

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF DOWEL BAR MISALIGNMENT IN THIN RIGID PAVEMENT JOINTS

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Abstract

Dowel bars transfer loads across transverse joints in jointed plain concrete pavements while allowing joint movement. Angular misalignment can increase restraint and local stresses at the dowel-concrete interface. Previous studies have mainly focused on thicker highway and airport pavements with relatively large dowels, while thin rigid pavements with smaller dowels remain less studied. This study experimentally and numerically investigates dowel misalignment in 150 mm thick concrete slab pairs connected by a 20 mm diameter steel dowel. Six specimens representing aligned, horizontal, vertical, and combined misalignment conditions were tested under progressive horizontal displacement. A three-dimensional nonlinear finite element model incorporating Concrete Damaged Plasticity (CDP) and dowel-concrete contact was developed. Misalignment generally increased pull-out resistance and local stress concentration; the 6.3° vertical case produced the highest experimental resistance of 7.5 kN and the most pronounced tensile damage. Excluding the compromised H3.1 test, the model reproduced the aligned and single-plane peak loads within 4.0-15.6%. The findings indicate that vertical misalignment requires particular construction control because increased joint restraint and localised damage may contribute to premature joint deterioration.

Keywords: Jointed plain concrete pavements, Nonlinear finite element modelling, Stress distribution, Pull-out resistance

1. Introduction

Dowel bars transfer load across transverse joints while permitting movement caused by temperature and shrinkage. Misalignment during construction can restrict this movement, increase restraint at the dowel-concrete interface, and contribute to cracking, spalling, and joint deterioration [1-5]. Recent numerical studies have also demonstrated the value of nonlinear finite element modelling for evaluating dowel response, stress redistribution, and concrete damage. Most previous studies have considered conventional highway and airport pavements with thicker slabs and larger dowels. The behaviour of thin rigid pavements using smaller dowels, relevant to low-volume roads, remains less understood, particularly the influence of misalignment orientation on restraint and local damage.

This study therefore evaluates the pull-out response, stress development, and concrete damage associated with aligned, horizontal, vertical, and combined dowel misalignment using experimental testing and three-dimensional nonlinear finite element analysis.

2. Methodology

Six paired concrete-block specimens were prepared using 150 mm thick Grade 30 concrete slabs separated by a 3 mm joint. Each specimen contained a 20 mm diameter, 400 mm long steel dowel. The programme comprised an aligned control, horizontal and vertical

misalignments of 3.1° and 6.3° , and a combined case with approximately 3.1° horizontal and 3.1° vertical misalignment. One specimen was tested per configuration; therefore, the programme was intended to identify comparative behavioural trends rather than quantify specimen-to-specimen variability.

Horizontal displacement was progressively applied using a jack, with load measured by load cells and displacement by LVDTs. Roller supports and lateral restraints maintained the intended configuration. Load-displacement response and visible cracking, crushing, and spalling around the dowel-concrete interface were recorded.

A three-dimensional nonlinear finite element model reproduced the specimen geometry, loading, and restraint conditions. Concrete was represented using CDP calibrated for Grade 30 concrete, while the steel dowel was modelled as elastic-plastic. Hard normal contact and penalty friction were used at the interface, with coefficients of 0.05 on the greased side and 0.30 on the bonded side. The mesh was locally refined around the dowel-concrete interface, where high stress gradients were expected. Displacement-controlled nonlinear static analysis with automatic incrementation was adopted for convergence. Experimental load-displacement response and observed distress were used to assess the model. A formal mesh-sensitivity study was not included in the present experimental-stage analysis and is recognised as a numerical limitation.

3. Results and Discussion

The experimental results in Table 1 show that misalignment substantially influenced joint restraint. Greater angular misalignment generally increased pull-out resistance, while vertical misalignment produced greater restraint than horizontal misalignment at comparable angles. V6.3 was the most critical single-plane case, reaching 7.5 kN and exhibiting the most pronounced distress. The combined case showed multidirectional interaction rather than a simple additive response. The H3.1 specimen experienced premature movement due to inadequate lateral restraint; consequently, it was treated as experimentally compromised and excluded from quantitative model validation and interpretation of the misalignment trend.

Table 1: Experimental and finite element peak pull-out loads.

Specimen	Misalignment	Exp. (kN)	FEM (kN)
C0	Aligned	0.90	1
H3.1*	Horizontal, 3.1°	0.60	4.6
H6.3	Horizontal, 6.3°	4.50	5.2
V3.1	Vertical, 3.1°	2.40	2.6
V6.3	Vertical, 6.3°	7.50	7.8
C3.1	Combined	2.20	3.1

*H3.1 was affected by inadequate lateral restraint and excluded from quantitative model validation.

Excluding H3.1, the FEM reproduced the principal experimental response. Absolute peak-load errors were 11.1% for C0, 15.6% for H6.3, 8.3% for V3.1, and 4.0% for V6.3. The combined C3.1 case showed a larger error of 40.9%, indicating that the model represented the single-

plane response more reliably than the multidirectional interaction. Numerical results also identified localised stress and tensile damage around the dowel-concrete interface, with V6.3 showing the strongest concentration, consistent with the severe experimental distress.

4. Conclusions

Dowel misalignment significantly affected pull-out resistance and local stress development in the tested thin rigid pavement joints. Vertical misalignment produced greater restraint than horizontal misalignment, with V6.3 reaching 7.5 kN and exhibiting the most pronounced distress. The FEM reproduced the valid aligned and single-plane peak loads within 4.0-15.6% and identified concentrated tensile damage around the dowel-concrete interface. The absence of replicate testing limits statistical assessment of experimental variability. From a practical perspective, the results indicate that vertical angular misalignment requires particular attention during dowel installation because increased restraint and localised damage can restrict joint movement and contribute to premature joint deterioration. The findings support improved construction control of dowel alignment in thin rigid pavements.

References

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Problem

Dowel bar misalignment at transverse joints **reduces load transfer efficiency** and can cause **high stresses and cracking** in concrete pavements.

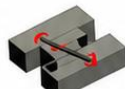
Misalignment Types



Vertical Skew
(Section View)



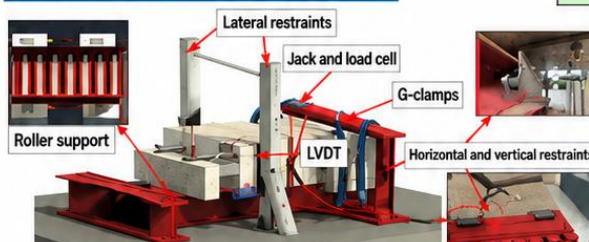
Horizontal Skew
(Plan View)



Combined Skew
(3D View)

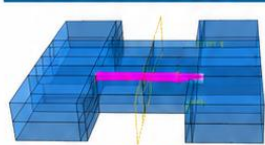
Test ID	Misalignment Type	Magnitude
C0	Control (Perfect Alignment)	0°
V 3.1	Vertical Skew	3.1°
V 6.3	Vertical Skew	6.3°
H 3.1	Horizontal Skew	3.1°
H 6.3	Horizontal Skew	6.3°
C 3.1	Combined Skew	3.2° V + 3.2° H

Experimental Program

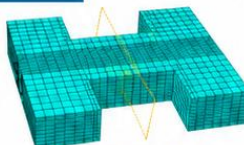


- ✓ One end debonded with grease
- ✓ Jack pull-out loading (displacement controlled)
- ✓ Load & displacement: Load cell + LVDT
- ✓ Roller plates & lateral restraints
- ✓ Tested to failure

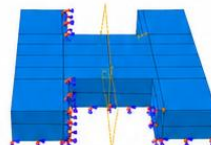
FEM Modeling



Model geometry and boundary conditions



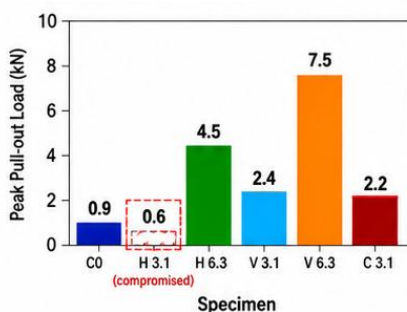
Mesh (refined near dowel)



Loading and restraints

- ✓ Concrete Damaged Plasticity (CDP)
- ✓ Dowel-concrete contact interaction
- ✓ Nonlinear static analysis
- ✓ Stress and damage evaluation

Results



Observed Concrete Distress



C0
(Aligned)



H 3.1
(Horizontal 3.1°)



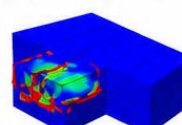
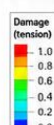
H 6.3
(Horizontal 6.3°)



V 3.1
(Vertical 3.1°)



V 6.3
(Vertical 6.3°)



FEM tensile damage
(V 6.3)



C 3.1
(Combined 3.1° + 3.1°)

Misalignment increases pull-out resistance and causes localized concrete damage, with vertical misalignment being more critical.