Effective Thickness of Bedding Sand Layer for Shell Groove-Underside Shaped Concrete Blocks for Pavement

M. Azman[a]*, M. N. Hasanan[b], M. R. Hainin[b], N. A. K. Hafizah[c]

[a]Department of Engineering, Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, International Campus, Jalan Semarak, Kuala Kumpur, Malaysia
[b]Department of Geotechnic and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Construction Research Centre (UTM CRC), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: az_man@ic.utm.my

Graphical abstract

USCB: Shell-R15

Abstract

Underside Shaped Concrete Block (USCB) is a groove shaped block on the underside surface. The USCB concept utilizes groove pattern to grip and produce better resistance to the underside surface of block units onto the bedding sand layer. However, the horizontal movement of block units is the major problem in pavement due to vehicle braking and accelerated action. This paper presents the laboratory evaluation on vertical and horizontal displacement of shell groove-USCB pavement laid onto different bedding sand layer thickness. The bedding sand layer thickness an essential parameter to produce better USCB's performance. A series of laboratory scale test were conducted to study USCB type of the Shell-Rectangular 15 mm (Shell-R15) laid on three different loose bedding sand layer thicknesses of 50 mm, 70 mm and 90 mm respectively. Then, push-in loading test and horizontal loading test were performed. The result indicates, the bedding sand layer thickness has significant influence to the vertical and horizontal displacement to USCB Shell-R15 compared to control of 50 mm loose bedding sand layer thickness. The loose bedding sand layer thickness of 70 mm performed better compared to others.

Keywords: Underside shaped concrete block; concrete block pavement; bedding sand thickness

■1.0 INTRODUCTION

The bedding sand layer is considered an essential component in a concrete block pavement. It is located below the concrete blocks to provide a smooth level running surface for placing the blocks. The sand which was used nevertheless contributes significantly to the structural capacity of the pavement. The bedding sand layer is very close to the traffic loadings.

Bedding sand plays an important role in distributing the load on concrete blocks and improved the performance of concrete block pavement (CBP). It provides uniform support for the blocks and to avoid stress concentrations which could cause damage to the blocks. The bedding sand layer acts as a cushion to provide an even surface which blocks laid on it. The bedding sand gives a frictional force between concrete blocks to prevent the block moving towards thehorizontal force. Thus, it fills the lower part of the joint space between adjacent blocks in order to develop interlock. Changing in the thickness of the bedding sand will effect the strength and performance of CBP. The behaviour of block pavement depends to a significant degree on the shape of concrete blocks. Different types of block shapes will give different load impact on concrete block pavement. Thus, many researchers [1, 2, 3, 13] had found that block shapes do contribute larger impact to the structural performance of CBP.

The laying course thickness differs between countries. Most European countries use the 50 mm thick compacted bedding sand [1, 2]. However, Australia has specified a compacted thickness of 20 mm to 25 mm. This is a very thin layer and will therefore require the surface of the underlying base to be very smooth [3]. According to the European practices [4,5], they specify the use of 50 mm as bedding sand thickness after compaction by considering a sub-base tolerance of ± 10 mm. Simmons [6] recommended a minimum compacted sand depth of 40 mm to accommodate free movement of blocks under initial traffic.

The river sand was used for the bedding layer. It also used as jointing sand in the most of the pavement [7, 8]. Additionally,physical and mechanical properties of sand was used in experimental work as suggested by Ling *et al.* [9] and followed the grading requirement from BS EN 12620+A1 [10] as bedding layer and joint filler.

■2.0 MATERIALS AND EXPERIMENTAL WORKS

The experimental works were undertaken to study the effect of bedding sand thickness to the USCB deflection and friction resistance. The blocks with no groove (control block) were compared to USCB Shell-R15 with a rectangular groove laid in

different bedding sand thickness. The push-in loading test and horizontal loading test were conducted in the laboratory.

2.1 Materials

The USCBs (Shell-R15) were manufactured in the laboratory. The length, width and thickness of rectangular concrete blocks were 200 mm, 100 mm and 80 mm, respectively, with the length to width ratio as 2 [11]. The blocks were exposed to air cured of 30°C average temperature with approximately 65% relative humidity for 28 days [12]. Concrete blocks were tested to ensure that the concrete mix satisfied the specification. The blocks were tested at the age of 28 days with average compressive strength meeting the minimum requirement of 25 MPa, as suggested by Shackel [13]. Figure 1 illustrates the control block (without groove) and USCB Shell-R15 (with rectangular groove of 15 mm depth).
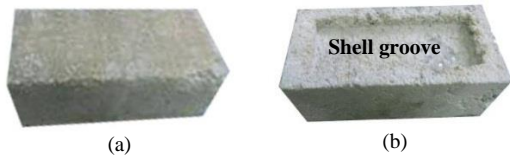

(a) (b)

Figure 1 (a) Control block and (b) USCB:Shell-R15

2.2 Test Setup

The tests of blocks were carried out in a rigid steel box with 1000 mm x 1000 mm square in plan. A reaction steel frame was used to apply vertical and horizontal load on the two pieces of 12 mm (thick), 100 mm (width) and 200 mm (length) steel plate. The loading was applied vertically straight at the center of the block in the middle of the pavement sample as shown in Figure 2. Meanwhile, Figure 3 illustrates the horizontal loading test setup with load horizontally straight applied at the center of one side of pavement sample using hydraulic jack with load cell of 200 kN capacity attached.
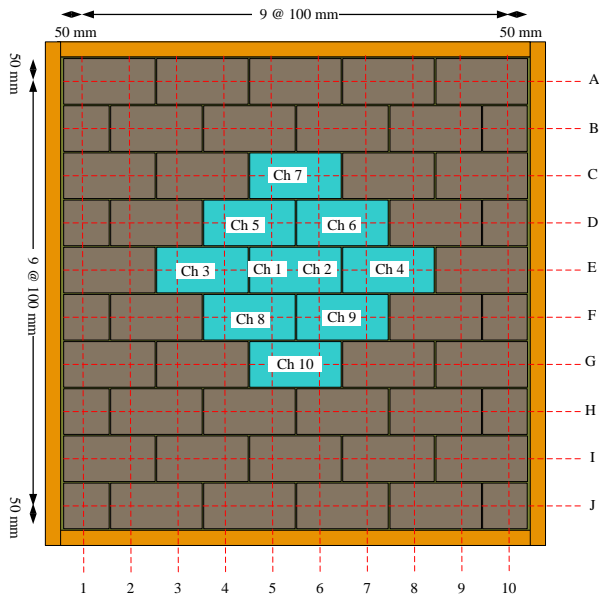

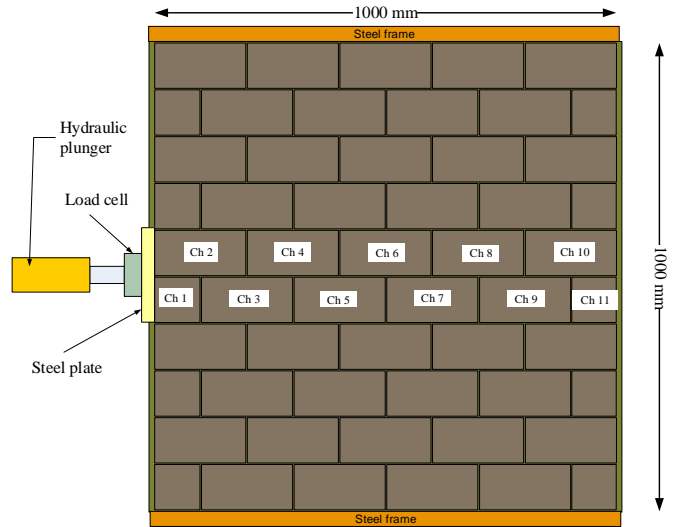**Figure 2** Grid line layout and push-in loading test point
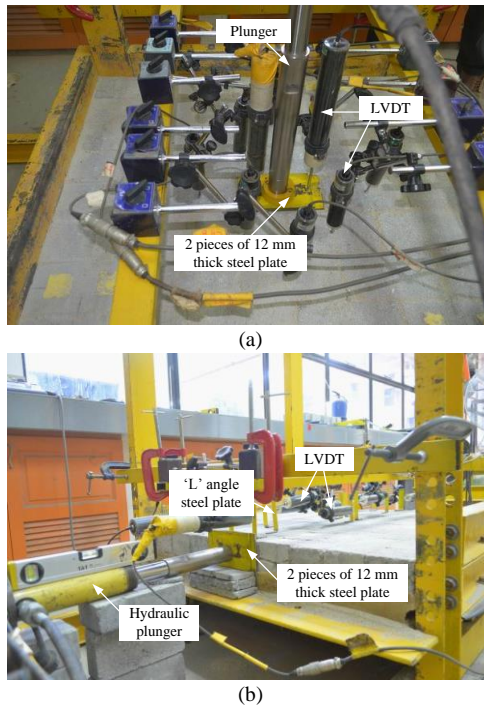

Figure 3 Horizontal loading test layout

2.3 Construction of Test Section

Bedding sand layer thickness of 50 mm, 70 mm and 90 mm with moisture content of 4% to 8% were spread out on the hard neoprene layer. The used of hard neoprene layer is to simulate a California Bearing Ratio (CBR) equivalent to 6% as used by Frank [14] and Ling *et al.* [15]. Then, the blocks were laid in a stretcher bond laying pattern on the bedding sand layer. Ten grid lines at two sides of the steel box frame and one hundred testing points were marked to measure the bedding sand settlement and block displacement as shown in Figure 2. The blocks were compacted by using plate vibrator of 800 N. The laying process was doneaccording to Cement And Concrete Association Of Australia (CCAA), TN 56 [16] and BS 7533-3:2005+A1 [17]. During the compaction process, the displacements of blocks were measured to obtain the settlement of bedding sand. After the compaction process was completed, the height of the bedding sand and displacement of concrete blocks were measured.

2.4 Test Procedures

The displacement measurements were made on bedding sand to obtain the desired thickness and the level of blocks before compaction, h_1, first cycle of compaction, h_2, and second cycle of compaction, h_3, throughout one hundred of measurement points.

A hydraulic jack fitted to the reaction frame appliesthe central load in the middle of the entire block pavement in vertical for push-in loading test (with 10 channels as shown in Figure 4-a) and in horizontal for horizontal loading test (with 11 channels as shown in Figure 4-b). While the loading was increased up to 25 kN, the displacements were measured to an accuracy of 0.01 mm using Linear Variable Differential Transducer (LVDT) connected to a data logger.

(a)

(b)

Figure 4 (a) Push-in loading test and (b) Horizontal loading test

■**3.0 RESULTS AND DISCUSSION**

3.1 Effects of USCB Shell-R15 on Bedding Sand

Figure 5 shows the settlement and compacted bedding sand layer thickness of the control blocks and USCB Shell-R15 after compaction. Settlement of bedding sand for control block was 15 mm (30%). It was in the range of 15 mm to 20 mm studied by Azman [18] and 20% to 35% by Shackel [13]. Meanwhile, settlement of loose bedding sand layer of 50 mm, 70 mm and 90 mm for USCB Shell-R15 were 18 mm (36%), 25 mm (35%) and 30 mm (34%), respectively. Thickness of loose bedding sand observably influences the percentage of bedding sand settlement. It showed that, with sufficient compaction, the bedding sand has ability to fill up the groove during the laying process as studied by Azman [19]. All the blocks (control block and Shell-R15) showed the compacted thickness of bedding sand between 35 mm to 46 mm, except 60 mm for 90 mm loose bedding sand. Compacted bedding sand thickness was in the range of 25 mm to 50 mm commonly used [1, 4].
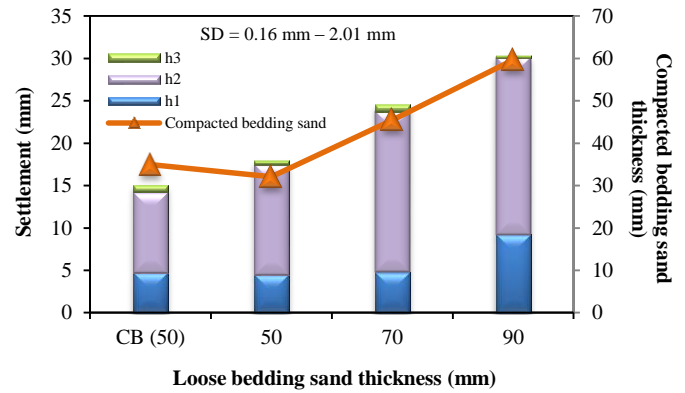
Figure 5 Settlement and compacted bedding sand

h_1 = Height of bedding sand after blocks laid, mm.
h_2 = Height of bedding sand after first cycle compaction, mm.
h_3 = Height of bedding sand after second cycle compaction, mm.

3.2 Push-in Loading Test

Channel 1 (ch1) and 2 (ch2) were the most received stresses up to 1.25 N/mm^2 and have highest deflection. The stresses were transmitted to the adjacent blocks caused by vertical friction and developed interlocking behaviour. Figure 6 presents the maximum deflection of USCB Shell-R15 at the loading of 25 kN. The deflection for USCB Shell-R15 of 50 mm and 70 mm loose bedding sand thickness was 5 mm (about 6%) better than control block. While, USCB Shell-R15 of 90 mm loose bedding sand deflected 6.5 mm and 23% more than control block. The experimental results indicate, the loose bedding sand thickness of 50 mm and 70 mm received stresses with lower deflection compared others. USCB with shell groove of 15 mm performed effectively on this bedding sand thickness. It was acceptance sufficient for loose bedding sand thickness inlay the USCB Shell-R15.

The loaded control block and USCB Shell-R15 had influenced the neighboring blocks as well as bedding sand thickness, causing them to deflect vertically. The load transfer mechanism reduced the vertical stress under the loaded block as shown in Figure 7-a. The greater the spread of vertical movement influence is, the greater the degree of vertical interlock and hence the higher the load transfer. Similar agreement has been found by Azman *et al.* [20]. This phenomenon was observed in all USCB where all the adjacent blocks had deflected vertically. This observation was recorded through visual inspection and 2D contour assessment as shown in Figure 7-b. From the figure, the darker colour shows the more extensive stress received from the load applied and vice versa. The lighter colour indicated that the stresses were transmitted to the adjacent block when the load was applied. This load transfer mechanism applies to both USCB and control block.
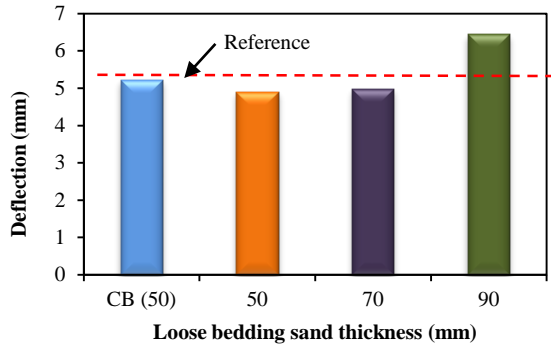
Figure 6 Deflection of USCB Shell-R15 at the middle test point of pavement compared to CB at the loading of 25 kN
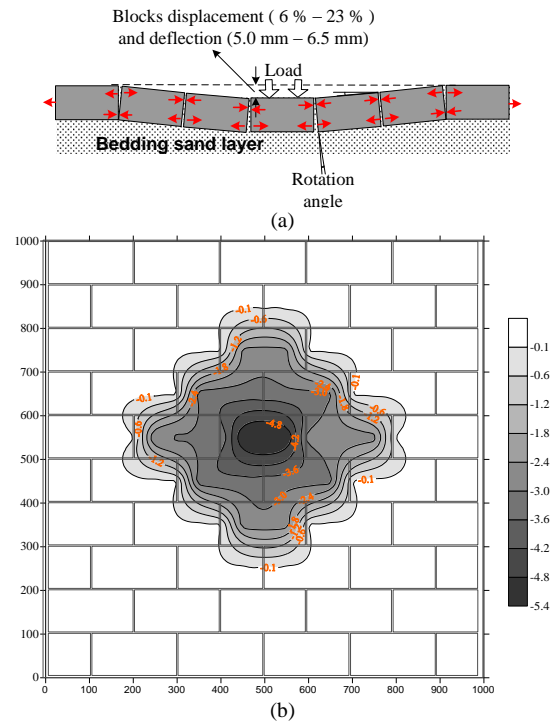

Figure 8 Horizontal resistance behaviour under horizontal loading

Figure 7 Load transfer mechanism; (a) Movement of blocks under load and (b) Deflection contour of USCB Shell-R15

Figure 9 Block movement with stress concentration

3.3 Horizontal Loading Test

The horizontal loading test was conducted to study the friction resistance of USCB Shell-R15 on the various loose bedding sand thicknesses as shown in Figure 8. The horizontal loading was applied at the maximum of 50 mm displacement because LVDT-50 mm can measure until this limit. This figure portrays the stage of the frictional resistance. The static friction and dynamic friction happened during the testing. In the first stage, the static friction occurred while the blocks sustain the load at the higher resistance before it started moving. Then, the blocks moved slowly toward the loading to reach the maximum measuring limit namely dynamic friction. Dynamic friction indicated the block's self weight resistance. The blocks moved without an increasing of loading due to no stress concentration occurred. Whereas, stress concentration (Figure 9) will increase the loading because block was concentrated at one block's edge.
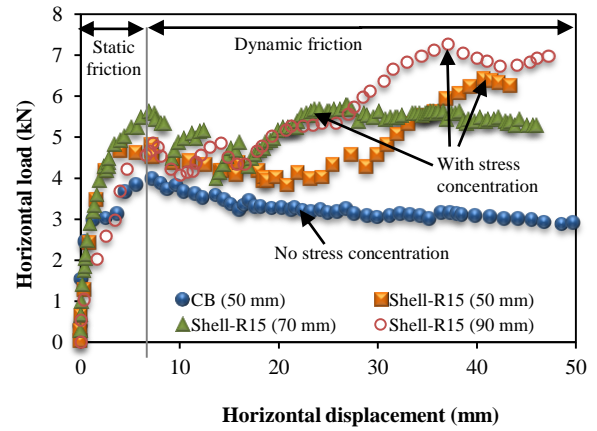
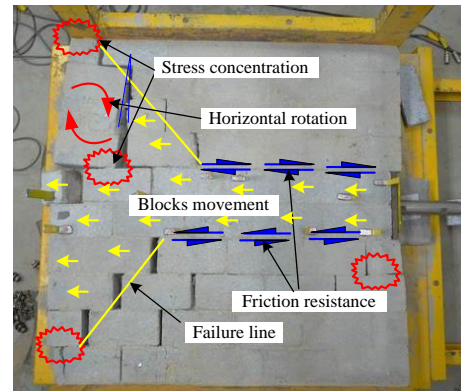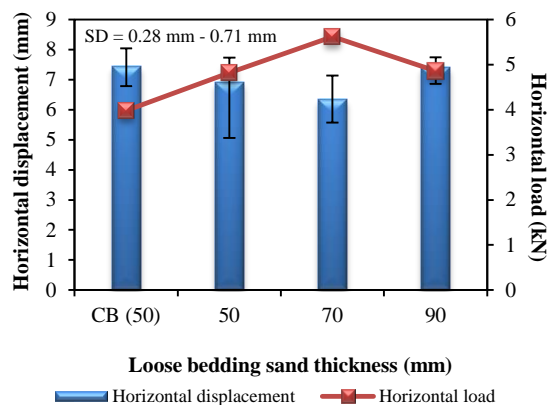Figure 10 shows the horizontal displacement and horizontal loading versus different thickness of loose bedding sand. The horizontal displacement of USCB Shell-R15 of 70 mm loose bedding sand thickness was 6.3 mm about 15% less than control block. It produced 5.6 kN the highest friction resistance with 41% better compared to others. Increasing loose bedding sand thickness, lead USCB Shell-R15 to increase the horizontal displacement, but little effect to horizontal loading except for 70 mm loose bedding sand thickness. Loose bedding sand thickness of 50 mm and 90 mm were increased 21% and 22% of friction resistance respectively. USCB Shell-R15 for 70 mm loose bedding sand thickness has shortest static friction, while 90 mm loose bedding sand thickness shows the opposite situation. Therefore, 70 mm loose bedding sand thickness give significant interaction between bedding sand thickness and USCB Shell-R15.

Figure 10 Average horizontal displacement and maximum horizontal loading at static friction

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◼4.0 CONCLUSION

The main conclusions can be drawn from this study are as follows:

i. Increasing the thickness of loose bedding sand would increase the bedding sand settlement of USCB Shell-R15.

ii. 70 mm loose bedding sand thickness was the effective thickness of bedding sand with a settlement of 35%.

iii. USCB Shell-R15 of 50 mm and 70 mm loose bedding sand thickness was 6% better withstand to reduce the deflection than control block.

iv. The horizontal displacement of USCB Shell-R15 of 70 mm loose bedding sand thickness was 15% less than control block and produced 41% friction resistance better compared to others.

v. 50 mm and 90 mm loose bedding sand thickness, lead to increase the horizontal displacement, but little effect to horizontal loading.

vi. 70 mm loose bedding sand thickness gives significant interaction between bedding sand thickness and groove shell of 15 mm.