INFILTRATION AND STRUCTURAL TESTS OF PERMEABLE ECO-PAVING

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SUMMARY

This paper describes experimental studies of eco-pavers. These studies included measurements of water penetration under heavy simulated rainfall and evaluations of the structural capacity of the paver surfaces. The principal experimental variables were the type of ecopaver and the choice of bedding, jointing and drainage materials. These ranged from conventional 2 mm sands to 10 mm aggregates. The experimental data showed that the best compromise between achieving optimal water penetration and the maximum structural load capacity was achieved using relatively uniform bedding, jointing and drainage materials having a maximum size between 4 and 5 mm. Water penetration rates ranged up to about 600 l/sec/ha and the values of the paver moduli were broadly comparable with those measured in similar tests of conventional pavers

INTRODUCTION

In Australia, as in most developed countries, there is increasing pressure for urban consolidation. This raises important environmental challenges. A fundamental concept underlying demands for urban consolidation is that existing services, such as water supply or sewerage, frequently have excess capacity. The benefits of utilising this excess capacity are, however, often offset by the costs of upgrading roads and stormwater systems. The development of the concept of permeable eco-paving now provides important new options for urban consolidation schemes.

CONCEPTS, BENEFITS AND BACKGROUND OF ECO-PAVING

Traditionally, highway engineers have been trained to prevent water entering pavements. By contrast, the essential basis of eco-paving is that the pavement should be permeable and that water infiltration should be actively encouraged. Permeable eco-pavers are a recent development in concrete block paving. By encouraging water infiltration through the

pavement surface they seek to accomplish a variety of environmentally sensitive tasks. These include the elimination or reduction of stormwater runoff, the replenishment of natural groundwaters, the trapping of many common pollutants and the biological decomposition of hydrocarbon contaminants. They also serve to reduce the size or need for rainwater retention facilities in roadworks by using the pavement itself for water retention. This, in turn, serves to reduce the size and cost of the drainage pipes etc needed.

The first steps towards the development of eco-paving came with the inroduction of grass-stone and grid pavers (1). Studies conducted in the USA have established that, although grid pavements may involve a higher initial cost than alternative forms of paving, this is more than offset by the advantages gained (1,2). These include:

a) A significant reduction in stormwater runoff.
b) Reduction in the pollutants reaching stormwater drainage systems.
c) Improved aesthetics. Grid lots exhibit the visual benefits of park-like green spaces.

Because of their size and shape, grass blocks and grid pavements are limited in their ability to carry traffic. Nevertheless, they have been used successfully in many landscaping applications ranging from overflow carparks to revetments and fire-engine access routes around housing developments (1).

Most of the benefits of grass blocks and grid pavers can be better achieved using the eco-paving systems newly developed in Germany. Such paving may be produced by clever modification of well-established concrete paver shapes so that, once layed, openings are provided at intervals along the joints. These can then be filled with a suitably graded gravel to act as vertical drains through the pavement. The evolution of one such eco-paver, the Ecoloc system, is shown schematically in Figure 1.

Eco-pavers such as that illustrated in Figure 1 are intended to duplicate all the benefits of grass pavers, with the exception of providing green space, but are much easier to manufacture and install. Because they are based on well-proven conventional paver shapes, and are intended to be installed on a fully engineered pavement sub-structure, they provide a useful alternative to conventional segmental paving.

The principal incentive for the development of eco-pavers in Germany was the need to achieve improved land-use with its attendant economic benefits. Indeed, the principal economic advantage of eco-paving was seen to be an increase in the proportion of a development that could be paved without violating the balance required by regulation between water shedding and absorption or retention. For this reason, most research to date has concentrated on laboratory and field studies of water infiltration in eco-pavements (eg. 3-6). These studies have shown that eco-pavers can accept the rainfall intensities expected in Germany (225-270 l/ha/sec) but, except for the work of Litzka and others (5,7,8), have given scant consideration to the problems of the pavement sub-structure or structural capacity.

In 1994 a program of experimental research at the University of New South Wales was commenced to examine whether eco-paving would be suitable for higher rainfall intensities than those studied in Europe, and to study the structural characteristics of such surfacings.

The pavers that were studied comprised 80 mm thick Uni-EcoStone and Uni-Ecoloc pavers manufactured in Germany. This paper reports the initial findings of this on-going research.

EXPERIMENTAL WORK

Bedding, Jointing and Drainage Materials

In North America it has been postulated that materials ranging from conventional fine (1mm to 4mm) bedding sands (ASTM Grading C33) to 10mm gravels (ASTM Grading 7) may be used in eco-pavements (9). To date, most studies of water infiltration have used materials with gradations between these extremes.

In the work reported here, the five gradations shown in Figure 2 were studied. These covered the full range of gradings discussed in the preceding paragraph, and ranged from a 2mm quartz sand to a 10mm basalt aggregate.

3.2 Infiltration Tests

The infiltration tests made use of techniques described in detail elsewhere (10). The tests involved placing the bedding material to be tested in a loose thickness of 30mm in a steel box, 1.5 m square. The eco-pavers were then layed by hand on the bedding and were guillotined to fit to the edge of the box. Gaps around the periphery of the pavement were filled with mortar. The pavers were compacted with three passes of a vibrating plate compactor and granular material was then brushed into the drains and joints. A further three passes of the plate compactor were then applied. After compaction the joint widths were measured at 20 or more randomly selected locations. Generally, the range of joint widths was 2mm to 4mm. This showed that the construction standards were similar to those normally achieved in practice.

The test pavements were subjected to a uniformly distributed simulated rainfall. Details were given earlier (10). As shown in Figure 3, the steel box containing the pavers and bedding material was arranged so that water draining through the bedding layer and runoff from the pavement surface could be collected and measured separately.

Initially, the extremes of the gradings shown in Figure 2, ie. the 2mm sand and the 10mm gravel, were selected for the bedding, jointing and drainage materials. In the case of the gravel, relatively little material penetrated the joints. For this reason, a further test was conducted in which the 10mm gravel was used as the bedding and jointing material, but the 2mm sand was brushed into the joints after compaction. This not only filled the joints but effectively blinded the drainage openings.

The results of infiltration tests on these pavements are given in Figure 4. This figure shows that the pavements utilising the coarse gravel accepted the full intensity of simulated rainfall. However, there was about a 50% reduction in water infiltration in the pavements laid using only sand or where sand was used to blind the surface. Although such a practice has been recommended in Germany (3,4), Figure 4 shows that there is little or no benefit in using gravel in the drainage openings if it is to be capped with sand. For this reason, in all subsequent tests, only a single material was used as the bedding, jointing and drainage

medium and no further infiltration studies were conducted using conventional 2 mm bedding sands. Moreover, because of the lack of joint filling fractions the 10 mm gravel was excluded from further study, which was restricted to the three other materials shown in Figure 2, ie. to materials having particle sizes predominantly within the range 2 mm to 5 mm.

For such materials it was found that the simulated rainfall intensities that could wholly infiltrate the test pavements were greater than that studied in the initial tests summarised in Figure 4. Accordingly, the simulated rainfall intensity was increased in steps of approximately 75 l/ha/sec until surface runoff occurred. Typical results are shown in Figure 5. At crossfalls less than 2% the tests did not show any significant difference in water infiltration characteristics that could be attributed to the shapes or laying patterns of the eco-pavers. Rather, the principal determinant of performance appeared to be the grading of the drainage and jointing materials. However, at a crossfall of 10% the Ecoloc pavers accepted more rainfall than the EcoStone pavers.

As shown in Table, 1 for all three of the 5mm gravels, rainfall intensities of 150 l/ha/sec or more could be wholly accepted by the eco-paving surface. From the table, it may be seen that the highest rates of water acceptance were associated with the relatively uniform 2-5 mm gravel. Here, rainfall intensities of 600 l/ha/sec or more could be wholly accepted by the paving. Of the two materials containing fines, the 5 mm gravel with fines was associated with higher levels of infiltration than the 4 mm well-graded gravel. In general, the results indicated that uniform materials without fines had better drainage characteristics than where fines were present. Generally, the infiltration of water decreased with increase in the fines content.

Table 1. Water Acceptance

Type of Drainage Material	Rainfall Intensity (l/ha/sec) needed to cause surface runoff
2 mm sand	> 600
Well-graded 4 mm gravel	≤ 150
5 mm basalt + fines	≥ 450

Structural Tests

Most load distribution tests of pavers have been conducted on model or prototype pavements (1). Such tests share the common difficulty that they can only be interpreted in terms of some speculative stress distribution theory which may or may not be correct for block paving, and which *a-priori* requires untested assumptions about the interaction between the pavers and the pavement sub-structure. This makes it difficult, or impossible, to interpret the results in an unambiguous way. For this reason, a test procedure has been devised to allow the pavers to be tested in isolation from the pavement sub-structure. Details of this procedure have been given elsewhere (11). Essentially, the test involved laying and compacting the pavers in an open steel frame having internal dimensions of 1.5m x 1.5m placed upon a concrete floor. Following compaction, the frame, together with the intact paver mat, could be lifted off the floor. The mat of pavers could then be tested as if it were an articulated concrete slab (see Figure 6). This allowed the equivalent moduli of the pavers etc to be measured. Despite the simplicity of this test, it readily revealed the effects of paver shape and laying pattern without

the need to make any unproven theoretical assumptions about the pavement sub-structure. In this respect, it is instructive to note that the test has yielded the same ranking of the effects of paver shape and laying pattern, as that given by more complicated and expensive trafficking tests (11).

The pavers were laid flat without a crown or camber. In other words there was no built-in arching action in the trial sections. The Eco-Stone pavers were laid in herringbone bond. In the case of the Ecoloc pavers two laying patterns were tested. The first of these comprised the simple chevron pattern shown in Figure 7(a). This was chosen because it had been shown in trafficking tests to give a lower level of performance than other machine-layable patterns (12). The second laying pattern used for the Ecoloc is shown in Figure 7(b). This was chosen so that joints simulating the edge of laying clusters would run in both directions through the test pavements, ie. an attempt was made to simulate potential weakness in the pavement. Thus the Ecoloc pavers were deliberately installed in configurations that would intuitively be expected to perform at a lower in-service level than normally installed pavers. This was done so that the results reported herein would represent the "worst-case" conditions.

As in the infiltration tests, the pavers were compacted using a vibratory plate compactor. The joints and drains were then filled and the pavement was again compacted. The frame was then attached to a crane and was lifted off the bedding material leaving it on the laboratory floor. During lifting, some but not all of the drainage material fell out of the joints in the mat of pavers.

Under the self-weight of the pavers the centre of the mat of pavers sagged by amounts ranging between approximately 2 mm and 8 mm. 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.

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 so that the equivalent quasi-elastic modulus of the paver mats could be measured.

Because the pavers were provided with spacer nibs, an attempt was made to construct Eco-Stone test pavements in which the joints were left empty with paver-to-paver contact only through the nibs. This proved unsuccessful and it was not possible to lift the pavers as a structural unit. In other words, load transmission by spacer nibs alone did not provide significant structural capacity to resist self-weight stresses. For this reason, in all further tests, attempts were made to fill the joints before lifting the frame.

In the structural tests of the eco-pavers the load was increased to 0.5 kN, and then removed, and was then cycled with 0.5 kN increments in the peak load during each successive cycle. This was done to determine whether there would be any stiffening induced in the paver mat as a result of repetitive loading, such as is induced in pavers by traffic (1). A summary of the results, plotted in terms of the maximum loads applied in each cycle, is given as Figures 8 and 9.

From Figures 8 and 9, it may be seen that the moduli of the paver mats tended to decrease with successive load cycles. This was observed to be accompanied by a progressive loss of the jointing materials which drained under gravity during each successive cycle of loading and unloading as the deflections of the pavers increased. These deflections ranged up to about 30 mm at 6 kN. These values were much greater than the deflections commonly observed in block pavements under traffic which typically are less than 2 mm. In the tests such deflections were typically achieved at loads less than 2 kN. In other words, in Figures 8 and 9, only those moduli for loads less than about 2 kN are likely to be indicative of the values that would be achieved in practice for eco-pavers supported by a pavement sub-structure. From Figures 8 and 9 these will be seen to range from 100 MPa to nearly 1500 MPa. Earlier tests of conventional block paving, using the same methodology, yielded values of moduli between 500 MPa and 1000 MPa. Thus, the laboratory structural performance of the eco-paving was similar to that of conventional paving.

For both types of eco-paver it may be seen from Figures 8 and 9 that the best levels of performance (ie. the highest moduli) tended to be associated with those test pavements incorporating jointing materials containing significant proportions of fines capable of penetrating and filling the 2 mm-4 mm wide joints. In this respect, the pavements laid with the 10 mm gravel exhibited low values of moduli irrespective of whether or not the joints were blinded with sand. Overall, it can be concluded that, at realistic levels of test deflection (corresponding to loads less than 2 kN), the material used as the bedding, jointing and drainage material in eco-paving should be chosen to include a proportion of material smaller than 4 mm in size. Moreover, there is some indication that the gravels were associated with higher moduli than the conventional 2 mm bedding sand.

Of the two laying patterns studied for the Ecoloc pavers, the cluster pattern gave better performance than the chevron pattern. In other words, there appeared to be no structural problem associated with closely-spaced joint lines, similar to those encountered at the edge of normal laying clusters.

SUMMARY AND CONCLUSIONS

The laboratory studies showed that:

1. Pavements laid using 4 mm to 10 mm gravels as the bedding, jointing and drainage medium could accept rainfall intensities of up to about 600 l/ha/sec with the best performance being given by a clean 2 mm-5 mm basalt aggregate containing no fines.

2. Increase in the fines present in the jointing and drainage material led to a reduction in the ability of the pavements to accept rainfall.

3. Blinding the pavements with a conventional laying sand reduced the amount of water penetrating the pavement by nearly 50% at moderate rainfall intensities.

4. There was little significant difference in water infiltration in pavements blinded with sand from that observed for pavements using a sand complying with ASTM grading C33, as the bedding jointing and drainage medium.

5. The use of ASTM grading C33 appears inappropriate where water infiltration is the prime function of the pavement.

6. At crossfalls below 2% the type of Eco-paver and the laying pattern did not significantly affect the infiltration of water into the pavement.

7. At a cross fall of 10% the Ecoloc pavers accepted water more readily than EcoStone.

8. It was not possible to obtain any significant structural capacity in pavements where the joints were left unfilled, and where the mechanism of load transmission between the pavers was solely via the spacer nibs.

9. In pavements using a 10 mm basalt aggregate as the bedding, jointing and drainage material the joints were only partially filled when normal construction practices were followed. This did, however, impart some load-bearing structural capacity to the pavements.

10. Good load-bearing capability was achieved using gravels with a maximum particle size of about 4 mm to 5 mm. The values of mat modulus measured were then comparable to those reported for conventional pavers tested in the same way using normal sand jointing materials.

11. Sand blinding a pavement, using basalt as the laying medium, gave little improvement in structural capacity. This can be explained in terms of the difficulty of getting sand into joints that were already partially filled with aggregate.

12. There was no structural problem associated with closely spaced continuous joints running through the Eco-Coloc cluster pavements. Such joints are a severe simulation of the situation encountered when machine laying paving clusters. In other words, in the tests described here there was no intrinsic problem associated with cluster laying.

Generally, the tests demonstrated that it was possible to reconcile the requirements of obtaining good water infiltration with adequate structural capacity under laboratory conditions. Specifically the tests indicated that the surfacing could accept rainfall intensities similar to those to be expected in tropical conditions, whilst yielding values of structural capacity (expressed as surface stiffness) that were comparable to those observed when testing conventional concrete block paving.

Until now the use of eco-pavers has largely been restricted to areas carrying relatively light traffic such as parking lots. Nevertheless, the laboratory test results suggest strongly that eco-pavers may be used in many of the heavier traffic applications where conventional paving is now routinely employed. However, before using eco-paving under heavy loads it is necessary to verify the laboratory findings by full-scale field trials of eco-pavements and to consider the problems of choosing and designing suitable eco-pavement sub-structures to carry the full range of real traffic. To address these areas full-scale trafficking trials have been initiated in Sydney and research into the selection and thickness design of the pavement sub-structure has commenced. The results of this research will be reported later.

Overall, the test results indicated that permeable eco-paving may be able to fulfill many of the roles now served by conventional pavers even under significant traffic loads. This opens up new marketing opportunities for permeable eco-paving once suitable design and specification procedures are established and verified.

ACKNOWLEDGEMENTS

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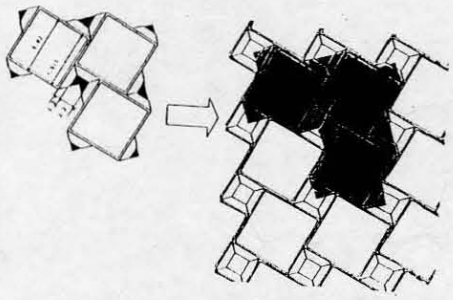


Figure 1. Evolution of Ecoloc Pavers from conventional Uni-Coloc.

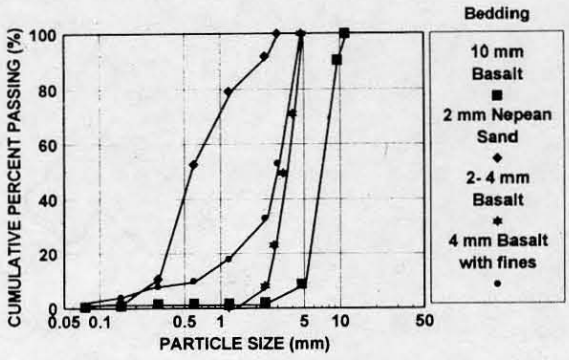


Figure 2. Grading curves for the bedding, jointing and drainage materials.

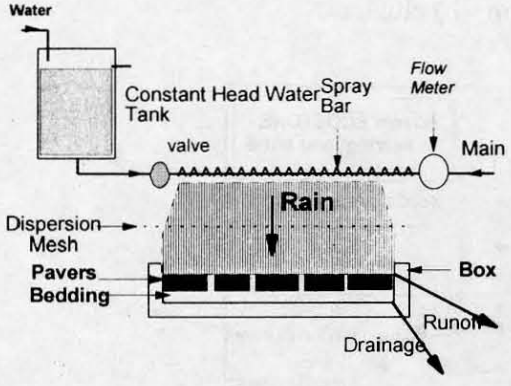


Figure 3. Schematic layout of the infiltration equipment.

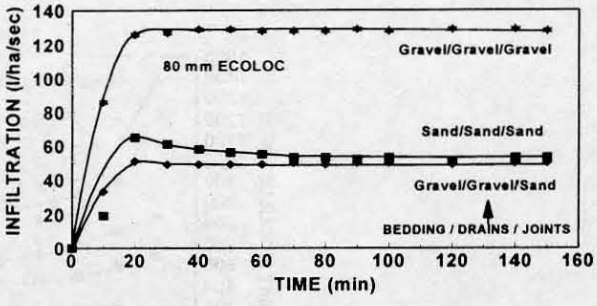


Figure 4. Infiltration of combinations of 10 mm basalt gravel and 2 mm sand.

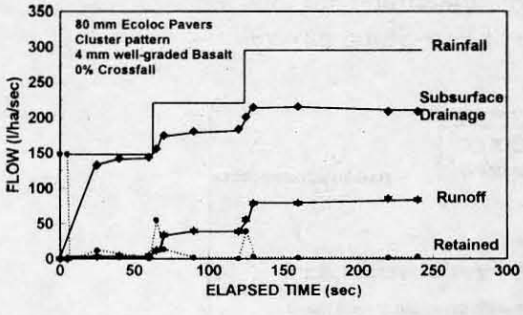


Figure 5. Typical infiltration test results.

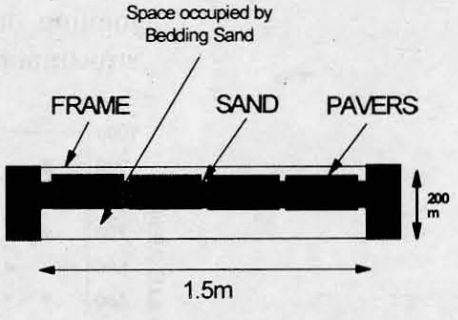
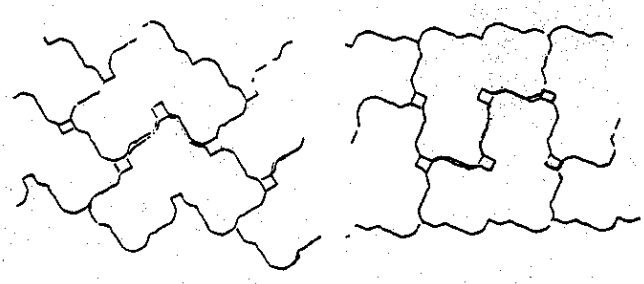


Figure 6. Schematic layout of the structural test frame.



(a) (b)

Figure 7. Laying patterns for the Ecoloc pavers - (a) chevron (b) cluster.

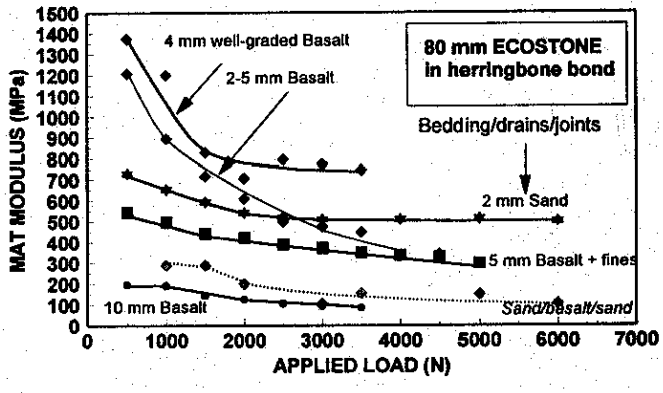


Figure 8. Effects of changes in the bedding, jointing and drainage materials on the structural performance of Eco-Stone pavers.

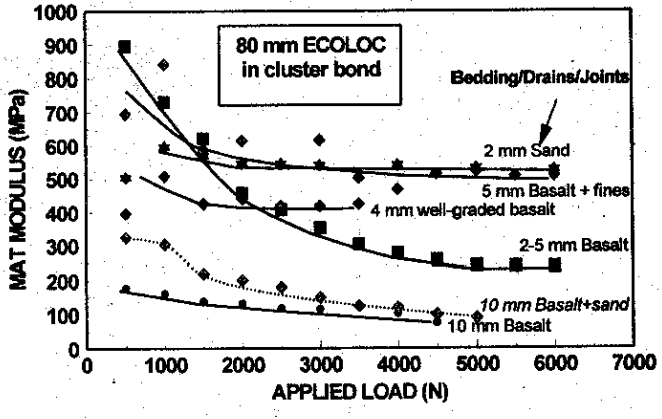


Figure 9. Effects of changes in the bedding, jointing and drainage materials on the structural performance of Ecoloc pavers.