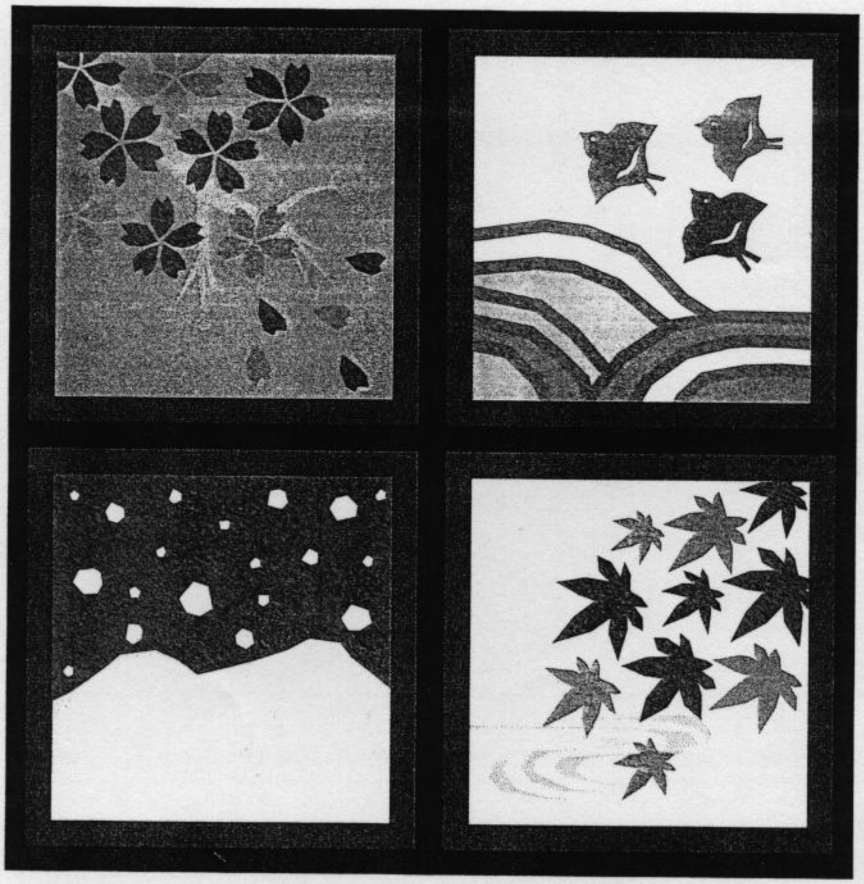
JIPEA
WORLD
CONGRESS
2000

The 6th International Conference on Concrete Block Paving

Proceedings



17 - 21 September, 2000
Keio-Plaza Intercontinental Hotel
Tokyo, Japan

Japan Interlocking Block Pavement Engineering Association

LOADING TESTS OF CONVENTIONAL AND ECOLOGICAL CONCRETE BLOCK PAVING

SHACKEL B, SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING,
UNIVERSITY OF NEW SOUTH WALES,
Sydney, Australia, 2052

TEL +612 9385 5022, FAX +612 9385 6139 E-mail b.shackel@unsw.edu.au
LITZKA J, INSTITUTE FOR ROAD CONSTRUCTION AND MAINTENANCE,
TECHNICAL UNIVERSITY OF VIENNA.
ZIEGER M, OFPZ ARSENAL LABORATORIES, VIENNA, AUSTRIA

ABSTRACT

This paper describes the experimental testing of a variety of both well-established and newly developed pavers. The pavers were evaluated under laboratory conditions using a special test designed to ensure that the paver surface could be characterised independently of any bedding or pavement sub-structure. The test allowed the pavers load distribution capabilities to be quantified in terms of their resilient modulus i.e. in a manner suitable for characterising them for the purposes of pavement analysis and design. Factors studied included the paver shape and the laying pattern. Both conventional and ecological pavers were studied. The tests showed that the main factor influencing the load distributing characteristics of the pavers was their shape. The effects of the laying pattern were minor and there was little practical difference between the performance of conventional and ecological pavers. Typical ranges of resilient moduli for the pavers studied are given and compared.

1. INTRODUCTION

Worldwide, during the last twenty years many full-scale tests of concrete block pavements (CBP) have been conducted with the objective of understanding how such pavements respond to loads and traffic. These have been reviewed elsewhere [1,2]. Such tests have both identified and quantified those factors which influence the performance of CBP but have provided relatively little information that is of direct use in modern mechanistic pavement design procedures for CBP. Rather, such design information has, of necessity, largely been inferred from Falling Weight Deflection (FWD) studies of actual block pavements. The principal design input needed is the modulus i.e. stiffness of the paver surface. FWD and other in-situ deflection tests of full-scale block pavements share the common disadvantage that the data can only be used to calculate the moduli by making a series of assumptions about the pavement structure and materials. Some of these assumptions are incapable of verification. Consequently, there must always be some degree of uncertainty concerning the values of modulus derived from such procedures. To address this problem a relatively simple test procedure has been developed whereby the mechanical properties of a paver surface can be measured under laboratory conditions. This technique has been applied to pavers first at the University of New South Wales in Sydney and subsequently in Vienna at the OFPZ Arsenal Laboratories in conjunction with the Institute for Road Construction of the Technical University. The purpose of this paper is to report the application of this procedure to a variety of conventional and ecological pavers. The factors studied have included the influence of the paver shape and the laying pattern. Typical values of modulus suitable for characterising paver surfaces for the purposes of mechanistic pavement design are then reported and compared.

2. THE NEED TO MEASURE THE STIFFNESS OF CBP

Mechanistic design applies routine analytical methodology to designing pavements based on computer analyses which are used to predict the long-term performance of the pavements from the stresses and strains that are caused by traffic. Many computer programs are already available for routine analyses of the distributions of stress, strain and deflection in layered elastic pavement systems and design programs such as LOCKPAVE have been developed for the structural design of concrete block pavements [3]. To use these programs requires knowledge of the isotropic elastic properties of each pavement material determined from laboratory tests. The parameters required are the elastic or Young's modulus, E, and the Poisson's ratio, v. Of these two parameters, E is the more important in controlling the material 'response. This modulus relates stress and strain and allows the strains and deflections resulting from the applied loads to be calculated. Once these strains are known it is possible to predict the in-service behaviour of the pavements in terms of the development of rutting and cracking as a function of traffic. By trial and error the layer thicknesses can be chosen so that satisfactory performance can be predicted throughout the planned life of the pavement.

The modulus that is most commonly used to characterise pavements materials is the resilient modulus, M_r; a quasi-elastic parameter. This is defined as the ratio of the repeated stress to the recoverable strain and is closely analogous to the Young's modulus, E. For base, sub-base and subgrade materials there are a variety of routine laboratory tests (e.g. repeated loading triaxial tests) for evaluating M_r. This paper now describes a test that fulfills a similar function for the paver surface. Background information on the role of M_r for pavers has been given elsewhere (4)

To obtain such a modulus requires that the surface be characterised as a whole rather than as individual pavers. To do this, it is necessary to determine the elastic modulus of a continuous layer which would have the same response to traffic loads as the pavers. In other words, for the purposes of analysis and design, the actual segmental paver surface is modeled by an equivalent continuous quasi-elastic layer that will give the same deflection. performance under traffic as the pavers themselves. In this context, equal performance implies that the model and the pavers will exhibit equal stiffness or modulus ie they will achieve equal load-spreading capability.

3. TEST PROCEDURE

A simple test procedure has been devised which allows the pavers to be tested in isolation from any pavement sub-structure. Results were first published in 1993. Full details have been given elsewhere [5]. Despite its simplicity the test has been shown to yield the same ranking of the effects of paver shape etc. as that given by more complicated and expensive accelerated trafficking tests [1,2,5-7]. The test sequence is illustrated schematically in Figure 1.

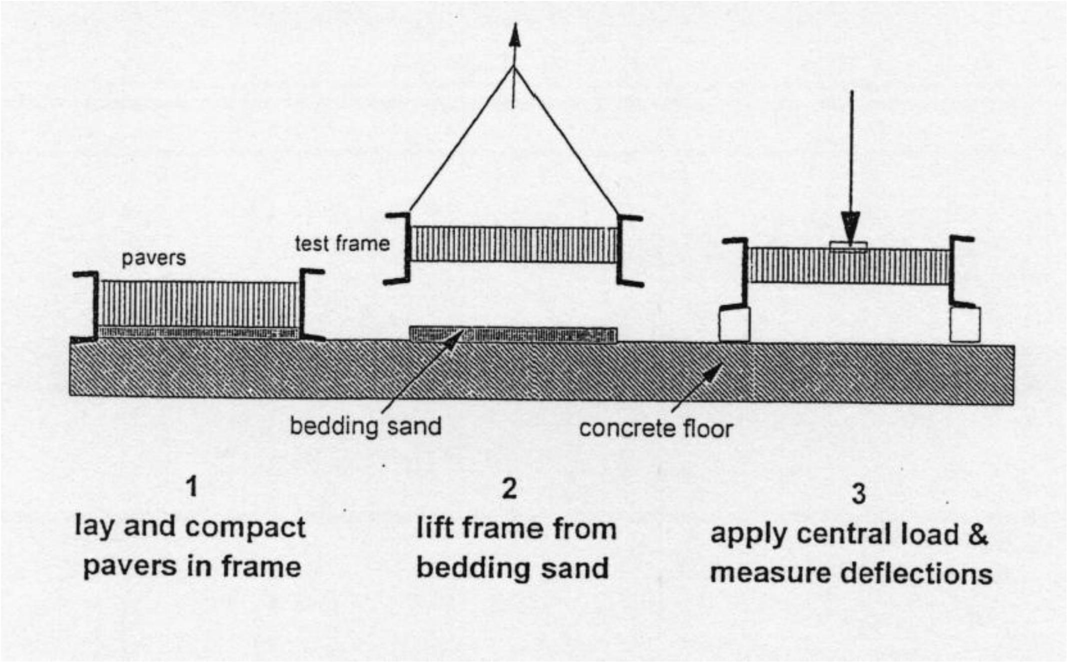


Figure 1. Schematic Sequence of the Loading Test

The test involves laying and compacting the pavers in a steel frame placed upon a concrete floor. Following compactinn, the frame, together with the intact paver mat, can be lifted by crane off the floor. Under the self-weight of the pavers the centre of the mat of pavers sags sufficiently to induce arching and wedging between the individual pavers, and between the pavers and the test frame. As a result the pavers achieve structural integrity and act like an articulated slab. Despite the lack of any support, the pavers are then capable of supporting significant vertical load. The unsupported mats of pavers can be tested like a slab beneath a jack having a capacity of 25 kN. This applies a central load to the mats via a rigid circular plate having a diameter of 150mm. The deflections of the mats are measured as a function of the applied load so that the equivalent quasi-elastic modulus of the paver mats can be calculated. Here it is assumed that the Poisson's Ratio is 0.3 and that the mat of pavers can be analysed as a continuous isotropic elastic slab supported around the periphery.

4. EXPERIMENTAL WORK

A series of proprietary pavers have been evaluated. These are illustrated in Figure 2 and will be seen to comprise both well-established paver shapes such as Uni-Coloc and recently developed pavers such as Uni-Priora and Uni-Optiloc. Two versions of the Uni-Priora were tested. One had sides of equal length (Uni-Priora Klassik) whilst the other had sides in a 2:1 ratio of lengths (Uni-Priora Rechtek). Both normal and ecological versions of the Uni-Priora pavers have been tested. The ecological pavers were designed to allow water to penetrate the pavement by providing wider joints (11 mm) except at the locking spacers. Only the ecological versions of Uni-Priora are shown in Figure 2. All the pavers were nominally 80mm thick. The Uni-Coloc and Uni-Optiloc were installed in patterns suitable for machine laying, the normal and ecological versions (oeko) of Uni-Priora were installed in both stack and stretcher bonds whilst the Uni-Priora-Rechteck (Eco-version) was laid in herringbone bond.

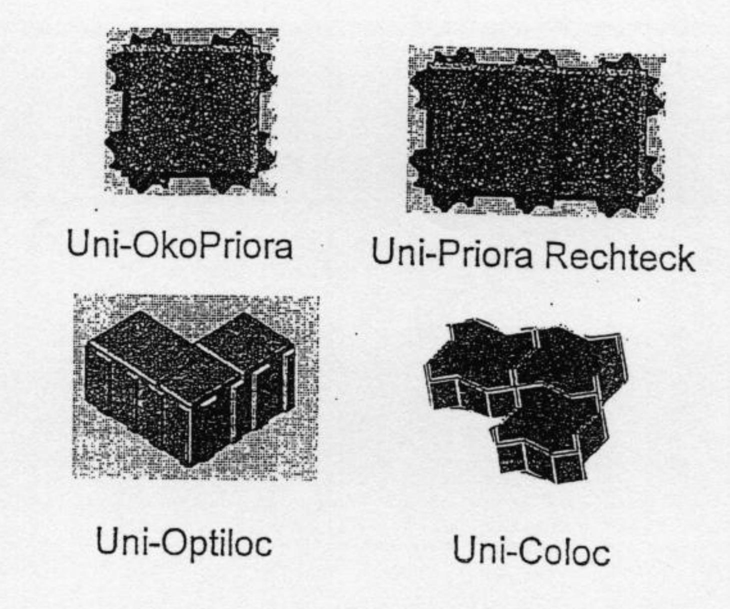


Figure 2. Pavers Evaluated in the Loading Tests

The pavers were laid by hand in a rigid steel frame nominally 1.5m square. The pavers were laid on a sand bedding. The joints between the pavers were generally maintained within the range from 2 to 4mm. The pavers were compacted using a plate vibrator. The frame containing the mat of pavers was then lifted off the bedding sand and placed beneath a computer controlled loading jack. Load was then progressively applied to the mat of pavers beginning with a load of 0.5 kN and increasing in steps of either 0.5 or 1.0 kN until the load capacity of the mat was reached. Each load increment was cycled 5 times and readings of deflection were made during both the loading and unloading cycles at 0.5 kN intervals.

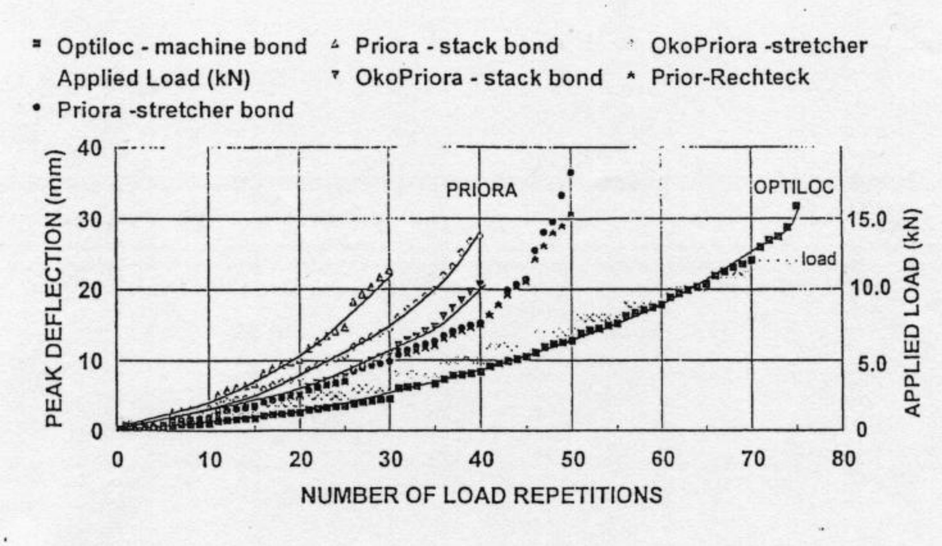


Figure 3. Peak

A summary of the test data showing the peak deflections and the applied loads as functions of repetitions is given in Figure 3. It will be seen that the Uni-Optiloc pavers exhibited less deflection at any given load than the various forms of Uni-Priora and had a higher load capacity than the other pavers. Amongst the Priora variants, the Uni-Priora laid in stack bond did not perform as well as the other stones.

A typical deflection-load curve for the Uni-Priora Rechteck pavers laid in machine bond is given as Figure 4. This type of response was typical of all the pavers tested. It may be seen that, irrespective of the applied load, the total deflection was made up of both a large recoverable or resilient component and a smaller non-recoverable or residual component. Each of these components is now considered in more detail

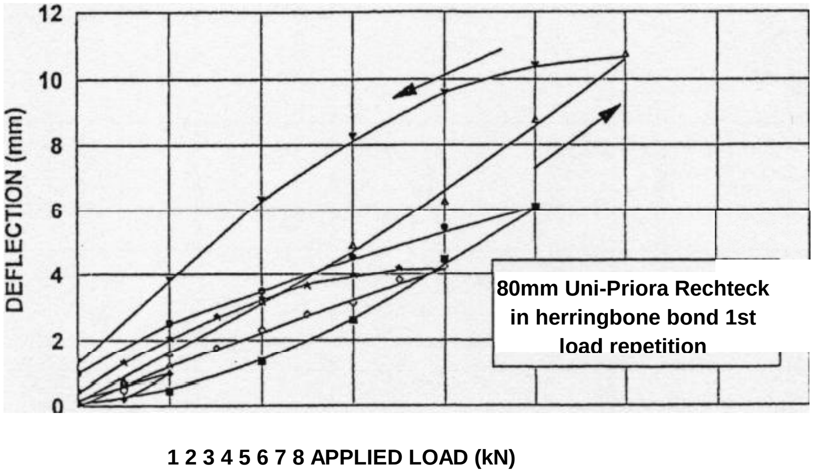
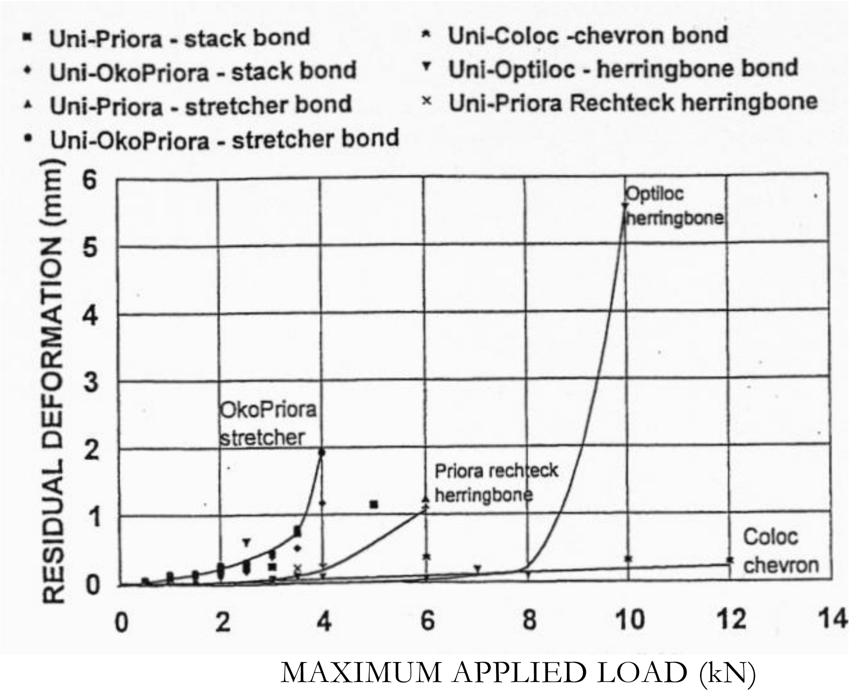


Figure 4. Deflection-Load relationships for Uni-Priora Rechteck Pavers.

4.1 Non-Recoverable Deflections.

As shown in Figure 4, the non-recoverable deformations accounted for only a small part of the total mat deflection. The data given in the figure is for the first load repetition. Here the residual portion of the deflection is greater than for subsequent load repetitions. This type of behaviour is typical of most flexible pavement materials.

The relationship between the residual deformations and thb applied load is shown in Figure 5. It may be seen that Uni-Priora laid in stretcher bond developed less deformation under load than when laid in stack bond. For the ecological versions of this paver there was little difference in performance between the two laying patterns. However, the ecological pavers exhibited slightly more deformation at a given load than the conventional pavers. Overall the deformation data suggested that the use of stretcher bond was preferable to stack bond and that the normal stones behaved slightly better than the ecological stones. However, it should be noted that the differences between the various types of Uni-Priora were small and were of little



4.2 Resilient Behaviour

For all the pavers tested, without exception, it was found that, most of the deflection during a cycle of loading and unloading was recoverable i.e. resilient and that only a small portion of the deformation was non-recoverable (e.g. Figure 4). This was true at all load magnitudes. Therefore, to a good approximation, it was reasonable to model the mats of paving stones as behaving resiliently i.e. in a quasi-elastic manner. Here the mat behaviour could be modeled in terms of a secant resilient modulus relating the peak load and the resilient deflection in any given cycle of loading and unloading. This modulus is plotted as function of the peak deflection in Figure 6 for all the paving stones tested.

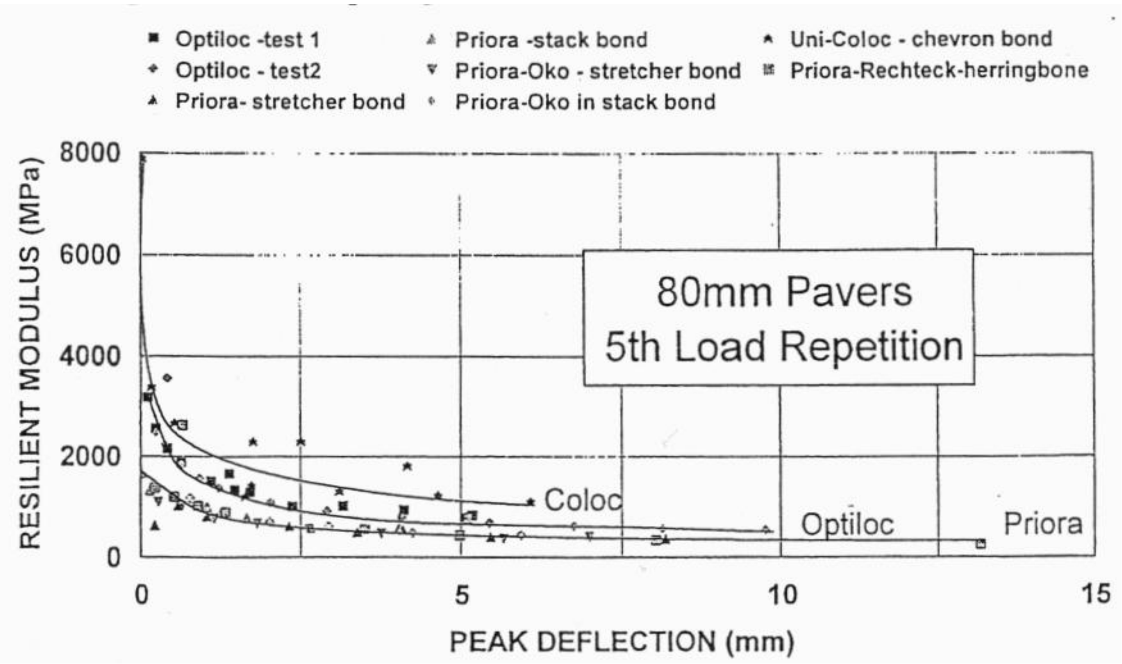


Figure 6. Resilient Modulus as a Function of Peak Deflection.

From Figure 6, it may be seen that there was little difference in response between the various forms of Uni-Priora. In other words, for a particular paver shape, similar moduli were obtained for different laying patterns and for both normal and ecological types of paver. There was also little difference between replicate tests of Uni-Optiloc showing that the test method was accurate and repeatable. However, there were significant differences in modulus between the tests of different paver shapes. At low deflections the Uni-Coloc exhibited up to twice the modulus of the Uni-Optiloc which, in turn, was nearly twice as stiff as the various types of Uni-Priora.

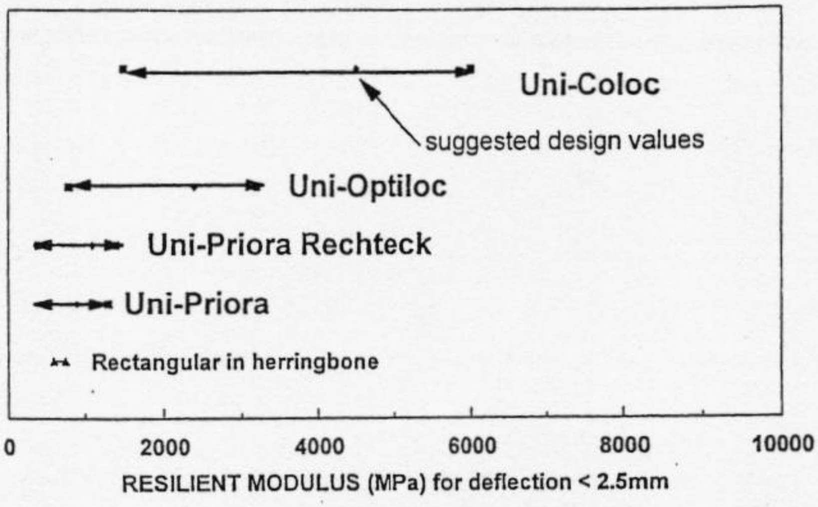


Figure 7. Ranges of Resilient Modulus for the Pavers.

Observations of concrete block pavements subjected to accelerated trafficking show that, in service, the pavements typically exhibit resilient deflections that are 10 or 20 times larger than those that can be tolerated by asphalt pavements (1,2,6,7). Here resilient deflections up to about 2.5mm can be tolerated without distress. For this reason the values of modulus shown in Figure 6 are of greatest engineering interest for deflections of less than 2.5mm. Ranges of resilient modulus are summarised in Figure 7 for the various paver shapes for deflections not exceeding 2.5mm.

The results shown in Figure 7 are for pavers installed in a variety of laying patterns but this had no obvious effect on the values of resilient moduli. Rather, it was found that the prime determinant of the magnitude of the modulus was the paver shape. Moreover, it was found that for the Uni-Priora pavers there was little difference between the normal and ecological pavers. ie the resilient moduli of the Priora and Oko-Priora pavers were similar. This suggests that there is no structural disadvantage in using such eco-pavers. For comparison, data obtained in earlier tests [5] of 80mm rectangular pavers laid in herringbone bond are also shown in Figure 7. It may be seen that all of the shaped pavers could develop higher moduli than the rectangular pavers.

The resilient moduli shown in Figure 7 can be used directly as inputs to existing design programs such as LOCKPAVE [3]. Suggested design values are shown superimposed on Figure 7. This enables the pavements to be designed with more confidence than where the values of paving stone stiffness must be just assumed rather than measured. However, it should be noted that the values of the resilient modulus reported here are conservative because the test did not fully take into account the stiffening of block pavements that

normally occurs under traffic as the stones progressively wedge more tightly against their neighbours. In this respect, increases in paver modulus caused by trafficking, sometimes called "Lock Up", can be significant amounting to twofold or larger increases over time [1,2,6]. This can require up to about 10 000 load repetitions [1,2,6]. By contrast, in the tests described here, there were only 5 repetitions of load. Despite this, it may be seen from Figure 7 that the suggested design values of the resilient modulus ranged from approximately 1000 MPa to 4500 MPa. These values are more than comparable with those of conventional asphaltic surfaces. For example, depending on the ambient temperature the modulus of asphalt may fall to as little as 500 MPa and seldom exceeds 3000 MPa except at very low temperatures.

5. SUMMARY AND CONCLUSIONS

Tests conducted over the last twenty years have shown that the load distributing properties of pavers depend *infer-alia* on **the paver shape, thickness and laying pattern (1,2,6-8). Many design methods for CBP ignore these factors and attempt to characterise all pavers as sharing a single universal set of design properties including some assumed value of the modulus. This can lead to designs which are either unduly conservative or which unsafely overestimate the contribution of the pavers to the load-distributing capacity of the pavement. For these reasons, it is desirable to treat each type of paver on its own merits and to characterise it in terms of the actual stiffness i.e. modulus that it is capable of developing in-service.**

The stiffness of pavers represents a crucial input for the mechanistic analysis and design of concrete block pavements but this has not received much study hitherto. The tests reported here have shown that the deflection response of a mat of pavers to load was predominantly elastic. Based on this observation this paper has described techniques whereby the real behaviour of concrete block surfaces can be idealised and modeled in terms of a continuous elastic layer (slab) having properties chosen to give the same deflections under load as the paver surface itself. Here it was convenient to express the paver stiffness in terms of the resilient modulus. The tests then demonstrated that

1. **For a given stone thickness, the resilient modulus of the pavers depended primarily upon the paver shape.**
2. **Slightly different rankings of the pavers were obtained in terms of modulus (deflection), load distributing capacity and residual deformation. However, overall, the paving stones could be ranked as follows**

    1. **Uni-Coloc in chevron bond (highest structural capacity)**
    2. **Uni-Optiloc in machine bond**
    3. **Uni-Priora Rechteck in herringbone bond.**
    4. **Uni Priora in any bond. (lowest structural capacity)**

3. **Irrespective of their ranking all of the pavers performed better than 80mm rectangular pavers laid in herringbone bond.**
4. **There was little significant difference between the moduli of normal and ecological versions of the Uni-Priora stones. This implies that there is no structural disadvantage in using such ecological stones despite their wide joints.**

5. For most practical engineering purposes the various forms of Uni-Priora could be treated as being equally effective.
6. Typical modulus values for the paving stones have been given. These values provide fundamental inputs for the design of concrete block pavements. The use of such values is preferable to the untested assumptions that many block pavement design methods require and overcomes many of the uncertainties hitherto associated with the analysis of concrete block surfaces.

Finally, it is important to recognise that the test data provide an unique perspective on the quantitative evaluation of paver performance that has not been available before. This arises because the tests enabled the pavers to be tested and characterised in isolation from any other paving materials or structures. The values of modulus reported here can therefore be used with confidence in the analysis or design of concrete block pavements without some of the uncertainties that have been associated with previous methods of determining the load distributing capacity of pavers.

6. REFERENCES

I. Shackel B. (1990). Design and Construction of Interlocking Concrete Block Pavements,Elsevier Applied Science, London.
2. Shackel, B.(1992). (Translated by Miura, Y., Makiuchi, K. and Hayashi, S.). Concrete Segmental Pavements. Kajima, Japan, 226pp (in Japanese).
3. Shackel B. (1992) Computer Methods for Segmental Concrete Pavement Design Proc . Workshop on Concrete Segmental Paving. 16th Conf. Australian Road Research Board, Perth.
4. Shackel B. (1999) The Resilient Modulus Of Paving Stones. Betonwerk + Fertigteil Technik, Vol 64 No 9.
5. Shackel B., Winarno and O'Keeffe L. (1993) Concrete Block Paving Tested as Articulated Slabs. Proc. 5th Int. Conf, on Concrete Pavement Design and Rehabilitation, Purdue Univ.
6. Shackel, B. (1979). An experimental investigation of the response of interlocking block pavements to simulated traffic loading. AustRoad Res. Board Res. Rpt ARR 90, pp I I-44.
7. Shackel, B. (1979)A pilot study of the performance of block paving under traffic using a Heavy Vehicles Simulator. Proc.Symp.on Precast Concrete Paving Block, Johannesburg:
8. Shackel, B.(1987) Accelerated Trafficking trials of machine-layable concrete block paving. Aust. Road Research, Vol 17, No 1, pp 13-27.

7. ACKNOWLEDGEMENTS

The work described in this paper was funded by Uni International Bausysteme GmbH and Co, Iffezheim, Germany. The authors wish to thank Ing. Michael Schmitz of Uni International for organising the tests and for his many helpful comments.

1]