

Concrete Block Paving Tested as Articulated Slabs

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SYNOPSIS

This paper describes the experimental evaluation of articulated slabs composed of concrete block paving laid and compacted within a steel frame. By testing the paving in isolation from the bedding sand, basecourse and other elements of a complete block pavement it proved feasible to study the load spreading and other structural characteristics of the pavers themselves. This provided insights into the structural behaviour of concrete block paving under load.

Factors studied in the project included the effects of paver shape, laying pattern, joint width, spacer nibs and load repetition. Each of these factors was shown to significantly influence the structural capacity of the paving course. By analysing the paver performance as a quasi-elastic slab it was possible to quantify the behaviour of block paving in a form suitable for inclusion in mechanistic pavement design and analysis. Where appropriate these measures were compared with data obtained both from Accelerated Trafficking Tests and Falling Weight Deflection studies of full scale block pavements.

INTRODUCTION

During the last fifteen years there has been considerable full-scale testing of concrete block pavements (CBP) with the objective of obtaining information on the manner in which such pavements respond to traffic. This has been reviewed elsewhere (1). Although such testing has served to both identify and quantify those factors which influence the performance of CBP it has provided relatively little information that is of direct use in modern mechanistic design procedures. Accordingly such information has largely been inferred from Falling Weight Deflection (FWD) studies of actual block pavements. The purpose of this paper is to describe a relatively simple laboratory-scale test devised to characterise the stiffness of pavers which is independent of any support from the pavement substructure. Such tests can then serve both to supplement and verify FWD studies.

BACKGROUND TO THE TESTS

A cross-section of a typical block pavement is shown in Figure 1. It may be seen that the surface comprises pavers bedded and jointed in sand. Beneath the bedding sand the sub-structure is similar to that of a conventional flexible pavement. Accordingly, most design methods for CBP have been adaptations of flexible pavement design procedures. These include computer-based mechanistic procedures (2-5). Such procedures require the moduli of all the pavement layers as a design input. For normal flexible pavement materials such data can be obtained from repeated triaxial load tests or similar. Clearly this cannot be done where the surfacing comprises pavers. Here the properties of the concrete *per se* are largely irrelevant. Rather, it is the combined performance of the pavers and sand that is of interest. In most design procedures (eg 5) it is possible to model the performance of the pavers and sand in terms of an equivalent elastic layer chosen to have similar behaviour to CBP under traffic. To date the properties of this equivalent layer have been derived by FWD evaluations of block pavements. Such tests are inexact and do not properly isolate the properties of the pavers from those of the base, sub-base and subgrade. Moreover, the FWD methodology is prone to errors of interpretation. For this reason, it is necessary to devise tests which enable the structural performance of the pavers alone to be evaluated.

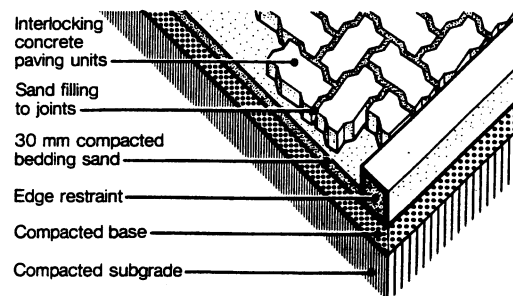


Figure 1 Cross-section through typical block pavement

The test method adopted here was based on a procedure developed by L.R. Marais of the Portland Cement Institute, Johannesburg, in 1967, but hitherto unpublished. Marais tested pavers installed on sand in a steel frame having a trapdoor base which was lowered and removed once the pavers had been compacted. The pavers were then tested as quasi-slabs spanning between 0.7 m and 1.1 m with conditions of either one or two-way support. From these experiments Marais estimated the equivalent elastic modulus of SF roadstones to be approximately 900 MPa.

PAVER DETAILS

Three shapes of paver were selected for study. Each had been investigated in earlier accelerated trafficking trials of full-scale block pavements (1, 6, 7.). The selected shapes are shown in Figure 2. Here, the letters used to designate the different shapes are those set out in the interim Australian industry standard for pavers (8). Generally, the pavers were 80 mm thick. However, in the case of the rectangular pavers, shown as shape C in Figure 2, both 60 mm and 80 mm paver thicknesses were studied.

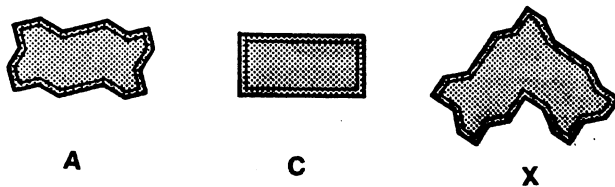


Figure 2 Paver shapes studied in the experimental work

All of the pavers were normal commercially produced units. The shape X pavers were manufactured with 1.5 mm spacer nibs designed to prevent the joints closing during mechanical laying. One set of the rectangular pavers studied was fitted with 1.9 mm nibs.

The pavers were installed in the laying patterns shown in Figure 3. Normally, shape X pavers are mechanically installed in 1 sq m clusters (1, 7). This was impractical in the experiments described here. Instead the simple chevron pattern shown in Figure 3 was adopted although earlier trafficking tests had shown that this pattern did not perform as well as where the pavers were laid in a machine-layable pattern (7). Shape A and C pavers were installed in the conventional herringbone and stretcher bond patterns shown in Figure 3.

TEST SECTIONS

The test sections were constructed within a rigid steel frame having internal dimensions of 1.5 m x 1.5 m. The frame was placed on a concrete floor and bedding sand complying with current Australian standards for CBP (9) was uniformly spread and screeded to a loose, uncompacted depth of 30 mm. Pavers were then laid on the bedding sand by hand using unskilled and inexperienced labour. Care was taken to ensure that laying procedures complied with Australian practice for CBP (9).

Where necessary, at the edges of the test frame, pavers were either sawn or guillotined to fit to the frame. Gaps between whole pavers and the edge that were smaller than about one quarter of a paver were filled with a dry packed sand-cement mortar.

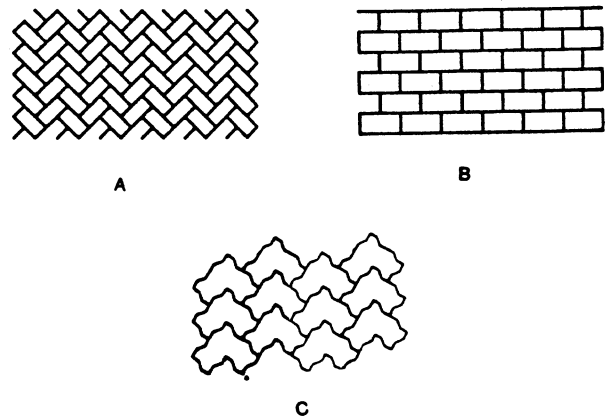


Figure 3 Laying Patterns: (a) Herringbone, (b) Stretcher and (c) Chevron

Once the pavers were laid they were compacted by a vibrating plate compactor. This compacted the bedding sand and drove the sand approximately 20 mm up the joints between the pavers. The joints were then filled by brushing and washing in the jointing sand. The section was then again subjected to plate compaction. Both stages of compaction involved not less than 3 coverages by the vibrating plate.

It is important to note that the pavers were never hammered together or forced into the test frame, ie. there was no attempt to wedge the pavers tightly into the frame during laying. Measurements of joint spacing were made at 20 randomly selected locations. These are summarised in Table 1. From this table it may be seen that, on average, the joint widths were around 2.8 mm. This is consistent with normal practice which requires joints generally to be within the range 2 mm to 4 mm (9).

The pavers were laid flat without a crown or camber. In other words there was no built-in arching action in the trial sections. Once the pavers had been compacted and the joints filled with sand it proved possible to lift the test frame and the pavers enclosed within it off the bedding sand. Under the self-weight of the pavers the centre of the mat of pavers sagged by amounts ranging between approximately 2.0 mm and 2.5 mm (see Table 1). This was sufficient to induce enough arching and wedging between the individual pavers and between the pavers and the test frame for the pavers to retain structural integrity and to act like an articulated slab. At this stage, despite the lack of any support beneath the pavers, they were capable of supporting significant vertical load. As described below the loads needed to cause failure of the mats ranged between approximately 4 kN and 21 kN (Table 1).

TABLE 1 JOINT WIDTHS, FAILURE LOADS AND MODULI

Paver Shape	Paver Thickness (mm)	Laying Pattern	Mean Joint Width (mm)	Sag Under Self-weight (mm)	Failure Load (kN)	Mat Moduli at 3kN load (MPa)
A	80	Herringbone	2.70	2.58	21.0	900
A	80	Stretcher	2.75	2.63	19.0	800
C	80	Herringbone	2.80	2.60	19.0	750
C	80	Stretcher	2.75	2.65	19.0	600
C	60	Herringbone	2.75	—	3.8	175
C	60	Herringbone	2.75	—	7.5	900
(+nibs)						
X	80	Chevron	2.80	2.10	13.0	950
(+nibs)						

TEST PROCEDURES

The unsupported mats of pavers contained within the test frame were placed beneath a screw jack having a capacity of 25 kN. This applied a central load to the mats via a rigid circular plate having a diameter of 150 mm. The deflections of the mats were measured to an accuracy of 0.01 mm at the 14 locations shown in Figure 4.

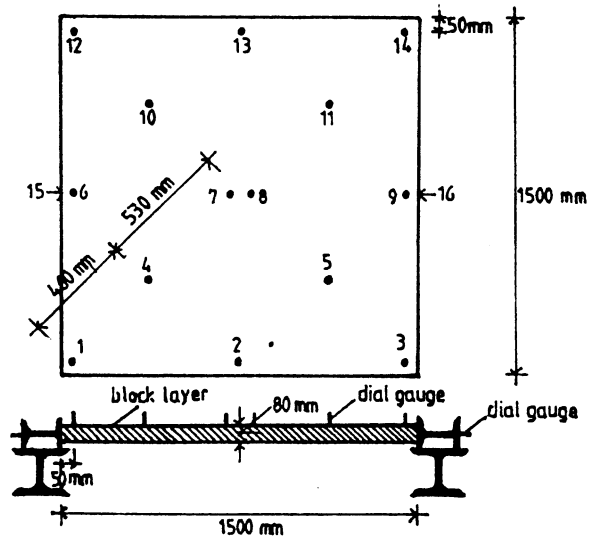


Figure 4 Location of the measuring points

The following test regime was adopted. The load was increased in 0.5 kN increments up to 4 kN and at 1.0 kN increments thereafter. For each increment of load the mats of pavers were subjected to 5 cycles of loading and unloading and the corresponding deflections were measured. In a few tests the load was cycled up to 100 times. Unless stated to the contrary, the results reported here are for the fifth cycle of loading at each load increment. Typical effects of cycling the load are shown in Figure 5. From this figure it may be seen that the response was non-linear and that the deflections upon unloading were different

from those during loading. In other words small permanent residual deflections gradually developed as the result of load repetition. Nevertheless, within a given cycle of loading, the performance of the mats could be approximated as being linearly elastic.

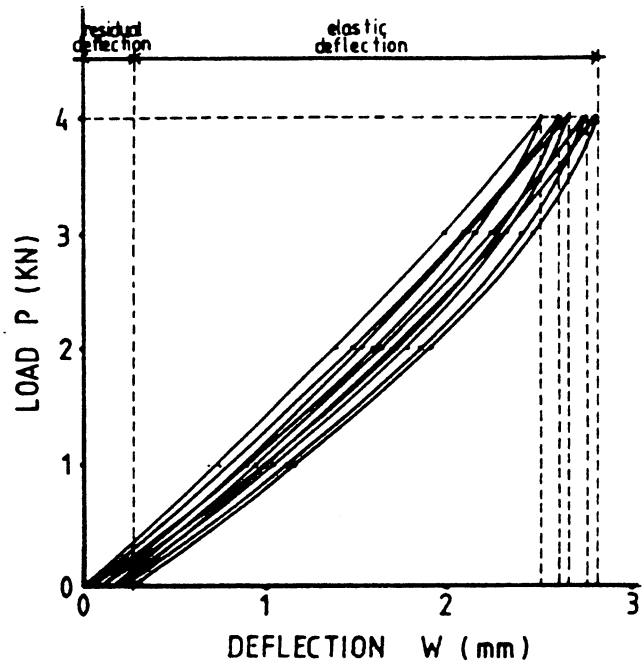


Figure 5 Effects of cycling a 4 kN load on Shape A pavers laid in herringbone bond

Typical deflection profiles measured along a mat diagonal are given in Figure 6. It may be seen that the mat deflections increased in a non-linear manner from the corners of the centre of the mat. It was observed that little or no deflection or rotation of the pavers occurred relative to the test frame around

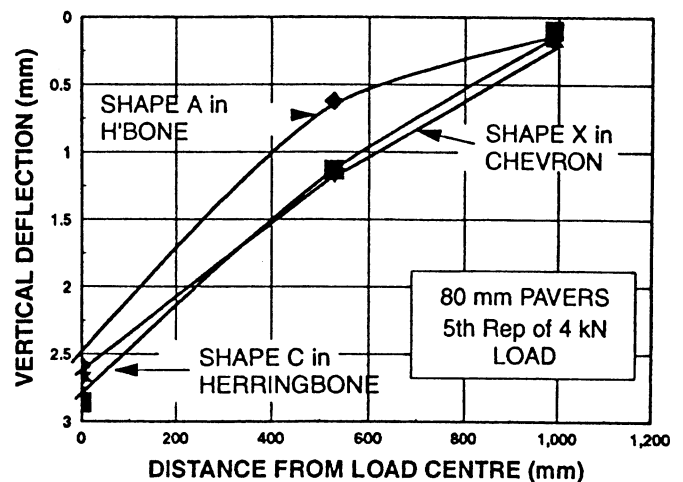


Figure 6 Deflections measured on mat diagonal

the edges of the paver mats. Effectively the mat edges could be regarded as being fixed relative to the centre. As noted above, the prime objective of the experiments was to characterise the pavers in terms of an equivalent quasi-elastic isotropic elastic modulus. This was accomplished by calculating the apparent moduli of the mats based on centre deflections and assuming fixed edge conditions. Here a Poisson's Ratio of 0.3 was assumed. These moduli were then used to assess the effects of

- a) Paver shape
- b) Laying pattern
- c) Paver thickness
- d) Load repetition
- e) Spacing nibs

Each of these factors is now discussed in detail. In addition the ultimate load capacities of the paver mats is discussed.

Effects of Paver Shape and Laying Pattern

The combined effects of shape and laying pattern are shown in Figure 7 as a function of the applied load. It may be seen that, for some pavers, there was an initial drop in modulus with increase in load but that, thereafter, the moduli were relatively unaffected by changes in load. Shape X pavers (Figure 2) laid in chevron bond exhibited the highest moduli measured in the experiments. For paver shapes A and C the moduli were generally higher when the pavers were installed in herringbone bond than when they were laid in stretcher bond. Moreover, shape A pavers were generally associated with higher moduli than shape C pavers installed in the same laying pattern. Overall the ranking of the various shapes/laying patterns was, in order of decreasing moduli:

1. Shape X laid in chevron bond.
2. Shape A laid in herringbone bond.
3. Shape A laid in stretcher bond.
4. Shape C laid in herringbone bond.
5. Shape C laid in stretcher bond.

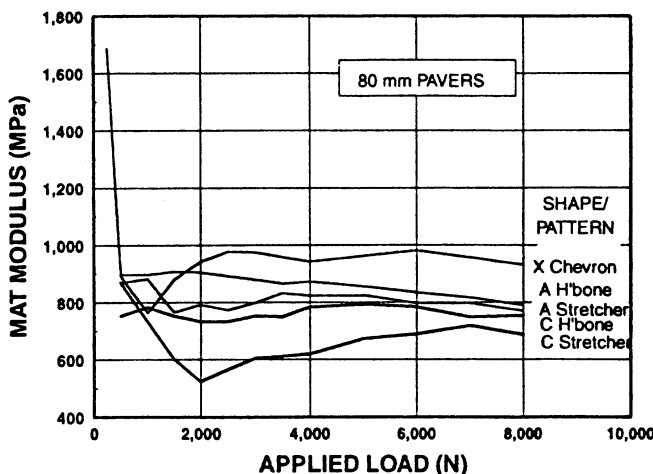


Figure 7 Effects of paver shape and laying pattern

It is interesting to note that this ranking of shape and laying pattern is similar to that established in earlier full-scale accelerated trafficking tests of pavers (1, 6, 7).

Overall, it will be seen that the equivalent elastic moduli of the pavers typically lay between 600 MPa and 1000 MPa. These values are somewhat lower than those assumed in many earlier studies of blocking paving but are consistent with the results obtained by Marais (*unpublished data*).

The Effects of Paver Thickness

For rectangular (shape C) pavers installed without nibs a change in thickness from 60 mm to 80 mm had a major effect on the block moduli. This is shown in Figure 8. From this figure it may be seen that the 80 mm pavers were associated with moduli of around 800 MPa which were relatively unaffected by the magnitude of the applied load. However, in the case of the 60 mm pavers, the moduli decreased from a maximum value of 318 MPa to 108 MPa with relatively small increases in the applied load. The trend in the effect of paver thickness is similar to that found in trafficking and static load tests (1, 9, 11).

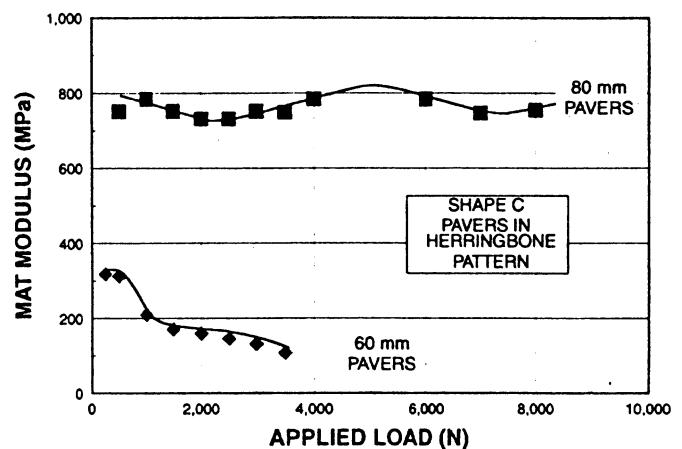


Figure 8 Effects of paver thickness

The Effects of Load Repetition

As noted above, in a few tests the load applied to the pavers was cycled up to 100 times. In accelerated trafficking tests the stiffness of block pavements often tends to increase under traffic (1, 6) and it was expected that this might occur in the tests reported here. However, as shown in Figure 9, the mat modulus tended to decrease slightly with load repetition. In this respect it was observed that sand was being lost from the joints during each repetition of load. This may explain the small loss in modulus shown in Figure 9.

The Effects of Spacer Nibs

The effects of the presence or absence of spacer nibs was assessed for 60 mm rectangular pavers laid in herringbone bond.

The results of the tests are given in Figure 10. It was found that the pavers manufactured with nibs consistently exhibited higher moduli than those without nibs. This may again reflect the loss of sand from the joints that was observed to occur during each load repetition. In this respect, pavers fitted with nibs could maintain continuous paver-to-paver contact without necessarily relying on the transmission of load through the jointing sand. Thus the presence of nibs may be beneficial to the in-service performance of block pavements.

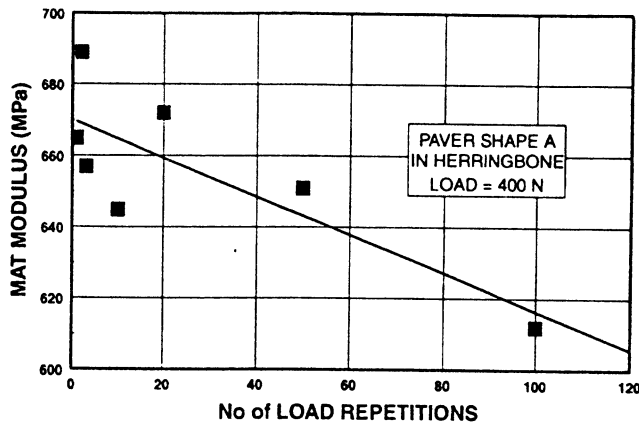


Figure 9 Effects of load repetition

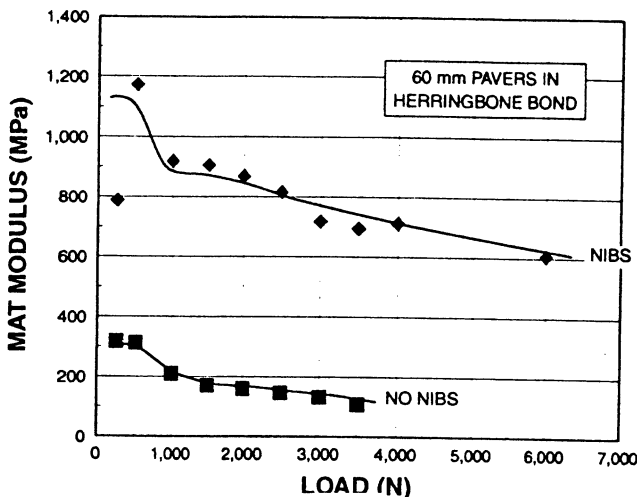


Figure 10 Effects of spacer nibs

Ultimate Load Capacity

The progressive application of load to the unsupported mats of pavers eventually induced failure at loads ranging between about 4 kN and 21 kN (Table 1). Failure was manifest by the pavers situated immediately under the load faulting relative to their neighbours. At no time did a complete collapse or disintegration of the paver mats occur. Indeed, at the conclusion of the test it

often proved necessary to break up the pavers in order to remove them from the test frame. In other words, throughout the test program the paver mats exhibited performance similar to that of thin slabs of low to medium rigidity.

The loads at failure are given in Table 1. As might be expected intuitively the ultimate load increased with increase in paver thickness. However, neither paver shape nor laying pattern appeared to influence the load needed to cause failure. In this respect, the variations in failure load probably reflect the different numbers of individual pavers that were in immediate contact with the loading plate.

TABLE 2 RESULTS OF FWD TESTS OF CBP

Author	Reference	Paver Moduli (MPa)
a) Trafficked Pavements		
Fuchs et al (1983)	11	500 - 7000 (mean 2975)
Armitage (1988)	12	720 - 9600
Shackel (1988)	3	1570 - 12495 (mean 3400)
b) Untrafficked Pavements		
Shackel (1986)	Unpublished	75 - 1181 (mean 432) - on crushed rock base 75 - 19666 (mean 2905) - on cement-treated base

DISCUSSION

Falling Weight Deflection data for CBP have been reported by a number of workers (3, 12, 13). Typical moduli calculated from these data are summarised in Table 2. It will be seen that the paver moduli measured in the tests described here tended to be towards the lower end of the range of values derived from FWD data. In this respect it should be noted that FWD data have, in general, been obtained from block pavements that have been under traffic for some time. As detailed elsewhere (1) the stiffness of block paving often increases under traffic. This is the result of progressive traffic-induced rotation and wedging of the pavers. This phenomenon is referred to as 'lock-up'. In the work reported here, there was no opportunity to traffic the pavements by moving (rolling) loads. Accordingly the pavers had no opportunity to develop lockup. Support for this hypothesis is provided by data obtained by the senior author for FWD tests on newly laid untrafficked CBP test pavements (see Table 2). It will be seen that the moduli calculated from FWD data were, on average, of similar magnitude to those reported above.

Overall, it can be concluded that the test data reported herein are consistent with FWD results but are likely to lie at the lower end of the range of values encountered in practice. The question then arises whether the moduli values are suitable for use in the thickness design of CBP. Using the mechanistic design methodology developed by the senior author (5) it can be demonstrated that variations in paver modulus within the range reported here have only a minor effect on the design thicknesses of base and sub-base. In other words, the use of paver moduli

obtained by the procedures described above, although conservative, do not exact any significant penalty in the design thicknesses obtained. In this respect, factors such as the resistance of the pavers to horizontal creep are of more practical significance than the selection of paver modulus. Such aspects of performance, have been shown by accelerated trafficking tests to be a function of factors such as paver shape and laying pattern (1, 6, 10).

CONCLUSIONS

The principal conclusions that can be drawn from the experimental studies are

1. It was possible to test pavers as small articulated slabs without continuous support. In other words, the pavers could be assessed independently of any pavement substructure.
2. Over an unsupported span of 1.5 m the pavers could support concentrated central loads of up to 21 kN.
3. As a good approximation the pavers could be modelled in terms of an equivalent thin isotropic elastic slab exhibiting moduli of up to about 1700 MPa depending on paver shape, thickness, laying pattern and the presence or absence of spacer nibs.
4. Except in the early stages of deflection, the moduli of the pavers were relatively unaffected by the applied load for 80 mm pavers but tended to decrease with increase in load for 60 mm pavers.
5. Shaped pavers generally exhibited higher moduli than rectangular pavers of similar thickness installed in the same laying pattern.
6. For a given shape and thickness of paver, blocks laid in herringbone bond exhibited higher moduli than blocks laid in stretcher bond.
7. Paver performance tended to improve with increase in paver thickness.
8. Pavers fitted with spacer nibs performed better than pavers without nibs. This probably resulted from the better paver-to-paver contact provided by the nibs than by the jointing sand which tended to fall out of the joints during each repetition of load.
9. Load repetition caused a decrease in the measured paver mat moduli. This may have been due to the progressive loss of sand from the joints between the pavers during the tests.

Many of the conclusions given above are consistent with earlier accelerated trafficking trials of block pavements in respect of such factors as paver shape, thickness and laying pattern. Effects such as the progressive loss of stiffness with load repetition

appear to be a function of the techniques followed here. Overall, however, the procedures provide a convenient methodology for studying paver properties independently of those of the pavement sub-structure. Such tests are likely, therefore, to be valuable in verifying and supplementing full-scale pavement test procedures such as the Falling Weight Deflectometer.

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