

INNOVATIVE PAVERS INCREASE PERFORMANCE OF AIRCRAFT PAVEMENTS AND SUSTAINABLE DRAINAGE SYSTEMS (SUDS)

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SUMMARY

A unique concept known as the Innovative Paver System (IPS) has been developed to resolve inherent problems associated with existing conventional block paving systems. It features a distinctive ‘tongue and groove’ locking and locating system incorporated within each individual unit. This provides a mechanical interlock which is additional to the frictional interlock provided by the presence of sand in the joints of other paver systems. This locking system will ensure that vertical, horizontal and rotational interlock is maintained and will avoid the problem of units dropping from clusters of pavers when being laid mechanically.

Tests and trials have indicated that the system is particularly appropriate for aircraft pavements and that it will resist jet blast from aircraft engines. The result of the tests and trials are discussed with particular reference to a failure of an aircraft pavement surfaced with conventional concrete block paving and suggests that the IPS will restore confidence in the use of block paving on aircraft pavements. The paper will recommend the appropriate applications for which this block paving system may be used on aircraft pavements

The mechanical interlock developed between individual IPS units makes it possible to lay them without jointing sand whilst still maintaining surface stability. For this reason the system may be used as a permeable pavement. Permeability tests have shown that the infiltration rate of these units when laid without jointing sand is about 15 times that of conventional permeable pavement systems. Other permeable paving systems depend on wider joints and built-in apertures to increase infiltration through the pavement which may present problems for pedestrian traffic. The accepted use of concrete block permeable pavements as a primary technique for achieving source control within sustainable drainage systems (SUDS) has led to a dramatic growth in their uptake in the more developed regions of the world. Additionally, because of their mechanical interlock, the IPS may be used on steep slopes and for lining channels subject to turbulent water flow.

1. INTRODUCTION

A radical concept known as the Innovative Paver System (IPS) has been developed to resolve inherent problems associated with existing conventional interlocking block paving systems. It features a unique 'tongue and groove' locking and locating device incorporated within each individual unit. This provides a mechanical interlock which is additional to the frictional interlock provided by the presence of sand in the joints of other block paving systems. It will ensure that vertical, horizontal and rotational interlock is maintained and will avoid the problem of units dropping from clusters of pavers when being handled mechanically. The results of performance and compliance tests made on IPS units by an independent and accredited laboratory are given in this paper. These laboratory tests together with an in-situ trial have indicated that the system is appropriate for aircraft pavements subjected to low jet engine blast.

The paper reports on the use of concrete block paving on aircraft pavements and in particular the failure of concrete block paving used on the aircraft turning circles at the end of the runway at London Luton Airport and hypothesizes that the IPS will prevent such a failure.

The mechanical interlock developed between individual units of the IPS makes it possible to lay them without jointing sand whilst still maintaining surface integrity. For this reason the system may be used as an effective surfacing for permeable pavements. Permeability tests have shown that the infiltration rate through these units, when laid without jointing sand, is 285,000L/s/hectare. This is some 15 times the rate for conventional permeable paving systems which operate by having wide joints and built-in apertures containing coarse sand or grit to increase infiltration through the pavement surface. The narrower joints and absence of sand in the joints of the IPS avoids the inevitable problems of clogging and 'silting up' of joints associated with other permeable paving systems and avoids problems of 'tripping' for pedestrian traffic.

The mechanical interlock provided by the IPS units also enables the system to be used on steep slopes and areas subjected to turbulent water flow.

2. BACKGROUND

2.1 Aircraft pavements

From its initial use as a surfacing for footpaths and roads Concrete Block Paving (CBP) is now used as an integral structural element of heavy industrial pavements such as lorry parks, ports and bus lanes etc. These advantages were recognised by Emery (1987) at Luton International Airport in the UK. Following the success of a small-scale trial in 1981 it was extensively used for surfacing apron stands and runway turning areas. It is now in use at many airports worldwide for aircraft parking stands, for example at Chek Lap Kok Airport in Hong Kong and in one case in Australia, on a runway.

The advantages of using CBP on aircraft pavements may be summarised as follows:

- Pavements may be put into use immediately after pavers are installed.
- It has greater strength and durability than other pavement surfaces as each individual unit is factory-made where quality assurance is more effectively controlled.
- Ease of maintenance and capability of rapid repair.
- Its macro-texture rapidly removes surface water
- When correctly installed it resists low power jet blast and propeller wash

2.2 Permeable pavements

The accepted use of concrete block permeable pavements as a primary technique for achieving source control within sustainable drainage systems (SUDS) has led to a dramatic growth in their uptake in the more developed regions of the world. As an example, in Germany alone, more than 20,000,000 m² is installed annually and in the UK the compound annual growth rate is currently well in excess of 25%.

In addition to the hydraulic benefits of concrete block permeable pavements, they have also been proven to act as an effective stormwater pollution treatment facility through effective filtration, adsorption and the biodegradation of hydrocarbon contamination. Correctly designed concrete block pervious pavements have been shown to remove most pollutants present in stormwater run-off.

Historically, a lack of independent design guidance has been a barrier to the large-scale uptake of these systems. This is not now the case as more and more published information becomes available such as the CIRIA (2002) and Interpave (2005) guides which provide in-depth guidance on the design, construction and maintenance issues.

Although, to date, these pavements have been used primarily for lightly trafficked applications such as car parks (see Figure 1) and minor highways, there has been a noticeable growth in the desire to utilise them in more heavy-duty applications and this will happen as the structural and hydraulic performance requirements become more fully understood. It is the authors' contention that it will be possible for the IPS to be used for heavy-duty permeable pavements.

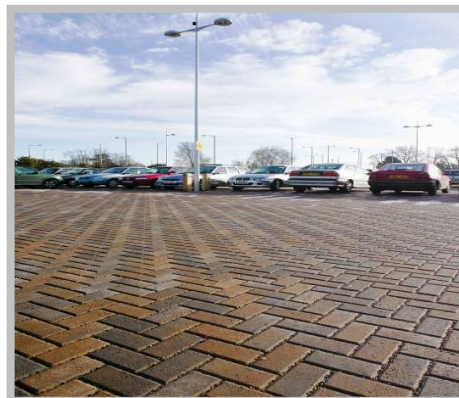


Fig. 1. – Permeable paving car park

3. FAILURE OF CONCRETE BLOCK PAVING AT LONDON LUTON AIRPORT

Notwithstanding the huge success of block paving on aircraft pavements there was a series of failures of the concrete block paving used at London Luton Airport and these are discussed below.

Between March 1989 and November 1992 areas of block paving were displaced on three occasions on the turning circle at the East end of the runway after aircraft operating at maximum thrust at take-off. Figure 2 shows the damage to the pavement surface and Figure 3 the damage to an aircraft by displaced blocks following one of the failures.



Fig. 2 – Displacement of blocks



Fig. 3 – Damage to aircraft

These incidents gave reason to question the stability of the paver joints and to doubt the suitability of block paving for aircraft pavements and John Knapton and the author were commissioned by the Civil Aviation Authority to report on the failures of block paving on aircraft pavements at Luton Airport and its use worldwide. Their report, (Knapton & Emery 1996), concluded that the failure incidents occurred as a result of the use of pavers in a critical location where the combination of large horizontal forces and severe jet effects applied over long periods led to the gradual reduction of interlock so that ultimately little more than the weight of individual unconnected pavers prevented failure. The unusual bedding material (6mm single sized grit, the presence of water in the bedding sand, the laying of the pavers by mechanical means in clusters and the lack of joint stabilization may have each contributed to the failures.

In the recommendations given in this report it was stated that block paving may be used to surface aircraft stands, slow speed taxiways and aircraft maintenance areas not subjected to jet blast but not on runways, areas subject to aircraft operating at high thrust values and on high speed taxiways. Since the problems at London Luton airport and following publication of the report, concrete block paving continues to be used for surfacing aircraft pavements for both military airfields and civilian airports, in particular its successful use at Chek Lap Kok Airport in Hong Kong, the largest block-paved aircraft pavement project ever. However, there still remains reluctance in certain organisations to use block paving for this purpose.

It was with this reluctance in mind and an endeavour to improve the performance of block paving on aircraft pavements that the IPS was developed with support from the Economic Development Board of Singapore.

4. THE INNOVATIVE PAVER SYSTEM (IPS)

The IPS utilizes a ‘tongue and groove’ locking and locating device incorporated into each unit as shown in Figure 4.

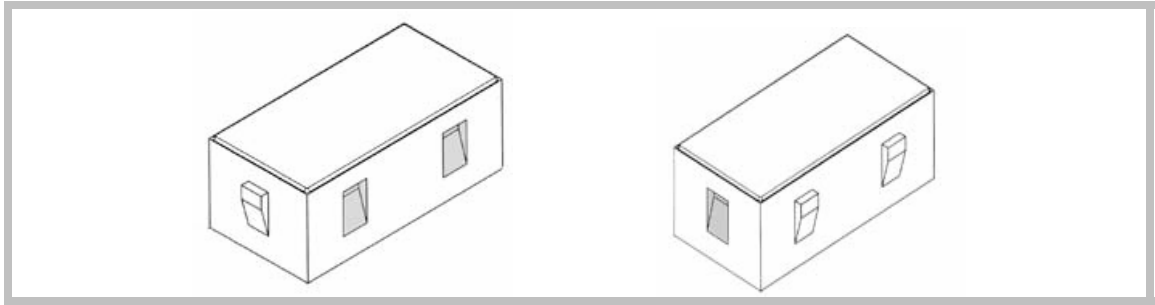


Fig. 4 – Details of the IPS units

The superior pullout resistance of the IPS ensures the surface stability of the pavement even under jet-blast conditions. It redefines the concept of ‘interlock’ as applied to block paving. The term ‘interlock’ has been defined by Knapton & Barber (1980) as “...the inability of a block to move in isolation from its neighbours, thus resisting horizontal vertical and rotational movement” and is provided by the presence of sand between joints. However, the ‘tongue and groove’ feature of the IPS provides ‘interlock’ in the true sense of the word, namely, “...to engage with each other by overlapping or by the fitting together of projections and recesses”. In other words - a ‘mechanical’ interlock. This mechanical interlock is additional to the frictional interlock provided by the presence of sand in the joints of conventional block paving systems. The mechanical interlock enables the paving to articulate more effectively than conventional blocks making it ideal for example constructing ‘traffic humps’ and other cambered surfaces. Figure 5 shows an extreme situation where there has been severe deformation of a pavement but it will be noted that the IPS units remain securely held in position.



Figure 5 – Ability of IPS units to articulate

The superior interlock of the IPS units ensures surface stability of the pavement surface and it is the authors’ hypothesis that this system is ideal for use on aircraft pavements subject to jet blast.

The intention of the new paver concept described in this paper is to resolve many of the known problems associated with conventional block paving systems. The unique tongue and groove feature of the IPS provides a considerably greater pullout resistance than that provided by the presence of sand in the joints of conventional pavers. Complicated shapes developed to increase performance are unnecessary although manufacture of shaped units incorporating the ‘tongue & groove’ technology is possible if required for aesthetic purposes. This tongue and groove feature will also help to prevent the problem of units dropping from clusters of blocks when being handled mechanically.

5. LABORATORY TESTING OF IPS UNITS

To substantiate the claims made for this new system, tests were made to measure the mechanical and frictional interlock developed between IPS units by means of compression and pullout tests and comparing their performance with similar tests made on conventional rectangular pavers. As the IPS units will be particularly beneficial for use on aircraft pavements, jet-blast tests were made to confirm its suitability for this application. Testing of the IPS units was made by an independent accredited laboratory, (STATS Testing Ltd. of St Albans, UK) and jet efflux tests were made at Cranfield University in the UK using equipment specifically developed in their gas turbine laboratories for these tests. The testing procedures used are comprehensively reported in a paper by Lazar and Emery (2006). The results of the comparative tests made between the IPS and traditional rectangular blocks are given in Tables 1 and 2.

Table 1 - Compression test results

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

Table 2 – Pullout test results

Block type	Maximum sustained load (kN)	Maximum Pullout Movement (mm)	Mode of failure
IPS	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

As will be seen from these results, the maximum sustained load for the compression tests was **twice** that of traditional rectangular blocks and the pullout load was **seven times** that of the conventional blocks. These tests confirm the superior interlocking efficiency the IPS units.

6. IN-SITU TESTING OF IPS UNITS

The benefits of concrete block paving are given in Section 2 of this paper and were reported at length by Emery (1987). An essential prerequisite for any aircraft pavement surface is that the pavement does

not give any risk of Foreign Object Damage (FOD) to aircraft engines. One such risk is the ingress of jointing sand into aircraft intakes. With any form of block paving used on aircraft pavements this is achieved by sealing the jointing sand to prevent its erosion as detailed in the Defence Estates Specification 035 (2005). Although the IPS, when used on aircraft pavements, will still make use of the interlock provided by the presence of sealed sand in joints, its tongue and groove feature will ensure a safer and more stable surface than conventional paver units and will provide greater FOD protection.

To compare its performance with conventional block paving, a trial was made at RAF Northolt in London where over 15,000 m² of conventional 80 mm thick rectangular paving units have been used to surface aircraft apron areas. An 80 m² area of conventional block paving units and bedding sand was removed and replaced with IPS units laid on new bedding sand. To assess and compare the performance of both types of blocks in terms of overall stiffness and load transfer between adjacent blocks a Falling Weight Deflectometer (FWD) survey was carried out. The results of the FWD tests concluded that the IPS paving had an increased stiffness compared to the conventional pavers.

The trial area has now been in use for 2 years and continues to perform satisfactorily. In addition to the RAF Northolt trial a further in-situ trial area of IPS units was placed at a port area owned by the Port of Singapore Authority (PSA). Results have shown that even where significant deflection of units had occurred the mechanical interlock has not been compromised and the pavement continues to perform satisfactorily.

7. FUTURE USE OF THE IPS ON AIRCRAFT PAVEMENTS

One of the primary reasons for the development of the IPS was to restore confidence in the use of concrete block paving on aircraft pavements. It is the authors' opinion that it will impart greatly improved interlock and stability to an aircraft pavement surface. It is believed that the use of the IPS will enable its use to be extended to surfacing high speed taxiways.

The introduction of the A380 aircraft faces significant challenges on the ground. To integrate into existing airports, upgrading of taxiways will be necessary as the plane's nearly 262-foot (80 m) wingspan will extend beyond existing taxiway surfaces. This will necessitate the construction of 'shoulders' at each side of these taxiways and the superior interlock of the IPS will provide the ideal surfacing for this purpose.

8. THE USE OF IPS FOR PERMEABLE PAVEMENTS

The use of concrete block permeable pavements is now an accepted technique within a sustainable drainage system - see Interpave (2005). However, a major problem is that of its long term structural performance, particularly where used for heavily trafficked applications – see Knapton, Cook & Morrell (1992). Of specific concern is the degree of interlock which can be developed between blocks. The 'mechanical' interlock developed between individual IPS units makes it possible to lay them without jointing sand whilst still maintaining surface strength and stability. For this reason the system may effectively be used as a permeable pavement even for heavy-duty pavements. Typical permeable pavements (Figure 6) rely on wide joints and voids filled with grit to facilitate flow of water through its surface. The IPS (Figure 7), on the other hand, does not require either wider joints or voids or grit in its joints, thereby reducing any risk of tripping by pedestrians.



Fig. 6 - Typical permeable paving



Fig. 7 - IPS used as permeable paving

Vacuum sweepers will remove dirt and debris from the IPS joints without risk to the stability of the surface as may be the case with other permeable pavements. Additionally, conventional types of permeable pavements tend to become contaminated with silt and debris which will eventually have to be removed at considerable expense. The IPS moulds may be configured to enable units to be manufactured in variety of shapes and laying patterns.

8.1 Infiltration testing

To determine the 'coefficient of permeability' of the IPS, a series of 'falling head' permeability tests was made and was carried out on a 400 mm x 400 mm panel of IPS units. The panel, comprising ten either full or half units were contained within a timber frame. The gap between units was governed by the interlocking system incorporated in the IPS design, being approximately 1mm. The test method employed was an adaptation of the falling head method used for the measurement of permeability of soils (formerly included in BS 1377, "Methods of test for soils for civil engineering purposes"). A plywood tank was constructed of internal dimensions 480 x 480mm and height from the upper surface of the units of 1200mm. This was fixed to the outer faces of the timber frame. The vertical joints of the tank were sealed internally with silicone sealant.

The coefficient of permeability measured by the falling head method is given by the equation:

$$k = 2.3a1/At \times \log_{10} (h^0/h^1)$$

Where:

k = coefficient of permeability (m/s)

a = cross sectional area of burette (i.e. cross-sectional area of tank) (cm²)

l = height of sample (cm)

A = cross-sectional area of sample (cm²)

t = elapsed time (s)

h⁰ = head of water at beginning of test (cm)

h¹ = head of water at end of test (cm)

The measured Coefficient of Permeability for the three tests was 0.01 m/s. This lies within the range given for clean sands and sand-gravel mixtures (approximately 10⁻² to 10⁻⁴).

These permeability tests show that the infiltration rate of these units when laid without jointing sand is 283,500 L/s/hectare. This is some **15 times** the reported rate of conventional permeable pavement systems.

9. THE USE OF THE IPS ON STEEP SLOPES

Full scale testing by Ishai *et al* (1992) was made on block paving laid on slopes between 5% and 13% and subjected to turbulent water flow conditions to investigate (a) sand erosion from the sand bedding layer and joints due to water flow and (b) uplift forces due to water seepage.

Among the conclusions made from their studies were:

- The use of conventional bedding sand was inappropriate due to lack of stability.
- Coarse aggregate (termed 'bird's-eye' aggregate) should be used for bedding purposes.
- For additional safety the use of block paving having extra high interlock is recommended.
- Additional engineering methods should be considered for increasing the resistance of concrete block paving to high velocity water flow.

It is evident that the mechanical interlock provided by the IPS units, when bedded on a coarse aggregate or ('bird's-eye' aggregate layer and its ability to be laid without jointing sand makes the system ideal for steep slopes generally and paving subject to turbulent flow in particular.

Consequently, it is considered that the IPS units will also provide the additional engineering means to increase resistance of concrete block paving to high velocity water flow on steep slopes.

10. 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 whatever frictional interlock is provided by the presence of sand in joints.

Pullout testing indicated that the force required to remove a single tongue and groove IPS units is seven times greater than that required for conventional rectangular block of similar thickness i.e. 22 kN compared with 3 kN. This 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 IPS was twice that of conventional rectangular blocks further corroborating the improved interlock performance of the system.

The mechanical and frictional interlocking properties of the IPS together with stabilization of the jointing sand will provide a much improved surface for aircraft pavements and will restore confidence in the use of concrete block paving on aircraft pavements.

IPS units can be used as a highly efficient permeable pavement and has demonstrated infiltration rates some fifteen times that of conventional permeable paving systems and is therefore commended as a technique for achieving source control within sustainable drainage systems (SUDS). It has the aesthetic advantage of being able to be manufactured in various shapes and a wide range of colours.

In summary, the Innovative Paver System may be adopted for:

- Aircraft pavements and other heavy duty applications
- Permeable pavements used as part of Sustainable Drainage Systems
- Steep slopes
- Paved areas subjected to turbulent water flow

11. ACKNOWLEDGEMENTS

To Mr Phil Cooper of 'The Environmental Protection Group Ltd.' for his assistance and advice on Sustainable Drainage Systems (SUDS).

To 'Interpave' for their permission to use their photographs of permeable pavements.

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