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CONSTRUCTION AND REHABILITATION OF AIRCRAFT PAVEMENTS USING CONCRETE BLOCKS HAVING MECHANICAL INTERLOCK

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

The first use of concrete block paving for improving existing aircraft pavements was made at London Luton Airport UK in October 1981. Initial trials comprised two rectangular panels each 9 m x 2 m constructed on an apron stand directly beneath undercarriage gear positions. Rectangular block paving units 100 mm x 200 mm x 80 mm thick were used as an inlay to replace damaged bituminous overlay material. Block paving surfacing has now been adopted worldwide with some 1.5 million m^2 now in use.

Concrete block pavements rely on the presence of sand in their joints to provide interlock and hence stability of the pavement surface. To optimize the stability of the pavement surface and to overcome many of the problems associated with existing block paving systems, an innovator pavement system has been developed that provides a mechanical interlock in addition to the frictional interlock provided by the jointing sand of conventional block paving. This mechanical interlock is provided by means of a tongue and groove device on each unit as detailed within this paper.

The suitability of this form of paving for civilian and military aircraft pavements will be discussed in general and in particular mention its use at Zia International Airport in Bangladesh on a proposed project for the rehabilitation and extension of aircraft pavements there.

A comparison is made between this tongue and groove system and the 'G-Block' system reported at the 1984 Conference which is also claimed to have improved vertical or mechanical interlocking properties.

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. At Luton International Airport in the UK, following a small-scale trial in 1981, the concept of using CBP for surfacing aircraft pavements was established [Emery, J., 1986].

Shortly after this, trials were made by the Property Services Agency Airfields Branch at Royal Air Force Stations, where it is now deployed for surfacing aircraft ramps and helicopter pads. British Airports Authority and MOD's Defence Estates Department have developed and implemented entirely successful concrete block paving specifications and have each made a wide and successful use of pavers. Furthermore, pavers are approved as a surfacing material by the Federal Aviation Administration and the US Army Corps of Engineers for aircraft stands and for low speed taxiways which has led to their worldwide use on aircraft pavements. CBP is now widely used at military airfields and civilian airports with over 1.5 million m^2 in use worldwide [Emery, J., 1998].

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 intended 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. These have failed to prove conclusively the superiority of one over the other. All these CBP units have to rely on the presence of sand in their joints to maintain frictional interlock.

A new paver concept, known as the Innovative Paver System (IPS) has now been developed. The system utilizes a 'tongue and groove' (T & G) 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 improved overall interlock of the system assures the surface stability of the pavement surface. The T & G system has been comprehensively tested and found to perform exceptionally well on heavy duty applications, particularly aircraft pavements.

In the early 1980's another innovatory paving development was that devised by Glickman and known as the G-Block System [Glickman, M., 1984]. He designed a block paving surfacing which also had the intention of providing a mechanical interlock system and which was claimed to be suitable for mechanical laying. A comparison will be made between the new 'tongue and groove' system and the 'G-Block' system.

2. INTERLOCK

Continuing research on small element paving has shown the importance of 'interlock' in the performance and life span of a pavement. A generally accepted definition of it is given in British Standard (BS) 7533 (1997) namely: "...the effect of frictional forces between paving units which prevents them moving vertically in relation to each other". For conventional paving systems this 'interlock' is provided by the presence of compacted sand between the joints of the pavers. However, the authors believe 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 the interpenetration feature of the IPS system that sets it apart from other paver designs.

Three forms of interlock should be present in any block paving system, i.e. rotational, vertical and horizontal. These are achieved by the use of effective 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 pavers are used.

3. DEVELOPMENT OF THE TONGUE & GROOVE PAVER SYSTEM

The primary reason for the development of the T & G paver system was the fact that major clients in Singapore had refused to consider CBP for roads and at ports following too many failures of conventional paving systems. Studies over a two year period revealed the following problems:

- Rotation of blocks.
- 'Creeping' of blocks.
- Differential settlement or uneven pavement surface.
- Corner spalling of blocks.
- Thermoplastic and paint markings did not adhere well to pavers.
- Coloured pavers lacked luminance properties.

A radical system of pavers, having an interlocking device, was developed and intended to prevent or minimize the problems mentioned above. The paving system was designed and developed with support from the Economic Development Board of Singapore using the latest technological methods in mould design and manufacture. The paver system utilises a 'tongue and groove' locking device within each individual unit which can be applied to shaped and rectangular blocks (See Figures 1 and 2). As with most block paving systems spacers are provided.

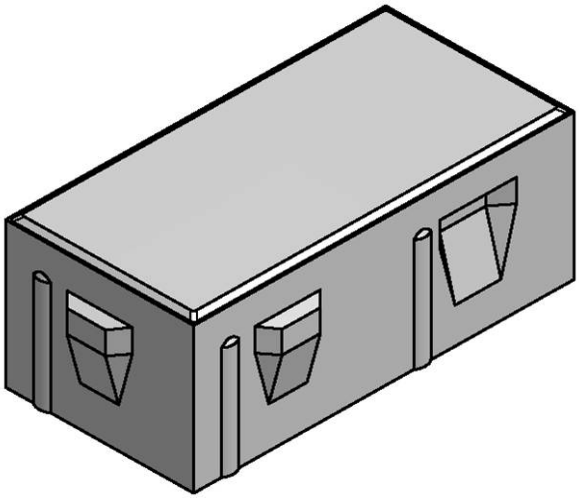

Figure 1. T & G Rectangular block.

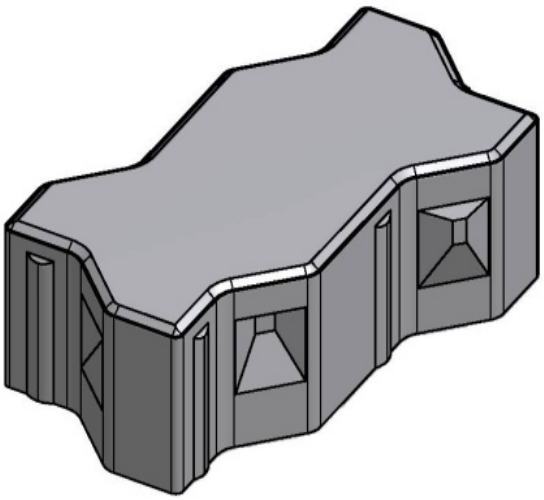

Figure 2. T & G Shaped block.

The blocks are manufactured using moulds having a hydraulically operated mechanism to form tapering tongues and grooves to enable demoulding during manufacture. However, in tapering the tongue, the blocks were able to slide down and cause uneven settlement if there was some movement or sand erosion. The tongue was re-designed to ensure that not only would the tongue slot into place it would also lock in position to facilitate any maintenance requirement.

The tongue feature of the units is compacted using additional ram head protruding bars. This ensures that the tongue is very strong and will be able to withstand extreme stresses without cracking. The pullout tests mentioned below indicate failure at the female lug and not the tongue.

Technical evaluation and testing requirements were based on existing standards. This was followed by product evaluation for any further improvements after meeting the required criteria for the T & G system's production and processing. Fine tuning of the design, specifications and testing methods were made prior to marketing of the concept.

The surface appearance of the pavers may be either shaped or rectangular and like any other standard paving units fit within the specified dimensions of 395 mm x 395 mm. Orientation of the

tongues and grooves on the sides of the units (see Figures 1 and 2) determines the laying pattern of the units, which in the case of the units illustrated is for 'herringbone' pattern.

The unique T & G 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 are treated as sacrificial 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 the aid of 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 when used on aircraft pavements sealed with a urethane sealer to prevent jointing sand erosion.

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, 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 [Knapton, J. and Emery, J., 1996]. This report provides design procedures and recommendations for the use of block paving on airfields.

The units can be manufactured in a wide range of colours and with an integral reflective surface for special marking situations [Lazar, M. and Emery, J., 2009]. 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 s 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 premium to pay when compared with the higher performance of this new paving concept. Once the units are deposited on their platforms all other production sequences are the same as for conventional paver production.

4. COMPARING THE IPS TONGUE & GROOVE BLOCK WITH THE 'G-BLOCK'

The aims of the development of Glickman's G-Block were similar to those for the T & G system in that it was intended to provide a vertical and mechanical form of interlock. The development of the G-Block was born out of an exploration and analysis of Greek Platonic solids by Leonardo da Vinci in the 15th Century, in particular the tetrahedron (See Figure 3).



Figure 3. Leonardo da Vinci's Tetrahedron.

The G-Block essentially comprises truncated tetrahedral units having two sides sloping inwards and the other two sides sloping outwards as illustrated in Figure 4. Adjacent blocks are alternately laid with top and bottom surfaces reversed to form an interlocking surface.

Glickman is dismissive of what he calls 'traditional joinery techniques', e.g. tongue and groove, mortise and tenon and dovetail devices, which, in his view were more appropriate for larger scale precast concrete building products and not suitable for use for 'small scale use on paving blocks.

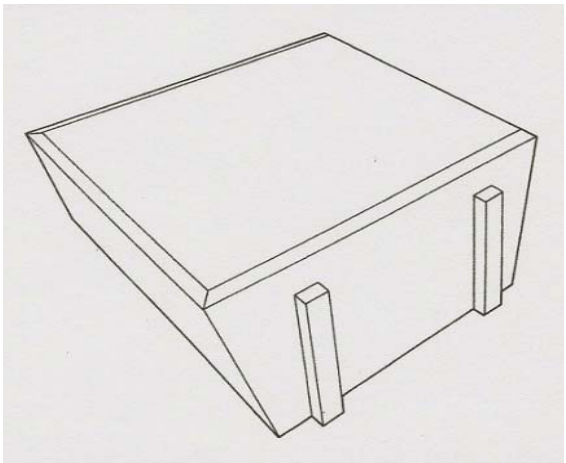

Figure 4. Detail of G-Block.



Figure 5. G-Block trial area at Luton Airport.

The authors' strongly disagree with this contention. Their system does indeed embrace a 'traditional joinery technique' i.e. a tongue and groove device which has proven its effectiveness in providing mechanical interlock and demonstrated its suitability for use on aircraft pavements.

There is no evidence that the G-Block was ever exposed to the rigorous testing regime to which the T & G system was subjected - as detailed in Section 5 of this paper. Although testing is mentioned in Glickman's paper no results were given . It is therefore impossible to make a meaningful qualitative or quantitative comparison between the G-Block and the T & G system or to prove the claims made by Glickman for his system. Emery was persuaded to install a trial area of the G-Blocks in the early 1990s on the apron taxiway at Luton Airport as shown in Figure 5. Unfortunately, the G-Blocks rapidly failed when exposed to the harsh realities of aircraft loading and, ignominiously, had to be replaced with asphaltic material. These particular blocks did not have spacers and it is thought that intense pressures developed at mid height of the units caused fracturing and disintegration of the blocks. The comments given above are not made pejoratively and the authors have nothing but admiration for the elegance of the design and analytical work made by Glickman.

5. TESTING

Testing of the T & G units reported below was made by an independent accredited laboratory (STATS Testing Ltd. of St Albans, UK). The purpose of the tests was;

- To determine the quality of these units and confirm their compliance with European Standards.
- To compare their interlocking properties with those of conventional rectangular blocks.
- To determine infiltration rates by means of permeability tests.
- To confirm the suitability of the IPS for aircraft pavements.

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. A further field trial area was laid at RAF Northolt (see Figure 6) where Falling Weight Deflectometer (FWD) tests were made. This area is still performing satisfactorily after five years in use. Further details of the testing methods used have previously been reported in a paper by the authors [Lazar, M. and Emery, J., 2002].



Figure 6. Trial area of T & G units at RAF Northolt.

5.1 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.

5.2 Compression & pullout testing

To demonstrate the improved interlocking properties of the IPS compared with conventional rectangular block paving, compression and pullout tests were made on a 600 mm x 600 mm test panels.

Table 1. Compression and Pullout test results.

BLOCK TYPE	MAXIMUM SUSTAINED PULLOUT LOAD (kN)	MAXIMUM SUSTAINED COMPRESSION LOAD (kN)
I P S	34	22
Conventional rectangular blocks	16	3

The results given in Table 1 summarises the results of these tests. It is notable that the maximum sustained pullout load achieved by the T & G units was more than TWICE that of the conventional pavers and that the sustained compression load was SEVEN (7) times greater. These results demonstrate the excellent interlocking properties of the system.

5.3 Jet engine exhaust testing

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. 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. A more comprehensive explanation of the jet blast testing is given in a previous paper by the authors [Emery, J. and Lazar, M., (2004)]).

5.4 Permeability testing

Permeability testing was carried out on a panel of blocks with plan dimensions of 400 x 400mm. Using these permeability test results it can shown that the infiltration rate of these units when laid without jointing sand is 285 000 l/s/ha. The calculated infiltration rate is some 15 TIMES that of conventional permeable pavement systems. Other permeable paving systems need wider joints and built-in apertures to increase infiltration through the pavement and it is considered that these may present problems for pedestrian traffic. These results of these tests are reported in Lazar M. and Emery, J. [2008].

6. SUITABILITY OF THE T & G SYSTEM FOR AIRCRAFT PAVEMENTS

The characteristics of the wide range of aircraft using aircraft pavements in terms of their speed, weight, tire pressures and susceptibility to foreign object damage (FOD), impose strict requirements on these surfaces. Aircraft using them may vary from a small jet training aircraft of 6.5 t to large aircraft such as the Airbus 380 having a maximum takeoff weight of 560 t (see Figure 7) Moreover, as newer and heavier aircraft are introduced the demands on pavements serving these aircraft will inevitably increase.



Figure 7. Airbus 380.

New design techniques and improved materials for pavement construction will be essential for safe and economic pavements. Innovations in concrete block paving technology, specifically the T & G system, will help aircraft pavement engineers 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 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. The T & G system is perhaps an overdue advance in the state of the art of airfield pavement design and construction. It is thought that its use for a large project in Bangladesh on a proposed project for construction of apron stands and for taxiway widening scheme will help to establish a more widespread confidence in the system.

Finally and significantly, the T & G system will permit the rapid construction of airfields in hostile or remote environments. Its surfaces can be far more rapidly established than airfields constructed with conventional in-situ concrete and asphaltic materials.

7. CONCLUSIONS

The T & G system represents a major advancement in concrete block paving technology by virtue of its mechanical interlocking feature which 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 units is SEVEN times greater than that required for conventional rectangular blocks of similar thickness. This is an indication 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.

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

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

Whilst the authors acknowledge the exquisite elegance and esoteric design of the G-Block system of paving, they are convinced that the more pragmatic and engineering approach of the T & G system has proven itself to be a more suitable form of paving for heavy duty applications. The fact that it has been selected for use on a proposed project for the rehabilitation of aircraft pavements at Zia International airport is an indication the confidence in this form of paving.

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