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A study on behavior of block pavement using 3D finite element method

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Abstract

Three dimensioned finite element analysis were conducted on concrete block paving. In order to verify the calculated results, an experimental case study was analyzed. Good agreement was observed between the measured and the calculated results. Based on the finite element analysis results and available failure models, comprehensive design charts were developed for port and industrial pavement which can take into account; the sub grade and pavement layers properties as well as the tire pressure and the number of repetitive loads. In addition by using 3D finite element model mechanism of interlocking between pavers was discussed. Parametric study were conducted on 3D models and it was found that jointing width, shape, size and thickness of blocks have a significant influence on the behavior of block pavement.

Keywords: Finite element; Block pavement; Interlocking; Failure model; Jointing.

1. Introduction

The analysis presented in 1984 was restricted solely to a consideration of the block surfacing but was valuable in providing theoretical confirmation of the difference in performance of Pavement installed is different lying patterns [1]. Another study conducted in 1984 demonstrate that finite element analysis were capable of pavement more accurately than elastic layer theory [2]. Two and three dimensional finite element model was made in 2003 consist of all component of concrete block pavement that using solid elements for simulation [3]. In this analysis which concrete Block laid as stretcher pattern, a good agreement between results calculated with the linear and non-linear FE models and the measured result from case study was observed. Finite element method is on of the strict way to design of concrete block pavement which considers discontinuous nature of Block Pavers. It is difficult to model block pavement by finite element for structural analysis because their layers consist of a large number of very small elements especially while using herring bone pattern.

In this study, the analysis of the 3-dimensioned finite element model was carried out using the ANSYS finite element package. In order to determine the accuracy of above analyses a

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comparison was made between the vertical displacements of pavement obtained from the analysis with those measured from a case study which are discussed in the following sections. Furthermore, this paper discusses the finite element analysis results relating to the effect on Pavement Performance by changing parameters such as joint width, concrete block characters (i.e. shape, thickness, size and compressive strength associated with concrete blocks).

2. Case study

In order to verify the analysis results, a laboratory-scale test on block pavements was selected as a case study[2]. Figure 1 illustrates the vertical deflection of pavement against load.

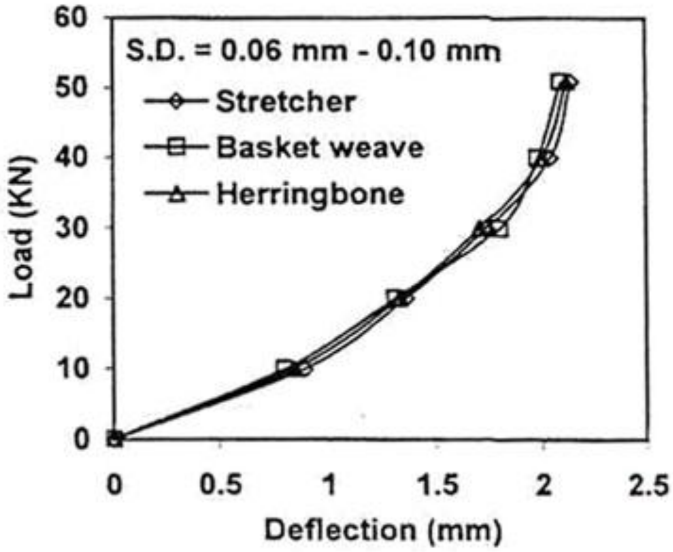

Figure 1. Deflection of block pavement against load increasing [2].

3 dimensional finite element model are shown in Figure 2 which the height, length and width of mesh are 755 mm, 775 mm and 450 mm, respectively. It consists of blocks having 106 mm width, 212 mm length and 80 mm thickness and laid in herring bone pattern. The pavement structure is modeled as a combination of solid elements and contact elements. The blocks, base, subbase, subgrade, joints and bedding sand are divided into the solid elements and interface between block and sand joints are represented by contact elements.

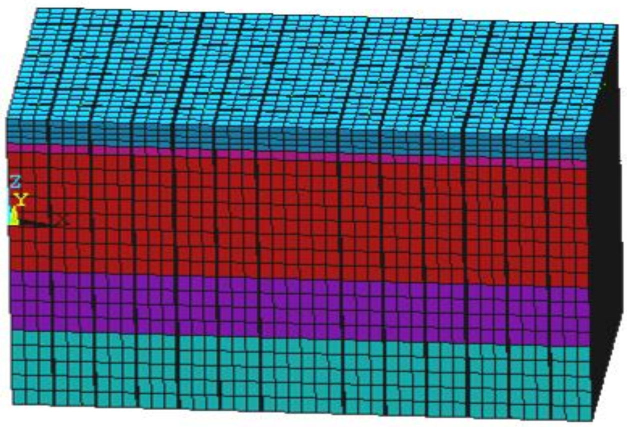

Figure 2. Three – dimensioned FM model.

Vertical displacement is fixed on all side faces of the layer and other displacements are set to be free. All displacements are fixed at nodes on the bottom of the structure. Loads are applied on the surface as uniformly distributed circler shape. Material properties that have been used in analysis selected from the case study report and in the absent of specification, properties recommended by shackle were used [3]. The layers properties are presented in Table 1.

Table1. Material Properties.

Material	Geotechnical Parameter				
	E MPa	ρ ton/m^3	μ	C kN/m^2	ϕ Deg.
Con. block	2500	2	0.3	---	---
gravel	350	1.8	0.33	---	41
base	225	1.8	0.35	10	30
subgrade	5.10	---	0.40	10	30

For the analysis, concrete block is considered to be elastic, bedding sand, base, subbase and subgrade layers were assumed to have elasto perfectly plastic behavior and Drucker-Prager model [4] was utilized as their failure criteria. Figure 3 shows the contours of vertical deflection of pavement under vertical load, for non linear 3-dimensioned analyses.

There is reasonable agreement between numerical and the laboratory-scale test results as has been shown in Figure 4. Following results obtained from parametric study on 3D finite element analysis.

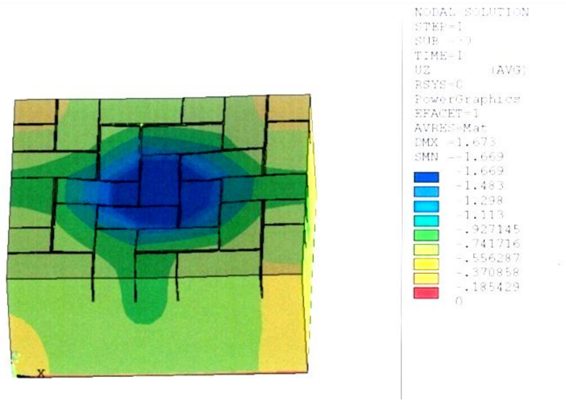

Figure 3. Contours of vertical deflection of concrete block paving from 3D finite element analysis.

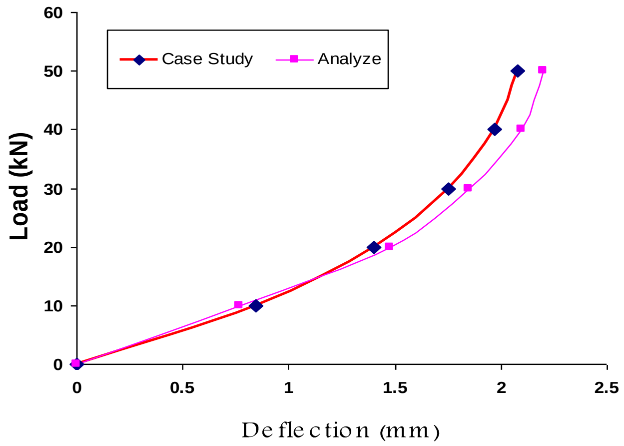

Figure 4. Deflection of pavement against load.

3. Parametric study

3.1. Joint width

Figure 5 shows the response of pavement for joint widths of 1.5~9 mm. As the joint width decreases, the deflection of the pavement also decreases up to a certain point, and then slightly increases with decreasing in joint width. The optimum joint width is found to be 2.3mm. The increase of joint width cause lesser normal stiffness of the joints. This results in rotation and translations occurrence in concrete blocks and there would be more deflection under the same load for joints with higher width.

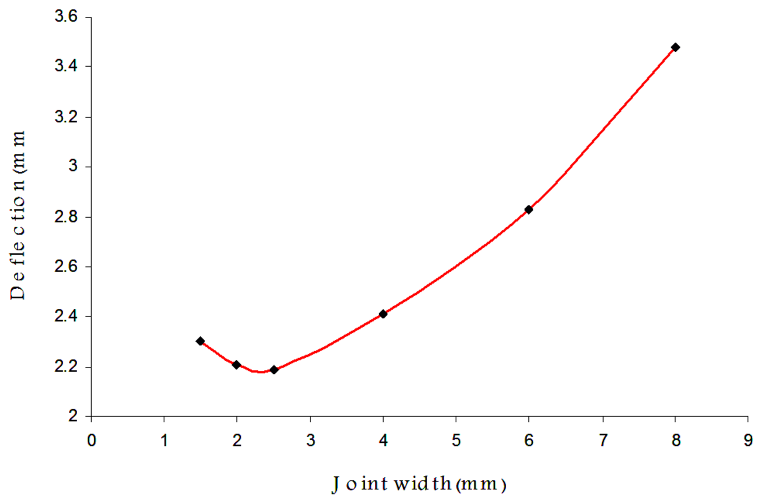

Figure 5. Pavement deflections with varying joint width.

3.2. Effect of block size

Three sizes of square block were analyzed with same thickness. The blocks were laid in a herringbone bond pattern for each test. Figure 6 shows the response of pavement against block size. Lesser deflections of pavement have been obtained with increasing size of the block due to increasing of wedging action caused by block rotation between the blocks, then as the result of interlocking, better performance of pavement is obtained.

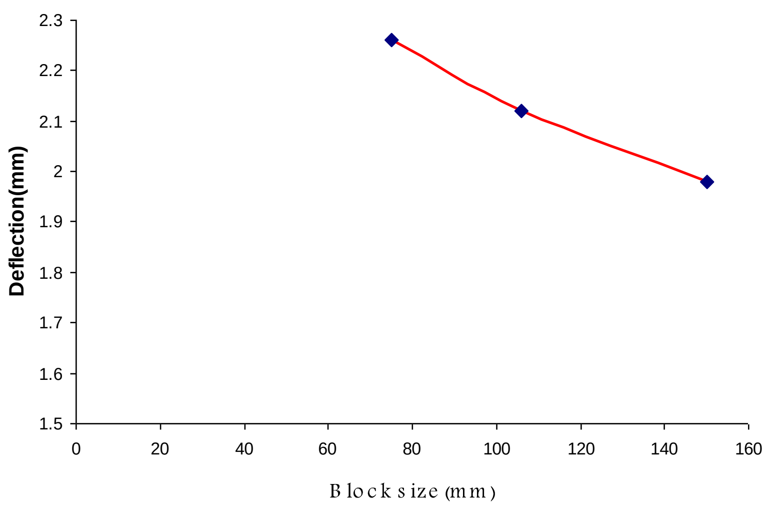

Figure 6. Effect of Block Size on behavior of Block Pavement.

3.3. Effect of block strength

With three different strengths of block paver the analysis was conducted. The compressive strengths were considered to be 250, 300 and 420 Mpa. Block was laid as a herring bone pattern. Deflections of pavements are almost the same for all analysis (Figure7). Discontinues nature of block paving and small size of blocks causes bending stress being negligible.

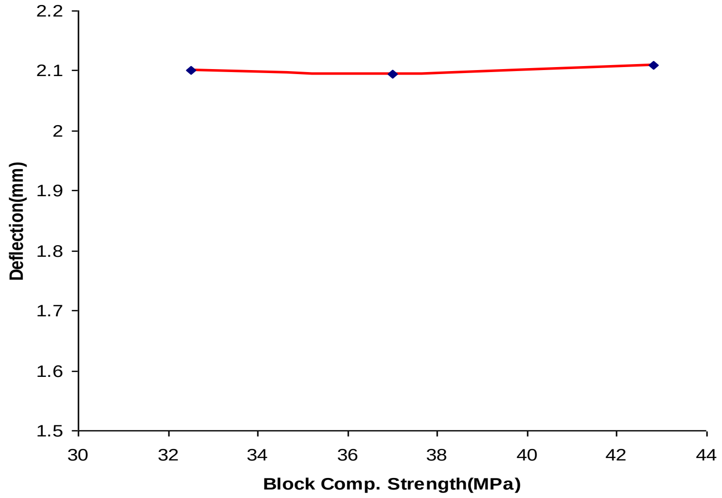

Figure 7. Effect of Block Strengths on behavior of Block Pavement.

3.4. Effect of block thickness

Three different thicknesses were selected for analyzing. The thicknesses were 100, 80 and 60 mm. blocks were laid in a herringbone pattern for each analysis. Variation of thickness from 60 to 100 mm reduces the vertical deflection of pavement significantly (Figure 8). The load transferred to the base layer is reduced as the thickness of block increases. Similar finding for effects of main component of pavement on block pavement behavior were observed in a laboratory scale test on concrete block pavement [5].

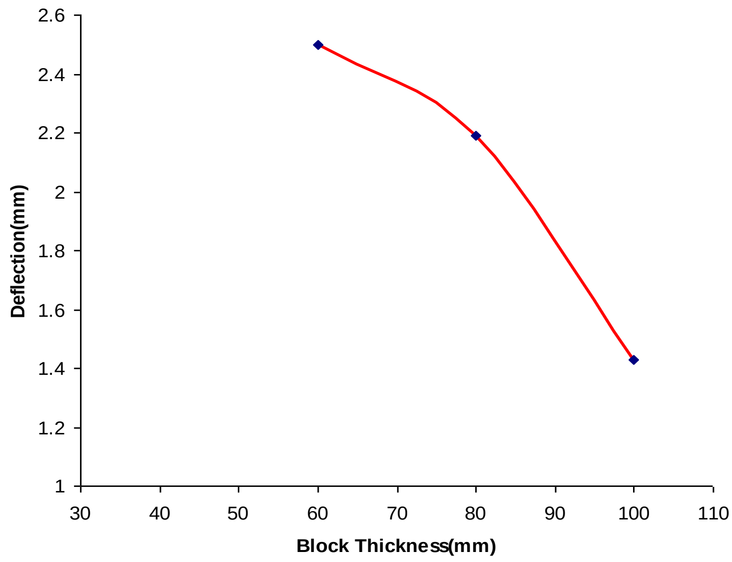

Figure 8. Effects of Block thickness on of Block Pavement behavior.

3.5. Mechanism of pavers interlock

Even Block Pavement which is judged to be well laid typically exhibit small rotations of the pavers relative to one another [6]. As shown in Figure 9 schematically in the cross-section, the wedging action caused by rotation of paver B around a horizontal axis leads to the development of horizontal forces within the paving. The wedging action explains why pavers act as structural surfacing rather than merely providing a wearing course [6].

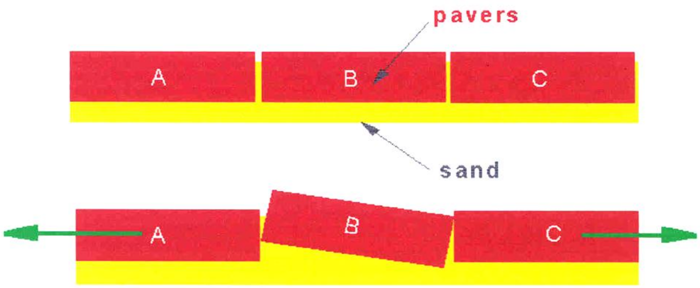

Figure 9. Rotation of Paver B causing outward wedging of paver A and B [6].

Figures 10, 11 show deflection of block pavement against vertical load obtained from 3D finite element analysis. As shown in these figures wedging action caused by rotation of pavers results in developing horizontal forces within the paving. This result confirms the hypothesis presented by][6].

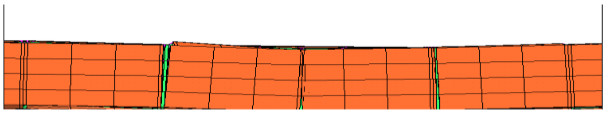

Figure 10. Mechanism of interlocking in block pavement.

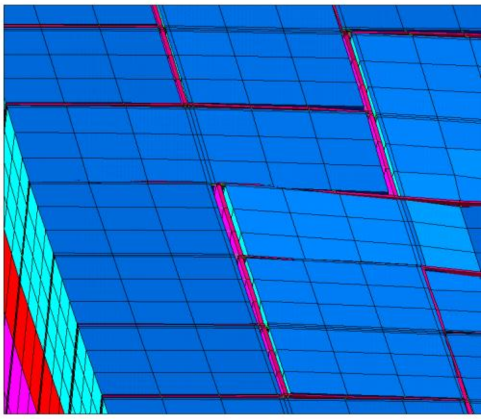

Figure11. Rotation of block for development of interlocking in herringbone patterns.

4. Conclusion

Important results that can be drawn from this study are as follows:

- The joint width should be limited to 2 mm up to 4 mm for the better performance of the pavement.
- With increasing block size, the better performance of pavement would be obtained.
- The performance of block pavement is independent from block compressive strength.
- The vertical deflection of the pavement is highly influenced by block thickness. Increasing in block thickness decrease the deflection of pavement.
- Interlocking in block pavers is caused by rotation and wedging action between blocks.

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