INNOVATIVE PAVER SYSTEM

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ABSTRACT

Small element paving has developed from its initial use as a surfacing for footpaths and roads to having a capability to form an integral structural element of heavy-duty pavements.

Various shaped units have been added to the traditional rectangular shape in attempts to increase paver interlock and to improve mechanical-laying ability. As yet there is no proof of the superiority of one shape over another.

This paper reports on a new paver system featuring a 'tongue and groove' locking and locating device that significantly improves interlock and mechanical lying.

Compression and pullout tests made on the system have demonstrated an improved interlock performance and jet blast testing confirms its suitability for aircraft pavements by demonstrating its ability to withstand jet efflux from aircraft currently in use at civilian airports.

1. INTRODUCTION

Small element paving has, over the last 30 years, developed from its initial use as a surfacing for footpaths and roads to having a capability to form an integral structural element of heavy-duty pavements. During this time various shaped units have been added to the traditional rectangular shape including, 'X' 'L' and 'Y' formats. These various shapes were developed to increase 'interlock' between pavers and to improve their mechanical laying capability. Much debate and scientific analysis has centred on the relative benefits of rectangular and shaped pavers and has failed to prove conclusively the superiority of one over the other.

The new paver concept described in this paper is intended to resolve many of the known problems associated with small element paving. The unique tongue and groove feature of the system provides a mechanical interlock which is additional to the interlock provided by the presence of sand in the joints of conventional pavers. Complicated shapes developed to increase interlock are unnecessary, although manufacture of shaped units incorporating the tongue and groove technology is possible if required for aesthetic purposes. The tongue and groove feature will also help to prevent the problem of units dropping from clusters of pavers when being handled mechanically.

To substantiate the claims made for this new system, tests were made to measure the mechanical interlock developed between units by means of compression and pullout tests and comparing their performance with similar tests made on conventional blocks.

As the tongue and groove units will be particularly beneficial for use on aircraft pavements jet blast testing was made to confirm their suitability for this application.

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The results of these tests are reported in section 4 of this paper.

2. INTERLOCK

Continuing research on small element paving has shown the importance of interlock in the performance and life span of a pavement. Interlock has been defined as, "…the inability of an individual paver to move independently of its neighbours". Knapton & Barber (1980).

Three forms of interlock should be present in a block paving system, namely, rotational, vertical and horizontal which are achieved by the use of edge restraints, the presence of sand in joints and perhaps by the use of shaped pavers. The use of a 'herringbone' pattern is known to assist in avoiding horizontal movement or 'creep' where conventional block paving systems are used.

3. THE INNOVATIVE PAVER SYSTEM

This system was designed and developed with support from the Economic Development Board of Singapore and has now been awarded patents worldwide. Using the latest technological methods in mould manufacture the paver system utilises a 'tongue and groove' locking device within each individual unit (see Figure 1). The blocks are made using moulds having a hydraulically operated feature to form the tongues and grooves which have sloping sides to ease demoulding. The surface appearance of the pavers will be much the same as conventional rectangular units, having dimensions of 200 mm x 100 mm x 80 mm thick. Orientation of the tongues and grooves on the sides of the units determines the pattern in which they may be laid, which in the case of the unit illustrated here is for 'basket weave' pattern. To facilitate 'herringbone' pattern the long sides of the units would have a tongue and a groove detail. As with conventional pavers the units have spacers but for the sake of clarity these are not shown in the figure.

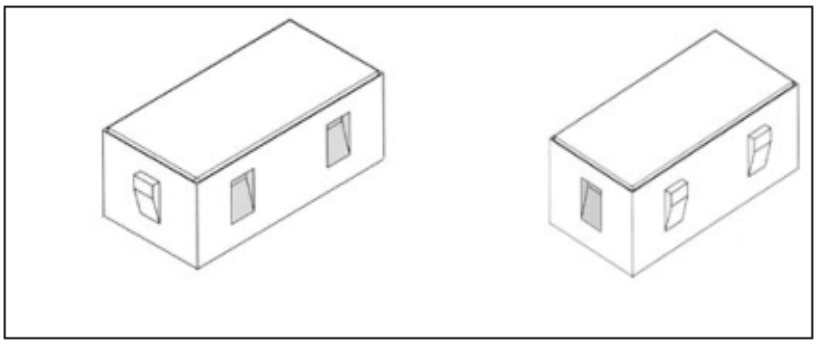

Figure 1. Details of 'tongue and groove' paver.

The unique tongue and groove feature of this system provides a mechanical interlock that is superior to and additional to the frictional interlock provided by the presence of sand in the joints of other paver systems. It is for this reason that the generally accepted view that 'herringbone' pattern is not necessary to prevent horizontal movement or 'creep'.

Laying procedures, whether hand or mechanical methods are used, are the same as for conventional blocks. If removal and reinstatement of the units is necessary, then at least 4 to 5 units need to be broken out and removed. Reinstatement is a simple matter of replacing broken units and relaying the affected area until the last unit which is knocked into position with a rubber or wooden mallet. The tapered tongue design facilitates the entry of the last paver which is mechanically locked in position. Finally, the area is sanded and vibrated.

A further problem avoided by the use of this system, is that of the, so-called, 'cluster effect'. This is a consequence of groups or 'clusters' of pavers being paletted in a final laying pattern to facilitate

mechanical laying. Unfortunately, for various reasons, it is difficult for one cluster to lock precisely into adjacent clusters. The result of this is a tendency for a widening of joints to an unacceptable level as mechanical laying progresses.

The mechanical locking feature of the system is effective in helping to overcome the problem of dislodgement of pavers from the centre portion of clamped pavers whilst being lifted during 'cubing' operations at the manufacturing plant.

This feature also permits the laying of pavers at steeper angles, for example, at bridge abutments. It will also improve paver performance when used for waterway lining and other marine projects by improved resistance to displacement of pavers caused by turbulent water flow.

Where a permeable pavement is required, the units may be laid without jointing sand thus permitting a copious flow of water through the pavers whilst still retaining a stable surface. A further benefit of the system is that it will enhance the stability of the paving surface by preventing displacement of individual units whilst still maintaining the essential flexible nature of the pavement. For this reason the system is particularly suitable for aircraft pavements where surface stability is an essential prerequisite. The increasing use of block paving at airports prompted the UK Civil Aviation Authority to commission a report on the use of block paving at airports worldwide, Knapton & Emery (1996). This report provides design procedures and recommendations for the use of block paving on aircraft pavements. The improved stability and interlock provided by the tongue and groove blocks will ensure additional safety where they are used for surfacing aircraft pavements.

The units can be provided in a wide range of colours and with an integral reflective surface for special road marking situations, Lazar & Emery (2002). They can be manufactured using existing automated paving block machines although some hydraulic modifications and adjustments to machine controls will be necessary. The mould layout for the pavers will be approximately half that of existing moulds, i.e. 20 rectangular pavers compared with up to 50 pavers of similar size.

The manufacturing processes of the tongue and groove units takes 15 seconds longer than the time taken for conventional rectangular pavers due to the hydraulic functions of the mould cavities and ram heads. This is considered a small price to pay when compared with the higher performance of this new paving concept. Once the units are deposited on the platforms all other production sequences are the same as for conventional paver production.

4. TESTING

Testing of the tongue and groove units reported below was carried out by an independent accredited laboratory, namely, STATS Testing Ltd. of St Albans, UK, (a) to; establish the quality of the tongue and groove units and confirm their compliance with BS 6717:200, and (b) to compare their interlock performance with conventional rectangular concrete pavers by making compression and pullout tests.

To confirm their suitability for aircraft pavements, jet efflux tests were made at Cranfield University in the UK using equipment specifically developed in their gas turbine laboratories for these tests.

A trial area of these units has been laid at a port area owned by the Port of Singapore Authority. This has shown that even where significant deflection has occurred 'interlock' had not been compromised.

4.1 Conformity testing

Tests were made at the independent accredited laboratory mentioned above to check dimensional tolerances, tensile splitting strength, abrasion-resistance and slip/skid resistance. The results confirmed compliance with the requirements of BS 6717:2001.

4.2 Compression testing

Compression tests were carried out on 600 mm x 600 mm panels of the tongue and groove units and conventional rectangular blocks. The layout of the 18 units used for each test is shown in figure 2.

In order to obtain a comparative indication of the behaviour under the application of a vertical load to the two central blocks of both panels, the blocks were laid on 20 mm thick layer of bedding sand laid upon a sheet of dense polystyrene, 600 mm x 600 mm x 50 mm thick. A steel frame comprising two uprights and a horizontal cross-beam was used to provide the vertical reaction force, the uprights being bolted to the laboratory floor using masonry anchors. The panels were positioned centrally under the frame reaction beam as indicated in Figure 3.

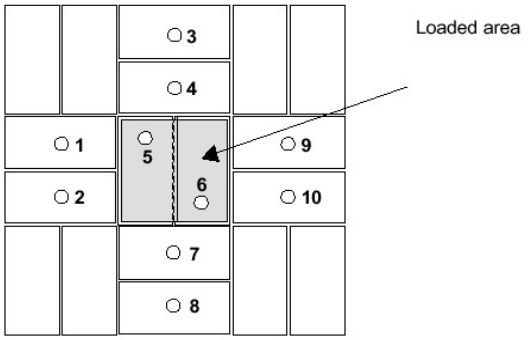

Figure 2. Layout of units in test panels.

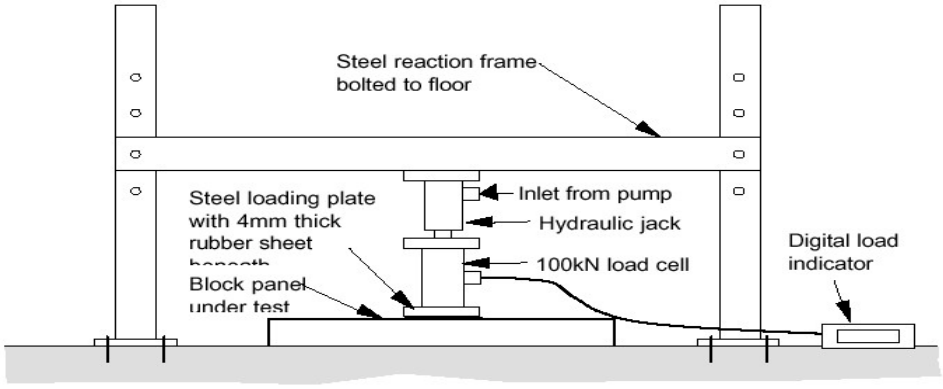

Figure 3. Schematic diagram of compression test rig.

Vertical displacement under load was measured centrally on the upper surfaces of ten blocks at the positions indicated in figure 2. Deflection was measured by means of dial gauges of 0.001 mm/division. In each test, load was applied in 2kN increments. Loading was continued until excessive displacement of the two loaded blocks occurred with little increase in applied load. The results of the tests are given in Table 1. Further analyses of the results have yet to be made and will be reported at the Conference.

Table 1. Compression test results.

Block type	Maximum Sustained load (kN)	Maximum displacement Before gross Distortion (mm)
Tongue and groove	34	23.5
Conventional rectangular blocks	16	15.9

4.2 Pullout Testing

Pullout tests were made using the same panels as for the compression tests with blocks laid in the same pattern.

One of the two central paving blocks within the two panels was selected for test. Two 12 mm diameter holes spaced at 125 mm and along its centreline, were drilled to a depth of 70 mm and 12mm diameter masonry anchors were installed into the drilled holes as shown in Figure 4.



Figure 4. Pullout test rig.



Figure 5. Showing mode of failure.

A steel reaction plate of dimensions 400 mm x 300 mm x 20 mm thickness, with a central cut-out of 220 mm x 120 mm was positioned on the surface of the test panel such that a gap of 10mm was present around the periphery of the test block to allow unrestrained upward movement under load.

A steel reaction beam was placed transversely across the reaction plate. Load application and measurement were facilitated using a hydraulic jack and an electronic load cell of 100 kN capacity stacked centrally on the reaction beam. The two anchor bolts were extended in length using threaded studding and studding connectors. A steel cross-plate was fixed to the studding with two nuts. A 25 mm diameter steel ball bearing was positioned between the underside of the cross-plate and the jack to minimise uneven load application during the test.

The upward movement under load was measured at each end of the block at mid-point using two dial indicators accurate to 0.01 mm, impinging upon datum brackets bonded to the surface of the block.

Load was applied incrementally taking movement readings after each loading increment and continued until failure of the block occurred as shown in Figure 5. The results of the tests are given in Table 2. - NB. The pullout movement shown is the average of the readings taken at each end of the block tested.

Table 2. Pullout test results.

Block type	Maximum sustained load (kN)	Maximum Pullout Movement (mm)	Mode of failure
'Tongue and groove'	22	6.73	Fracture of block at female lug end
Conventional rectangular blocks	3	0.7	Pullout of block with no visual signs of cracking or other distress

4.4 Jet engine exhaust velocities and temperatures

A programme of jet erosion testing was made at Cranfield University using their gas turbine facilities to prove the ability of the system to withstand jet blast conditions equivalent to the typical jet velocities and temperatures encountered on civilian aircraft pavements.

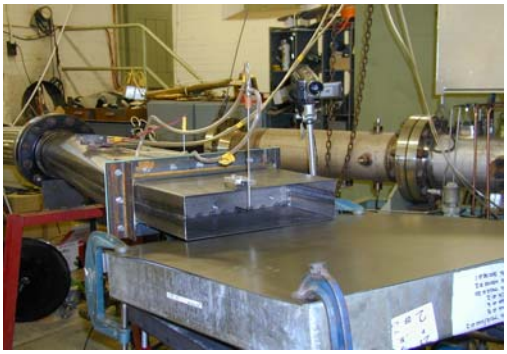

Figure 6. Cranfield University jet erosion testing equipment.

The equipment used provided distributed high-pressure air from a central compressor plant to a number of dedicated cells (see figure 6). A metal shield is seen covering the units to protect them during initial calibration.

Air was delivered to each of these cells through 150 mm diameter pipes at velocities of between 45 and 57 m/s.

Published data by aircraft manufacturers generally report on three engine settings, namely, take-off, breakaway and ground idle. Under normal conditions, where block paving is installed, it will be subjected only to breakaway thrust conditions. Breakaway thrust may be defined as the amount of thrust necessary from all engines to overcome inertia, or more prosaically, 'the thrust required to commence the aircraft rolling'.

Table 3. Operational conditions of selected aircraft.

Aircraft	Breakaway Temperature	Breakaway Velocity
Airbus A380	38 ^{0} C	40 m/s
Boeing 707	52 ^{0} C	22 m/s
Boeing 737	< 30 ^{0} C	22 m/s
Boeing 747	27 ^{0} C	59 m/s
Boeing 777	<38 ^{0} C	22 m/s

Table 3 indicates jet blast breakaway temperatures and velocities that will impinge on a pavement surface aft of the aircraft listed. The aircraft selected represent those typically in use at most civilian airports. The operational temperatures are not considered significant enough to affect the performance of pavers or the sealer mentioned below.

To determine the effect of the breakaway thrust conditions on the units two 600 mm x 600 mm test panels were prepared, each with units laid in 'basket-weave' pattern as shown in figure 2.

One of the recommendations given in the CAA report referred to earlier is that block paving used on aircraft pavements should be sealed to prevent displacement of sand which could cause 'foreign object damage' (FOD) to aircraft. For this reason one panel was sealed with a proprietary urethane sealer, applied at an approximate spreading rate of 2.5 m^2/litre and the other left unsealed. The rate of spread used is typical for most block paving applications but may vary according to conditions such as width of joints and permeability of the units – see Emery (1994) for information on sealing of pavers.

As reported elsewhere in this paper, orientation of the blocks was considered unimportant and this remained the case as far as jet blast testing was concerned.
Both test panels were subjected to velocities of up to approximately 60 m/s. Each panel was exposed to jet efflux for a period of 60 seconds in a series of ten tests. The whole testing procedure was recorded by video camera and after each test, a close inspection was made of the specimens and a still photographic record made.

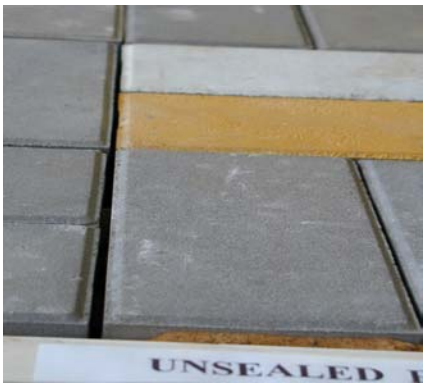

Figure 7. Unsealed units after testing.



Figure 8. Sealed units after testing.

The conditions of the unsealed and sealed panels of tongue and groove units after completion of the jet efflux tests are shown in Figures 7 and 8.

Visual inspection focussed on the following conditions:

- Concrete spalling
- Erosion of the jointing sand
- Lifting of the paving blocks
- Erosion of the sealer from the surface of the blocks
- Erosion of the sealer from the jointing sand

The unsealed units exhibited immediate sand erosion after the first exposure to jet efflux. However, no spalling or lifting of the units was noted during the complete testing programme. It is of some significance that sand erosion extended only as far as the top level of the tongue and groove feature of the blocks, suggesting that the tongue prevents complete erosion of the jointing sand. The sealed units were unaffected during the jet efflux tests.

Previous testing on unsealed conventional rectangular block paving (Emery, 1993) revealed that complete jointing sand erosion had taken place and because of the higher jet pressures used the bedding sand had been fluidised.

5. CONCLUSIONS

The Innovative Paver system represents a major advancement in concrete block paving technology by virtue of its mechanical interlocking feature. This is additional to the frictional interlock provided by the presence of sand in joints.

The units comply with the relevant sections of BS 6717:2001.

Pullout testing indicated that the force required to remove tongue and groove units is seven times that required for conventional rectangular blocks of similar thickness (i.e. 22 kN compared with 3 kN). This, in effect, is a measure of the improved interlocking properties of the system over conventional pavers. The compression testing demonstrated that the maximum sustained load of the tongue and groove system was twice that of conventional rectangular blocks further suggesting the improved interlock performance of the system.

Further testing and analyses of the test results will be made to determine what contribution the system may make to the structural performance of a pavement surfaced with these pavers.

Jet efflux testing confirms that the system will withstand the operating conditions to which block paving is subjected at civil aviation airports and will improve stability of pavement surfaces on which it is used. When sealed, it will resist jointing sand erosion from jet engines thus reducing the risk of 'foreign object damage' (FOD) to aircraft.

Further benefits envisaged for this new form of paving are that they may be laid at steeper angles than conventional pavers, that they may be laid without jointing sand thus increasing permeability of the pavement surface whilst retaining its surface integrity and that when being laid they will have the added benefit of more accurate location of individual units and 'clusters'.

6. ACKNOWLEDGMENTS

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Mr Michael Lazar is the Managing Director of Acme Paving Consultants Pte Ltd. He graduated with a Masters Degree in Business Studies from the University of Ireland and has now had over 20 years of experience in the concrete block paving industry. He has undertaken many studies into the problems associated with concrete block design, production and paving in Asia. He is the inventor of '"Reflective pavers and kerbs" for which patents have awarded in 23 countries and pending in four other countries. He has also invented and developed the "Innovative Paver System", which has a unique 'tongue and groove' locking system to improve concrete block paving performance. A Patent Application was filed for this system as well as for a "Reflective-mix markings for road surfaces" in 30 Patent Co-operation Treaty Countries.

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