PERFORMANCE OF CONCRETE BLOCK PAVEMENT ON SLOPED ROAD SECTION

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ABSTRACT: The construction of Concrete Block Pavement (CBP) on slopes provides interesting challenges for road engineers. The horizontal (inclined) forces exerted on the road surface are greatly increased due to traffic accelerating (uphill) and braking (downhill). These forces will cause horizontal creep of the blocks down the slope, resulting in opening of joints at the top of the road section. The objective of this study was investigate the effect of parameters include degree of slope, laying pattern, joint width, and thickness of paving block on the performance of CBP on slopes. A laboratory-scale test was used to study these parameters based on steel frame horizontal force and push in tests. Three different laying pattern (stretcher bond, herringbone 90^{o} and herringbone 45^{o}) and joint width (3 mm, 5 mm and 7 mm) were used in the test program. The pavement responses are characterized in terms of horizontal creep and deflection due to applied load for half of an allowable single axle limit. The results indicate that herringbone 45^{o} laying pattern and 3 mm joint width performed best on slopes section. The 100 mm paver thickness is found to be more stable than 60 mm thickness from aspect horizontal force resistant. The results also indicate that the increase of the slope increase the horizontal creep, but decrease of the pavement displacement.

KEY WORDS: Concrete block pavement, paver, laying pattern, joint width, slope, horizontal creep

1. INTRODUCTION

Interlocking concrete blocks are precast concrete units about the size of a normal house brick. They are manufactured with close dimensional tolerances in a wide variety of shapes. Interlocking concrete block pavement is constructed with individual block being laid in patterns with close, unmortared joints on a bedding sand layer between restraints [1].

The pavement structure below the surfacing is similar to that provided beneath bituminous surfacing. Figure 1, shows the structure layer of CBP. The pavement is designed and constructed generally as conventional flexible pavements in which the blocks and their laying course take the place of the bituminous surfacing [2].

A typical CBP cross section is constructed of individual blocks of brick-sized units, placed in patterns with close, unmortared joints on a thin bed of sand between edge restraints overlaying a subbase. The joint spaces are then filled with sand. The blocks are available in a variety of shapes and are installed in a number of patterns, such as stretcher bond, herringbone bond, etc [3].

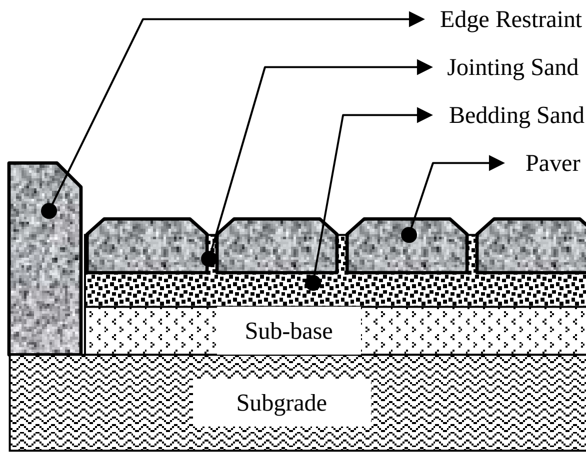

Figure 1. Structure of concrete block pavement

The construction of roads on steep slopes provides interesting challenges for road engineers. The horizontal (inclined) forces exerted on the road surface are markedly increased due to traffic accelerating (uphill) and braking (downhill). These horizontal forces cause distress in most conventional pavements, resulting in rutting and poor riding quality as shown in Figure 2. Experience has shown that CBP performs well under such severe conditions. Although CBP performs well on steep slopes, there are certain considerations that must be taken into account during the design and construction of the pavement and the alternative used of the anchor beam [4,5].

1.1 Anchor Beam

It is common practice to construct edge restraints (kerbing and anchor beams) along the perimeter of all paving, to contain the paving and prevent horizontal creep and subsequent opening of joints. Due to the steepness of the slope, the normally vertical traffic loading will have a surface component exerted on the blocks in a downward direction. This force is aggravated by traction of accelerating vehicles up the hill and breaking of vehicles down the hill. If uncontained, these forces will cause horizontal creep of the blocks down the slope, resulting in opening of joints at the top of the paving. An anchor beam at the lower end of the paving is necessary to prevent this creep. Figure 3 and Figure 4 shows, a typical section through an anchor beam.

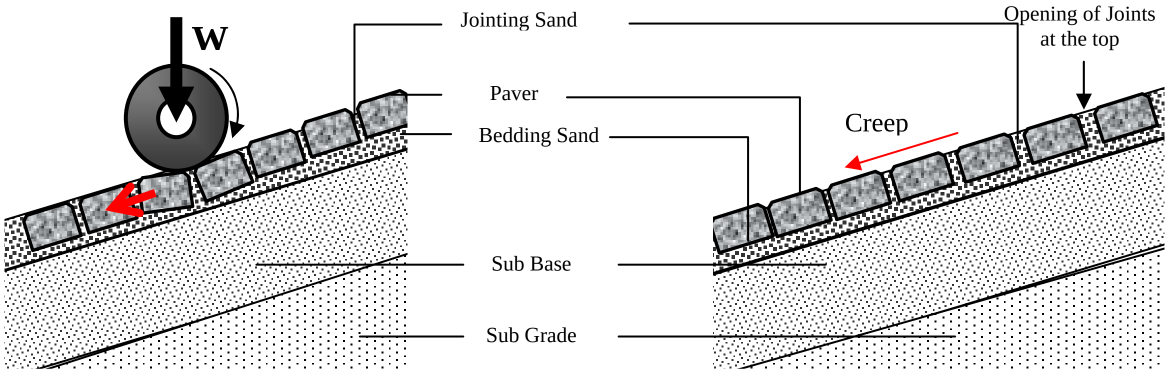

Figure 2. Deformation and horizontal creep of CBP for sloping road section

1.2 Construction of Anchor Beam

For ease of construction, it is recommended that the blocks be laid continuously up the gradient. Thereafter, two rows of blocks are uplifted in the position of the beam, the sub base excavated to the required depth and width and the beam cast, such that the top of the beam is 5 – 7 mm lower than the surrounding block work. This allows for settlement of the pavers [6]. This method of construction will ensure that the anchor beam interlocks, with the pavers and eliminates the need to cut small pieces of block.

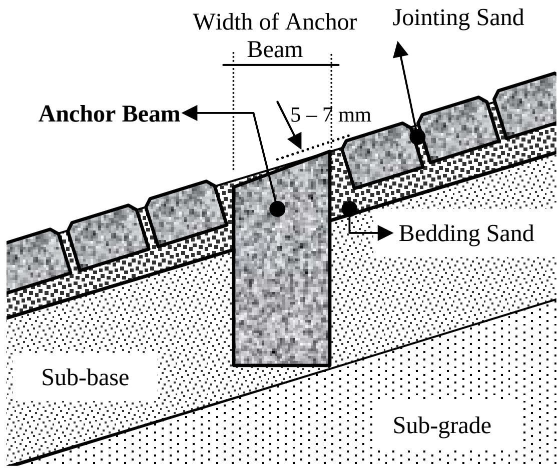

Figure 3. Detail of Anchor Beam

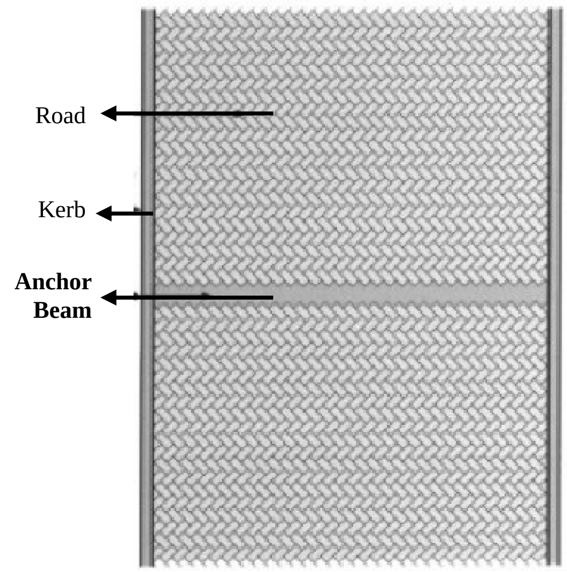

Figure 4. Anchor Beam used on CBP

1.3 Spacing and Position of Anchor Beams

Based on the degree of sloping road section, laying pattern, joint width between blocks, shape and thickness of paver, there are estimated rules of the anchor beam spacing [7]. In this research, horizontal force test and push in test were conducted the on the concrete block pavement in sloping position.

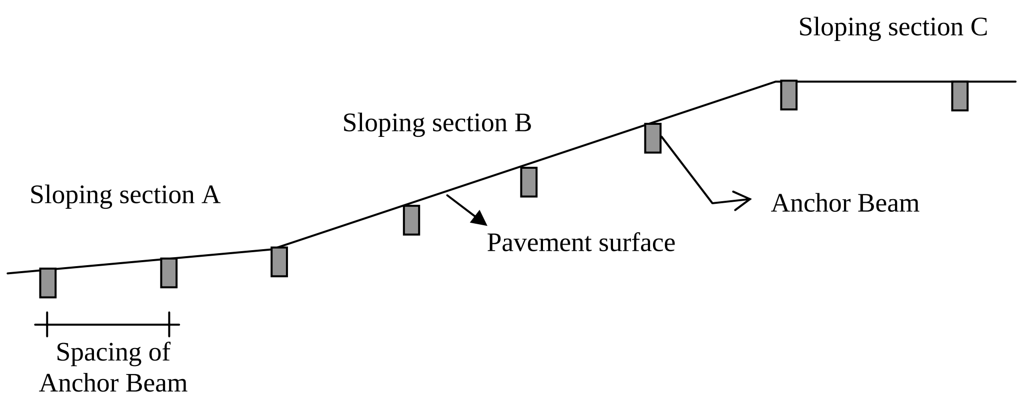

Figure 5. Spacing and position of anchor beam

2. OBJECTIVE

The objectives of the study is to study performance of CBP deformation (horizontal creep and vertical displacement) that effected by bending sand thickness, laying pattern, block thickness, block shape and joint width between blocks. To test and analyses various experiment of CBP in the laboratory with horizontal force and push-in tests on various degree of slopes.

3. EXPERIMENTAL INVESTIGATION

A laboratory-scale model of 2.00 m x 2.00 m was set up to study the behavior of concrete block pavement to test in relation to joint width, block laying pattern, block thickness when subjected to horizontal force and vertical loading.

3.1 Materials

Sand: River sand from Kulai in Johor-Malaysia was used. The particle size distribution of bedding and jointing sand follow the grading requirement as tabulated in Table 1. Prior to use in each experiment, the sand was oven dried at 110°C for 24 h to maintain uniformity in test results. A maximum dry density of 1.73 gm/cc was obtained, corresponding to an optimum moisture content of 8.2 %. Two separate sand gradations were be used for the bedding layer and in the block joints.

Table 1. Grading requirements for bedding sand and jointing sand

Sieve Size	***Percent Passing For Bedding Sand***	***Percent Passing For Jointing Sand***
3/8 in. (9.5 mm)	100	-
No. 4 (4.75 mm)	95 to 100	-
No. 8 (2.36 mm)	80 to 100	100
No.16 (1.18 mm)	50 to 85	90 – 100
No. 30 (0.600 mm)	25 to 60	60 – 90
No. 50 (0.300 mm)	10 to 30	30 – 60
No. 100 (0.150 mm)	5 to 15	15 – 30
No. 200 (0.075 mm)	0 – 10	5 – 10

BS 1377 Part I (1990) and TN 35: CCA (1996)

Paver: The concrete paving block conform to ASTM C 936, and 60 mm and 100 mm thickness, and rectangular in shape. Concrete blocks of 60 mm thickness and 110 x 220 mm of rectangular shape were used as the surface layer of the experiments. The mean compressive strength of the blocks was 32.30 MPa.

4. TEST SET UP

The horizontal force test was conducted using steel frame as edge restraint of 2.00 m wide and 2.00 m length. The test set up (shown in Figure 6) was varieties construction of CBP with laying pattern (stretcher bond, herringbone 90^{o} and herringbone 45^{o}) and joint width (3mm, 5 mm and 7mm). Loads were applied to the test pavement from side by using a hydraulic jacking system of 100 kN capacity clamped to the reaction steel frame.

The push-in test was conducted using steel frame in a laboratory-scale model assembled for this purpose as shown in Figure 7. The test set up was a modified form of that used by Shackel [8], where the pavers were laid and compacted within a steel frame in isolation from the bedding sand, sub-base course, and other elements of CBP. Here, instead of a frame, the tests were conducted in a box to incorporate the elements of CBP (i.e. bedding course, jointing sand and paver). It consists of a rigid steel box of 1000 x 1000 mm square in plan and 200 mm depth, in which pavement test sections were constructed. The box was placed on a steel plate 10 mm thickness, beneath the reaction frame. Loads were applied to the test pavement through a rigid steel plate using a hydraulic jacking system of 100 kN capacity clamped to the reaction frame.

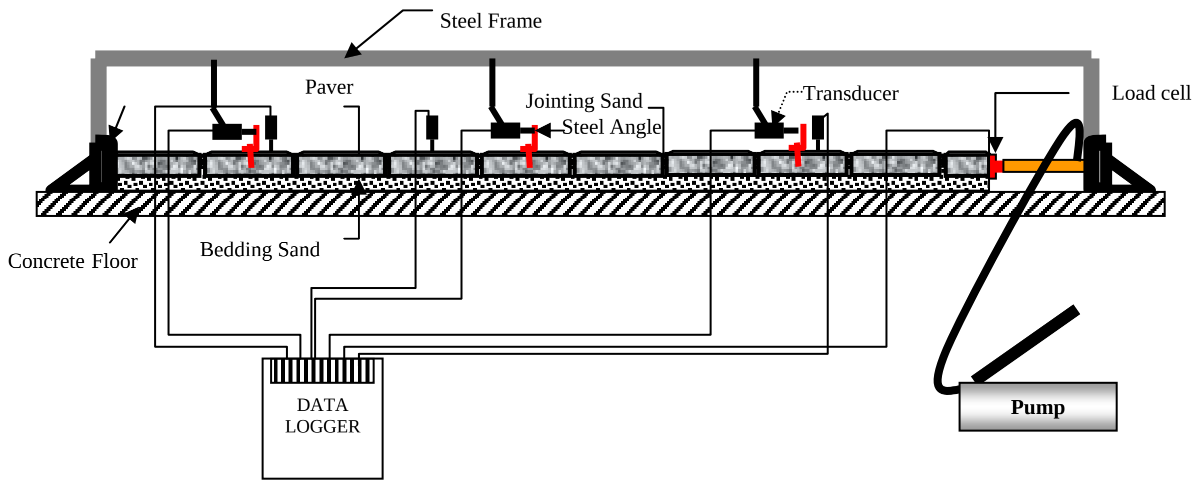

Figure 6. Horizontal force test set up

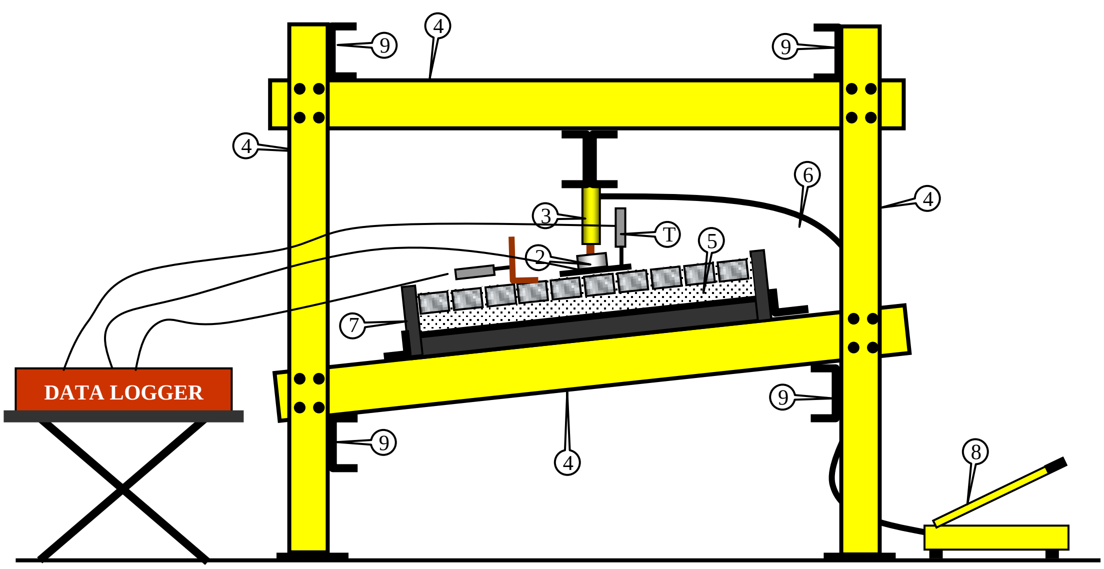

Figure 7. Push-in test setup

1. Transducer
2. Load Cell
3. Hydraulic Jack
4. Steel Frame C Profile
5. Bedding Sand
6. Oil Pipe
7. Steel Frame Box 1mx1m
8. Hydraulic Pump
9. Cross Steel Frame

5. CONSTRUCTION OF TEST SECTIONS

The test sections of CBP were constructed within the box. A steel plate of 10 mm thick covered with sand was supported by steel frame (I beam profile). This thickness is reasonable for use in CBP to prevent immediate shear failure along the joints between blocks [9]. At any two adjacent edges of the test pavement, side steel plates of required thickness were placed to control the desired width of joints in each test. The length and depth of side plates were 1000 and 200 mm, respectively. The depth was selected such that the side plates, when placed on the base, would reach the top of the block layer. Bedding sand of a particular gradation and thickness as per test requirements was uniformly screeded to a loose state. Pavers were then manually placed on the bedding sand in stretcher bond. Once the pavers were placed, they were compacted by a vibrating plate compactor of 250 N static weights vibrating at a frequency of 3,000 rpm. The compaction was continued until the top of each paving block was level with the adjacent blocks and to refusal of further settlement under vibration. The joints were then filled by brushing in the jointing sand. The joint filling operation was continued until all joints were completely filled with sand. Finally the top surface of pavement was cleaned of excess sand.

6. TEST PROCEDURES

A hydraulic jack fitted to the reaction frame applied a central load to the pavement through a rigid circular plate with a diameter of 300 mm. This diameter corresponds to the tire contact area of a single wheel, normally used in pavement analysis and design [10]. A maximum load of 51 kN was applied to the pavement. The load of 51 kN corresponds to half the single axle legal limit. Deflections of the pavements were measured using four transducers to an accuracy of 0.01 mm corresponding to a load of 51 kN. The transducers were placed on two opposite sides of the plate at a distance of 100 mm from the center of the loading plate. The average value of four deflection readings was used for comparing experimental results.

The parameters, including joint width, thickness of bedding sand, and thickness of paver, were varied in the experimental program. For each variation of a parameter, the test was repeated three times to check the consistency of readings. The average of the three readings is presented in the experimental results in graphical form. The range of the standard deviations (SD) of the readings for each parameter is presented in the respective figures. For each test, measurements of joint width were made at 20 randomly selected locations. The mean and standard deviation were calculated to assess the deviation from the design joint width. Design joint width as referred to herein be the desired width established in the experiment; however, the achieved joint widths always varied. The mean and standard deviation of joint widths description with and without sand before compacted are summarized in Table 2. While discussing experimental results, pavement deflections were compared referring to design joint widths.

Table 2. Width joint description with sand

Design Joint Width (mm)	Range of Joint Width (mm)	Standard Deviation of Joint Width (mm)
3	3.04	0.38
5	5.01	0.49
7	7.10	0.89

7. RESULTS AND DISCUSSIONS

7.1 Load Spreading Mechanism

Sand was used both in the bedding and joints. The thickness of bedding sand was 30 mm, 50 mm and 70 mm. For each parameter, tests were carried out for 3 mm, 5 mm and 7 mm joint widths. Figure 8 presents the deflections for pavements with and without application of jointing sand. For each joint width, the pavement without jointing sand deflected three times more than that of the pavement with jointing sand. This shows the importance of jointing sand. The concrete blocks in the pavement without jointing sand behave as individual units. Individual blocks do not transfer the applied load to adjacent blocks. Thus, the block layer has little load spreading capacity. The block layer obtains load spreading capacity if the individual blocks are interconnected. For this purpose, the joints between the blocks should be filled with sand.

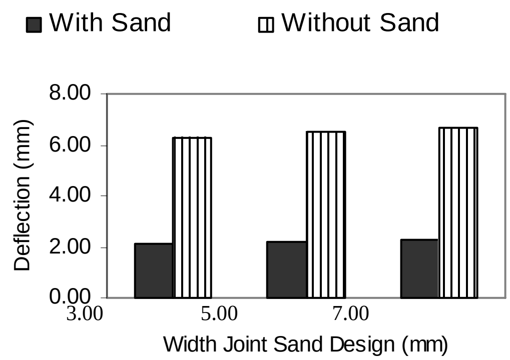

Figure 8. Pavement deflection with and without sand in joints

7.2 The Effect of Joint Width

The sand was used in bedding course with a 50 mm loose thickness for all of these experiments. Figure 9 shows the response of pavement for design joint widths of 3, 5 and 7 mm with uniform quality of sand in the joints. As the joint width decreases, the deflection of the pavement also decreases.

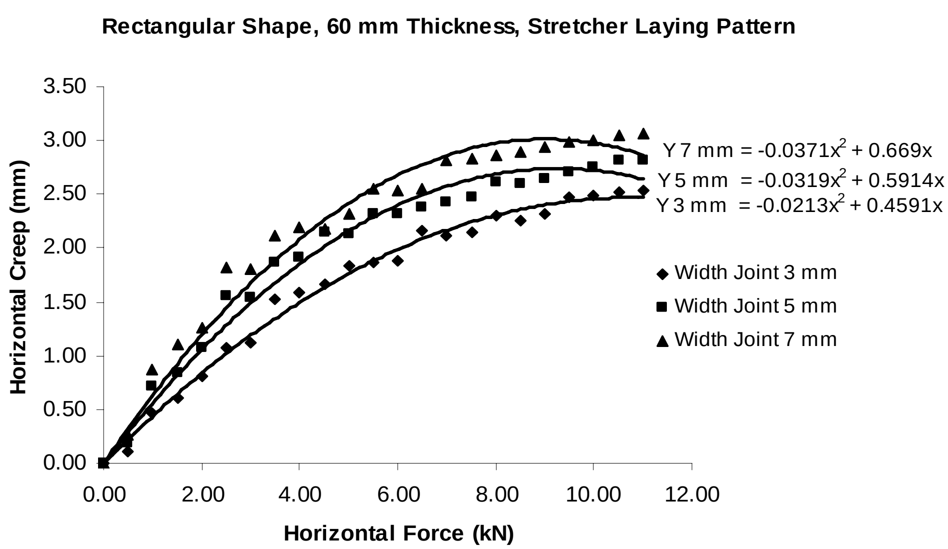

Figure 9. The effect of joint width (3mm, 5mm and 7mm)

7.3 The Effect of Laying Pattern

The experiments were conducted that blocks lain in a herringbone 45^o and herringbone 90^o bond performed better under traffic than blocks laid in a stretcher bond. The results from these tests, are incorporated in Figure 10. Here, for block rectangular shape, a comparison is possible between a pavement laid in a herringbone 45^o bond, herringbone 90^o bond and a pavement laid in a stretcher bond with the long axes of the blocks parallel to the direction of trafficking. It was found that the pavement lain in stretcher bond did not fully develop interlock. Indeed, this pavement failed by faulting along the joints as the wheel load was increased. By contrast, the pavement laid in herringbone bond developed full interlock and successfully withstood increases in the wheel load up to 51 kN. This suggests that pavements laid in herringbone bonds will yield superior performance to pavement laid in stretcher bond.

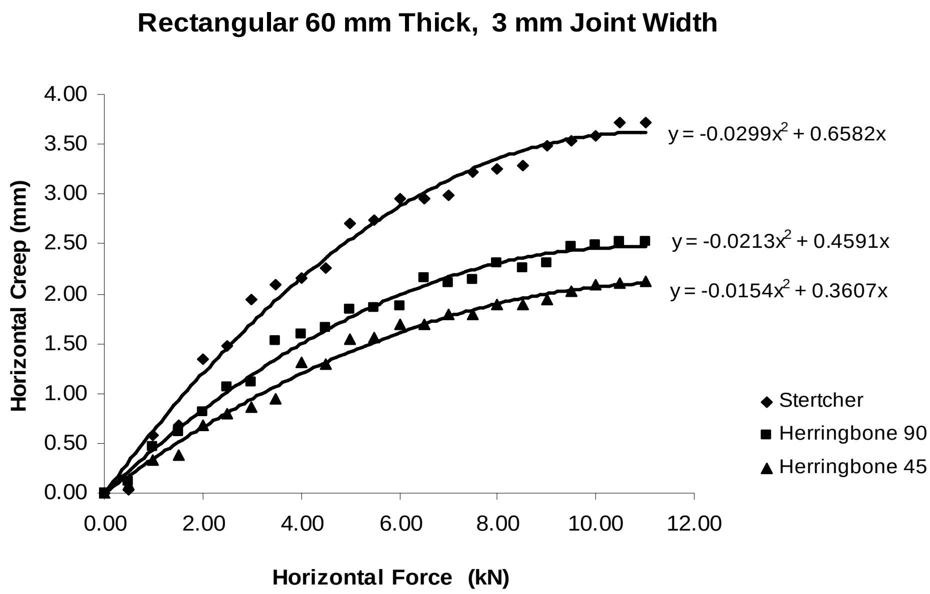

Figure10. The effect of laying pattern (stretcher bond, herringbone 45^o and herringbone 90^o)

7.4 The Effect of Paver Thickness

The concrete block pavement performance was essentially dependent of surface course (block thickness) whereas Clark (1995) reported a small improvement in performance with increase in paver thickness [6]. For this reason the study included and examination of paver thickness 60 mm and 100 mm. The parameter was used to assess the respond of the pavement was maximum horizontal creep until failure (uplift) the long axes of the blocks parallel to the direction trafficking. As shown in Figure 11, it was determined that an increase the thickness of the paving blocks led to reduction in the horizontal creep and uplift of the blocks. Here, increase of paver thickness would increase of the contact areas of the blocks, thus increase the friction resistance between blocks. It should be noted that, at the force horizontal (11 kN), block thickness was the principal arbiter of pavement performance in respect of horizontal creep and uplift of several blocks.

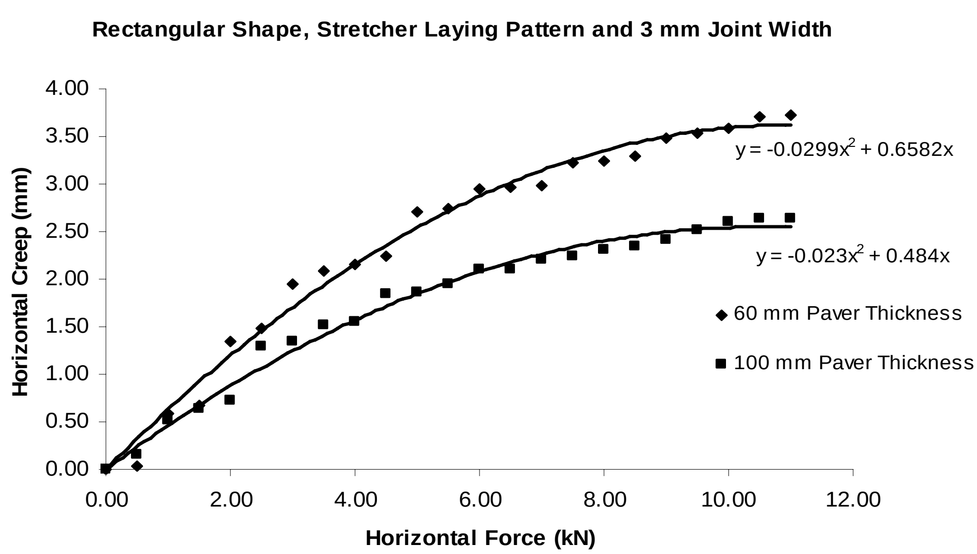

Figure 11. The effect of paver thickness (60mm and 100mm) under horizontal force loading

7.5 The Effect of Degree of The Slope

The constructions of concrete block pavement on sloping road section, that must be contain the paving and prevent horizontal creep and subsequent opening of joints. The normally vertical traffic loading would have a surface component exerted on the blocks in a downward direction. This force was aggravated by traction of accelerating vehicles up the hill and breaking of vehicles down the hill. The results of full-scale experiment in the laboratory shown in Figure 12, that increase of the slope increase the horizontal creep, but decrease of displacement. Here, increase of the slope, causes wide of the contact area increase the resistance friction between blocks.

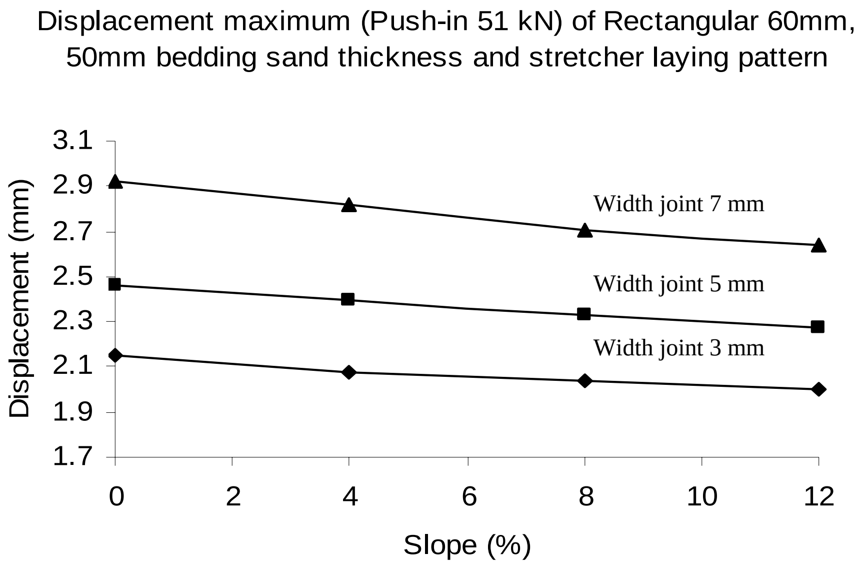

Figure12. The effect degree of slope

8. CONCLUSIONS

Based on the limited test results provided in this part, the following conclusions can be drawn:

- The pavement without jointing sand deflected three times more than that of the pavement with jointing sand, this shows the importance of jointing sand.
- The Displacement of pavement decreases up to a certain point and then slightly increases with decrease in joint width, 3 mm is an optimum joint width.
- The herringbone 45^o laying pattern better then stretcher bond also herringbone 90^o laying pattern from aspect horizontal force resistant and interlocking concrete block pavements
- The 100 mm paver thickness more stable than 60 mm thickness from aspect horizontal force resistant because the cross surface area between blocks and also weight pavers themselves.
- The displacement of pavement decreases with the degree of the slope was increase, it was caused the friction of jointing sand between blocks was increase.

ACKNOWLEDGEMENT: The authors express their sincere thanks to the Universiti Teknologi Malaysia, UTM for their encouragement and support.

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