

Assessment of Load Response in Interlocking Concrete Block Pavements By ANSYS

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HIGHLIGHTS

- EEM for the EBL, calibrated via dynamic tests + FEM, predicts CBP deflection.
- Jointing sand cuts $\approx 30\%$; thicker blocks, larger plates, and thicker sub-bases lower it further.
- Herringbone best (basket-weave mid, stretcher worst); Ansys FEM ≈ 8 mm matches measurements.

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ABSTRACT

Concrete Block Pavement (CBP) consists of discrete masonry units arranged in engineered patterns, unlike monolithic concrete or asphalt surfaces. Because load paths are transferred through interlocking blocks, bedding, and joints, overall structural stiffness depends on block shape, thickness, and the laying pattern, making a single elastic modulus difficult to define. This study develops a practical deflection-prediction model for CBP using dynamic plate load tests combined with Finite Element Method (FEM) analysis. We propose a procedure to estimate the Equivalent Elastic Modulus (EEM) of an Equivalent Block Layer (EBL)—a composite representation of blocks and bedding sand—calibrated to measured surface deflections. Results indicate that properly compacted jointing sand can reduce peak pavement deflection by as much as 30%. Additional reductions are achieved by increasing block thickness, using larger loading plate diameters, and providing thicker, well-graded sub-bases that limit shear deformation. Among common laying patterns, the herringbone bond offers the most efficient load dispersion due to multidirectional interlock; basket-weave performs moderately; stretcher bond shows the least effectiveness under dynamic loading. FEM simulations in Ansys reproduced the measured deflections with good fidelity, matching manual calculations of approximately 8 mm and thereby validating the modelling approach. The framework offers practitioners a rational way to select block geometry, pattern, and layer thicknesses to meet serviceability targets while optimizing material use. The methodology can support maintenance planning and lifecycle cost evaluation.

1 INTRODUCTION

With rapid urbanization, road designers seek durable and economical alternatives to traditional pavements. Interlocking Concrete Block Pavement

(ICBP) offers lower life-cycle cost and efficient load transfer through blocks, sand joints, and the supporting layers, with performance improving over time due to sand dilatancy, inter-block shear, and traffic-induced compaction (Concrete Manufacturing

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Association, 2004; Knapton, 1976; Mampearachchi & Gunatilake, 2013). Block shape and laying pattern strongly influence structural response, and jointing sand stiffness can increase markedly once interlock is established (Barber & Knapton, 1980; Mampearachchi & Senadeera, 2014). Reported surface elastic modulus values span roughly 500–4,000 MPa, underscoring that no single modulus is adequate for design across configurations (Hassani & Jamshidi, 2006; Jacobs & Houben, 1988; Lin, Cho, & Kim, 2016; Lin, Ryu, Hao, & Cho, 2016). Building on this foundation, past experimental and analytical studies—including wheel-track tests and finite-element investigations—have clarified load dispersion and distress mechanisms in block pavements (Barber & Knapton, 1980; Jacobs & Houben, 1988; Nejad, 2003; Nejad & Shadravan, 2006).

The present work develops a deflection-prediction model for Concrete Block Pavement (CBP) using dynamic load testing coupled with ANSYS®-based FEM analysis, explicitly considering multiple block shapes and laying patterns (Gunatilake & Mampearachchi, 2014; Hassani & Jamshidi, 2006; Lin, Cho, & Kim, 2016; Lin, Ryu, Hao, & Cho, 2016; Mampearachchi & Gunarathna, 2010). We propose a method to compute the Equivalent Elastic Modulus (EEM) of an Equivalent Block Layer (EBL) that treats the block layer and bedding sand as a composite, enabling practical mechanistic evaluation of deflections and stresses. Sub-base parameters and detailing are informed by established guidance and mechanistic/empirical design insights to aid performance-based design (Concrete Manufacturing Association, 2004; Knapton, 1976; Miura, Takaura, & Tsuda, 1984).

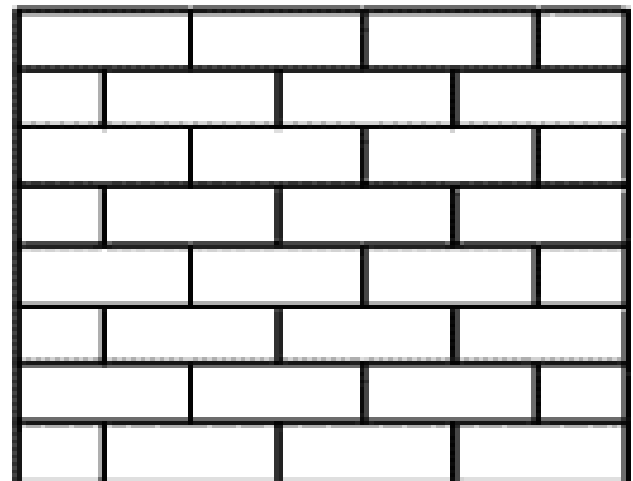
To evaluate load response, CBP test sections were assessed under a static load of 51 kN—half the legal single-axle load in India (IRC:37-2012)—using Grade III sub-base (MOST, 1995), Zone III bedding sand, and a uniform 200 mm sub-base. Loading plates of 150-, 200-, and 300-mm diameter and block thicknesses of 80, 100, and 120 mm were examined predominantly in basket-weave bond, with comparisons to herringbone and stretcher patterns, and multiple load positions were applied to capture vertical displacement and stress distribution (Gunatilake & Mampearachchi, 2014; Mampearachchi & Senadeera, 2014). Prior modeling frameworks and support-condition studies inform our setup and validation, including earlier SAP-based and FEM/3D-FEM approaches that consistently identify vertical deflection as the critical criterion—typically several times horizontal deflection—for selecting block geometry and patterns (Gunarathna, 2009; Jacobs & Houben, 1988; Mampearachchi & Gunarathna, 2010; Nejad, 2003;

Nejad & Shadravan, 2006). Collectively, this introduction positions the study to optimise block dimensions and patterns via calibrated FEM in ANSYS®, with findings intended to guide practical design and detailing for durable ICBP systems (Hassani & Jamshidi, 2006; Lin, Cho, & Kim, 2016; Lin, Ryu, Hao, & Cho, 2016).

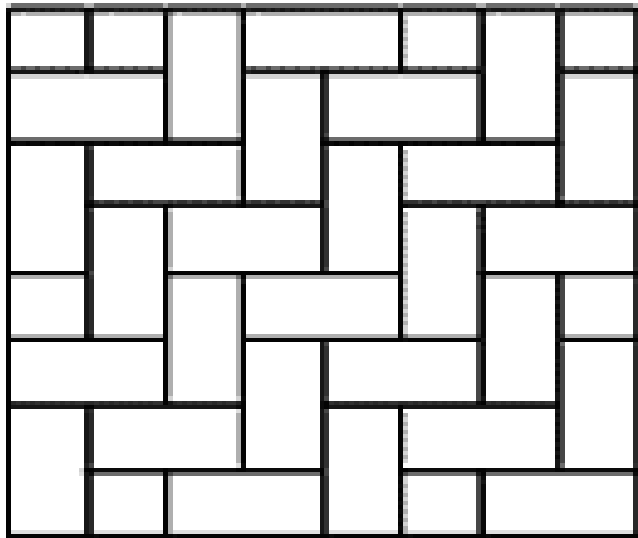
This study evaluated Concrete Block Pavement (CBP) performance under a static load of 51 kN, representing half the legal single axle load in India (IRC:37-2012). Test sections used Grade III sub-base (MOST, 1995), Zone III bedding sand, and uniform 200 mm sub-base thickness. Loading plates of 150-, 200-, and 300-mm diameters with block thicknesses of 80, 100, and 120 mm were tested, mainly in Basket-weave bond, with comparisons to Herringbone and Stretcher patterns. Different load positions were applied to assess vertical displacement and stress distribution. Results highlight the influence of block thickness, pattern, and loading conditions on CBP deformation, providing insights for optimized pavement design (Figure 1).



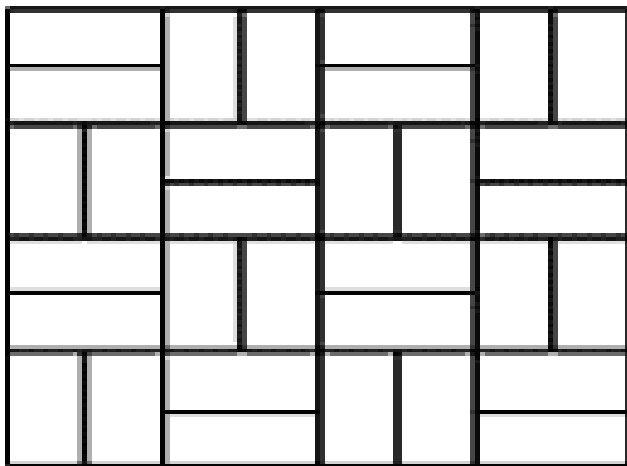
Figure 1. Details of the block thickness used in the experiment



a) Stretcher



b) Herringbone



c) Basket bone

Figure 2 (a-c). different laying patterns

2 METHODOLOGY

Finite element models are widely used to analyse block pavements by representing modular concrete blocks over underlying pavement layers. In such studies, wheel loads are typically applied as uniformly distributed tyre pressures over a rectangular or circular contact area, often extending across multiple blocks when small modular units are considered (Zheng et al., 2012). To improve computational efficiency without losing accuracy, simplified finite element meshes were adopted, as supported by Korunovic et al. (2012). The models, developed in ANSYS®, simulated blocks over flexible pavement layers with a plan area of 1.5 m × 1.5 m and a thickness based on pavement depth. This size was selected after sensitivity analysis to minimise edge effects and ensure near-zero stress and strain values at model boundaries.

The pavement models used solid hexahedral elements with 8-point integration and quadratic shape functions for accurate strain and displacement estimation. Mesh refinement was applied in loaded areas with a minimum size of 20 mm, gradually coarsening to 40 mm near boundaries. All materials were assumed homogeneous, isotropic, and linearly elastic, except the sand-filled joints between blocks. These joints were modelled with elastic-plastic behaviour to capture nonlinear load transfer and interlocking effects, providing a realistic representation of the block pavement system under traffic loads.

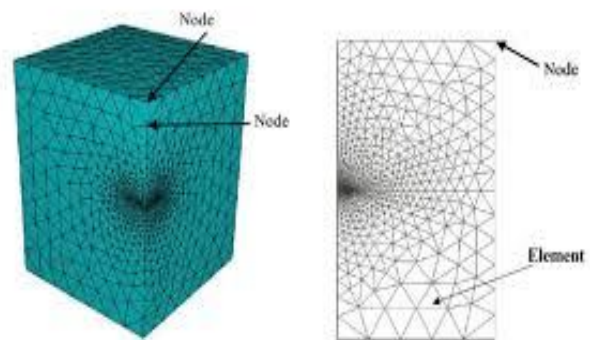


Figure 3. Finite element model developed using ANSYS®

3 RESULTS AND DISCUSSION

The experimental study aimed to assess the deflection behaviour of Concrete Block Pavements (CBP) under a standard load by examining the influence of jointing sand, block thickness, laying patterns, loading plate diameters, and sub-base thickness. Results showed that pavements with jointing sand performed significantly better, reducing vertical deflections by up to 30% compared to pavements without sand, which experienced 1.45 to 3.25 times higher deflections. Among different configurations, the Herringbone bond with 120 mm thick blocks exhibited the greatest reduction in deflection, highlighting the effectiveness of its zigzag interlock geometry and increased thickness in minimising surface deformations. Deflection also decreased as the loading plate diameter increased from 150 mm to 300 mm, confirming the role of larger contact areas in reducing localised stresses.

Further tests investigated the effects of varying block thickness and bond patterns while keeping sub-base thickness and loading plate diameter constant. Across Herringbone, Basket-weave, and Stretcher bonds, thicker blocks consistently showed lower deflections due to improved interlocking and greater frictional resistance. The Herringbone pattern consistently produced the least deflection because of

its superior load distribution, while Stretcher bonds showed the highest deflections and Basket-weave gave moderate results. Additionally, larger loading plate diameters distributed stresses more effectively, resulting in lower deflections. Finally, increasing sub-base thickness from 200 mm to 450 mm further reduced deflection, with thicker sub-bases significantly improving pavement stiffness, reducing deformation under loads, and enhancing long-term durability (Tables 1 and 2).

Table 1. Influence of jointing sand on the load dispersion behaviour of CBP for a block thickness of 120 mm with Herringbone laying pattern

Distance of dial gauge from Center (mm)	Deformation (mm) Without Jointing Sand	Deformation (mm) With Jointing Sand
-1500	0.2	0.3
-1000	0.3	0.2
-500	1.2	0.8
0	3.8	1
500	1.3	0.8
1000	0.4	0.3
1500	0.2	0.3

Table 2. Influence of block thickness on the load dispersion behaviour of CBP (Herringbone bond).

Distance from center (mm)	HB (mm)	BW (mm)	SB (mm)
-1500	-0.01	0	-0.03
-1000	0.05	0.06	0.03
-500	-0.3	-0.35	-0.4
0	-0.7	-0.9	-1
500	-0.3	-0.35	-0.4
1000	0.05	0.06	0.03
1500	-0.01	0	-0.03

4 VERIFICATIONS OF THE ANSYS FEM

The study revealed that the effects of jointing sand, block thickness, bond pattern, loading plate diameter, and sub-base thickness on pavement deflection closely correlated with numerical simulations conducted using ANSYS® finite element software. Following the framework of previous

ANSYS-based CBP studies, the models replicated actual pavement behavior under vehicle loads, simulating concrete blocks, sub-base layers, and loading conditions. Except for the jointing sand, which was modelled as an elastic-plastic material to reflect its load-dissipating properties, all layers in the finite element models were assigned linear elastic material properties and solid hexahedral elements, with refined meshing under the load application area. The ANSYS simulation results matched experimental findings, showing, for instance, a 25–32% reduction in vertical deflection in pavements with jointing sand, consistent with the 30% decrease observed experimentally.

The bond patterns and block thickness effects were similarly reflected in both numerical and physical tests. Herringbone bond layouts exhibited the least deflection due to their interlocking zigzag configuration, followed by Basket-weave and Stretcher patterns. Blocks 120 mm thick showed minimal deformation, whereas 80 mm blocks experienced the highest deflection. Larger loading plate diameters reduced stress intensity and deflection, while increasing sub-base thickness (200 mm, 300 mm, 450 mm) decreased deflection, supporting experimental results and previous studies. These consistencies confirm the reliability and accuracy of the ANSYS-based FEM models, validating their use for predicting and optimizing CBP performance under realistic traffic conditions.

5 CONCLUSION

The paper identifies structural performance of Concrete Block Pavements (CBP) in the context of different influencing variables, including plate diameters of loading, thickness of sub-base, thickness of block, bond patterns and jointing sand. It has been experimentally and computationally found using Finite Element Method (FEM) simulations in ANSYS that interlocking patterns, especially the herringbone bond, lead to a superior load transfer, and surface deflections are smaller in magnitude. The CBPs have better performance in the presence of jointing sand, and deflections are lowered by a factor of up to 30 per cent in the presence of jointing sand because of enhanced inter-block friction and containment. This is further enhanced by the use of heavier blocks, which increases mechanical interlock. The effect of deflection continually declines with the width of loading plates, since these distribute loads imposed on a broad region. The 120 mm thick blocks exhibit the least deflections in all configurations, and they have greater load transfer and structural stiffness. The herringbone bond is the most suitable in the group of patterns assessed in laying, as it has a zigzag interlocking

design, thus facilitating lateral confinement and stiffness. The stretcher bond, on the other hand, causes maximum deflections, and the basket-weave is moderate. The significance of the tyre footprint in pavement response is that smaller loading plate diameters result in greater deflections. Adding sub-base thickness to 450 mm enhances the rigidity of the system and reduces further deflections. FEM gives predicted surface deflections that are refined to within 8 mm of the experimental results, which are close enough to validate the simulation model. Also, herringbone patterns allow 10-15 per cent more loads repetitions and increase the resistance to rutting and increase pavement resistance to repeated loads during traffic. On the whole, this research offers a holistic performance-based analysis to optimize CBP design to achieve a higher service life and structural resilience.

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Conflicts of Interest: The authors declare no conflicts of interest.

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