Engineering Structures 174 (2018) 256–266

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

# Experimental investigation on the combined effect of dowel misalignment and cyclic wheel loading on dowel bar performance in JPCP

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ARTICLE INFO

*Keywords:*
Experimental test
Dowel misalignment
GFRP
Dowel bars
Load Transfer Efficiency (LTE)
Dowel looseness
Relative deflection (RD)

ABSTRACT

A number of previous studies indicated that the joint lockup due to misalignment and looseness of dowel bars may cause joint distress in Jointed Plain Concrete Pavement (JPCP). This article reports a detailed experimental investigation of pull-out load and joint lockup due to dowel misalignment; and dowel looseness caused by the combined effect of misalignment and cyclic traffic load. The test slabs were supported on steel beams with an appropriate amount of vertical stiffness so as to incorporate the effects of underlying layers of real pavements. The article also provides an experimental investigation to assess the suitability of Glass Fibre Reinforced Polymer (GFRP) bars as alternative dowel bars to reduce joint lockup and associated detrimental effects at the dowel-concrete interface compared with epoxy-coated steel dowels. The results show that the 38 mm GFRP dowels that have equivalent flexural rigidity (*EI*) to 25 mm steel dowels can withstand the cyclic traffic load, significantly reduce joint lockup and dowel looseness, and can provide adequate Load Transfer Efficiency (LTE). It was also observed that misalignment affects dowel looseness significantly more than the number of cycles for traffic load. The slab-base separation and orientation of misaligned dowels have significant effects on the load required to open the joint.

## 1. Introduction

Concrete pavements suffer several types of volumetric changes and stresses after casting due to thermal expansion or contraction, and concrete shrinkage. The transverse joints are introduced to relieve these stresses. Almost all highway agencies around the world recommend using dowel bars to transfer the load across the joints and to reduce the relative deflection (RD) of the pavements.

Many concrete pavement problems come from joint distress [1]. Dowel looseness and dowel misalignment are two important sources of joint distress. These two phenomena have been investigated previously in isolation. Dowel looseness is an enlargement of the dowel bar socket that usually occurs due to repeated traffic load, wearing or corrosion of steel dowel bars [2]. Dowel misalignment occurs during the construction process of the joints when the dowel bars are misplaced in positions and/or orientations. The misaligned dowels restrain the slab movement by locking the transverse joints; this may initiate mid-span cracks, breakage of the corners of slabs and joint spalling [3].

Dowel misalignment can be classified into two types: (a) translational misalignment, which occurs when the whole dowel bar is offset from the central plane of the concrete slab in any direction (horizontally, vertically or longitudinally) but it remains parallel to the centreline of pavement; (b) skew (rotational) misalignment, which occurs when the centroid of the dowel is in the correct position but the dowel tilts horizontally or vertically or in both directions [4]. In practice, a particular dowel bar set may contain both types of misalignment. The focus of this study is on the skew (rotational) misalignments since they lead to more restraint to the slab movement, and as a result have more detrimental effect than the translational misalignments [4,5] (see Fig. 1 for some types of skew misalignments).

The current article presents a detailed experimental investigation into the evaluation of dowel bars' performance when they are subjected to the combined effect of wheel load and misalignment issues. The study also evaluates the suitability of GFRP dowel bars in those problem scenarios as alternative to steel dowels. GFRP is a corrosion free material and possesses low coefficient of friction which may reduce joint lock-up. The experimental programme also addressed the effect of vertical stiffness of the underlying layers of pavement which had been omitted in most of the previous tests [3,5,6].

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https://doi.org/10.1016/j.engstruct.2018.07.052
Received 30 June 2017; Received in revised form 9 June 2018; Accepted 16 July 2018

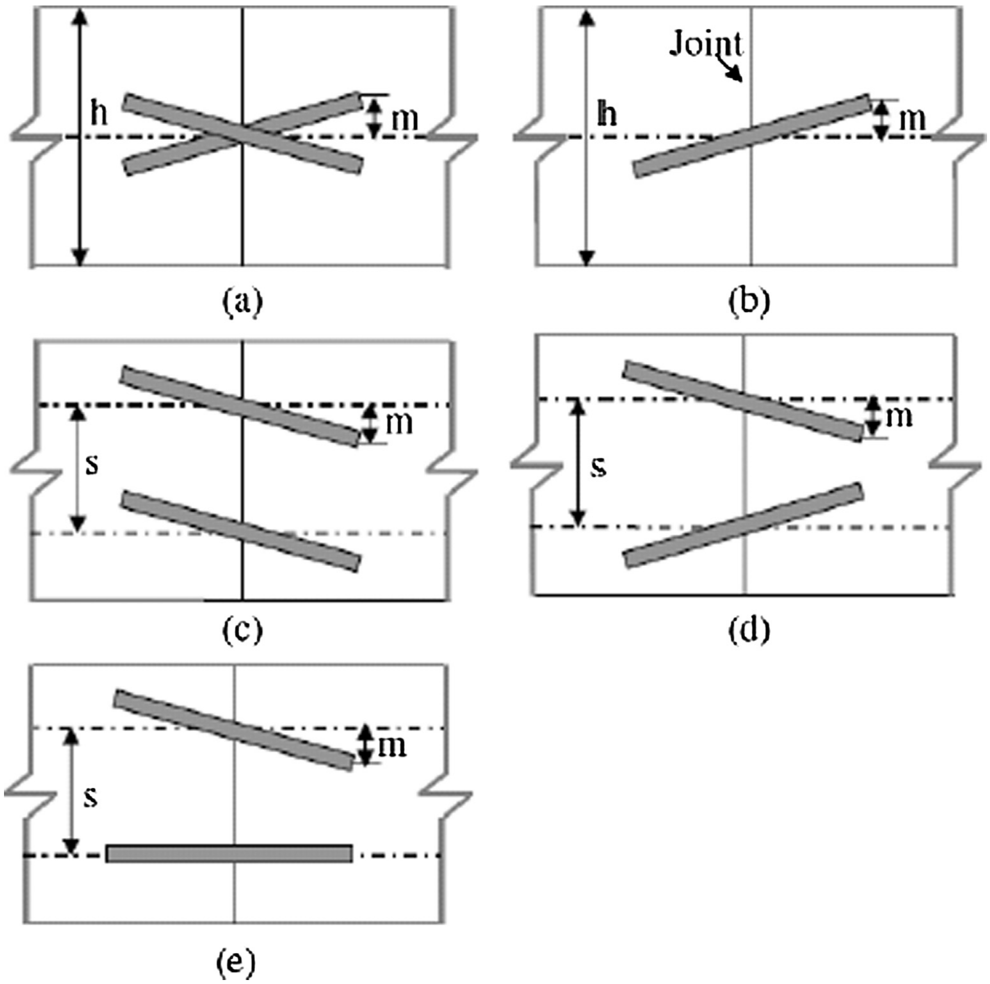


**Fig. 1.** Different types of skew misalignment: (a) Section view, non-uniform vertical misalignment; (b) Section view, uniform vertical misalignment; (c) Plane view, uniform horizontal misalignment; (d) Plane view, non-uniform horizontal misalignment; (e) Plane view, partial horizontal misalignment (h: slab thickness, s: dowel bars spacing, m: misalignment magnitude).

## 2. Previous studies

There are limited number of studies on the effects of dowel misalignment in the literature, considering its huge detrimental effects on joints and pavement performance. Most of the previous investigations focused on the determination of magnitude and types of misalignment that would cause joint distress [7,8]. Segner and Cobb [8] tested concrete pavement sections of 1.83 m (6 ft) wide, 1.68 m (5.5 ft) long and 0.25 m (10 in.) thick. Their results showed that the load required to open the joint increased noticeably for the misalignment magnitude greater than 6.4 mm compared with aligned dowels.

Tayabji [3] carried out laboratory tests on slab sections of 0.92 m (3 ft) wide, 2.1 m (7 ft) long and 0.2 m, 0.25 m (8 in., 10 in.) thick with sets of one and two dowels. The tests involved misalignment levels of 0, 3.2, 6.4, 12.7, 25.4 and 50.8 mm per half-length of dowel (225 mm). The results showed no significant difference in pull-out load for single misaligned dowel specimens, whereas a significant increase in pull-out load was observed for the specimens containing two misaligned dowels when the misalignment magnitude exceeded 12.7 mm per half dowel length. It should be noted that there are multiple dowels bars along a typical transverse joint and the interaction effect during pull-out cannot be ignored [9].

Prabhu et al. [5,10,11] carried out experimental as well as numerical investigations to produce guidelines for allowable dowel misalignment. Their investigations involved one, two, three and five 32 mm diameter steel dowel bars with different misalignment magnitudes (0, 6.35, 12.7, 19, and 25.4 mm per half-length of the dowel bar) and different misalignment types (vertical, horizontal and combined). The results showed that all joints in a concrete pavement start initial slipping when the load per dowel exceeds 5–7 kN. They also concluded that in general the joint-opening load per dowel increases for an increase in the magnitude and non-uniformity of dowel misalignment. However, in their test arrangement the slabs were fixed to the foundation, restricting any separation between the slab and the bottom layer of pavement that may happen in reality during an event of joint opening or closing. For this reason, there was insignificant difference between the loads required to open the joint for vertical and horizontal misalignments. The current set of experiments was designed by allowing for possible base separation and the effect it may have on the pull-out load.

Hoegh and Khazanovich recently carried out experimental and numerical investigations to study the effect of dowel misalignment on LTE [6,12]. The test consisted of a concrete beam (457 × 1200 × 203 mm) fitted with four 38 mm round steel dowel bars (greased and ungreased). Each bar was 457 mm long, of which 229 mm was embedded in concrete with different levels of misalignment. The dowels were pulled out individually in the longitudinal direction for 6.4 mm (0.25 in.) and the pull-out force versus displacement was recorded. The shear capacity of the dowel bar was evaluated by turning the beam on its side and applying direct shear on the non-embedded part of the dowels. Their results suggested that dowel misalignment has an insignificant effect on the pull-out load required to open the joint [6,12]. Since the test