

A NEW PAVER SYSTEM FOR AIRFIELDS

Innovative Paver System (IPS) and Reflective Pavers

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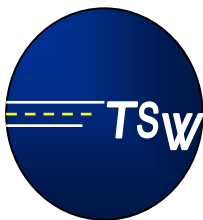
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1. INTRODUCTION

Concrete block paving (CBP) has, over the last 30 years, developed from its initial use as a surfacing for footpaths and roads to having the capability to form an integral structural element of heavy industrial pavements, particularly at airports and airfields. The concept of using concrete block paving (CBP) for surfacing modern aircraft pavements was recognised by the author at Luton International Airport in the UK following a small-scale trial in 1981. (1).

Shortly after this, the Property Services Agency Airfields Branch at Royal Air Force Stations, where it is now widely deployed, generally for surfacing aircraft ramps and helicopter pads, also made trials. Approval has also been given and standards set for the use of CBP by the Federal Aviation Administration (FAA), and the U.S. Army Corps of Engineers on behalf of the United States Air Force. CBP is now widely used at military airfields (2) and civilian airports with over one million square metres in use worldwide.

Throughout this period of increased CBP usage, a wide range of shaped units has been added to the traditional rectangular paver. The development of these various shapes was to increase 'interlock' between units and to improve their mechanical laying capability. Much debate and scientific analysis has centred on the relative benefits of rectangular and shaped pavers and have failed to prove conclusively the superiority of one over the other.

A new paver concept, known as the Innovative Paver System (IPS) has now been developed. The IPS system utilizes a 'tongue and groove' locking and locating device incorporated into each paver unit. This feature provides a mechanical interlock, which is additional to the frictional interlock provided by the presence of sand in the joints of conventional paver systems. The superior interlock of the IPS system assures the surface stability of the pavement surface.

The intention of the new paver concept described in this paper is to resolve many of the known problems associated with conventional small-element paving systems. The unique tongue and groove feature of the IPS system provides a mechanical interlock offering considerably greater pullout resistance to that provided by the presence of sand in the joints of conventional pavers. Complicated shapes developed to increase interlock are unnecessary with the advent of the IPS system, 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 and frictional interlock developed between units by means of compression and pullout tests and comparing their performance with similar tests made on conventional rectangular blocks.

As the 'tongue and groove' units will be particularly beneficial for use on airfields, jet-blast testing was also undertaken to confirm the suitability of the IPS system for this application. The results of these tests are reported in section 4 of this paper.

A further innovative feature of the system is that individual units can be manufactured with an integral reflective surface to facilitate highly visible markings within the pavement surface. Further information of this feature is given in Section 5 of this paper.

2. INTERLOCK

Continuing research on small element paving has shown the importance of what is termed 'interlock' in the performance and life span of a pavement. The British Standard (BS) 7533 (3) definition of 'Interlock' is "Effect of frictional forces between paving units which prevents them moving vertically in relation to each other". For conventional paving systems 'interlock' is provided by the presence of compacted sand between the joints of the pavers.

However, it is the authors' view that this definition is imprecise if one considers that, most dictionary definitions of 'Interlock' have a common theme of "locking or clasping together and interpenetration". It is this interpenetration feature of the IPS system that sets it apart from traditional block paver designs.

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

3. THE INNOVATIVE PAVER SYSTEM

This system was designed and developed with support from the Economic Development Board of Singapore and has 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).

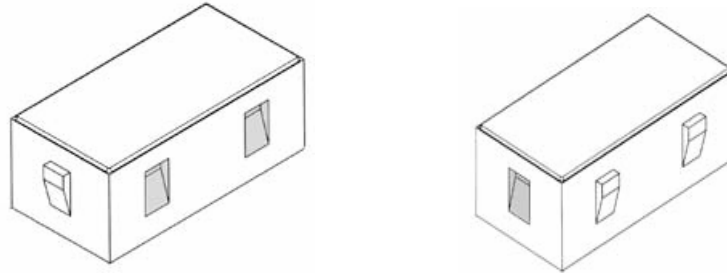


FIGURE 1 - Details of 'tongue and groove' paver

The blocks are manufactured using moulds having a hydraulically operated feature to form tongues and grooves that have sloping sides to ease demoulding during manufacture (Figure 2).



FIGURE 2 – Manufacture of IPS units

The surface appearance of the pavers is much the same as conventional rectangular units, having dimensions of 200 mm x 100 mm x 80 mm thick (approx. 8 in. x 4 in. x 3 in.). Orientation of the tongues and grooves on the sides of the units determines the laying pattern of the units, which in the case of the units illustrated 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 omitted in the figure.

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 traditional pavers.

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 four to five 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 can be sanded, vibrated and sealed, where appropriate.

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 stacked 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 also effective in helping to overcome the problem of dislodgement of pavers from the centre portion of clamped pavers while being lifted during stacking 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 while retaining a stable surface.

An additional benefit of the system is that it will enhance the stability of the paving surface by preventing displacement of individual units while maintaining the essential flexible nature of the pavement. For this reason, the system is particularly suitable for airfield 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, (4). This report provides design procedures and recommendations for the use of block paving on airfields. The improved stability and interlock provided by the tongue and groove blocks will ensure additional safety where they are used for surfacing airfields.

The units can be manufactured in a wide range of colours and with an integral reflective surface for special marking situations (5). They can also 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 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 made by an independent accredited laboratory, namely, STATS Testing Ltd. of St Albans, UK. The purpose of the tests was; (a) to determine the quality of the tongue and groove units and confirm their compliance with British Standards requirements and ; (b) to compare their interlocking properties with those of conventional rectangular concrete pavers by performing compression and pullout tests.

To confirm the suitability of the IPS system 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 (PSA). This has shown that even where significant deflection has occurred 'interlock' was not 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 (2 ft. x 2 ft.) of IPS units and conventional rectangular blocks. The layout of the 18 units used for each test is shown in Figure 3.

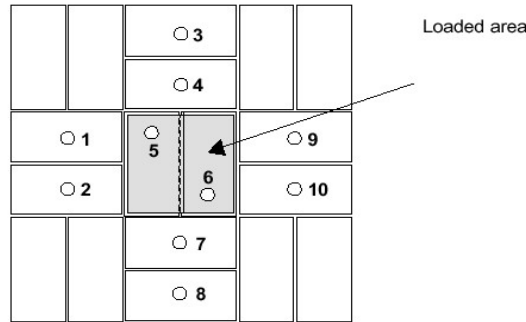


FIGURE 3 - Layout of units in test panels.

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 ($\frac{3}{4}$ in) thick layer of bedding sand laid upon a sheet of dense polystyrene, 600 mm x 600 mm x 50 mm thick (2ft x 2ft x 2 in.) as shown in Figure 4.

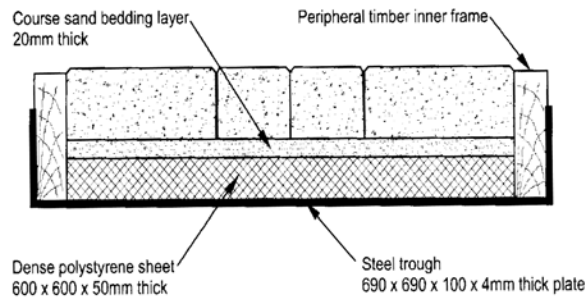


FIGURE 4 - Details of test panel

A steel frame comprising two uprights and a horizontal crossbeam 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 5.

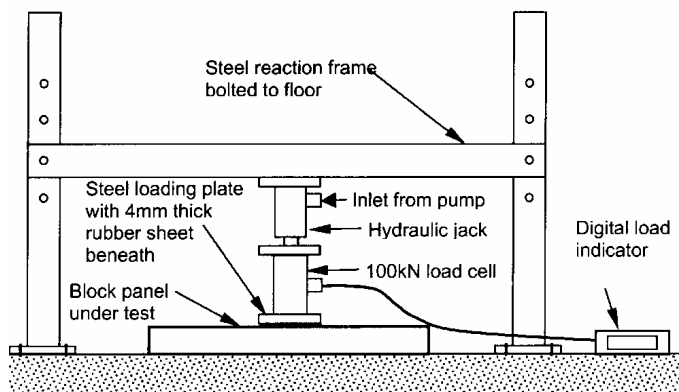


FIGURE 5 - Diagram of compression test rig.

Vertical displacement under load was measured centrally on the upper surfaces of ten blocks at the positions indicated in Figure 3. Deflection was measured by means of dial gauges of 0.001 mm/division (3.9×10^{-5} in.). In each test, load was applied in 2kN (approx. 450 lbf) 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 shown in Table 1.

TABLE 1 Compression test results

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

It is significant that the applied load on the conventional rectangular blocks produced considerably lower deflections on the blocks surrounding the two units receiving the applied load than was the case for the IPS units. This is clearly indicative of the improved interlocking properties of the IPS units. The fact that the maximum sustained load achieved by the IPS units was more than twice that of the conventional pavers demonstrates its superior interlocking properties.

4.3 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 ($\frac{1}{2}$ in.) spaced at 125 mm (5 in.) and along its centreline, were drilled to a depth of 70 mm ($2\frac{3}{4}$ in.) and 12mm ($\frac{1}{2}$ in.) diameter masonry anchors were installed into the drilled holes.

A steel reaction plate of dimensions 400 mm x 300 mm x 20 mm thickness (approx.16 in. x 12 in. x $\frac{3}{4}$ in.), with a central cut-out of 220 mm x 120 mm ($8\frac{3}{4}$ in. x $4\frac{3}{4}$ in.) was positioned on the surface of the test panel such that a gap of 10mm (0.4 in.) 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 (10 Ton) 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 (1 in.) 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 (3.9×10^{-4} in.), 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 6.



FIGURE 6 - Pullout test – Showing mode of failure

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& 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

As will be seen from these results, the maximum sustained pullout load was seven times that of the conventional blocks, which, again, demonstrates the superior interlocking efficiency the IPS units.

4.4. JET ENGINE EXHAUST TESTING ON IPS UNITS

The IPS system is considered eminently suitable for use on aircraft pavements by virtue of its enhanced interlocking properties and its greater surface stability than conventional pavers are. For this reason, IPS units were subjected to simulated jet blast conditions. These tests were made at the Department of Aerodynamics at Cranfield University in the UK using a test rig developed at their gas turbine facility. A program of jet erosion testing was made to prove the ability of the IPS units to withstand jet blast conditions equivalent to the typical jet velocities and temperatures encountered in civil aviation pavements.

The equipment used provided distributed high-pressure air from a central compressor plant to a number of dedicated cells (see Figure 7).



FIGURE 7 - Cranfield University jet erosion test equipment

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 (approx. 6 in.) diameter pipes at velocities of between 45 and 60 m/s (100 and 134 mph). Published data by aircraft manufacturers generally report thrust at three engine settings: 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 can be defined as the amount of thrust necessary to overcome inertia, or more prosaically, 'the thrust required to get the aircraft rolling'.

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.

TABLE 3 – Operational conditions of selected aircraft

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

To determine the effect of the breakaway thrust conditions on the units two 600 mm x 600 mm (2 ft. x 2 ft.) test panels were prepared, each with units laid in 'basket-weave' pattern as shown in figure 3.

One of the recommendations given in the CAA report (4) 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 (6). For this reason one panel was sealed with a proprietary urethane sealer, applied at an approximate spreading rate of 2.5 m²/litre (88 square feet/gallon) 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 porosity of the units.

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 (134 mph). 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.

The conditions of the unsealed and sealed panels of tongue and groove units after completion of the jet efflux tests are shown in figures 8 and 9.



FIGURE 8 - Unsealed IPS units after test



FIGURE 9 – Sealed IPS units after test

Visual inspection focussed on the following conditions:

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

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 program. It is of some significance that on the unsealed units sand erosion extended only as far as the top level of the tongue and groove feature of the blocks, suggesting that the tongue prevented complete erosion of the jointing sand. The sealed units were unaffected during the jet efflux tests.

Previous testing on unsealed conventional rectangular block paving (7) revealed that complete jointing sand erosion had taken place and because of the higher jet pressures used the bedding sand had been fluidised.

5. SUITABILITY OF THE IPS SYSTEM TO MILITARY AIRFIELD USE

The characteristics of the wide range of aircraft using military airfields in terms of their speed, weight, tire pressures and susceptibility to foreign object damage (FOD), impose strict requirements on airfield surfaces. Aircraft using military fields may vary from a small jet training aircraft of 6,500 kg (14,300 lbs.) to large in-flight refuelling aircraft in excess of 250,000 kg (550,000 lbs.). Moreover, as newer and heavier aircraft are introduced the demands on pavements serving these aircraft will inevitably increase.

New design techniques and improved materials for pavement construction will be essential for safe and economic military aircraft operations. Innovations in concrete block paving technology, specifically the IPS system, will help military airfield operators to meet these challenges.

To date, the development of airfield pavement technology has not kept pace with advances in military aircraft over the last 50 years. This is hardly surprising when one considers the vast funds invested in military aircraft research and development compared to the far smaller expenditures allotted to the improvement of airfield pavement. We still use the empirical California Bearing Ratio (CBR) test value and the Equivalent Single Wheel Load (EWSL) as the starting point for the design of pavements. The CBR test was developed in the 1920's for highway design work and adapted by the U.S. Corps of Engineers for airfield pavement design in the early 1940's. IPS is perhaps an overdue advance in the state of the art of airfield pavement design and construction.

Finally and significantly, the IPS system allows for the rapid construction of airfields in hostile or remote environments. IPS system surfaces can be far more rapidly established than airfields constructed of conventional asphalt or in-situ concrete materials. Engineer Battalions could readily construct FOD-resistant airfields to support strike aircraft, helicopters, and next generation V/STOL aircraft including the V22 Osprey and the F35. The significant down blast of next generation V/STOL aircraft make the FOD and pullout resistance characteristics of the IPS system particularly valuable to military operators.

6. REFLECTIVE PAVERS

Pigmented standard pavers are often used to provide contrast for markings on block-paved surfaces. However, these tend to lack visual impact and soon fade. Alternatively, pavers may be painted using specialist paints or thermoplastic materials. These deteriorate rapidly and become visually inefficient due to their poor luminosity

To overcome these problems a comprehensive range of directional and informational designs has been developed using reflective pavers. The notable feature of the reflective pavers is the enhancement of the visibility of markings in daylight, at night and in adverse weather conditions. The coloured reflective surface, being an integral part of the manufactured units, is as permanent as the paver units are and, apart from occasional cleaning, maintenance-free(7).

Such reflective pavers can be used to form centreline and edge markings on taxiways and lead-in markings for apron areas where surfaced with pavers.

Reflective pavers are manufactured using standard block-making machines having a face-mix or composite layer facility. The reflective face-mix has an average thickness of 6.5 mm (¼ in.) in compliance with BS 6717:2001. A cement-based reflective-mix is fed into a mixer and thoroughly mixed for 2 minutes, then discharged into the hopper of a block making plant. The production process thereafter is similar to that for normal composite pavers.

Should an enhanced luminance factor be required for the pavers, glass beads are added to the reflective mix. This is achieved by attaching a bead dispenser to the feeder box, which dispenses the beads to 28 automatically controlled nozzles to apply them evenly. A spraying device is attached in-between the ram head to apply an additive when beads are used. If the bead dispenser is not use then the spraying device is not activated. The reflective mix has sufficient glass beads and other additives to provide an average luminance factor of 60. Skid resistance of the reflective pavers comply with current BS requirements. Independent testing has confirmed compliance of reflective pavers with BS 6717 standards.

A trial made on pavements owned by the Port of Singapore Authority (PSA) compared existing thermoplastic markings with reflective pavers. Under similar traffic conditions, the thermoplastic markings had disappeared within a month whereas the reflective pavers have continued to perform satisfactorily after seven years in use.

During this trial, luminance-factor index (LFI) measurements were made on the thermoplastic markings and the reflective pavers. The thermoplastic markings exhibited an initial high LFI (above 70), but dropped to below 40 within two weeks due to rapid abrasion of glass beads within the matrix. By comparison, the reflective pavers indicated an average LFI of 45 shortly after installation but after three years, it had increased to 55. The reason for this increase is that as traffic abrasion occurs it exposes glass beads in the face-mix of the pavers. The low initial LFI is the result of the coating of glass beads with cement paste etc. during production.

Following this long-term trial, it is now possible to give a five-year warranty for the performance of reflective pavers. The PSA have affirmed the successful performance of the reflective pavers over a period of five years in the form of a certificate of approval. They have also estimated that they have saved approximately US\$ 114,000.00 over five years by not having to repaint the markings on 113 of their 'chassis' lanes. Conventional markings in the same area at the port were repainted four times a year. After the installation of reflective pavers, no repainting or cleaning has been necessary and these pavers have now exceeded their warranty period by two years and are still in good condition.

7. 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 the tongue and groove IPS units is SEVEN times greater than that required for conventional rectangular blocks of similar thickness i.e. 22 kN (4,946 lbf) compared with 3 kN (674 lbf). 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 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.

The IPS system could serve an increasing demand for rapid military airfield construction in multi-theatre conflict scenarios. Significantly, the IPS system allows for the construction of flexible, multi-member airfield pavements that are highly FOD resistant and therefore suitable for next generation V/STOL aircraft.

Where used on aircraft pavements such as parking ramps and taxiways, reflective IPS units may be used to provide highly visual surface markings in daylight, at night and adverse weather conditions. Reflective IPS units also reduce the total life cycle cost of the paving system and attendant airfield maintenance.

In sum, the IPS system offers a combination of true mechanical jointing, consistent compressive strength in paver units, quick laying time, and very high resistance to pullout forces. This combination of qualities makes the IPS paver system worthy of serious consideration by civil airport planners and military airfield operators.

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