Physical Modelling in Geotechnics

Experimental approach on evaluation of interlocking block pavement performance

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ABSTRACT: Laboratory interlocking block pavements (IBPs) model test has been conducted by several researchers in order to evaluate the performance of the block pavement. The conclusions drawn from the previous experiments, however, revealed contradictory results due to the limitation on the previous experimental program and lack of geotechnical information for the paving system. Generally, in the previous model tests, linear variable displacement transducers (LVDTs) and pressure cells were used to evaluate the performance of the pavement. These superficial measurements, however, cannot capture the deformation characteristic underneath the ground, where the major deformation takes place. In this study, newly designed 2D physical model chamber was developed and the preliminary loading test results on the effect of the presence of the joint sands were provided for its validation purposes. For the test, Particle Image Velocimetry (PIV) analysis, which can quantify the subsurface displacement were applied together with the conventional measurements. The test results showed that the IBP's resistance towards repetitive loading is higher in block pavements with jointing materials due to the greater load transfer efficiency. PIV analysis results revealed that the vertical displacement has been developed over a wide area in shallower depth indicating a greater stiffness of the pavement. Based on the test results, the suggested experiment was able to provide the link between the conventional measurements and the subsurface deformation characteristics of the pavement.

Keywords: Interlocking Block Pavement (IBP), physical model test, Load-settlement, PIV analysis, joint sands

1 INTRODUCTION

Interlocking block pavements (IBP) have gained rapid popularity in many countries as an alternative to the conventional pavements. IBP are unique from other pavement types, since the discrete blocks and jointing materials make up the pavement surface. IBP system is constructed by compacting the blocks into the loose bedding sand and recompacting after the installation of the joint sands. Generally, when the construction is completed the blocks are wedged together and shows higher strength than before compaction and it is further strengthened under repeated traffic loads (Clifford, 1984; Shackel and Lim, 2003).

When the IBP are subjected to repeated traffic loads, the block tends to deflect and cause shear behavior within the joints, inducing the compressive strength (Lin et al., 2018). In such way, the load is transferred to the adjacent blocks and the pavements are no longer a discrete element but functions as a structural system. Accordingly, the joints play an important role in gaining the overall performance of the IBP system.

The load transfer efficiency within the joints is affected by several influential factors such as, joint width, degree of joint filling (relative density) and grain size distribution (GSD) of the joint sands. Therefore, numerous researchers have conducted laboratory IBP model tests, in order to evaluate such factors and to provide appropriate construction guidelines (Panda and Ghosh, 2002; Ling et al., 2009; Lin et al., 2018).

The evaluation on the performance of the IBP, however, showed contradiction in conclusions, especially on the appropriate size of the joint width. The reason for the discrepancy can be explained with the lack of understanding of the deformation characteristic within the subsurface area of the pavement and geotechnical properties of the paving materials.

Generally, in the previous model test measurement devices, such as LVDTs and pressure cells were used to obtain the load - settlement and load - load dispersion data, to evaluate the performance of the IBP. The limitation of these indirect measurement, however, is that it cannot evaluate the subsurface displacement, where 30 to 70% of the surface rutting is known to be generated from (Qiao et al., 2015). The relative density of the joint sand is an important parameter on transmitting the applied traffic load to the adjacent blocks. Generally, it is known that the higher degree of joint filling leads to the greater load transfer efficiency (Ascher et al., 2006). Nevertheless, the information about the relative density of the joint and bedding sands

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are often neglected and not clearly defined.

Therefore, in this study, newly designed experimental setup has been suggested in order to tackle the abovementioned limitations. Additionally, preliminary test results on the effect of the presence of the joint sands has been provided based on the geotechnical properties of the paving materials. The repeated loading test was conducted on 2D physical model chamber, which the face was replaced with an acrylic window. During the test, images of the subsurface layer were taken for the Particle Image Velocimetry (PIV) analysis. Finally, the analysis results made in comparison to the data obtained from the conventional measurement are provided.

2 LABORATOY BLOCK PAVEMENT TEST

2.1 Experimental setup

A repetitive loading test was conducted on a 2D physical model chamber (1500×100×1000 mm) made of steel. For the PIV analysis, the face of the model chamber was replaced with a 1200 mm wide × 500 mm high × 40 mm thick poly(methyl methacrylate) (PMMA) window. Reaction frame was installed to balance the repeated load from an actuator of 100kN capacity. Five LVDTs were installed on the top center of each block to measure the settlement. Additionally, five pressure cells were installed at the boundary between bedding sand and granular base layer to measure the stress distribution during the repeated loading. The pressure cells were installed at the centerline of the blocks in order to avoid stress transmitted from the joints (Lin et al., 2018). The settlement and dispersed stress data were collected by the dynamic data logger.

2.2 Test materials & Pavement section

Seven blocks with compressive strength of 8Mpa were used in the model test. Joint and bedding sands (JS and BS) were reconstituted by mixing the silica sand with different grain size according to the ASTM C144 and the ASTM C33, respectively. Granular base (GB) materials consist of gravels and sand were prepared based on the standard of ASTM D2940. For the subgrade, well-graded residual soils (SG) with low plasticity were used for the model test. Fig. 1 shows the GDS of the materials used for the model test.

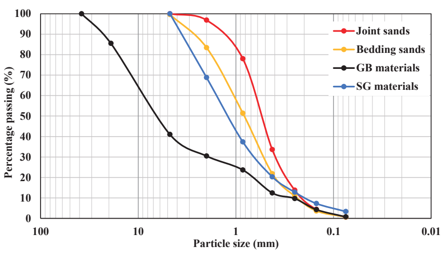

Fig. 1. GSD of paving materials used in the model test.

In order to prepare the model ground, the BS was spread homogeneously over the GB layer to reach 50 mm thickness at 47% of relative density. GB layer of 600 mm and SG layer of 200 mm were compacted to reach the target modified proctor density of 98% (CBR≈87.5%) and standard proctor density of 95%, respectively according to the Interlocking Concrete Paving Institute (ICPI) guidelines. The geotechnical properties of the paving materials are summarized in Table 1. The pavement section is described in Fig. 2 together with the abovementioned experimental setup.

Table 1. Geotechnical properties of the paving materials.

Materials	JS	BS	GB	SG
USGS	SW	SW	GW	SM
Specific gravity	2.64	2.64	2.70	2.65
Max. Dry unit weight (g/cm^3)	1.74	1.88	2.36*	1.88*
Min. Dry unit weight (g/cm^3)	1.36	1.45	-	-
Friction angle (°)	41	45	87.5%**	40.5

*Dry unit weight provided for GB and SG soils are based on modified proctor compaction and standard proctor compaction test, respectively.
**For the GB materials, California bearing ratio (CBR) test was conducted to evaluate the strength parameter.

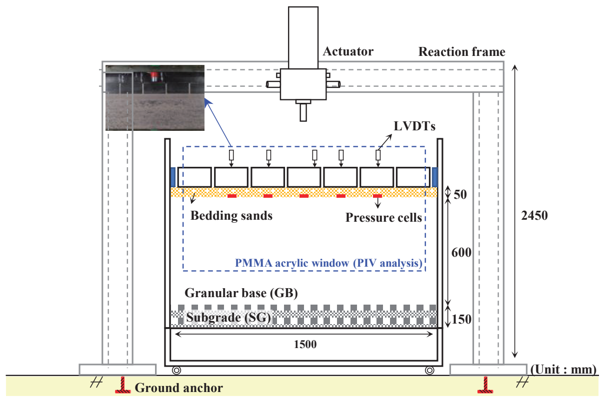

Fig. 2. Schematic diagram of newly designed experimental setup.

2.3 PIV analysis

In this study, Particle Image Velocimetry (PIV) algorithm was applied to quantify the vertical displacements within the BS and GB layer. For the analysis, the present study relied on GeoPIV software which uses close-range photogrammetry to accurately establish the image-to-object space transformation (White et al., 2005).

Since the performance of the PIV is affected by the size of the pixel subset, the analysis was initially conducted on two different digital images (original image and the image artificially shifted upwards by 10 pixels) with various pixel subset size. The image was taken by Nikon D90 camera with 4288×2848 pixel resolution. As a result, 30×30 turned out to be the optimum size with a 0.0078-pixel average error in accuracy.

2.4 Experimental program

In order to evaluate the effect of the joint sands on the performance of the IBPs, the model tests were conducted on block pavements with no jointing materials (NJ test) and the one which the joints were filled up with joint sands (JS test). For the model test, the blocks were firstly laid on a loose bedding sand (50 mm) with 5 mm joints and compacted using the sand rammer (1800 BPM / 50 mm stroke), until all the blocks showed the same degree of settlement (5 mm). Then, for the JS test a given amount of soils were swept into the joints using the brush and blocks were vibrated using the sand rammer to densify the joints.

In order to reach the target relative density of 78%, the soils were divided into two portions and the blocks were vibrated using the sand rammer inducing the settlement of the initial portion of the joint sand. Subsequently, the blocks were vibrated again after filling up the joints with the rest of the soils. until the mass of the joint sands calculated, based on the dry unit weight and volume of the joints, were all installed within the joints.

When the preparation of the test section was completed, the pavement was subjected to 10 times of loading cycles at 0.25 mm/sec loading velocity. For each loading, maximum 15kN of load was applied on the steel plate ($200 \times 100 \times 100$ mm), installed on the central block of the pavement. The exerted stress on the plate was approximately 1000kPa, higher than the single axle legal limit suggested in India based on the commonly used rigid circular plate with a diameter of 300 mm (Panda and Ghosh, 2002).

3 TEST RESULTS AND DISCUSSION

3.1 Load-settlement

Fig. 3 shows the relationship between the number of loading cycles and the maximum settlement developed at the center of the pavement during the repeated loading. In the JS test, the rate of increase in settlement were reduced with the number of loadings, indicating the progressive stiffening of the block pavement (Ling et al., 2009), whereas such phenomenon was not observed in the NJ test. The maximum settlement developed in NJ test was of 4.82 mm, approximately two times greater than that of the JS test.

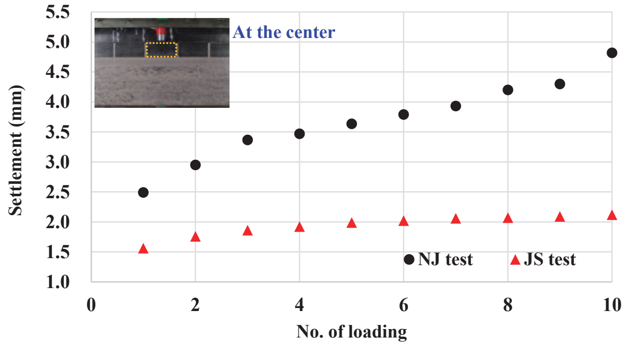

Fig. 3. Developed settlement during the repeated loading cycles.

The deflection bowl which represents the indented surface during the final loading cycle (10th) is provided in Fig. 4. The NJ test result shows that significant settlement has been developed mainly at the center of the pavement. It should be noted that, however, the settlement of the adjacent blocks was smaller than the JS test result. For the JS test, it is expected that the load transfer between the block through the joints caused a greater settlement of adjacent blocks resulting in the reduction of settlement at the center.

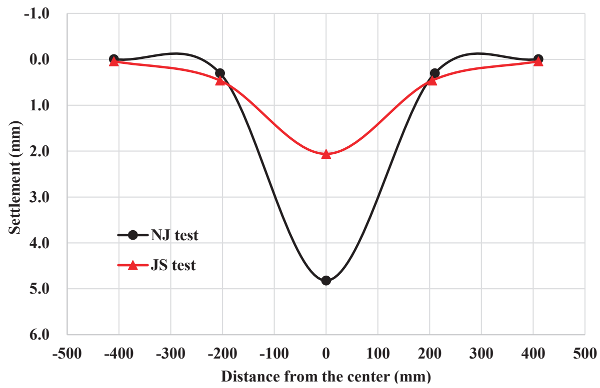

Fig. 4. Deflection bowl developed from both loading tests.

3.2 Load-dispersed load

Fig. 5 shows the maximum stress distribution above the GB layer during the final loading cycle (10th). The transmitted stress in the NJ test was approximately 20% of the applied pressure, which was two times higher than the NJ test. Additionally, analogous to the settlement results, the measured stress adjacent to the central block was higher in JS test results, indicating the higher load transfer efficiency between the blocks. For the NJ test, the pressured measure under the adjacent blocks were almost close to zero. Based on the conventional measurement results, it can be assumed that in the JS test, the applied load has been dissipated over the wide area resulting in the higher settlement resistance.

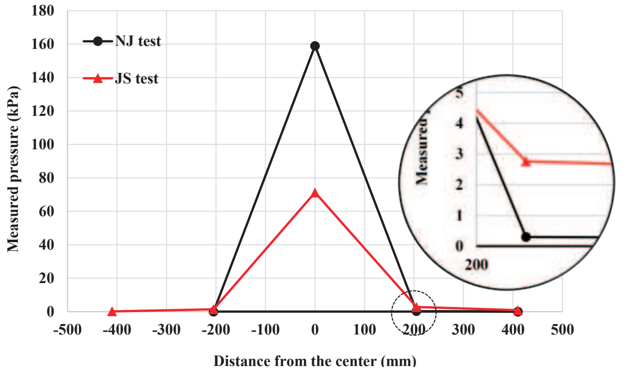

Fig. 5. Transmitted stress above the GB layer at the final loading step.

3.3 PIV analysis

Based on the PIV analysis, vertical displacement at the BS and GB layer during the final loading cycle (10th) has been provided in Fig. 6 with different level of color scale bar. In the NJ test, it can be seen that the vertical displacement is more concentrated to the area beneath the loaded block and it tends to penetrate deeper. The displacement developed tends to expand along the depth after passing through the BS layer. On the other hand, the JS test result shows that the displacement has been developed in a wider area along the shallow depth, resembling a typical displacement field of a flexible pavement.

At 200mm depth in NJ test, the vertical displacement at the center was about over 70% of the maximum surface settlement (4.82 mm). At the same depth in JS test, however, the displacement was about 25% of the maximum surface settlement (2.06 mm), suggesting that the joint sands has played an important role in gaining the higher stiffness of the IBP. It is shown that the results obtained from the PIV analysis, support the load-settlement and load-dispersed load data and furthermore provides the deformation characteristics of the subsurface layer, which is generally not investigated.

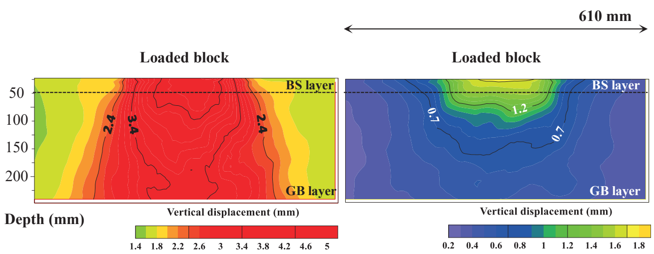

Fig. 6. Contours of vertical displacement estimated based on the PIV analysis (left = NJ test; right = JS test).

4 CONCLUSIONS

In this study, to tackle the limitation of the previous model test on IBPs, newly designed experimental setup has been provided together with the preliminary test results. The 2D physical model chamber consists of an PMMA face which allows to quantify the subsurface displacement based on the PIV analysis. For the test, geotechnical properties of the paving materials are provided, and the IBP was subjected to repeated loading to evaluate the effect of the presence of the joint sands.

Block pavements with jointing materials showed higher resistance toward repeated loading. The maximum settlement and transmitted stress were approximately two times greater in the pavement with no jointing materials. The reversed trend discovered from the blocks adjacent to the central block suggested that the load has been dissipated over a wide area. PIV analysis results revealed that the IBP with jointing materials showed a typical vertical displacement trend of the pavement with higher stiffness, supporting the settlement and stress results.

The test results obtained from this study suggests that the newly design 2D physical model test provided a successful link between the surface settlement and the subsurface deformation. Moreover, it is expected that the present contradiction in previous model test results could be solved through further experiments.

REFERENCES

Ascher D., Lerch T., Oeser M. and Wellner F. 2006. 3D-FEM simulation of concrete block pavements. In: The 8th international conference on concrete block paving sustainable paving for our future. San Francisco, USA: Interlocking Concrete Pavement Institute (ICPI); p. 457–65.

Clifford J. M. 1984. A description of "Interlock" and "Lock-up" in block pavements. In Second International Conference on Concrete Block Paving, Delft (pp. 10-12).

Lin W., Kim D., Ryu S., Hao H., Ge Y. E. and Cho, Y. H. 2018. Evaluation of the load dissipation behavior of concrete block pavements with various block shapes and construction patterns. Journal of Materials in Civil Engineering, 30(2), 04017291.

Ling T.C., Nor H.M., and Hainin M.R. 2009. Properties of concrete paving blocks incorporating crumb rubber and SBR latex. Road Mater Pave Des, 10(1): 213–222.

Panda B.C. & Ghosh A.K. 2002. Structural Behaviour of Concrete Block Paving I: Concrete Blocks. Journal of Transportation Engineering. (April).130–135.

Qiao Y., Dawson A., Huvstig A. and Korkiala-Tanttu, L. 2015. Calculating rutting ofsome thin flexible pavements from repeated load triaxial test data. Int. J. Pavement Engng 16, No. 6, 467–476.

Shackel B., & Lim D. O. O. 2003. Mechanism of block interlock. Proc., 7th Int. Conf. on Concrete Block Paving, Small Element Pavement Technologists, Leicester, U.K.

White D., Randolph M. and Thomsan, B. 2005. Image Based Deformation measurement system for geotech centrifuge.pdf. Int. J. Phys. Model. Geotech., 01–12.