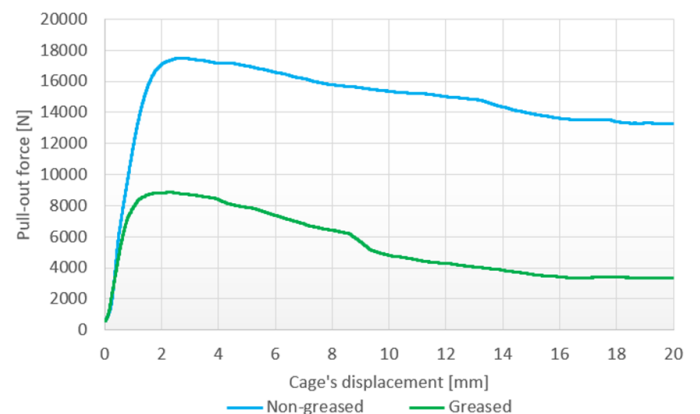


Fig. 4. Pull-out forces of lubricated and unlubricated dowels in the pull-out test.

4 DISCUSSION

While dowel misalignment has traditionally been associated with joint lockup and related distresses, this study, as well as the United States National Cooperative Research Program 10-69 study (Khazanovich et al. 2009), demonstrates that dowel-concrete friction primarily influenced by the presence or absence of grease might have a more significant detrimental effect on joint performance than dowel misalignment. Ungreased dowels experience much higher friction with the surrounding concrete,

leading to a substantial increase in the force required to pull them out. In contrast, dowel misalignment led to only a marginal increase in pull-out force and often resulted in a decrease. These findings are supported by other laboratory studies, which have often been misinterpreted (Prabhu 2007; Al-Humeidawi and Mandal 2018). Although previous studies observed a significant increase in pull-out forces due to dowel misalignment, they simulated unrealistically high joint openings. For smaller, more realistic joint openings, no significant increase in pull-out forces was observed.

The results of finite element modeling reported by (Saxena et al. 2009) also showed that high friction between ungreated dowels and surrounding concrete generates significantly higher stresses in the concrete. These stresses, primarily tensile, concentrate near the dowel and can easily exceed the concrete's tensile strength, making it susceptible to cracking and spalling, which compromises the pavement's structural integrity and leads to premature deterioration.

It should be noted, however, that previous experimental and laboratory studies primarily investigated the effect of dowel greasing and misalignment on relatively mature concrete pavements, i.e., after the concrete has reached substantial strength and stiffness. The effect of these factors may be even more pronounced immediately after concrete placement. At early ages, when concrete stiffness is low, ungreated dowels may provide significant reinforcement against crack formation, which would increase the effective slab length and contribute to random cracking in the slab. This, in combination with the slow rate of concrete strength gain due to cold ambient temperatures, a stiff foundation, and high friction with the base layer, could cause premature cracking.

5 SUMMARY

This study highlights the critical role of dowel lubrication and positioning in the performance of Jointed Plain Concrete Pavements (JPCPs). The findings demonstrate that unlubricated dowels experience significantly higher friction with the surrounding concrete, leading to increased pull-out forces and restricting the dowel's movement within the joint. This impedes the natural expansion and contraction of the concrete slabs, potentially contributing to premature pavement distress. In contrast, lubricated dowels reduce friction and allow for greater dowel mobility, improving long-term joint performance. The results align with previous research, emphasizing that dowel lubrication has a more significant impact on joint function than dowel misalignment.

The field and laboratory tests also revealed that dowel misalignment, while traditionally associated with joint lockup and related distresses, has a rela-

tively minor effect on pull-out forces compared to the impact of lubrication. Additionally, the study suggests that the effects of dowel lubrication and misalignment may be more pronounced immediately after concrete placement, when the slab is less stiff and more susceptible to cracking. To enhance the durability and performance of JPCPs, it is essential to ensure proper dowel lubrication and alignment during construction, and to implement regular inspection and maintenance practices.

6 REFERENCES

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