EXPERIMENTAL INVESTIGATION OF THE PULL-OUT BEHAVIOUR OF MISALIGNED DOWEL BARS IN CONCRETE PAVEMENTS

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ABSTRACT

Dowel bars in Jointed Plain Concrete Pavements transfer wheel loads across transverse joints while permitting joint movement caused by temperature and moisture variations. However, improper dowel alignment during construction may restrain joint movement and generate stress concentrations within the surrounding concrete, leading to premature pavement distress. This study experimentally investigated the pull-out behavior of single dowel bars subjected to horizontal, vertical, and combined skew misalignments of 3.1° and 6.3°, representing the allowable tolerance limit and twice the tolerance limit, respectively. Pull-out tests were conducted on six concrete specimens using a manually operated loading arrangement, while load and displacement responses were recorded using a load cell and Linear Variable Differential Transformers (LVDTs). The results demonstrated that pull-out resistance increased with increasing misalignment magnitude. The control specimen exhibited the lowest pull-out load of 0.9 kN, while the highest pull-out load of 7.5 kN was recorded for the 6.3° vertical skew specimen. Visible cracking was observed near the dowel-concrete interface in the vertically misaligned specimens, indicating increased stress concentration caused by joint restraint. The findings demonstrate that dowel bar misalignment significantly influences pull-out resistance and crack development, highlighting the importance of maintaining dowel placement within specified construction tolerances to reduce the risk of premature pavement distress.

Keywords: dowel bar misalignment, pull-out behavior, rigid pavement, concrete pavement

1. INTRODUCTION

Jointed Plain Concrete Pavements (JPCP) use dowel bars across transverse joints to transfer wheel loads between adjacent slabs while allowing horizontal joint movement caused by temperature and moisture variations (Al-Humeidawi & Mandal, 2021). Improper dowel alignment during construction may restrain this movement and generate stress concentrations within the surrounding concrete. Such conditions can lead to premature pavement distress, including joint locking, spalling, transverse cracking, and corner breaks (Prabhu et al., 2007).

Previous studies have shown that dowel misalignment significantly influences pull-out resistance and the interaction between the dowel and surrounding concrete. Experimental pull-out testing has been widely used to evaluate the effects of dowel misalignment on bond, friction, and bearing behavior (Prabhu et al., 2007). However, limited experimental studies have comparatively investigated the pull-out response and crack initiation behavior associated with different misalignment orientations under controlled single dowel conditions.

Therefore, this study experimentally investigates the pull-out behavior of single misaligned dowel bars embedded in concrete specimens under control, vertical skew, and horizontal skew conditions.

2. LITERATURE REVIEW

Dowel misalignment is generally classified as translational or rotational misalignment, with horizontal skew and vertical tilt identified as critical forms affecting pavement performance

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(Tayabji, 1986). Previous experimental studies have shown that increasing misalignment magnitudes significantly increases pull-out resistance and restrains joint movement. Severe misalignment conditions may further induce cracking and spalling in the surrounding concrete (Prabhu et al., 2007).
Earlier pull-out investigations primarily focused on identifying critical misalignment limits and corresponding joint opening resistance. More recent studies expanded the investigation towards dowel-concrete interaction mechanisms, including bond, friction, and bearing stresses. (Saxena et al., 2009) Researchers have also investigated alternative dowel materials to reduce frictional resistance and mitigate joint locking effects (Al-Humeidawi & Mandal, 2021).
Although extensive research has been conducted on dowel misalignment, limited experimental studies have comparatively evaluated crack initiation and pull-out behavior associated with different skew orientations using controlled single dowel specimens. Therefore, this study focuses on experimentally evaluating the influence of vertical and horizontal skew misalignments on pull-out response and cracking behavior.

3. METHOD

3.1 Specimen Preparation

A total of six concrete specimens containing a single dowel bar were prepared to investigate the pull-out behavior of misaligned dowel bars. The specimens were designed based on recommendations provided in the AASHTO and FHWA guidelines for dowelled concrete pavements. Each specimen consisted of two concrete blocks connected through a centrally embedded dowel bar separated by a 3 mm joint gap.

The concrete slabs had a thickness of 150 mm and were cast using Grade 30 concrete. Mild steel dowel bars with a diameter of 20 mm and a total length of 400 mm were used. The experimental program consisted of six specimens representing control, vertical skew, and horizontal skew conditions. Misalignment angles of 3.1° and 6.3° were selected to represent the specified dowel placement tolerance limit and twice the tolerance limit, respectively. These magnitudes were chosen to evaluate the influence of increasing construction-induced misalignment severity on pull-out behavior and crack development.

To simulate field conditions, one half of each dowel bar was debonded using grease to permit relative longitudinal movement between the dowel and the surrounding concrete. Following casting, all specimens were cured under laboratory conditions for 28 days prior to testing.

3.2 Experimental Setup

Pull-out tests were conducted using a manually operated loading system consisting of car jacks (Figure 1). The concrete specimens were restrained using roller plates, steel restraining members, and G-clamps to maintain stability during testing. Load was applied through the two openings provided in the specimen to induce axial pull-out of the dowel bar. The applied force was measured using a load cell, while the corresponding displacement was recorded using Linear Variable Differential Transformers (LVDTs). The load cell and LVDTs were connected to a data acquisition system for continuous recording of load and displacement. Loading was applied gradually until significant cracking and failure of the specimen were observed. The recorded load-displacement response and crack patterns were used to evaluate the effect of dowel bar misalignment on pull-out behavior.

3.3 Pull-Out Testing Program

The pull-out behaviour of each specimen was evaluated using the recorded load-displacement response and observed cracking patterns to assess the influence of dowel bar misalignment on joint restraint and damage development.

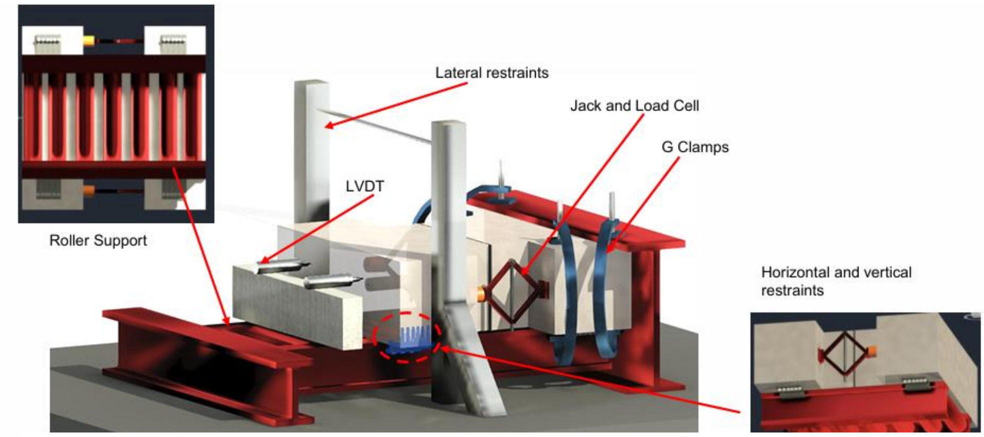

Figure 3. Schematic view of experimental setup

4. RESULTS AND DISCUSSION

4.1 Pull-Out Behavior

Figure 2 presents the peak pull-out loads obtained for the tested specimens. The control specimen (C0) exhibited the lowest pull-out load of 0.9 kN. In general, pull-out resistance increased with increasing dowel bar misalignment. The highest pull-out load of 7.5 kN was recorded for the vertical skew specimen with a 6.3° misalignment (V6.3), while the horizontal skew specimen with the same misalignment angle (H6.3) recorded 4.5 kN. These results indicate that vertical skew misalignment produces greater restraint against dowel movement than horizontal skew. The H3.1 specimen was excluded from interpretation due to issues identified in the lateral restraint system during testing.

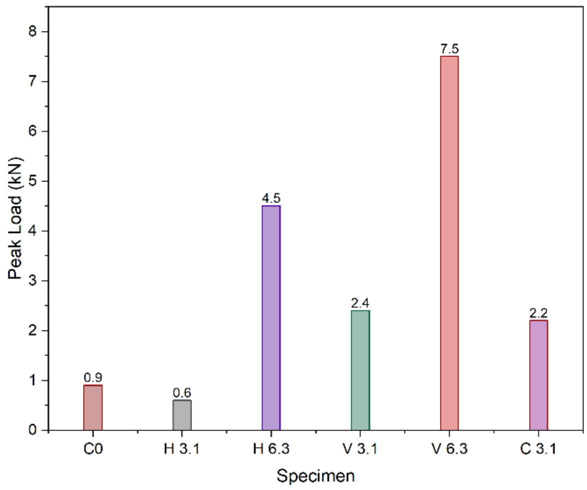

Figure 4. Peak load comparison graph

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4.2 Crack Initiation and Failure Behaviour

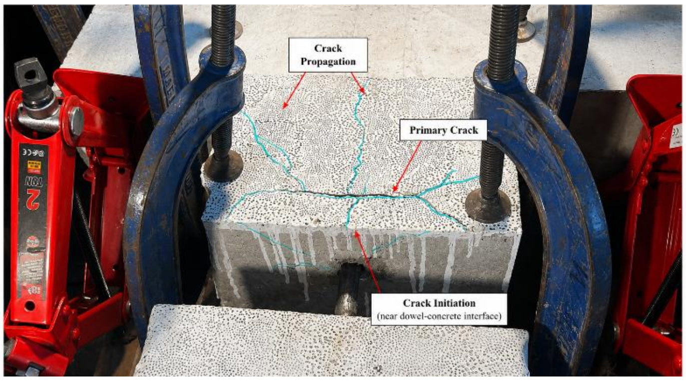

Figure 5: Crack pattern observed in the vertical skew specimen after pull-out loading.

Visible cracking was observed near the dowel–concrete interface in the vertically misaligned specimens, as shown in Figure 3. Crack propagation extended from the dowel region towards the specimen surface, with the 6.3° vertical skew specimen exhibiting the most severe cracking. Compared to the control and horizontal skew specimens, vertical skew misalignment generated greater restraint against dowel movement, resulting in higher stress concentrations and accelerated crack development. These observations are consistent with the higher pull-out loads recorded for the vertical skew specimens.

5. CONCLUSION

This study experimentally investigated the influence of dowel bar misalignment on the pull-out behaviour of thin concrete pavement specimens. The results showed that pull-out resistance increased with increasing misalignment magnitude, with the 6.3° vertical skew specimen exhibiting the highest peak load. Vertical skew misalignment produced greater restraint and more severe cracking than horizontal skew, indicating a higher potential for premature pavement distress. The findings highlight the importance of maintaining dowel placement within specified construction tolerances to minimize joint restraint and reduce the risk of cracking in rigid pavements.

6. REFERENCES

1. Al-Humeidawi, B. H., & Mandal, P. (2021). Laboratory investigation of dowel bars' misalignment using pull-out test. *Al-Qadisiyah Journal for Engineering Sciences*, *14*(4), 201–204. https://doi.org/10.30772/qjes.v14i4.853
2. Prabhu, M., Varma, A. H., & Buch, N. (2007). Experimental and analytical investigations of mechanistic effects of dowel misalignment in jointed concrete pavements. *Transportation Research Record*, (2037), 12–29. https://doi.org/10.3141/2037-02
3. Saxena, P., Hoegh, K., Khazanovich, L., & Gotlif, A. (2009). Laboratory and finite element evaluation of joint lockup. *Transportation Research Record*, (2095), 34–42. https://doi.org/10.3141/2095-04
4. Tayabji, S. D. (1986). Dowel Placement Tolerances for Concrete Pavements. In *Transportation Research Record* (Vol. 1062).