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Laboratory investigation of dowel bars' misalignment using pull-out test

Basim H. Al-Humeidawi *[a] and Parthasarathi Mandal [b]

[a] *Roads and Transport Department, College of Engineering, University of Al-Qadisiyah, Iraq*

[b] *School of Mechanical Aerospace and Civil Engineering, University of Manchester, M13 9PL, Manchester, UK*

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A B S T R A C T

Joint lockup due to dowel misalignment significantly affects joint and concrete pavement performance by causing joint distresses. The current paper presents an experimental study to assess the effectiveness of the standard pull-out test in the evaluation of the dowel misalignment effect on joint lockup of Jointed Plain Concrete Pavement (JPCP). The tests were conducted at two different ages of concrete ; 3 and 28 days. The results showed that the standard pull-out test or individual pulling of misaligned dowels cannot reflect the realistic defect of dowel misalignment. It also showed that the vertical orientation of misaligned dowel bars during the concrete casting reduces the pull-out load due to more distance from the exposure surface. Another observation was for all specimens, the pull-out load increases with an increase in concrete age.

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1. Introduction

Jointed plain concrete pavement (JPCP) consists of multiple concrete pavement slabs supported by one or more foundation layers. These slabs are separated by transverse and longitudinal joints or cracks. These joints/cracks allow for concrete pavement to move during the expansion and contraction process. Hence, the JPCP inevitably need a proper mechanism to transfer the load across these joints, otherwise joint distress could occur. Dowel bars are mostly used across these joints to provide such mechanism by maintaining slab movement and by distributing the load between adjoining slabs. Improper function of the dowel bars could be source of joint deterioration and/or overall pavement deterioration. Joint lockup significantly affects the performance of concrete pavement by producing spalling, faulting and/or corners breaks. Joint lockup normally results from either bonding of the dowel bars to the concrete pavement due to improper debonding of dowel or corrosion of steel dowel bars, or due to dowel misalignment or misallocation. Dowel misalignment significantly contributes to joint lockup and associated distress such as joint spalling and joint faulting [1]. Several experimental tests were carried out to evaluate the dowel misalignment effects on JPCP performance [1-7]. However the conclusions are varied and often do not agree with each other. For example, some of these studies showed that the dowel misalignment has insignificant effects on joint performance [3, 4], whereas the other studies showed that the pull-out load and joint distress increase with an increase in misalignment level. This variation may be attributed to the difference in testing procedure. The current study was carried out to show suitability of the standard pull-out test or individually pulling of dowel bars in assessment of the dowel misalignment effect on the JPCP in terms of pull-out load magnitude and concrete deterioration. The test also aims to show the effect of the orientation of misaligned dowel bars during concrete casting, and the distance from the exposure surface on the pull-out load magnitude. It also shows the effect of concrete age on the pull-out load

* *Corresponding author.*
E-mail address: Basim.alhumeidawi@qu.edu.iq (Basim Hassan Al-Humeidawi)

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required to slip the dowel bar from the concrete cube. Previous studies by the authors showed that Glass Fibre reinforced Polymer (GFRP) dowels provide adequate load transfer efficiency under static and cyclic load, and produce significant reduction in the pull-out load especially in the presence of dowel misalignment. Therefore, these dowel bars were used in the current investigation [8-12]. As GFRP dowels have very low frictional and bond stress with concrete, it is suitable for the current study to clarify the dowel misalignment effect on the pull-out load.

2. Material and specimen fabrication

The experimental pull-out test program involved six samples with different misalignment magnitudes. All samples were cast together in the same mould that had six partitions as shown in Fig.1. The mould was fabricated so that the faces A1 & A2, and B1 & B2 were attached together before the mould assembly. These faces were drilled carefully at a specific angle for each specimen to obtain the required misalignment type and magnitude. Subsequently, these faces were assembled with the other parts of the mould with the dowel bars been fitted inside (see Fig.1). The misalignment magnitudes were checked again for the dowel bars within the mould before sealant was applied to fix the position. The samples were cast in concrete laboratory on the vibrating table. The concrete mix was designed using the British Method reported in Teychenne et al. [13]. The target nominal compressive strength at 28 days was 28 MPa. According to that, the following mix ratio was adopted (cement: fine aggregate: coarse aggregate) 1:1.5:2.6 and water/cement ratio of 0.55. However, a total of six cubes were cast from the same concrete batch to measure the concrete compressive strength on the day of the test. As mentioned earlier, only 38 mm diameter GFRP dowels were used in this test programme. The dimensions of each specimen were 300 × 200 × 200 mm in which the embedded length of the dowel bar was 227.5 mm as shown in Fig.1 and Fig.2

3. Test procedure

The pull-out tests were carried out in the Heavy Structures Laboratory using a universal testing machine. The concrete block was held down to the base of the machine using a steel frame.

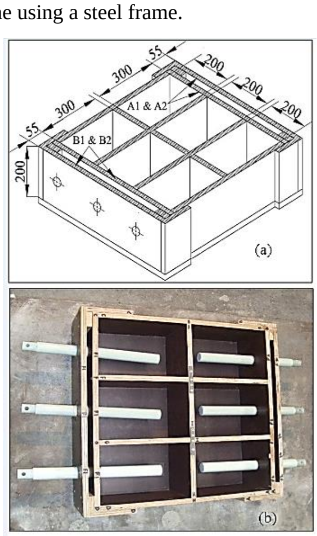

Figure 1. Pull-out test: a) Mould fabrication, b) Preparing for casting

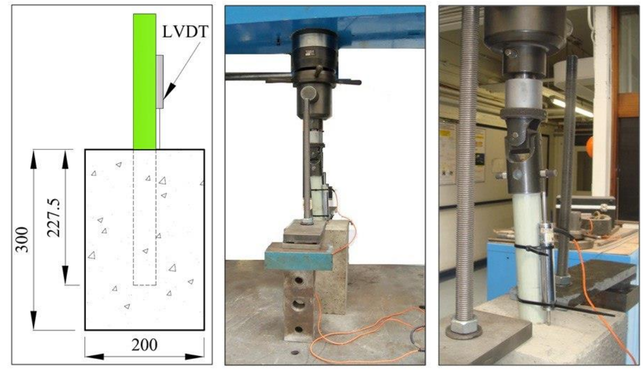

Figure 2. Pull-out test, specimen dimensions, and test setup

This frame consisted of two transverse thick steel plates that held the top of the specimen to the machine base by two long threaded bolts. The free ends of these plates were supported on steel blocks on both sides of specimen as shown in Fig.2. The steel plates were kept at distance of 40 mm away from the dowel bar circumferential (according to a preliminary FE analysis) to avoid any bearing stress from these plates on the concrete surrounding the dowel bar to allow for any possible concrete spalling (see Fig.2). A special hinge was fabricated to connect the end of the dowel bar to the testing machine, so that the pull-out load direction always remained parallel to the centreline of concrete block irrespective of the dowel bar orientation. The dowel bar slip was measured using LVDT attached to the dowel bar as shown in Fig.2. The load was applied with a constant loading rate of 0.5 mm/min.

Five specimens were pulled-out up to a slip value of 12 mm. While, only one specimen was subjected to four cycles of pull-out and push back up to 3 mm to show the effect of this movement on any possible deterioration at the dowel-concrete interface which may cause permanent displacement for the dowel bar. Permanent displacement could also occur due to the dislodging of some fine particles in the bottom of the hole due to the breakage of the bond between the dowel bar and the concrete pavement.

4. Results and discussion

As it was stated before, the experimental program involved six specimens. Two of these specimens contained aligned dowel bars while two contained horizontal misaligned dowel bars and two contained vertical misaligned dowel bars. Since there is no difference in test technique for the vertical and horizontal misalignment, the misalignment type was considered according to the orientation of the dowel bar during the casting of the concrete. The misaligned dowel bars both vertical and horizontal had a misalignment magnitude of 19 mm per embedded length of the dowel bar. Dowel bars in specimens that contained aligned and horizontally misaligned dowel bars, had the same distance from the exposure surface of the specimen which is 100 mm from the centreline of dowel bar, the ends of the dowel bar in the specimens that contained vertically misaligned dowel bars were 119 mm from the exposure surface of the specimen. In order to show the effect of concrete hardening on the pull-out load, the tests were performed on one specimen from each type after 3 days while the other three specimens were after 28 dayes of concrete casting. Fig.3 and Fig.4 present the pull-out loads for three specimens at ages of 3 days and three specimens at 28 days including one with cyclic loads. These results show that there is no significant difference in pull-out load magnitudes for the specimens of the same age compared with the effect of dowel misalignment on specimens containing two concrete slabs and two dowel bars across the joint shown in

Fig.5 [8]. This behaviour is attributed to the missing of the interaction of the group of dowel bars across the joint. However, it can be observed that the pull-out loads for specimens that have horizontally misaligned dowel bars are slightly higher than that of other specimens, which could be due to the effect of bearing stress of a misaligned dowel bar. The specimens that have a vertically misaligned dowel bar exhibited slightly lower pull-out compared to the other specimens including the aligned dowel bars. This behaviour could be attributed to the effect of less shrinkage strain for further distance from the exposure surface [14, 15]. The results also showed that the pull-out load increases with the age of the concrete.

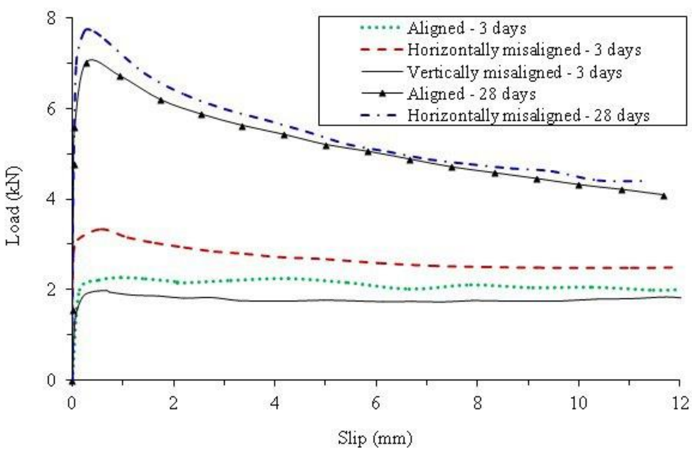

Figure 3. Pull-out load vs. slip distance at ages of 3 and 28 days

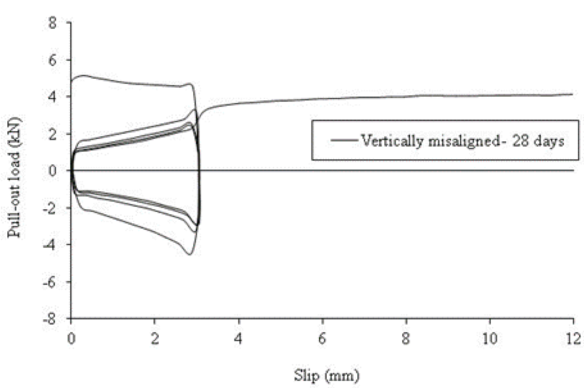

Figure 4. Cyclic pull-out load vs. slip distance for vertically misaligned dowel bar

Fig.4 shows that the repeated pull-out and push back of the specimen which has vertically misaligned dowel bar at age of 28 days did not cause deterioration at the dowel-concrete interface, because the dowel bar can be easily returned to the initial position without more pull-out load. This behaviour is attributed to the very low frictional stress and the higher uniformity of the GFRP dowel bar surface. This can be considered as a merit for the GFRP dowels because some tests in literature have shown a higher push back force compared with the pull-out force that would have been required for uncoated or bitumen coated steel dowel bars to push the dowel to initial position [16, 17]. More push back force reflects concrete cracking at the dowel-concrete interface and crushing of displaced concrete particles at the bottom of the hole of the dowel bar.

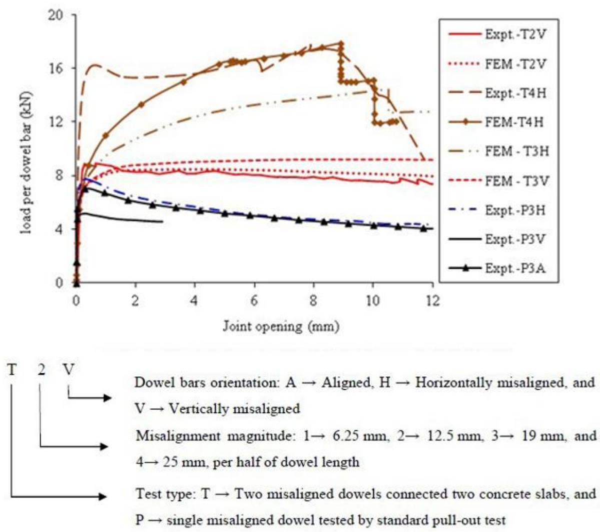

Figure 5. Comparison of pull-out load per dowel for specimens containing two concrete slabs connection ting by two misaligned GFRP dowel bars across the joint with pull-out from standard pull-out test at age of 28 days. Note: the nomenclatures in the legend were adopted in the figure above.

5. Summary and conclusions

An experimental investigation was carried out on six concrete cubes containing GFRP dowel bars with different orientations during concrete casting. These orientations involved horizontal, vertical and aligned dowel bar ordination. The tests were conducted at 3 and 28 days after concrete casting. The pull-out test results showed that the standard pull-out tests cannot precisely quantify the effect of dowel misalignment due to not considering the interaction between the group of dowels across the joint. It also showed that changing the distance from the exposure surface may affect the pull-out load magnitude, so the orientation of misaligned dowel bar may affect the required pull-out load to open the joint. For all specimens, the pull-out load increases with an increase in concrete age.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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