DEVELOPMENT OF A FINITE ELEMENT MODEL FOR CONCRETE BLOCK PAVING

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ABSTRACT

Concrete Block Paving (CBP), which is a predominant construction method used nowadays, is based on the ancient road construction technology “Stone Paving”. The use of CBP is a common sight in most of the developing countries due to its economic adaptability. Although it has emerged as a cost-effective paving material, it is yet being developed as a full-fledged construction technique. The aim of this research was to develop a finite element model for CBP and evaluate the deflections in pavement with the application of loads. A three-dimensional finite element model was built to measure the elastic deflection basin with ANSYS finite element modelling software. The reason for developing a finite element model is, as the construction of concrete block pavements for experimenting is costly and challenging, a finite element model simulating the field conditions could be used to overcome these issues and perform further research. Previously developed finite element models and laboratory models were studied. The results obtained from the developed finite element model were verified with the deflection values obtained in a laboratory scaled model. Similar deflection basins could be observed for different load cases. Further studies on the finite element model could be carried out to observe the effect on the deflection of a concrete block pavement with respect to the variation of the block shape.

Key words: Finite element model, Concrete block paving, Pavements

1. INTRODUCTION

The rapid urbanization during the past century has increased the demand for roads and related infrastructure. It has result the road designers to seek innovative construction methods which economize construction and enhance durability. Although different road surfacing materials have been used throughout the years, Concrete Block Paving (CBP) has proven to be a better alternative than the conventional paving methods; asphalt and concrete, having a low life cycle cost. It is the modern version of the ancient road construction technology “Stone Paving”.

Concrete Block Pavement consists of individual blocks of brick – size arranged closely with joint space filled with sand on a bed of sand. The horizontal movement of blocks is constrained by the edge supports (curbs etc.). The whole structure is supported by the sub base and subgrade. The load applied on the road surface is transferred horizontally to the substructure of the pavement. Hence, the interaction between the blocks, sand joints and support conditions are important to have efficient pavement designs (Concrete Manufacturing Association, 2004).

2. BACKGROUND

Literature reveals a reasonable amount of researches related to CBP which have been performed over the years. Several models of CBP also have been constructed, but only a few of them have validated the model with analytical results.

These researches analyse the performance with respect to various factors such as block shapes, thickness, size of the blocks, laying patterns, compressive strength, support conditions etc. Thus, ideas on most effective laying patterns and block shapes have been presented in several studies. Some contradictory ideas were also present in these findings. Most of the available CBP design methods were developed based on equivalent design concept, catalogue design method, research – based design method and mechanistic analysis and their evaluation criteria were based on substituted flexible pavement performance, field performance of the CBP, rut depth of the tested pavement and stress variation in base and subgrade material respectively. Therefore the evaluation criteria and the concepts used are different (Concrete Manufacturing Association, 2004). Eventually it was understood that the evaluation of performance for a new development in laying patterns or block shapes using the above mentioned methods are very expensive. Thus, focus was on a new analytical method which could evaluate the behaviour of the concrete block pavement. Some of the earlier studies by (Shackel, 1980), (Barber & Knapton, 1980), (Miura, Takaura, & Tsuda, 1984), (Jacobs & Houben, 1988) revealed that block pavement stiffen gradually with the repetition of the load. Due to this behavior after a certain number of repetitions, underlying layers achieve full compaction and no energy is lost with the additional loadings. Therefore, the deflection and the recovery induced by loading and unloading of the pavement is the same which indicates an elastic behavior. It was proven in some earlier studies that the elastic behavior can be used to develop accurate design methods using verified FEM (Nejad & Shadravan, 2006), (Nejad, 2003). Hence, a verified FEM could be used to identify more effective designs by analyzing design concepts.

Mampearachchi & Gunarathna, in 2010 confirmed that CBP could be simulated by linear elastic model, comparing their SAP2000 FEM developed initially with the results from the experimental study by (Panda & Ghosh, 2002b). For further analysis of CBP, another FEM using the same software was created by Mampearachchi & Gunarathna, in 2010. In order to verify this FEM, a laboratory scale experimental set up which was a modified version of the study by (Panda & Ghosh, 2002a) and similar to Shackel et al, 1993 was constructed. By monitoring the stress distribution of the initial FEM the dimensions of the test set up were decided as 1 m x 1 m square in plane and 1 m in depth. They have observed the stress distribution in the initial FEM reaching a perimeter of about 500 mm away from the center of the loading.

3. OBJECTIVES

The aim of the study was to develop a finite element model for CBP and evaluate the deflections in pavement with the application of load, since the construction of concrete block pavements for experimenting is costly and challenging, hence a finite element model could be used to overcome these issues by simulating the field conditions. The results obtained from the laboratory scale model and the SAP model of CBP by Mampearachchi & Gunarathna were used for the verification of the developed finite element model.

4. LABORATORY SCALE CBP MODEL AND SAP MODEL (by Mampearachchi & Gunarathna)

4.1 Laboratory Scale CBP Model

As mentioned above, test model with a 1m x 1m square plane had been used for the study. A strong wooden box with vertical and horizontal braced faces was the experimental setup. Then it had been filled with subgrade soil, base material and bedding sand respectively as shown in Figure 1. Finally the block paving units of 210 x 100 mm^2 had been laid at the top with a sand filled gap of 5 mm and compacted firmly with a plate vibrator.

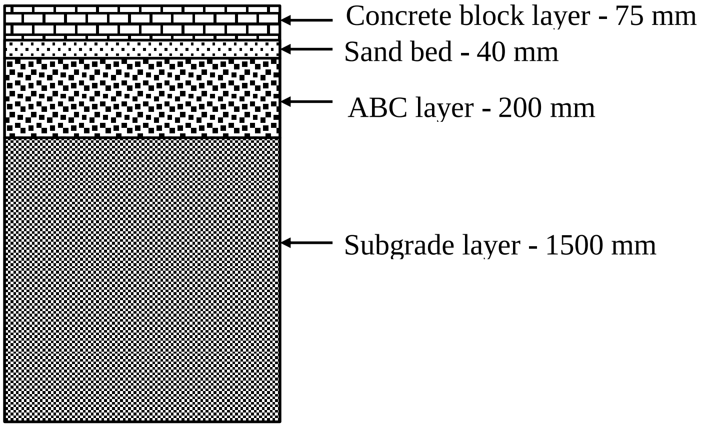
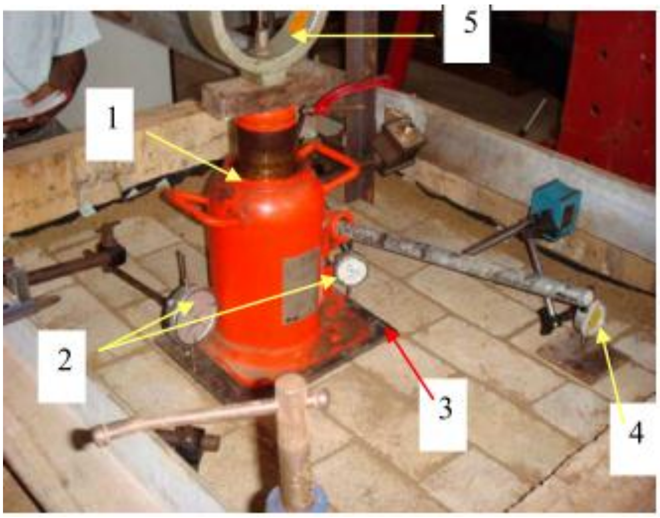


Figure 1: Section view of laboratory model

Two types of loading arrangements had been considered in the experiment and the loading arrangements have the same contact area 69 750 mm^2 (225 x 310 mm^2). This was approximately equal to tire contact area of a single wheel (Panda and Ghosh 2002a).

As shown in Figure 2 in the experimental set up, the compressive load was applied on a rigid rectangular plate using a hydraulic jack against a rigid steel frame. The load was increased in 10 kN increments from 0 to 60 kN. A wheel load of 60 kN is higher than the axle load of 22 kips (98 kN) which is the maximum allowable axle load in many countries (Mampearachchi & Gunarathna, 2010). Surface deflections were measured using six dial gauges as shown in Figure 2.



1- Hydraulic jack
2- Main dial gauge (on the loading plate)
3- Loading plate
4- Dial gauge
5- Proving ring

Figure 2: Experimental set up

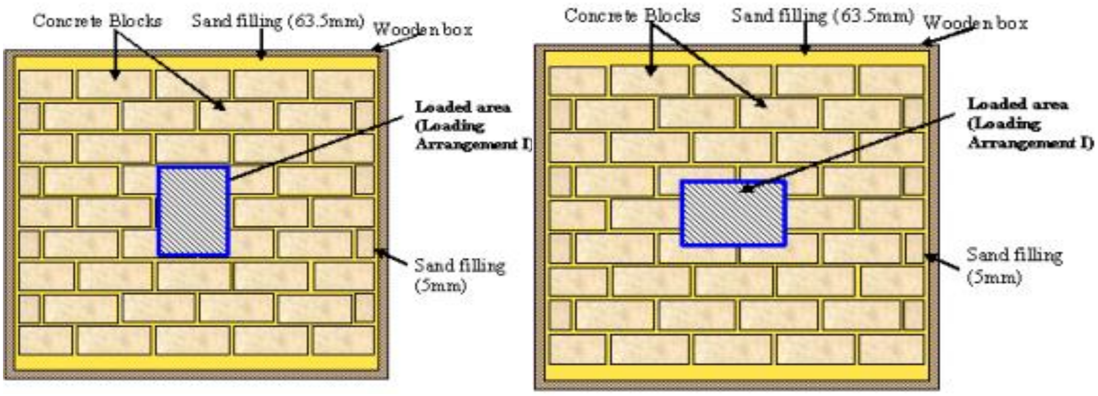


Figure 3: Loading arrangements

4.2 SAP Model

Deflection data obtained from the laboratory scale model were used to verify a FEM in the study by Mampearachchi & Gunarathna. The laboratory scale model and the FEM dimensions are the same. The materials were modelled using the properties given in Table 1 which were the properties of the materials used in the laboratory scale model.

Table 1: Material properties for SAP FEM

Material	Modulus of elasticity (E) (GPa)	Poisson's ratio	Shear modulus (G) (GPa)
Concrete	23.2	0.20	9.667
Sand	0.01	0.26	0.00396
ABC	0.24	0.30	0.0923
Soil Type II	0.12	0.40	0.0429
Soil Type I	0.077	0.40	0.0279

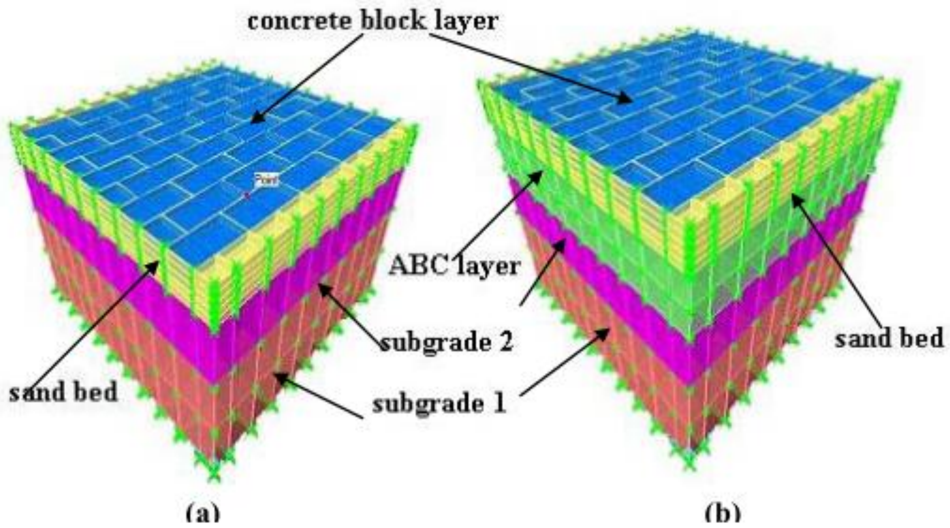


Figure 4: SAP model

This three dimensional model was developed using SAP2000 structural analysis software with eight node hexagonal finite elements. Figure 4 shows the SAP model of CBP for two types of support conditions.

4.3 Results

Following results were obtained from the laboratory scale model and the SAP model for the four tests performed for the two models.

Model I : concrete block lay on subgrade without base layer

Model II: concrete block lay on base layer (ABC)

Test 1 – Model I with Loading arrangement I

Test 2 – Model I with Loading arrangement II

Test 3 – Model II with Loading arrangement I

Test 4 – Model II with Loading arrangement II

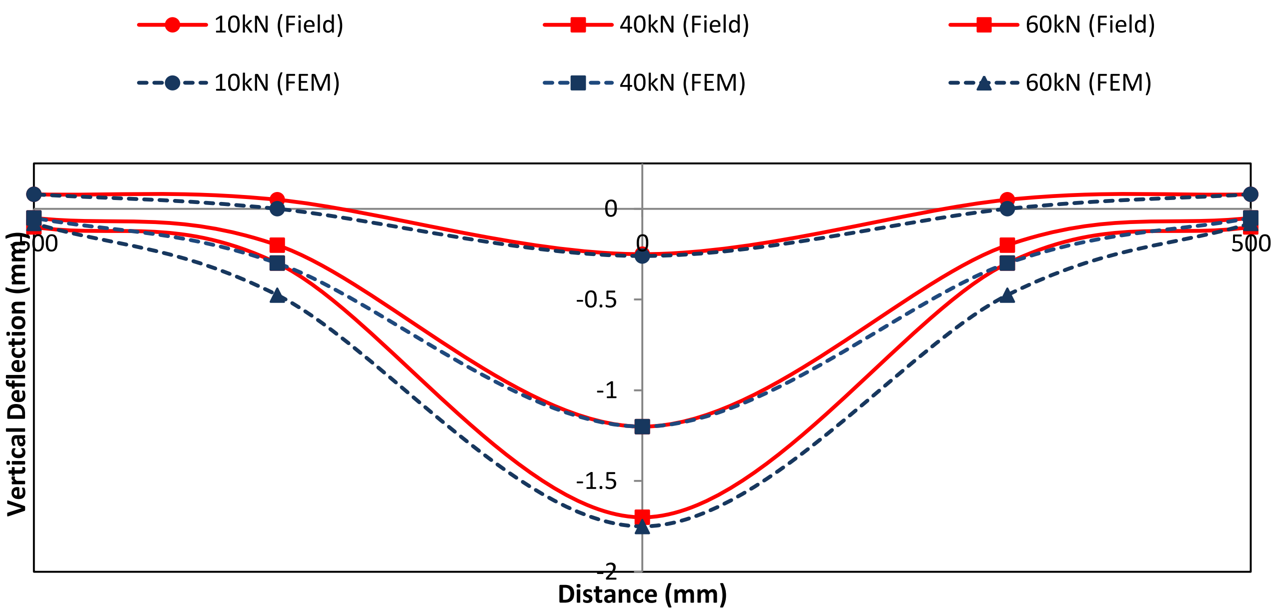


Figure 5: Verification of Test 1

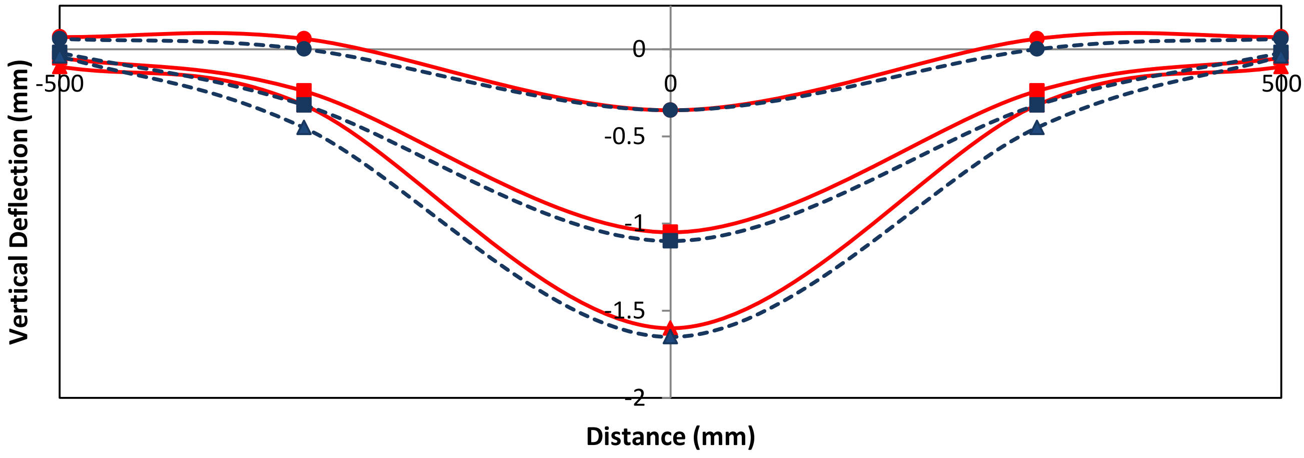


Figure 6: Verification of Test 2

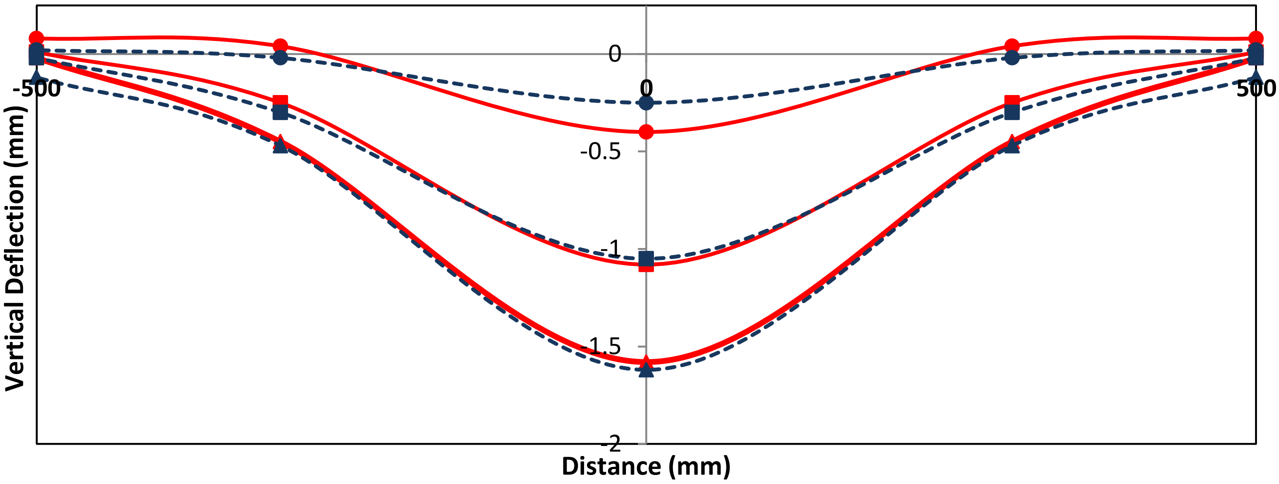


Figure 7: Verification of Test 3

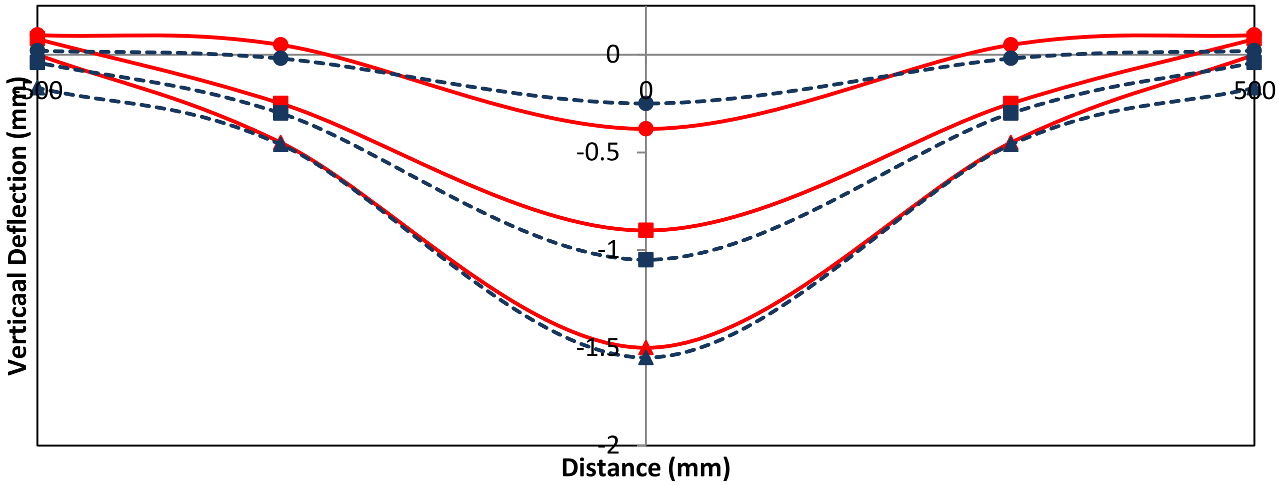


Figure 8: Verification of Test 4

5. DEVELOPMENT OF ANSYS MODEL

ANSYS 12.1 analysis software was chosen to develop the three dimensional (3-D) model as the SAP FEM developed was only could be used for the analysis of base and subgrade conditions. In order to perform analysis on block shapes and dimensions further it was decided to develop a FEM using a more advanced software. Initially the focus was on developing a 3-D model by ANSYS Mechanical APDL. Due to the difficulties arose in carrying out further analysis, later on it was decided to develop the model by ANSYS Workbench 12.1.

5.1 3-D model by ANSYS Mechanical APDL

Two element types were considered to model the different layers of concrete block pavement. Brick 8 node 45 elements were used for concrete blocks and 8 node 185 elements were used for sand bedding, ABC layer and subgrade.

5.1.1 Material properties

The concrete block, sand, road base and subgrade materials are modelled as isotropic and linearly elastic. They are characterized by their elastic modulus, Poisson’s ratio and shear modulus. Same material properties were used for filling sand and bedding sand. The contraction and expansion of the concrete due to temperature effect is neglected in the analysis.

Table 2: Material properties for ANSYS FEM

Material	**Modulus of elasticity (kN/mm^2)**	**Poisson’s ratio**
Concrete	23.2	0.20
Sand	0.01	0.26
ABC	0.24	0.30
Subgrade soil	0.12	0.40

5.1.2 FEM dimensions

FEM consisted of subgrade, filling sand, bedding sand base layer and concrete blocks. The dimensions of the FEM were based on the experimental model dimensions and SAP FEM dimensions used by Mampearachchi and Gunarathne in 2010.

Subgrade layer: 1500 mm

ABC layer: 200 mm

Sand bedding: 40 mm

Sand filling: 5 mm

Concrete block: 210 mm x 100 mm

5.1.3 FEM loading procedure

Loads were distributed as surface pressure at the centre across a rectangular area of 310 mm x 225 mm which is equal to the tire contact area of a single wheel (Panda and Ghosh 2002a). In the FEM, loads were applied at the nodes to simulate the pressure across the area. The applied load was increased as 10 kN, 40 kN and 60 kN for the verification of the FEM using previous results. A wheel load of 60 kN is higher than the axle load of 22 kips (98 kN) which is the maximum allowable axle load in many countries (Mampearachchi & Gunarathna, 2010). The movement of the bottom face was fully restrained, while only the vertical movement in the side faces was restrained, allowing the movement horizontally.

5.1.4 FEM Analysis

FEM analysis was carried out and vertical deflection variation was obtained as shown in Figure 9(a). As the analysis consumes time due to the large number of elements, same FEM eliminating the subgrade was analysed. The results obtained in this FEM showed an almost similar variation to the previous results (FEM with the subgrade). Hence it was decided to carry out the analysis without the subgrade. Deflection variation obtained in the FEM without the subgrade is shown in Figure 9(b).

Although this FEM was developed, when carrying out further analysis of CBP certain constraints were encountered. Difficulty in modeling blocks of different shapes and size as the top most layer of the pavement was the major issue. Hence it was decided to develop the FEM using ANSYS Workbench 12.1.

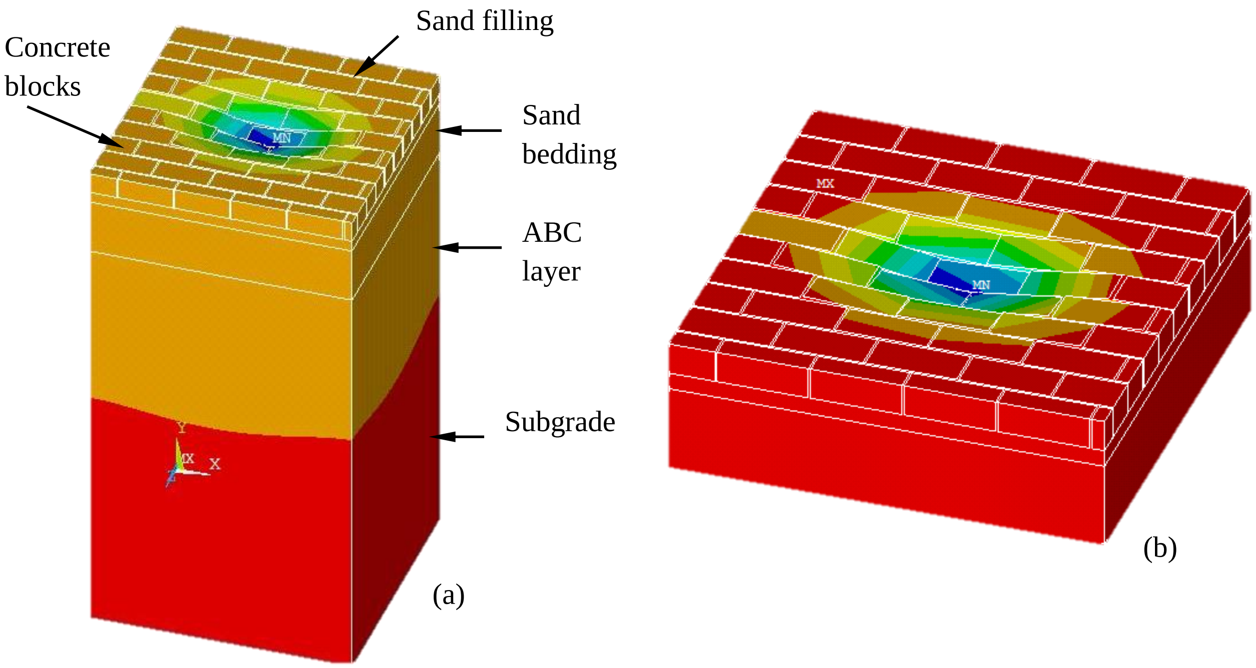


Figure 9: ANSYS Meachanical APDL FEM; (a) With subgrade (b) Without subgrade

5.2 3-D model by ANSYS Workbench 12.1

In order to perform further analysis on CBP and to obtain more accurate FEM results as mentioned earlier ANSY Workbench 12.1 software was used. The geometry of the pavement which was imported to ANSYS Workbench was created in Solid Works 2012 software (Figure 10(a)).

Once the geometry created in Solid Works, it was imported to ANSYS. Then the finite element model was developed adopting Hexa Dominant method for meshing (Mesh type: All quads – fine mesh) to have a smooth convergence of the solution (Figure 10(b)). The size of an element in Figure 10(b) is 5mm and there are about 40 620 elements.

Same dimensions and the material properties mentioned above were used. FEM was developed with the layers, ABC, sand and concrete blocks as shown in Figure 10.

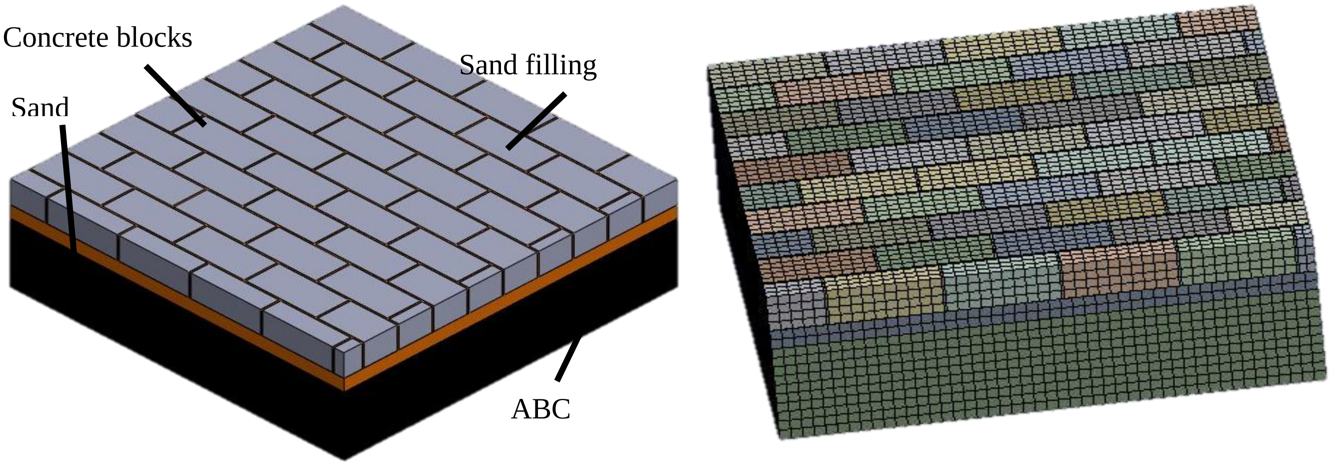


Figure 10: (a) Geometry developed in Solid Works 2012 ; (b) Mesh developed in ANSYS Workbench 12.1

5.3 Verification of the ANSYS Workbench FEM

In order to verify the developed ANSYS model, deflection basin results obtained from Test 4 in the previous study (Mampearachchi & Gunarathna, 2010) was used as it matches well with the condition in the new FEM. Figure 11shows the deflection variation of the FEM.

Deflection variation along the diagonal line was considered for the comparison with the previous results. Maximum deflection was observed underneath the loading position which becomes the most critical when failure loading is considered. Loading point deflection in this FEM is compatible with the same position deflection in the lab scale model and SAP FEM in the previous study.

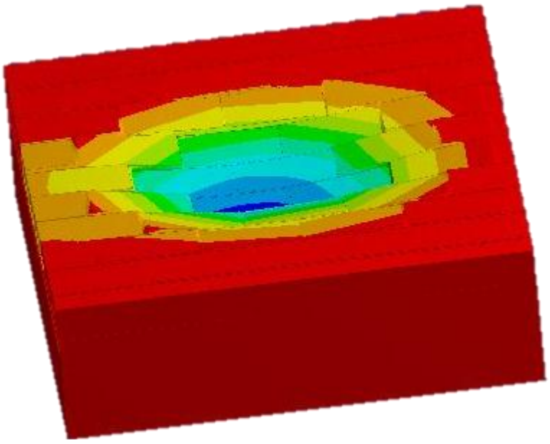


Figure 11: Deflection basin of FEM

Verification of the ANSYS model is illustrated in Figure 12. Similar deflection variation is apparent between the ANSYS model and the results obtained from SAP model and laboratory scale model. Thus, it could be concluded that ANSYS Workbench FEM could be used for the analysis of concrete block pavements. Further analysis with respect to block shapes and sizes could be carried out since the geometry can be created in Solid Works easily.

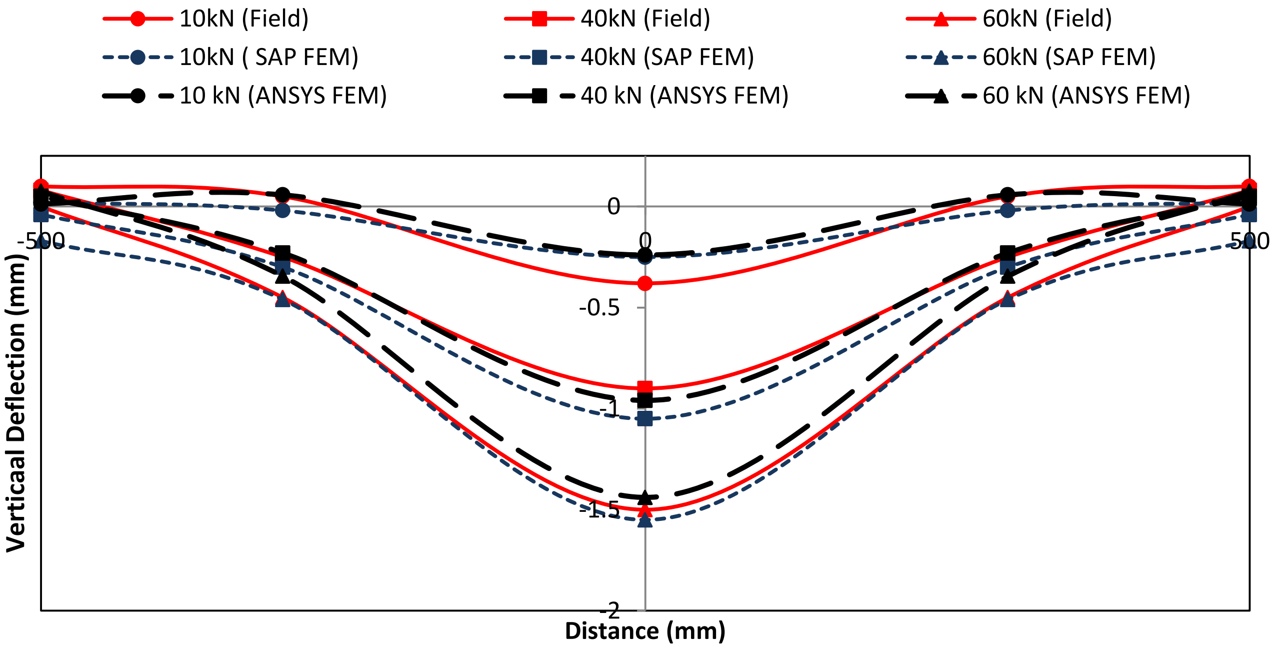


Figure 12: Verification of ANSYS FEM

Along the same path where deflection variation was observed, stress variation was plotted as shown in Figure 13. As the load was applied at the centre, stress is high at that location. Then it reduces gradually creating a curve as illustrated in the figure. This also proves the fact which was mentioned in the literature that the stress distribution reaches perimeter of 500 mm away from the centre of the loading.

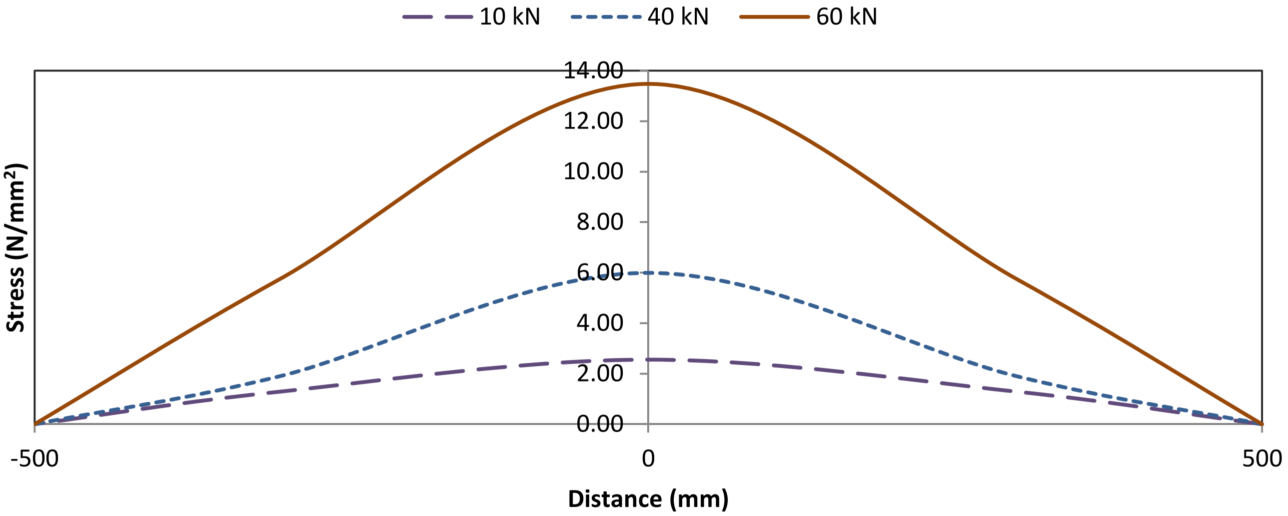


Figure 13: Stress variation of the ANSYS model

6. CONSLUSIONS

This FEM was developed using ANSYS Workbench 12.1 for the further analysis of CBP and to obtain more accurate results. The relevant parameters for the FEM were determined based on the past experimental studies and finite element modelling results.

- It was stated in literature that CBP transforms to elastic behaviour with stiffening of the pavement gradually
- Developed FEM has demonstrated the interlocking action of CBP with the application of load and has proven the findings in previous studies
- ANSYS FEM has also shown the fact that the stress distribution reaches perimeter of 500 mm away from the centre of the loading
- The deflection basin obtain from ANSYS FEM has shown similar variation to the results obtained from laboratory scale model and SAP FEM in the study by Mampearachchi & Gunarathna
- Developed FEM could be used to determine relative performance of the CBP for different block shapes of different dimensions and laying patterns. Thus this FEM could be used to identify improvements that could be made to CBP without carrying out expensive road tests.

Considering the above facts it could be concluded that ANSYS software model developed can be used to identify different aspects of CBP behaviour and the design parameters which could be used to increase the performance of the pavement.

7. REFERENCES

Barber, S. D., & Knapton, J. (1980). An experiment investigation of the behaviour of a concrete block pavement with a sand sub-base. *Instituion of Civl Engineers, 69(1)*, pp. 139-155.

Concrete Manufacturing Association. (2004). *Concrete block paving book 1, 2, 3, 4.* Midrand: South Africa.

Jacobs, M. J., & Houben, L. J. (1988). Wheel track testing and finite element analysis of concrete block pavement. *3rd International Conference on Concrete Block Paving*, (pp. 102-113). Pavitalia, Rome.

Mampearachchi, W., & Gunarathna, W. (2010, November 1). Finite element model approach to determine support conditions and effective layout for concrete block paving. *Journal of Materials in Civil Engineering, 22*(11), 1139-1147.

Miura, Y., Takaura, M., & Tsuda, T. (1984). Structural design of concrete block pavements by CBR method and its evaluation. *Conference on Concrete Block Paving* (pp. 152-157). Delft, The Netherlands: Delft University of Technology.

Nejad, F. (2003). Finite element analysis on concrete block paving. *7th International Conference on Concrete Block Paving.* Sun City, South Africa: Document Transformation Technology.

Nejad, F., & Shadravan, M. (2006). A study on behaviour of block pavement using 3D finite element method. *San Francisco International Conference on Concrete Block Paving*, (pp. 349-358). San Francisco.

Panda, B., & Ghosh, A. (2002b, March 1). Structural behaviour of concrete block paving II: Concrete blocks. *Journal of Transportation Engineering, 128*(2), 130-135.

Shackel , B., O'Keeffe, W., & O'Keeffe, L. (1993). Concrete block paving tested as articulated slabs. *5th International Conference on Concrete Pavement Design and Rehabilitation* (pp. 89-95). West Lafayette, Indiana: Purdue University.

Shackel, B. (1980). The performance of interlocking block pavements under accelerated trafficking. *1st International Conference on Concrete Block Paving*, (pp. 113-120). Newcastle-upon-Tyne, UK.