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FINITE ELEMENT MODELLING OF PLASTIC CELL FILLED CONCRETE BLOCK PAVEMENT

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Note: The following is the notation used in this paper: (.) for decimals and (   ) for thousands.

Summary

This paper presents the study of a two-dimensional finite element code (ANSYS), to model a Plastic Cell Filled Concrete Block Pavements of 75 mm and 100 mm thick subjected to Accelerated Pavement Tests that were placed over the bed of an Accelerated Pavement Test Facility (APTF). The model comprises of a 3 layer system in which the top layer consists of plastic cell filled concrete blocks, the second layer consists of subbase layer and the third layer consists of the subgrade. The geometric properties, equivalent elastic modulus of subgrade with Poisson's ratio of the different layers for the finite element model were taken from the experimental investigation and the evaluated properties obtained by backcalculation computer program, BACKGA.

The elastic moduli of subbase were determined using K-θ model and Park and Fernando model. Using the same FE model, material properties (k1, k_2 & k_3) of the subbase were analysed to evaluate the stress dependency of granular subbase layer using Park and Fernando model for characterization of granular material. The subbase moduli obtained by using Park and Fernando equation were found to be close to the backcalculated values using BACKGA, and these were fitted in the model to determine the equivalent elastic modulus of the plastic cell filled concrete block layer through iterative process.

The equivalent elastic moduli for different load repetitions were found to be slightly higher for the block pavement of 75 mm thick and for the block pavement of 100 mm thick; the elastic moduli as determined by FE Model are found to be as close to the backcalculated moduli. A design catalogue is presented for selection of pavement crust for new construction.

1. INTRODUCTION

Plastic cell filled concrete block pavement originated in South Africa [Visser, 2003; 1999; 1994; Visser and Hall, 1999]. This type of pavement consists of a formwork of polyethylene square cells 150 mm x 150 mm in size with thickness of 50 mm or greater (See Figure 1). The plastic cells are stretched over the carriageway under tension, filled with concrete, and compacted. During compaction, the cell walls get deformed (See Figure 2) bringing about interlocking among the concrete blocks.

Alternatively, the cells are filled with single size aggregates [Visser and Hall, 1999] and rolled with static or vibratory roller. A mortar of cement and sand is vibrated into the voids by a plate compactor and the road can be opened to light traffic within 24h of the construction. The cell-filled concrete blocks behave as a flexible layer which will conform to the deformed shape of the underlying subbase if there is any secondary compaction or settlement of the underlying layers. This type of construction is labour intensive, cost effective and appears to be highly suitable for rural areas of India where mechanized construction and strict quality control may not be possible.

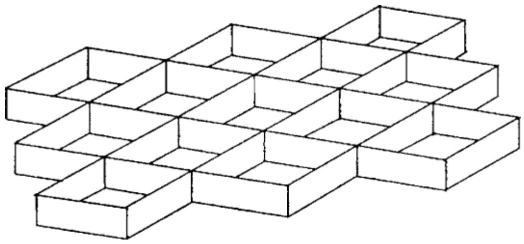

Figure 1. A formwork of Plastic cell after tensioning (150mm x 150mm) (Ryntathiang, 2005).

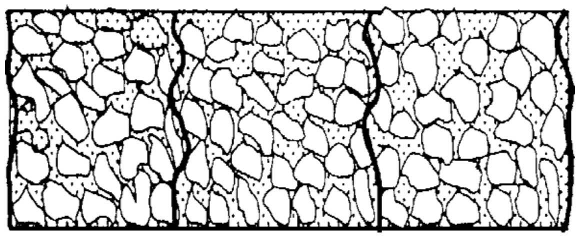

Figure 2. Deformed plastic cell walls after compaction bringing about Interlocking (Ryntathiang, 2005).

The paper deals with a simple 2-D Finite Element study on determining the Equivalent Elastic Modulus of Plastic Cell Filled Concrete Block Pavements that were laid on the bed of accelerated pavement test facility. A brief detail of the Test Set Up, Construction of test pavements that were laid on the bed of accelerated pavement and testing procedure is also presented. Test data that were reported in the paper by Ryntathiang et al. [2005] were used for the study so that the equivalent elastic modulus of plastic filled concrete block pavement at different standard axle load repetitions can be determined and compared with the backcalculated equivalent elastic modulus.

2. EXPERIMENTAL INVESTIGATION:

2.1 <u>Test set up</u>

The test setup consisted of a dual wheel set, which can be loaded up to 60 kN. The wheel can be moved to and fro by using 20 kW motor over a linear track of length 15 m. The numbers of cycles of loading were recorded in a counter. In their investigation, the loading bin was filled with steel rail sections, so that the load coming on the dual tires was about 40 kN. A tire pressure of 586 kPa was maintained and load on the wheel was checked by a portable weigh-bridge available in the laboratory.

2.2 <u>Construction of test pavement</u>

The test setup consists of two test pavements with thicknesses 75 mm and 100 mm of plastic cell filled concrete blocks, which were constructed at the test area of APTF, IIT Kharagpur. The test pavement was kept at 2.1 m x 2.0 m. The sectional details of the both test pavements are shown in Figure 3. The subgrade for both test sections consisted of compacted sand and the foundation for the sand subgrade was formed by the existing undisturbed lateritic soil having a CBR value between 3% and 4%. Over the granular subbase, the formwork of plastic cells was stretched in all four directions so that each cell was close to a square of 150 mm sides, depths being 75 mm and 100 mm.

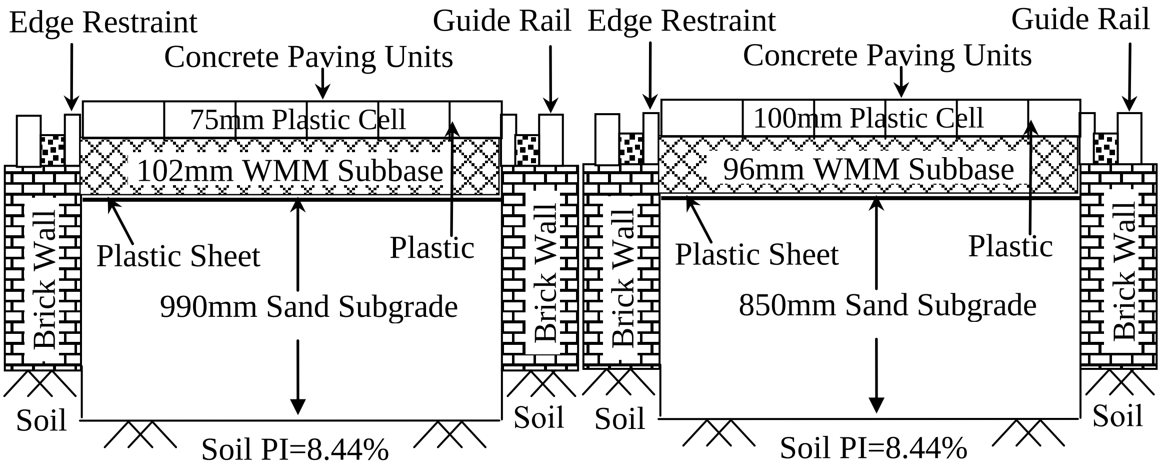

Figure 3. Plastic cell filled concrete block pavement of 75 mm and 100mm.

2.3 testing procedure

The entire operation of APTF is controlled by a microprocessor. After the electrical switch is put on, the dual wheel starts moving to and fro without any lateral wander. In the investigation, the number of repetitions of the wheel load per hour was found to be about 240. Surface levels of the pavement were recorded before the start of the test and after every 1 000 repetitions of the wheel load. The deflection profile of the test was determined by using falling weight deflectometer (FWD). The deflections were measured at 0, 300, 600, and 900 mm from the center of the loading plate of the FWD. A backcalculated computer program developed by IIT Kharagpur laboratory (BACKGA) is used to evaluate the modulus values of different layers and these values are compared with the values determined by FE Modelling.

3. 2-D FINITE ELEMENT STUDY

3.1 Model analysis

Axial symmetric 2-D finite element modelling was carried out using commercial FE software, ANSYS (6.0) to compare equivalent elastic modulus of the model with those of the experimental results. The finite element model dimensions were taken similar to that of the experimental investigation [Ryntathiang et al., 2005] and are shown in Figure 4. The thickness of the plastic cell filled concrete block, subbase and subgrade layers considered in the FE modelling are 75/100 mm, 102/96 mm and 990/850 mm respectively. For the FE model, the width of the pavement section adopted is 1050 mm. Figure 5 shows a typical FE mesh idealization using 4-nodded quadrilateral axial-symmetric elements. In this model analysis, the top plastic cell filled concrete block layer has been modelled as continuous layer for simplification.

The load applied to the pavement structure is of 40kN with a radius of contact 150 mm. The pavement was treated as a three-layer system of which, the first or top layer consists of plastic cell filled concrete blocks, second layer consists of subbase layer and third consists of subgrade wherein each layer is having an elastic property. The Poisson’s ratios were taken as 0.25 for the top layer, 0.35 for the second and third layer respectively. The elastic moduli of subgrade were taken from values obtained by Ryntathiang et al. [2005]. Equivalent elastic moduli of subbase for different repetitions of load were determined by using K-θ model [Naidu and Pandey, 1994] and Park-Fernando model [1998]. The elastic moduli as determined by Park and Fernando model for different repetitions of standard load were found to be close to the backcalculated moduli and these moduli were further used to determine the equivalent elastic modulus of the concrete block layer.

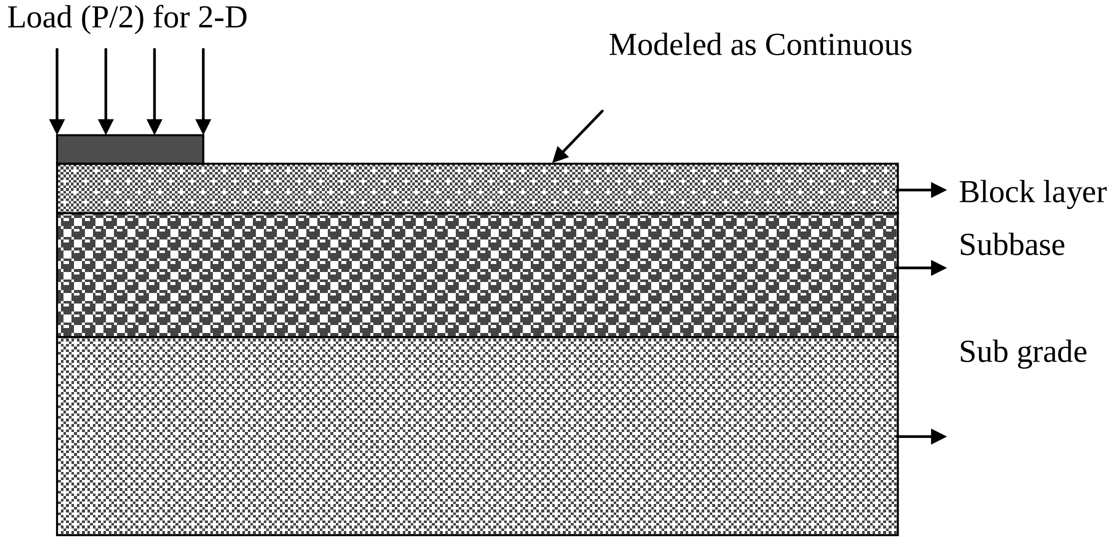

Fig.-4. Basic geometry of the pavement section

Because of symmetric conditions, one half of the pavement was analyzed. The nodes at the bottom of the model cannot move in z-direction whereas the nodes at the edge of the model can only move in the z-direction. These boundary conditions are simulated so that they represent the experimental test setup. The validity of the present model has been checked by comparing with the results of F-PAVE [Das, 1998] a multi-layer elastic program developed by civil engineering department, IIT Kharagpur.

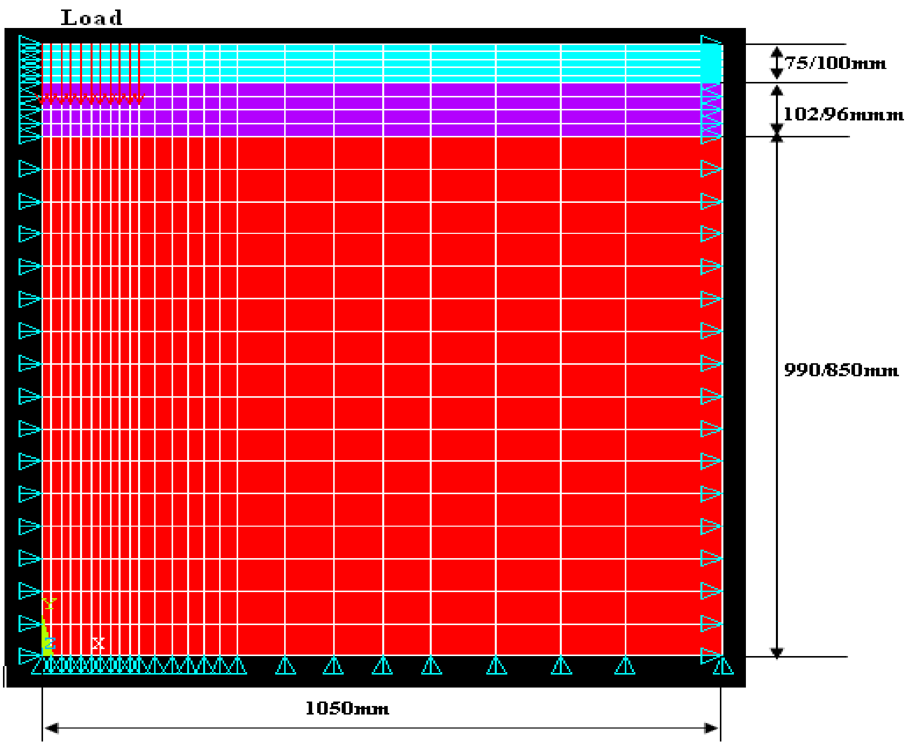

Fig. 5: FE meshes of the pavement section

3.2 characterization of equivalent elastic modulus of granular subbase

A two dimensional finite element model as shown in Figure 5 was used for the characterization of equivalent elastic modulus of granular layer. The two models used for the present study to evaluate the equivalent elastic modulus of the granular layer are Park and Ferdinand Model and *K-θ* model. Park and Fernando model was used to evaluate the material parameters of the subbase layer. For the study, stresses were computed at the mid-depth of the subbase layer vertically below the centre of the loaded plate.

3.2.1 Park and Fernando equation

Park and Fernando (1998) developed a non-dimensional Equation for modelling the modulus of granular materials. The equation is given as:

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Where

MR = Resilient modulus of granular material

Atm = Atmospheric pressure (0.1MPa)

θ = Sum of principal stresses (σ1+2σ3)

τoct = Octahedral shear stress = {√2(σ1–σ3)}/3

k1, k2 & k3 = Material parameters.

The above equation was used to evaluate the values of the material parameters from the known values of elastic modulus, θ and τ_{oct}. The values of θ and τ_{oct} at mid depths of the subbase were used in Equation 1. These material parameters were further used to determine the subbase modulus.

3.2.2 K-θ model

The K-θ model [Naidu and Pandey, 1994] is given as,

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Where:

MR = Resilient modulus of granular material

θ = Sum of principal stresses (σ1+ 2σ3), kPa

k1 and k2 = Material parameters = 3.47 and 0.7375 for WMM

The values of k_1 & k_2 were evaluated by Naidu and Pandey [1994] for granular material having gradation close to that of the WMM used in the present study.

4. RESULT AND DISCUSSION

The FE model analysis was conducted for various load repetition to obtain the material parameters for characterization of elastic modulus of granular subbase layer using Park- Fernando model and to find the modulus of the subbase by using K-θ models.

Table 1. Evaluated material parameters from Park and Fernando equation with different Load Repetitions.

LOAD REPETITIONS	GRANULAR SUBBASE ELASTIC MODULUS OF 75mm PLASTIC CELL(MPa)75 (MPa)			GRANULAR SUBBASE ELASTIC MODULUS OF 100mm PLASTIC CELL(MPa)		
	K_1	K_2	K_3	K_1	K_2	K_3
2 000	8.8153	4.1851	1.4552	189.942	0.6999	3.9477
3 000	23.3651	3.7466	0.5205	191.0426	0.6985	3.9444
4 000	153.6274	2.7585	-1.0604	189.942	0.6999	3.9477
5 000	8.8153	4.1851	1.4552	191.0426	0.6985	3.9444
6 000	128.2295	2.9655	-1.1404	191.0426	0.6985	3.9444

Table 1 shows the evaluated values of material parameters k_1, k_2 & k_3 obtained for different load repetitions. These material parameters were then used in Equation 1 for evaluating the granular subbase modulus through iterative procedure.

Table 2. Comparison of Equivalent elastic modulus of granular subbase layer with different load repetitions as evaluated by Park-Fernando equation and K-θ model with the Backcalculation computer program, BACKGA experimental modulus.

LOAD REPETITIONS	GRANULAR SUBBASE ELASTIC MODULUS OF 75mm PLASTIC			GRANULAR SUBBASE ELASTIC MODULUS OF 100 mm PLASTIC		
	PARK AND FER-	K–Θ MODEL	BACKCALCULATION	PARK AND FER-	K–Θ MODEL	BACKCALCULATION
2 000	175	214	181	75	162	82
3 000	195	212	202	70	160	80
4 000	205	209	216	75	162	82
5 000	175	214	184	70	160	80
6 000	170	214	180	70	160	72

Table 2 shows the comparison of the modulus of granular subbase obtained by FE analysis with the Backcalculation computer program, BACKGA of experimental investigation [Ryntathiang et al., 2005].

From the above table, it can be seen that granular subbase moduli at different repetitions of load evaluated by Park and Fernando equation are closer to the backcalculated moduli as compared to moduli computed by *K-θ* model. It is also observed that the granular subbase moduli obtained by *k-theta model* for 100 mm block thickness is about two times the moduli obtained through backcalculation. The moduli obtained by Park and Ferdinand equation for the 75 mm and 100 mm thick blocks were further used to determine the equivalent elastic moduli of plastic cell filled concrete block layer at different load repetitions.

5. EQUIVALENT ELASTIC MODULUS OF BLOCK LAYER

To determine the equivalent modulus of the plastic cells filled concrete block layer at different load repetitions, the subbase moduli obtained from Park and Ferdinand Equation given in Table 2 (being close to the backcalculated modulus) were used in the FE model. An assumed modulus (say 50 MPa) was assigned to the block layer for the first iteration, and the iteration was stopped till the old modulus and the new modulus obtained converged to the first decimal place and the deflection of the pavement was calculated. A plot between equivalent elastic modulus of the block layer versus deflection is drawn (Figures 6 to 15) to find the equivalent modulus of the block layer [Panda, 2000] corresponding to the deflection obtained during Falling Weight Deflectometer test at 40 kN load over a 300 mm diameter circular load. The deflection at D/20 mm (Stress being maximum at this distance from the centre) distance was chosen to find the equivalent elastic moduli of the concrete filled block pavement for different load repetitions.

Table 4: Equivalent elastic modulus of plastic cell filled concrete block pavement layer

LOAD REPETITIONS	COMPUTED ELASTIC MODULUS OF 75 mm PLASTIC CELL(MPa) 75 (MPa)		COMPUTED ELASTIC MODULUS OF 100 mm PLASTIC CELL(MPa)	
	FE Analysis	Backcalculation	FE Analysis	Backcalculation
2 000	3 162	2 978	1 900	1 766
3 000	2 903	2 988	1 845	1 598
4 000	2 944	2 990	2 132	2 378
5 000	3 021	2 966	2 102	2 337
6 000	3 203	2 995	2 166	2 542

Table 4 above shows comparison between backcalculated modulus and the modulus obtained by FE model for the different load repetitions. It can be seen that the equivalent elastic modulus of the cell filled concrete block pavement at different load repetitions is more or less of the same values as calculated by backcalculation method.

6. DEVELOPMENT OF DESIGN CATALOGUE

Based on the available literature and the data obtained in the present study, an equivalent elastic modulus of 2 500 MPa is appropriate in consideration for the design. Design chart was first developed and then design catalogue for low volume roads having $5x10^4$ to $2x10^6$ repetitions of standard axles are extracted from the design chart and proposed as a design for plastic cell filled concrete block pavement. As the performance of plastic cell filled concrete block pavement is found similar to that of Interlocking Concrete Block Pavement [Visser and Hall, 1999] where failure of the pavement is only through rutting, therefore, vertical subgrade strain (ε_z) is the criterion for the design.

For the development of design chart, several combinations of pavement sections were analysed using the computer program FPAVE developed by IIT Kharagpur [Das, 1998] to determine the vertical subgrade strain (ε_z)). Values of ε_z were computed at the top of subgrade, vertically below the center of standard dual wheel loads (40 kN) for tyre pressure of 0.56 MPa. The Poisson's ratios of the top layer, subbase layer and subgrade were taken as 0.3, 0.35 and 0.35. The subgrade modulus was calculated as given by Lister and Powell's Equations [Lister and Powell, 1987] and the subbase modulus was obtained from the SHELL's Equation [Claessen et al., 1977; Dormon and Metcalf, 1965]. The proposed design catalogue for selection of pavement crusts are given in Table 5 and Table 6.

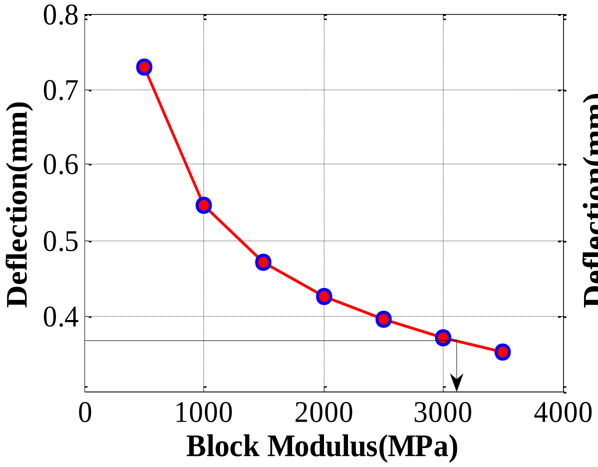


Figure 6. Modulus-Deflection curve for 2 000 times load repetitions.

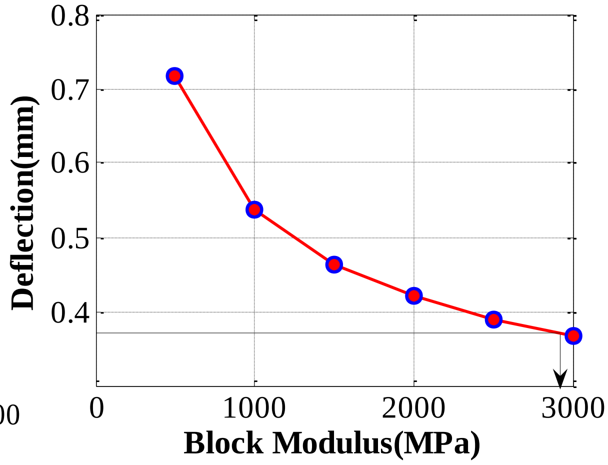


Figure 7. Modulus-Deflection curve for 3 000 times load repetitions.

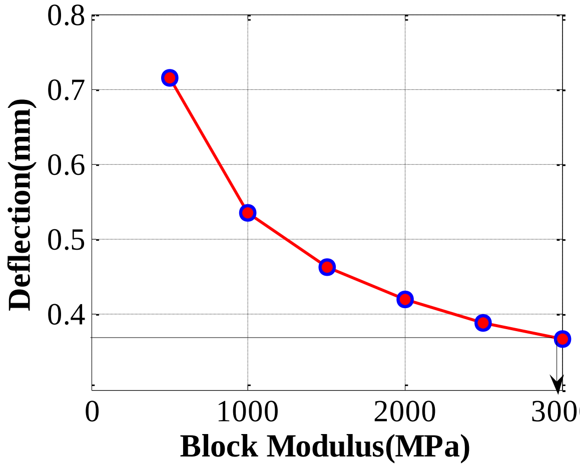


Figure 8. Modulus-Deflection curve for 4 000 times load repetitions.

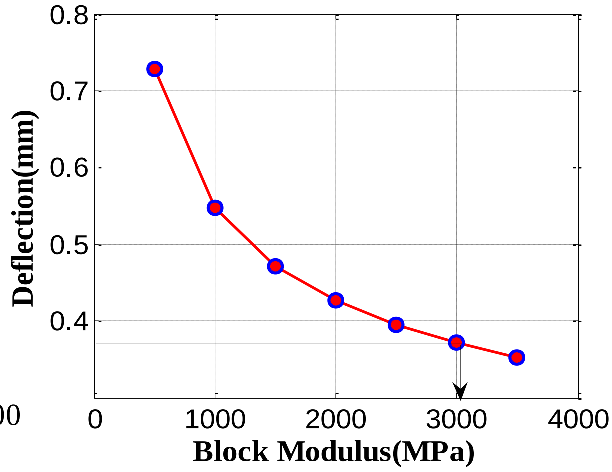


Figure 9. Modulus-Deflection curve for 5 000 times load repetitions.

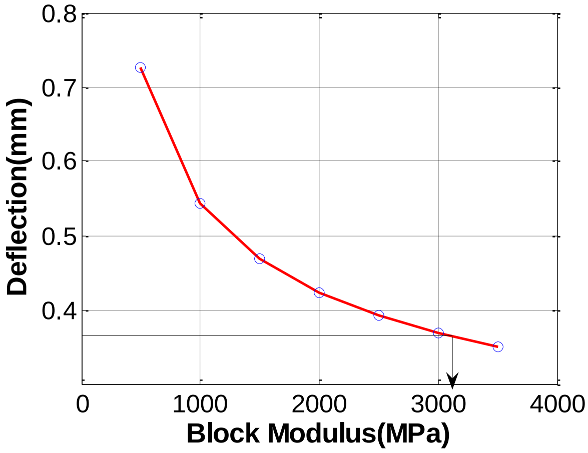


Figure 10. Modulus-Deflection curve for 6 000 times load repetitions.

Figures 6 to 10. Modulus-Deflection Curve for 75 mm thick block with granular subbase layer of 102 mm.

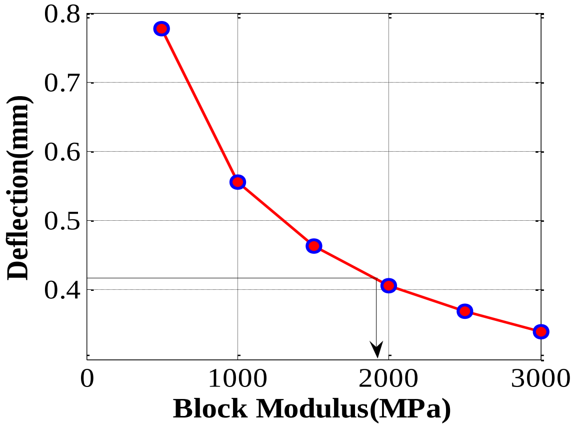


Figure 11. Modulus-Deflection curve.

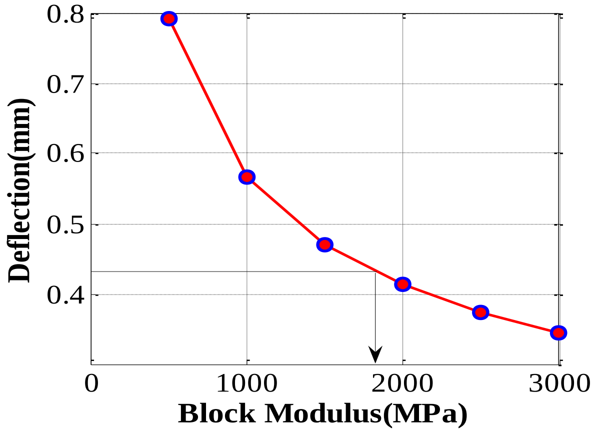


Figure 12. Modulus-Deflection curve.

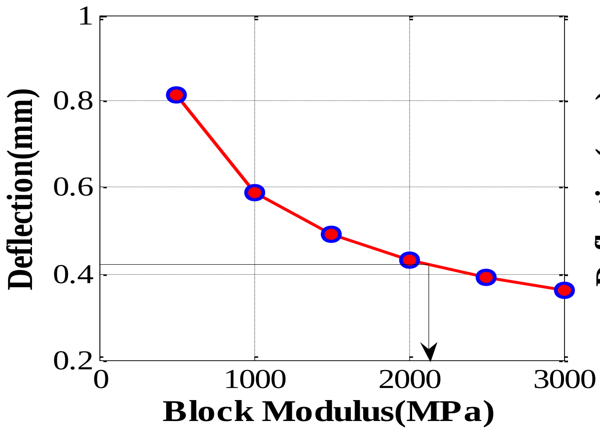


Figure 13. Modulus-Deflection curve.

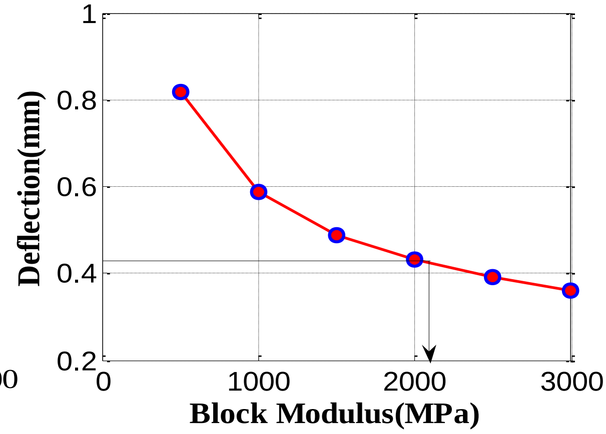


Figure 14. Modulus-Deflection curve.

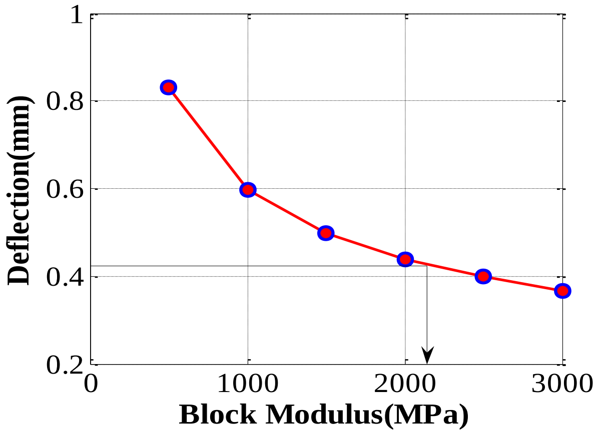


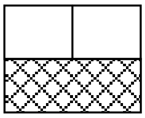
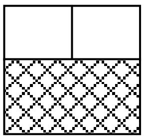
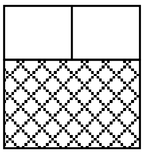
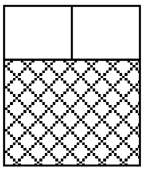
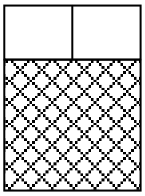
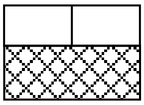
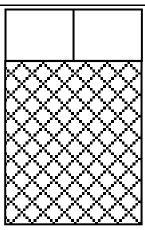
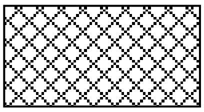
Figure 15. Modulus-Deflection curve.

Figures 11 to 15. Modulus-Deflection Curve for 100 mm thick block with granular subbase layer of 96 mm.

Table 5. Pavement codes of CISCBP for use with reference to Table 6.

SUBGRADE CBR (%)	VILLAGE ROAD					
	STANDARD AXLE LOAD REPETITIONS					
	Less than $5x10^4$	$5x10^4$ to $1x10^5$	$1x10^5$ to $2x10^5$	$2x10^5$ to $4x10^5$	$4x10^5$ to $9x10^5$	$9x10^5$ to $2x10^6$
2	A	A	A	B	C	D
3	A	A	A	A	E	F
4	A	A	A	A	A	E
5	A	A	A	A	A	A
> 5	G	G	G	A	A	A

Table 6. Pavement structures of CISCBP to be used with reference to Table 5.

PAVEMENT STRUCTURE	PAVEMENT COMPOSITIONS	PAVEMENT STRUCTURE	PAVEMENT COMPOSITIONS
 **A**	**100 mm concrete blocks** **Subbase layer=100 mm**	 **E**	**100 mm concrete blocks** **Subbase layer=140 mm**
 **B**	**100 mm concrete blocks** **Subbase layer=165 mm**	 **F**	**100 mm concrete blocks** **Subbase layer=200 mm**
 **C**	**100 mm concrete blocks** **Subbase layer=245 mm**		**75 mm concrete blocks** **Subbase layer=100 mm**
 **D**	**100 mm concrete blocks** **Subbase layer=320 mm**	 **Concrete block layer**  **Subbase**	

7. CONCLUSION

- The model analysis using axial symmetric 2-D finite element model was found to be satisfactory and reliable as the result obtained were close to the backcalculated analysis.
- The same 2-D finite element was used to evaluate the material parameters of granular layer for characterization of its equivalent elastic modulus by using K-θ model and Park-Fernando model. The Park-Fernando model was found to be close to the backcalculation computer program, BACKGA.

- The equivalent elastic modulus of plastic cell filled concrete block layer for the different repetitions of load for the two pavement thicknesses as determined by FE Model was found to have a difference of 0-15% as compared to backcalculated modulus.
- A simple design catalogue is proposed for the design of new roads.

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