LOAD DISPERSION ABILITY OF CONCRETE BLOCK LAYERS

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SUMMARY

The top layer of concrete block pavement (CBP) is discrete and discontinuous. Tests conducted around the world demonstrate that CBP responds to traffic in a way that differs from the response of flexible asphalt or rigid concrete pavement. It is too complex to incorporate the discontinuities (joints) in the structural modeling of the block layer. However, the design method can be simplified made similar to the method for flexible pavement by removing the block layer in the analysis and applying an equivalent reduced traffic load intensity spread over a larger area directly on the base course. The load dispersion behavior of the block layer depends primarily on the structural interactions among its individual components so as to build up resistance to applied loads. Plate load tests were carried out to quantify the ability of block pavers to distribute vertical load. The test pavements were studied under an applied load of 51 kN, which corresponds to half the legal single axle load limit at present in force in India. Blocks of five shapes and three thicknesses were used in the investigation. Pressure cells were embedded in the top of the subbase to measure the intensity of load transfer from the top of the block layer to the base course. The horizontal spread of the vertical load was also determined from pressure cells positioned so as to cover a wide area on top of the base course.

1. INTRODUCTION

Concrete block pavement (CBP) was only introduced into India in the early 1990s (Muraleedharan and Nanda 1992). Since then, the market penetration of paving blocks has been slow, restricted to architectural applications and the paving of pedestrian areas (Panda and Ghosh 1999). Over the past 50 years, CBP has been applied successfully worldwide in both roads and industrial hardstands. However, the evident advantages of ICBP have not yet been fully exploited in India because of a lack of proven indigenous design and construction information. The progress that has been made in this area has been reviewed elsewhere (Panda and Ghosh 2000). Overseas literature is referred to when a block pavement is designed and constructed.. However, the design practices of other countries have obvious limitations when applied to the very different traffic and environmental conditions in India. The quality and specifications of pavement materials used in India are different from those of other countries. There is therefore a need to develop a local design standard for CBP.

The principal components of a typical block pavement are illustrated in Fig. 1. The top layer is discrete and discontinuous. Beneath the bedding sand the substructure is similar to that of a conventional flexible pavement. The manner in which the top (block) layer resists the external load is similar neither to that of flexible or rigid pavement. Therefore, before any meaningful design method can be formulated, it is necessary to understand the load-spreading ability (LSA) of CBP under static and

repetitive loads in the Indian environment. This paper discusses the experimental results of the LSA of CBP.

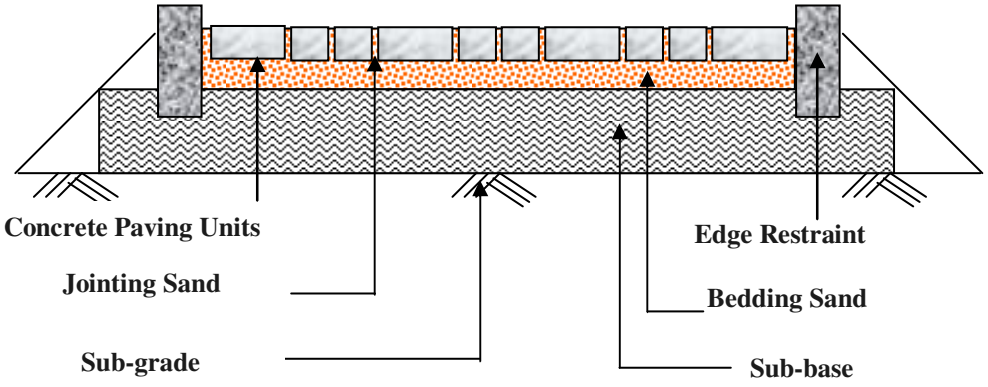


Figure 1. Components of a concrete block pavement

2. BACKGROUND

CBP differs from other types of pavement in that the wearing surface is made of small concrete paving units bedded and jointed in sand rather than continuous paving. The block layer is the major load-spreading component of the pavement. Below this layer, the substructure is same as that of a conventional flexible pavement.

The various test methods that have been used for identification and evaluation of the factors that influence block paving performance include:

(i) Simple plate load tests (Knapton and Barber 1979; Knapton and O'Grady 1983; Shackel et al. 1993; Emery 1986).
(ii) Accelerated trafficking trials of full-scale prototype pavements (Miura et al. 1984; Shackel 1982; Houben and Jacob 1988).
(iii) Field trials of actual block pavements (Emery and Knapton 1988; Knapton 1985; Sharp et al. 1982).

These tests have established a few behavioral aspects of CBP, namely:

(a) Block pavements tend gradually to accumulate rutting deformations under traffic loading, similar to conventional flexible pavements.
(b) Because of the articulated nature of block paving, large elastic deflections of up to 2 mm or more have been observed under truck traffic. This is generally unacceptable for other conventional flexible pavement design procedures to prevent surface fatigue cracking of the wearing course.
(c) Under traffic loading, block pavements tend to develop interlock, which causes the load-spreading ability of the blocks to increase and the rate of rutting deformation to decrease.

From the above discussions, it is clear that CBP responds to traffic in a way which is different from the response of flexible or rigid pavement. However, there is still widespread agreement that CBP should be designed as a flexible pavement (Houben and Jacobs 1988; Knapton and Smith 1998; Shackel 1988).

The structural model for CBP is generally developed for use in mechanistic design procedures. The models can be divided into three categories as described below.

I - Layered elastic model:
In the case of a layered elastic system, the pavement is modeled as a succession of layers, each having linear elastic properties. Such procedures are already well established for conventional flexible pavements. This approach is widely used to analyze block pavements in Australia, Japan, Netherlands, South Africa, the U.K. and the U.S.A. (Shackel 1980; Kasahara and Matsuno 1988; Houben et al. 1984; Clifford 1988; Barber and Knapton 1980; Rada et al. 1990). The layered elastic model ignores the discrete discontinuous nature of paving blocks, but rather assumes that the block course can be modeled in terms of an equivalent continuous elastic layer.

II - Finite element model:
The finite element model (FEM) was developed to include the discontinuities (joints) of a CBP.. Here the blocks are modeled as an articulated surface with defined load or displacement transference characteristics at the joints between adjoining paving units. For this purpose a special type of element known as a rigid body spring element is used. FEM studies of CBP have been developed in the Netherlands (Molenaar et al. 1984; Van der Heijden and Houben 1993; Houben and Jacob 1988; Huurman 1997). Here the formulation of the technique was more comprehensive as the analysis included an assessment of a complete block/base/subbase/subgrade system. The finite element model is more suitable as a research tool than a tool for routine design, particularly as the method is slow and requires expert computation time, and the models were too small.

III - Load substitution model:
This model was developed in Germany for design in industrial zones (Eisenmann and Leykauf 1988). The model uses multi-layer theory, the same as the elastic layered model. To simplify the analysis procedure, the load-distributing effect of the concrete blocks is taken into consideration by an increased circular area of radius $a^* = a + h + d$ with reduced contact pressure p^* on the top of second layer.

Where a = Radius of loading area.
h = Thickness of concrete block.
d = Depth of bedding sand layer.

Thus a two-layer system has to be evaluated. This model is simple and excludes the CB layer from the analysis, thereby avoiding the difficulty of representing the CB layer as in the previous models.. However, no experiments have been conducted to verify the model.

It was felt that the phenomenon of block interaction under applied load needed investigation in the light of above discussion. Such tests could then provide insights into the load-spreading ability and other structural characteristics of block pavement.

3. EXPERIMENTAL INVESTIGATION

3.1 Materials

The details of the block shapes used in the experiments are given in Fig. 2. Their strength and other geometrical properties are given in Table 1. River sand was collected from the bed of the Kasai River close to Kharagpur. Before being used in the experiment, the sand was oven dried at 110 ^{o}C for 24 hours to maintain uniformity of test results. Good quality dolerite aggregates were used for preparing the subbase of the test pavement. The gradation and angle of shearing resistance of the bedding sand,

the jointing sand and the sub-base materials are presented in Table 2. A flexible rubber sheet (Young's modulus of 5.10 MPa) 25 mm thick was used at the bottom layer of the test pavement to simulate the subgrade of real pavement.

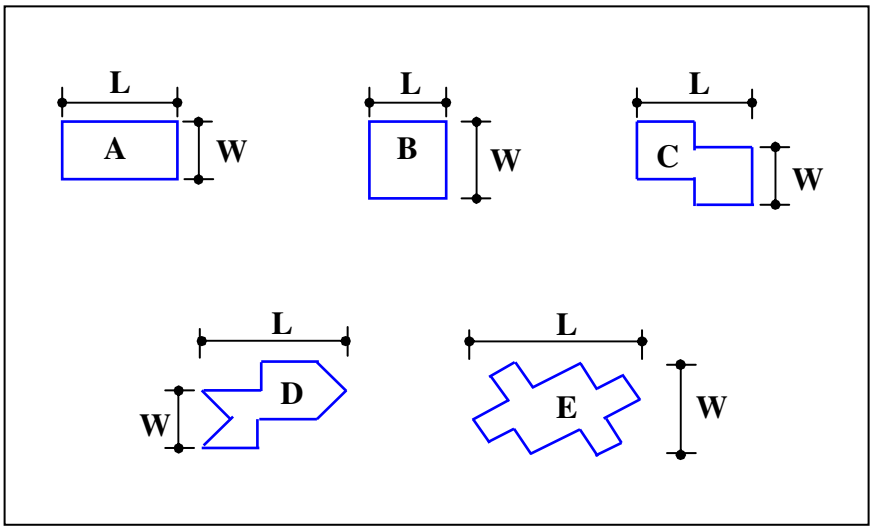


Figure 2. Details of block shapes used in the study

Table 1. Details of blocks used in this study

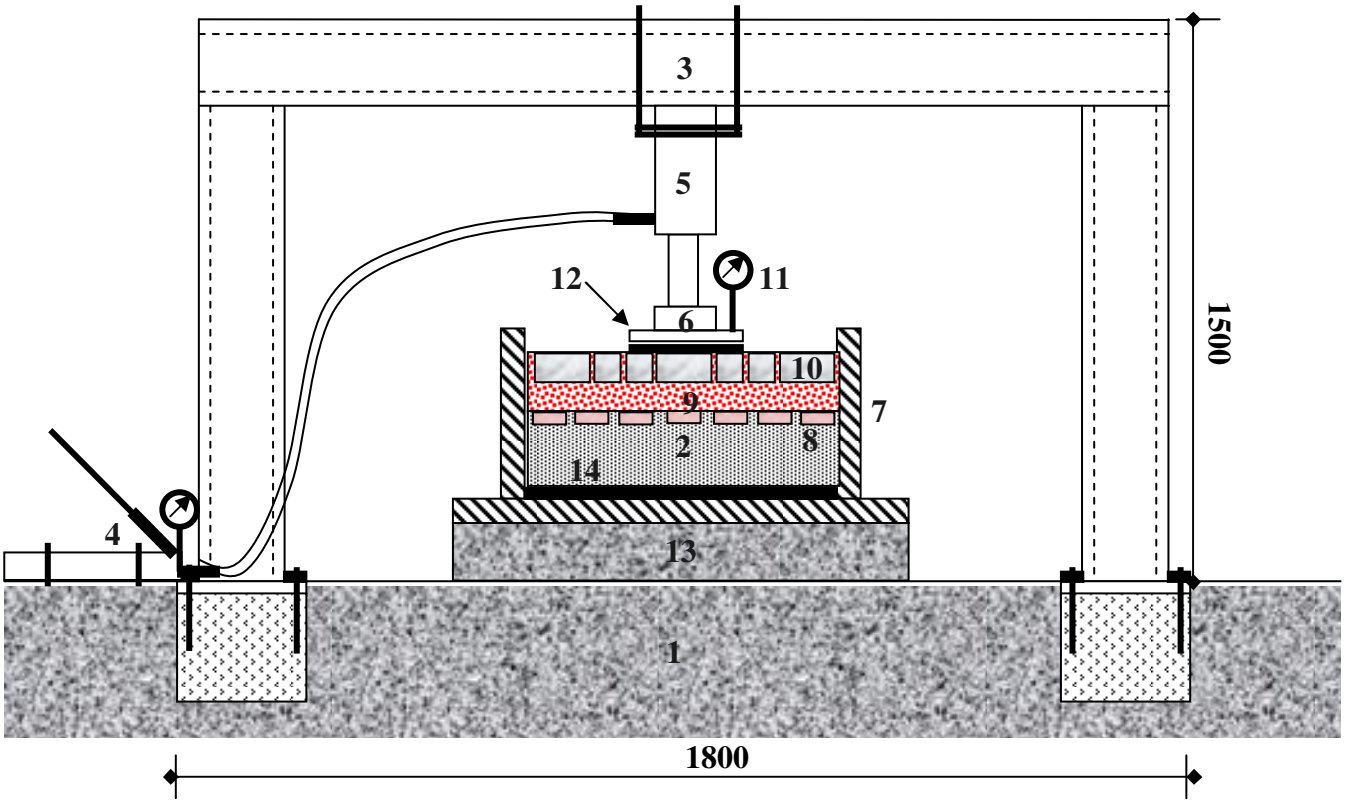
Block Type	Block Shape	Length "L" (mm)	Width "W" (mm)	Plan Area (mm^2)	Thickness (mm)	Vertical Surface Area (mm^2)
(1)	(2)	(3)	(4)	(5)	(6)	(8)
1	A	212	106	22,472	100	63,400
2	A	212	106	22,472	80	50,720
3	A	212	106	22,472	60	38,040
4	B	150	150	22,500	80	48,000
5	C	212	106	22,472	80	59,360
6	D	265	106	22,472	80	66,400
7	E	248	124	22,472	80	66,336

Table 2. Gradation of sand and subbase material and angle of shearing resistance

(a) Gradation			
Sieve size (mm)	Bedding sand % Passing	Jointing sand % Passing	Sub base material % Passing
(1)	(2)	(3)	(4)
20	-	-	100
10	100	100	77
4.75	94	100	66
2.36	70	100	50
1.18	46	68.23	34
0.60	30	47.05	25
0.30	16	28.52	15
0.15	6	15.29	8
0.075	2	10	4
(b) Angle of Shearing Resistance (ϕ) in degrees			
ϕ (Degrees)	42.62	41.08	-

3.2 Test set-up

The test was carried out in a laboratory scale model set-up assembled for the purpose (Fig. 3). The test set-up was a modified form of that used by Shackel et al. 1993. He tested pavers**,** laid and compacted within a horizontal steel frame, in isolation from the bedding sand, the subbase course and other elements of CBP. Here, instead of a frame, the tests were conducted in a box so as to incorporate all the elements of CBP. It consisted of a rigid steel box 775 mm square by 450 mm deep in which the pavement test sections were constructed. The box was placed on a raised concrete platform under the reaction frame. Load was applied to the test pavement through a rigid steel plate by a hydraulic jacking system of 300 KN capacity clamped to the reaction frame. A rubber sheet 25 mm thick with the same diameter as that of loading plate was placed under loading plate to simulate pavement tire contact and for uniform application of external pressure.



1. **Concrete floor**
2. **Crushed rock subbase**
3. **Reaction frame**
4. **Pumping unit**
5. **Hydraulic jack**
6. **Load cell**
7. **Test box**
8. **Pressure cell**
9. **Bedding sand**
10. **Concrete blocks**
11. **Deflection gauge**
12. **Loading plate**
13. **Concrete platform**
14. **Rubber sheet**

Figure 3. The test set-up

3. 3 Construction of Test Sections

The test sections of CBP were constructed within the box. To allow full shear deformation of the sand in the joints, the flexible rubber sheet was kept at the bottom layer. Crushed rock subbase of 200 mm compacted thickness was placed on the rubber sheet. This thickness is the value used in CBP which is reasonably required to prevent immediate shear failure along the joint between blocks (Knapton and Barber 1979). The pressure cells (total of seventeen) were embedded in the subbase layer so that their top surfaces were at same level as the subbase (Fig. 3). The positions of the cells in plan view are shown in Fig. 4. Bedding sand was uniformly screeded to a loose and uncompacted depth of 50 mm on the crushed rock subbase. Pavers were laid manually on the bedding sand in the desired bond. At any two adjacent edges of test pavement, steel side plates were placed so that the design joint width between blocks would be 2.5 mm. Once the pavers had been laid, they were compacted by the vibrating plate compactor of 250 N static weight vibrating at a frequency of 3,000 rpm. The joints were then filled with jointing sand by brushing and washing in.

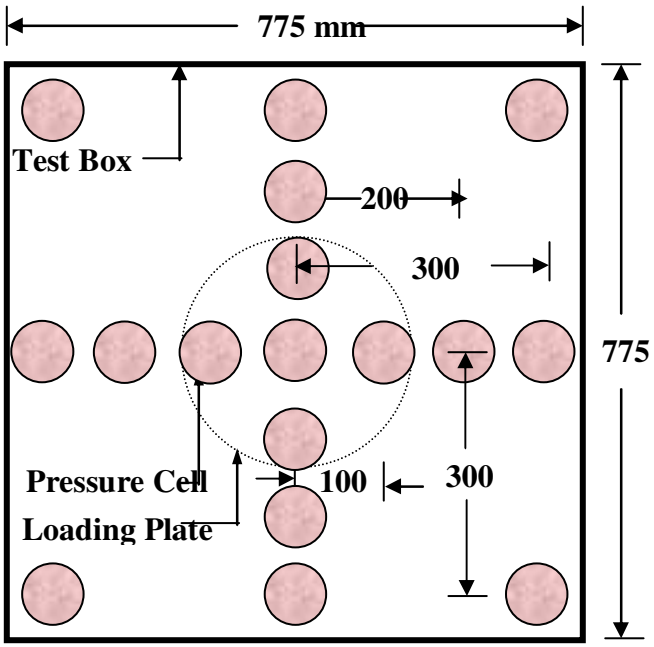


Figure 4. Arrangement of pressure cells in test box

3.4 Test Procedures

The hydraulic jack was fitted to the reaction frame. Load was applied to the pavement via a rigid circular plate 300 mm in diameter.. This diameter corresponds to the tire contact area of a single wheel normally used in pavement analysis and design (Bose 1994). The load was gradually increased from 0 kN to a final load of 51 kN. The load of 51 kN corresponds to half the legal single axle load limit at present in force in India (IRC-37 2000). The pressure of 51 kN transmitted to the top of the subbase was measured at all the pressure cells. Parameters such as block shape, thickness and laying pattern were varied in the test program. Details of the laying patterns used in the study are shown in Fig. 5. For each parameter variation, the test was repeated three times to check the consistency of pressure cell readings. The average pressure value obtained from the three test runs was determined.

Table 2. Details of parameters varied in the test program

Test Ref.	Loading Plate Diameter (mm)	Applied Pressure (MPa)	Constitution of pavement		
			Shape & Type	Thickness (mm)	Pattern
1	300	0.7215	Ty. 2 -Sh. A	80	St.
2	300	0.7215	Ty. 2 -Sh. A	80	Hr.
3	300	0.7215	Ty. 2 -Sh. A	80	Bs.
4	300	0.7215	Ty. 1 -Sh. A	100	St.
5	300	0.7215	Ty. 3 -Sh. A	60	St.
6	300	0.7215	Ty. 4-Sh. B	80	St.
7	300	0.7215	Ty. 5 -Sh. C	80	St.
8	300	0.7215	Ty. 6 -Sh. D	80	St.
9	300	0.7215	Ty. 7 -Sh. E	80	St.

Note: Ty. = Type, Sh. = Shape, Hr. = Herringbone, St. = Stretcher, Bs. = Basket weave

4. OBSERVATIONS AND DISCUSSION

4.1. Effects of Block Shape

Five block shapes were selected for the study. These were Type 2-Shape A, Type 4-Shape B, Type 5-Shape C, Type 6-Shape D and Type 7-Shape E (Fig. 2 and Table 1). These block types had the same thickness and nearly the same plan area. The blocks were laid in a stretcher bond pattern for each test. The results obtained are compared in Fig. 5. The trends of the curves were similar for all the block shapes. The stress applied to the top of the block layer was reduced drastically in magnitude and spread over a larger area on top of the subbase. The stress distribution above the subbase was not uniform, but rather parabolic. This in contrast to what was assumed by Eisenmann and Leykauf (1988). The reduction in stress is less for Shape A and Shape B and more for Shape C, Shape D and Shape E. The load spread on the subbase was greater for Shape C, Shape D and Shape E and less for Shape A and Shape B. In general shaped (indented) blocks tend to have a high load-spreading capability compared to rectangular and square blocks. This behavior is similar to that observed by Panda and Ghosh (2002).

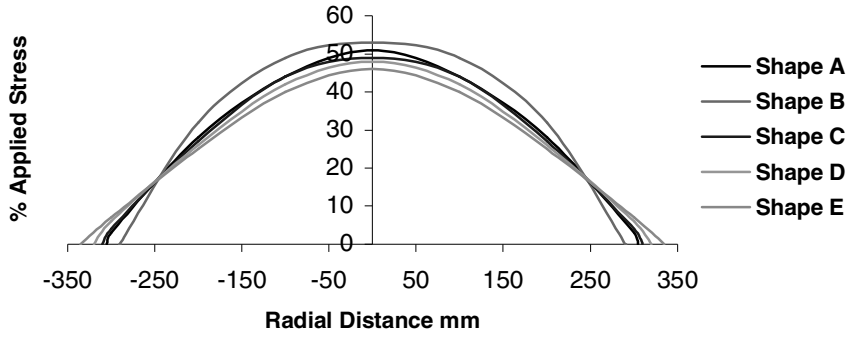


Figure 5. Stress Distribution with Varying Shapes

A block with a complex shape has a larger vertical surface area than a rectangular or square block of the same plan area (Table 1). Consequently shaped blocks have a larger frictional area for load transfer to adjacent blocks. Thus greater stress reduction is associated with shaped blocks.

4.2. Effects of Block Thickness

Rectangular blocks (Shape A) of the same plan dimension but of three different thicknesses were selected for testing. The thicknesses were 100 mm, 80 mm and 60 mm for Type 1, Type 2 and Type 3 respectively (Table 1). The Blocks were laid in a stretcher bond pattern for each test. The trends of the curves were similar for all block thicknesses. A change in thickness from 60 mm to 100 mm significantly reduces the applied vertical stress measured on the top of the subbase. This behavior is similar to that observed by Panda and Ghosh (2000). The spread of stress is greater for thicker blocks.

A comparison is shown in Fig. 6**.**

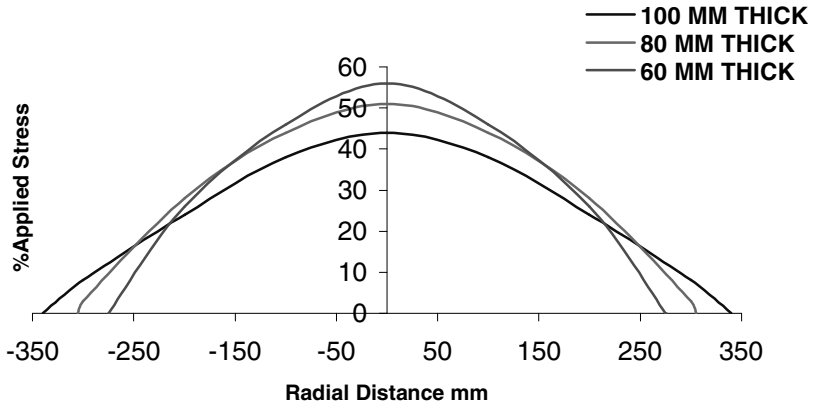


Figure 6. Stress Distribution with Varying Thickness

The greater the thickness of the blocks**,** the greater will be the frictional area. Thus load transfer will be high for thicker blocks. Again, for thicker blocks, displacement of individual blocks is greater with the same amount of block rotation. As a result, the back thrust from the edge restraint will be greater

which will increase the joint stiffness. Thus vertical stress reductions are much greater for thicker blocks. It is concluded that the response of the pavement is greatly influenced by block thickness.

4.3. Effects of Laying Pattern

Rectangular blocks (Shape A) of Type 2 were laid in three patterns, viz. stretcher bond, basket-weave bond and herringbone bond (Fig. 7) in the test pavement. The trends of the curves were similar for all the laying patterns, as shown in Fig. 8. Although the friction areas and the thickness of the blocks in all three laying patterns were the same, greater stress reduction was obtained with blocks laid in a herringbone pattern, whereas lower stress reduction is associated with the stretcher bond pattern. The vertical stress ratios are intermediate for the blocks laid in the basket-weave bond pattern.

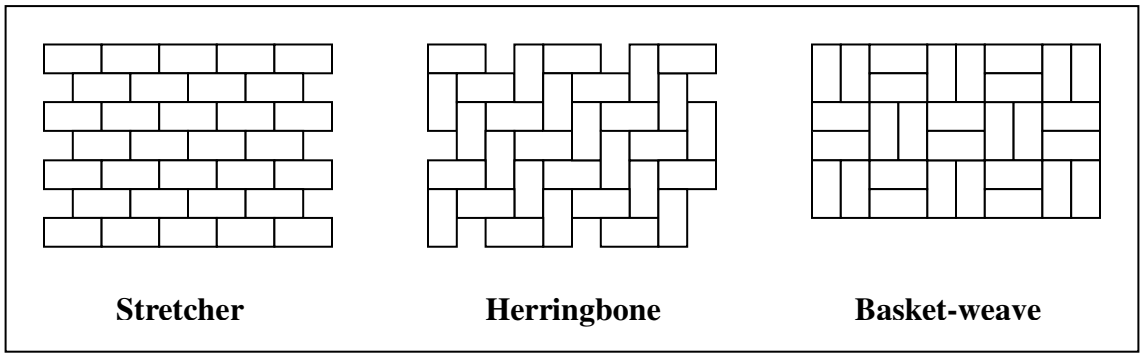


Figure 7. Details of laying patterns used in the study

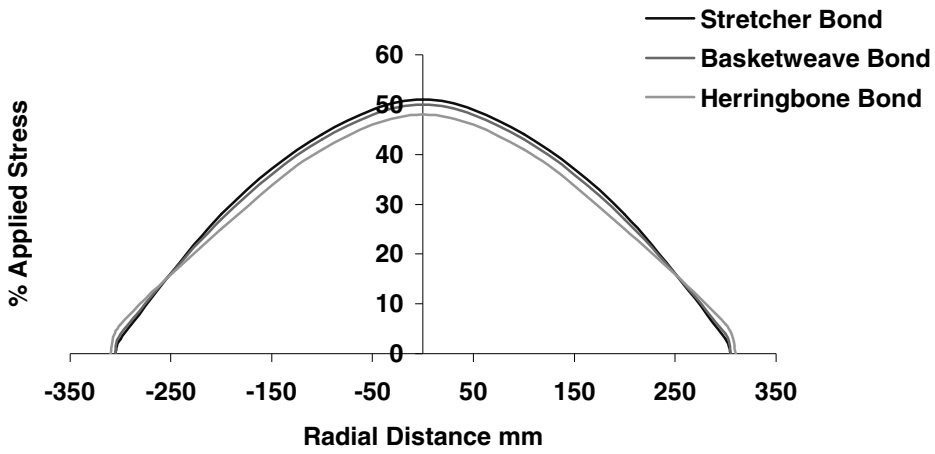


Figure 8. Stress distribution with varying bond pattern

With the herringbone pattern, the arrangement of blocks is such that the interactions between the blocks are more effective. Rotation and displacement of one block affects a greater number of blocks in the pavement. As a result, more blocks share the applied load than in the stretcher bond pattern.

5. CONCLUSIONS

This investigation of the load-spreading ability of concrete block pavement is a purely introductory study. The findings presented in this paper need to be verified by conducting experiments under field conditions The main conclusions that can be drawn from the test results are summarized as follows:

1. The stress distribution above the subbase is not uniform but rather parabolic, which is in contrast to previous assumptions.
2. It was established that block shape influences the load-spreading ability of block pavement under load. Shaped (indented) blocks perform better in pavement than rectangular or square blocks of similar thickness laid in the same pattern.
3. The response of the pavement is greatly influenced by block thickness. An increase in block thickness increases the load-spreading ability of the pavement.
4. It was established that a greater load-spreading ability of the blocks is achieved by laying them in a herringbone pattern.

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