EVOLUTION OF INTERLOCKING CONCRETE PAVEMENTS FOR AIRFIELDS
Larry Mujaj, Design Manager, Airport Authority Hong Kong
David R. Smith, Technical Director, Interlocking Concrete Pavement Institute

Summary
Some 40 commercial and military airports are presently using interlocking concrete pavements. As with conventional pavements, technical knowledge and experience with interlocking concrete pavements have developed through testing, trial and error to accepted design methods, specifications, and construction practices, with concrete pavers now being used successfully world wide as aircraft pavements. The components of interlocking concrete pavements are presented with a history of design and construction practices. Selected projects benchmark development of accepted practices. A substantial cost savings from this pavement system provides an incentive for agencies, airport owners, and engineers to compare its cost-effectiveness to asphalt and concrete. As future steps in development, the US Federal Aviation Administration may consider full-scale testing at the National Airport Pavement Test Facility to more accurately quantify the structural contribution of concrete pavers to airfield pavements. In addition, it may consider developing an Advisory Circular to synthesize the literature and experience by other federal agencies, airport authorities, and airfield pavement engineers.

Components of Interlocking Concrete Pavements
Interlocking concrete pavement (concrete block pavement) consists of high strength (typically higher than 55Mpa compressive strength) concrete units, or concrete “pavers.” They are nominally 100mm wide by 200mm long with a minimum thickness of 80mm and placed over conventionally designed, flexible sub-strata. Although concrete pavers can be produced in different shapes, rectangular and multi-sided, dentated shapes are commonly used at airports. Figure 1 illustrates the typical components of interlocking concrete pavements for airfields.

Upon construction of a base, the pavers are bedded by compaction equipment into approximately 20 to 25mm of high-quality bedding sand. Finer sand is used to fill the joints. The pavers are compacted again and also proof rolled to effectively bed and interlock them. This enables the paver/sand layer to integrate as a durable structural layer. A liquid polymer material is typically placed in the joints to stabilize the joint sand from jet blast and reduce water infiltration into the bedding sand.

Interlocking concrete pavements act as flexible pavements with an articulated, rigid surface. Unlike PCC pavement, the surface can be removed and rapidly replaced in small sections for repairs to underground utilities or to rectify base settlement. Reinstatement of the surface requires no special equipment, nor long periods of curing after completion. The result is a sound technical option to a growing need at airports: reducing runway, taxiway, and gate closure times while providing the benefits
of a concrete surface. They provide a surface with very good skid-resistant properties, high resistance to degradation from fuel and oil spills, resistance to damage from sudden dimensional changes thermally-induced by de-icing chemicals or from occasional jet blast, and to most concentrated loads from ramp equipment.

Use of Concrete Pavers in Airfields

Over 1 million m² are in service world-wide at approximately 40 commercial, and military airports with over 400,000m² at the new Hong Kong airport. Other major projects include (1):

• USA/Carribean – 24,000m² of taxiways at Dallas/Fort Worth (B727, B737, MD-80) and 10,000m² on Grand Cayman Island (B727, B737, MD-80).

• UK – Heavy aircraft (B747, B767) apron projects between 30,000m² and 40,000m² at Heathrow, Gatwick, Glasgow, Stanstead, Southampton, Luton and aprons at 10 other military airfields.

• Europe – Aircraft aprons (B737, B757) at Trondheim, Kristiansand, and Stavanger, Norway; tug and equipment stands at Amsterdam Schiphol (5,000m² to 26,000m²).

• Middle East – Aprons (B747) at Ben Gurion, Israel (13,000m²) and Fujairah, UAE (30,000m²)

• Australia – B747 aprons at Cairns (30,000m²) and a runway at Thevenard (26,000m²).

• Africa – B747 aprons at Jomo Kenyatta, Kenya, (56,000m²).

• Asia – Aprons (B747, A340) at Hong Kong Airport (400,000m²) and Subang, Malaysia (68,000m²)

In total, over 40 commercial and military airports have used interlocking concrete pavement for airfields.

Experience has refined design methods and guide specifications for interlocking concrete pavement. As a result, they have been accepted by agencies responsible for airfield design and construction. These include the US Army Corps of Engineers and the US Air Force (3), the US Federal Aviation Administration (FAA) (2), Australian, British (1), Canadian (4), and Hong Kong airport authorities, the British Ministry of Defense (5), and NATO. The FAA has accepted recommendations on design and specifications in a manual published by the Interlocking Concrete Pavement Institute (ICPI) and will pay for the use of interlocking concrete pavements with Airport Improvement Program (AIP) funds on a case-by-case basis (2). The 1995 ICPI manual includes an (unofficial) FAA-format specification, Item P-502, Interlocking Concrete Paver Block Construction for Airport Pavement. It is hoped that FAA will issue an Advisory Circular with a guide specification

Cost Implications

Interlocking concrete pavements can be constructed at a cost less than rigid PCC pavements. This has significant ramifications to airport operators and to FAA construction grant programs. The FAA has historically spent US$500 to $600 million per year on AIP funds (construction grants to airports) for construction and rehabilitation of apron and taxiway pavements. Approximately the same amount of money has been contributed from other sources such as local airport authorities.

For new construction, interlocking concrete pavements can be 10% to 20% less expensive than PCC pavements. For rehabilitation of asphalt with an inlay or overlay of concrete pavers, a savings as high as 40% can occur when compared to removing the asphalt and replacing it with full-depth PCC pavement. (Savings would likely be less when comparing the cost of pavers overlaid on asphalt to an unbonded PCC overlay.) Applying these savings to construction and rehabilitation of aprons funded by the FAA AIP program could yield annual saving of approximately $30 million. When applied to the
entire US commercial/cargo airport system, annual savings appear to range between $60 to $300 million, depending on the extent of apron and taxiway construction or rehabilitation.

History

Luton International Airport, England - The first application of interlocking concrete pavement in an airfield occurred in 1981 at Luton International Airport (6). Two 20m² test areas with 80mm thick concrete pavers on bedding sand were constructed to support landing gear for Boeing 737 aircraft. They replaced worn, 100mm thick asphalt that was overlaid on 250mm of PCC. Concrete pavers were found to be stable under wheel loads. From 1982 to 1984 a second trial area was constructed as well as nine 300m² areas within aircraft parking bays. All of these are known to have performed satisfactorily.

From November 1988 to February 1989, a new, elevated turning circle was constructed with approximately 5,500m² of 80mm thick concrete pavers placed on a thin layer of 6mm aggregate rather than bedding sand. This area was subjected to repeated full power, take-off thrust from jet engines, which dislodged 100m² to 200m² of concrete pavers in five separate incidents. (No stabilization material was placed in the joints to hold the sand in place.) Dislodged units in one incident damaged the surface of a B737 aircraft. The pavers were immediately removed from both turning circles. Luton airport, however, continued using concrete pavers in areas not subject to full-power jet thrust, specifically at gate parking positions, and placed 6,000m² at a new air cargo facility in June 1993.

The primary lesson learned from the Luton airport experience is that concrete pavers should only be used in areas not subject to full jet thrust such as low-speed areas and parking positions. These include areas subject to power-back or reverse thrust applied by departing aircraft at gates. The Luton experience also demonstrated the following, which are now considered standard practice:

• A joint stabilization sealer should be applied to the joints to prevent erosion of the sand from between the pavers. This is typically a urethane pre-polymer material.

• Joint widths need to be between 2 and 4mm.

• The paver pattern should be fully interlocking.

• The design must include drainage of the bedding sand layer at the edges and a lowest elevations in wide areas.

• The bedding sand should be concrete sand (2.3mm to 150mm in size) rather than 6mm sized aggregate. This will prevent loss of the finer joint sand into the bedding material.

• Regular inspection of the pavement (as with all airfield pavement) is important to preventing problems.

Cairns International Airport, Queensland, Australia – The first use of concrete pavers in Australia was in 1990 where pavers were used to repair deformed pavement with marginal base material on two aircraft parking positions at the domestic terminal (7). The repaired area consisted of pave-
ment under the main and nose landing gear, plus the tug track. The initial trial encountered inconsistent joint spacing, ingress of water into the cement-treated base, and movement of the pavers. While the interlocking concrete pavement performed satisfactorily in dry weather, the torrential, tropical rains softened the base and subgrade and deformation followed from wheel loads. This led to spalling and cracking of the pavers and thus a potential FOD problem.

The construction of a new international terminal in 1991 represented a fresh opportunity to address the problems encountered with the paving at the domestic terminal. Some 15,000m² of concrete pavers covered three parking positions for B747-200/400, DC10-30, A300B4, and B767-200 at the new terminal. See Figure 3.

The pavement design followed the US Army Corps of Engineers CBR procedure using the flexible pavement design chart for the B747. The 15-year design life assumed for the pavement resulted in a cross section of 80mm thick concrete pavers placed in a herringbone pattern. These were placed over 20mm thick bedding sand and 250mm of cement-stabilized base over a sub-base. The top surface of the base was sealed with 7mm chip seal to prevent loss of bedding sand into any cracks in the cement-stabilized base. After six weeks of use, a major 7,500L fuel spill occurred which had no effect on the pavement. Damage to the asphalt in the adjacent parking position necessitated closing it for over 1 month until the asphalt again hardened.

The project pointed to several requirements that appear in the most recent literature on design and specifications. First, the quality of the concrete pavers must be tied to high testing standards and criteria for compressive and/or tensile strength. They should be dimensionally consistent so that joint widths remain consistent and tight. In practical terms, the concrete pavers should not vary 1.5mm in size compared to their specified dimensions.

Second, the texture of the pavers should be consistent for the sake of achieving consistent skid resistance properties. This is achieved by accepting samples and using a mock-up panel placed on the job site. The surface of pavers can be manufactured to be smooth or rough depending on the mix design of the concrete. While the texture depth of the surface can be measured, visual comparisons to a panel are faster and easier.

Third, spacer bars or nibs on the vertical faces of the concrete pavers are essential. These nibs are typically no larger than 2mm thick. They keep the pavers from touching each other (except at the nibs) which helps prevent chipping and spalling the top edges. This decreases the likelihood of FOD. In addition, spacers enable open joints so they can be filled with sand and receive (liquid) stabilization materials such as urethane.

Fourth, joint spacing must be consistent in order to maximize a stable surface and facilitate interlock among the pavers. The recommended range for joint spacing is 2 to 4mm with 3mm being the average. Spacer bars, combined with dimensionally consistent pavers and trained installers, will enable consistent joint widths. Spacers are desirable for manually installed pavement such as done at Cairns, and they are considered essential on mechanically installed project such as those installed at Cayman and Hong Kong airports.

Fifth, the bedding sand layer should be 20 to 25mm thick. While slightly thicker (25-40mm) bedding
is adequate for roadways, 20 to 25mm of sand reduces instability under significantly greater wheel loads. A thinner layer can be achieved on airfields since base surface tolerances tend to be tighter than those for roads.

Finally, proof rolling the surface of the pavers is considered important to accelerating the development of interlock. After the pavers are placed on the bedding sand, they are compacted with a plate compactor, the joints filled with sand and compacted again. A plate compactor with a minimum force of 22kN is considered adequate to seat the pavers. However, after this compaction, the entire surface should be proof rolled with a high-pressure, pneumatic-tired roller of at least 10t. This contributes to stability of the surface, helps identify areas of deficient joint sand, and loose or broken candidates for replacement.

As a result of the Cairns project, a new industry specification was developed in Australia for airfields that addressed these issues. Much of what was learned at Cairns was later applied at Hong Kong airport, and to subsequent extensions of the Cairns apron.

**Dallas/Fort Worth (DFW), Texas International Airport** – As part of a 10-year plan to expand airport capacity, DFW plans the construction of two major runways and several new taxiways. Construction of cross-taxiways 23, 27, and 29 adjacent to the existing 18R/36L runway required night closure during the fall of 1991 (8)(9). Runway closure during construction had significant impact on air traffic, causing significant delays in both air and ground operations. These delays not only impacted DFW, they rippled through much of America’s air traffic since DFW is a major hub connected to dozens of other large, commercial airports.

The standard pavement cross-section at DFW is 430mm of jointed, reinforced concrete on 225mm of cement-treated base over 225mm to 460 mm of lime-stabilized subgrade. Use of this cross section required closures that were unacceptable to the airport and airlines. Interlocking concrete pavements were selected because they could reduce nightly closures from 14 to 12 hours over a 114-night construction period. See Figure 4.

According a study for DFW by the regional office of the Air Transport Association (ATA), this saved an estimated $37,130 per day in delays to the airlines, or $4,232,820 over the 114-night construction. In addition, concrete pavers had an unexpected safety benefit. When the cloud ceiling dropped below 325m, airport operations required that all construction cease and the closed 18R/36L runway be opened for traffic. Unexpected stoppage of construction required removal of all workers, material and equipment within 30 minutes after notification from airport operations. This time constraint was met with interlocking concrete pavement. In contrast, construction of PCC pavement for high speed exits next to the same runway involved two hours to clear equipment and personnel.

The basis of structural design was the flexible method for flex-

Figure 4. The first use of concrete pavers was at Dallas/Fort Worth, Texas International Airport, which saved over $4 million in construction-related delays.
ible pavement in the FAA Advisory Circular 150/5320-6 “Airport Pavement Design and Evaluation” (10). The FAA concurred with replacing 100mm thick asphalt normally used in their flexible pavement design method with 80mm thick pavers and 40mm of bedding sand in the structural design method.

Wheel loads assumed for 20-year-life design ranged from 182 kN to 2,680 kN with 15% of the aircraft over 1,334kN. Actual loads measured from traffic monitoring were converted to an estimated equivalent of MD-11 annual departures. An MD-11 has a gross load of 2,680kN and a wheel load in the range of 225kN. From 1991 to 1994 the equivalent MD-11 loads were 7,029 for Taxiway 23, 832 for Taxiway 27, and 938 for Taxiway 29 (10).

In 1990, prior to opening of the pavement, DFW staff measured elevations over a 3m grid. Skid resistance measurements taken with Saab skid tester ranged between 0.63 and 0.69 with 0.65 as an average. Structural capacity was measured using a falling weight deflectometer (FWD) to establish base line data for future evaluations.

Harding Lawson Associates of Reno, Nevada, a consulting engineering firm, conducted an evaluation of the taxiways in 1995. The evaluation included measurement of elevations, a pavement distress survey covering 50% of taxiway 27, and 25% of 23 and 29, plus structural analysis using a FWD (9).

The most common surface distresses were loss of bedding sand along the edges of the pavement adjacent to concrete shoulders and to a lesser extent at the joints along the PCC pavement. Loss of sand at the shoulders was from heaving of the clay soils under the shoulders, since they were not stabilized with lime-flyash. In the taxiway interiors, loss of bedding sand and depressed pavers mirrored paving lane joints in the CTB. No rutting, creep or swell was observed on the taxiways. In some areas of the taxiways, the joints had lost sand to a depth of 20mm to 30mm from jet blast.

Deflection measurements were taken in 1994 with a Dynatest FWD. Table 1 below presents the average values for the measurements taken in 1991 and 1994.

<table>
<thead>
<tr>
<th>Taxiway Deflection, mm</th>
<th>Concrete Pavers</th>
<th>CTB</th>
<th>Lime-stabilized subgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>0.60</td>
<td>0.47</td>
<td>986</td>
</tr>
<tr>
<td>27</td>
<td>0.56</td>
<td>0.47</td>
<td>1,331</td>
</tr>
<tr>
<td>29</td>
<td>0.70</td>
<td>0.60</td>
<td>1,014</td>
</tr>
</tbody>
</table>

Source: Reference 9

Overall average deflection of the CTB increased 15%, 17% and 23% in the three taxiways. However, the stiffness of the paver and bedding sand layer increased 69%, 75% and 88%. This demonstrates the progressive stiffening or “lock-up” of interlocking concrete pavements under wheel loads. Total deflection decreased indicating that the entire pavement system stiffened from 1991 to 1994.

All of the modulii of the pavers and bedding sand in 1994 exceed 1,724MPa. This value is the stiffness recommended by the FAA for a 100mm thick asphalt layer when using layered elastic modeling and design. The data provides substantiation for the FAA assuming a structural equivalency of asphalt to the paver/sand layer.

The evaluation by Harding Lawson projected that the 20-year design life will be fulfilled with the existing pavement structure. This was based on measured stiffness of the pavement materials, projected aircraft traffic, analysis of fatigue of the CTB, analysis of allowable subgrade vertical compressive strain, and allowable rut depth within the paver and bedding sand layer. The report concludes “concrete
Pavers can provide a functional pavement surface for aircraft at DFW.” The FAA provided US$930,000 in AIP funds to DFW to support the $1.8 million project. DFW airport represents the first use of interlocking concrete pavements in an airport application in the USA.

The study identified deficiencies in the subgrade stabilization in Taxiway 29, loss of bedding sand at the shoulders and at the junction with PCC pavement. Figure 5 illustrates the retrofit edge restraint for the shoulders showing the addition of the steel edge and geotextile to the original construction. Figure 6 shows the repair to the paver-PCC joints with the addition of steel angle. The L-shape of the edge restraint did not require the use of geotextile as shown in Figure 5. According to staff at DFW all repairs have been made to these edges. The repairs underscored the need to tie edge restraints to the base under the concrete pavers, and not onto adjacent materials.

**Grand Cayman Island International Airport** – Grand Cayman Airport in the British West Indies required major pavement rehabilitation due to a steady increase of traffic, and by heavier aircraft (11). While the condition of the existing asphalt aircraft apron was very good, it specifically required strengthening. The existing apron was subject to eroding from fuel spills. The apron also required an increase in slope to facilitate surface drainage.

The entire apron (consisting of 5 parking positions) was overlaid with 75 to 125mm of FAA P-401 asphalt for strengthening and then surfaced with 80mm thick pavers and 30 to 40mm of bedding sand. This saved approximately US$500,000 compared to using conventional PCC pavement (total project cost was $2.7 million). The concrete pavers enabled one parking position at a time on the apron to be renovated and immediately opened. Therefore, there were no interruptions in scheduled flight operations during the course of the construction. See Figure 7.

**Figure 5. Repair to pavement edge at shoulders**

**Figure 6. Repair to pavement edge at the PCC pavement.**

**Figure 7. Interlocking concrete pavement used at the apron at Owen Roberts International Airport, Grand Cayman Island, saved $500,000 and caused no interruptions in operations.**
Overall, the pavement has performed well. Like DFW, an inferior joint sand stabilization material was the substitute for a urethane-based material. This explains the loss of 20 to 30mm of joint sand in areas subject to jet blast similar to DFW (these have been refilled). A few of the pavers under the aircraft main gear have cracked in one or two parking positions. Small depressions have appeared in the pavement under the main gear. This is likely due to marginal local bedding sand. The cracked units have been replaced, and brought to their former elevations.

The owner accepted occasional minor repairs of pavers less costly than importing extremely hard bedding sand at initial construction.

The edge details to restrain the pavers and bedding sand were developed specifically for contact against asphalt. Figure 8 shows this construction detail. A key to the success of this detail is paving the asphalt 60cm past the location of the steel edge. The compacted asphalt is saw cut back to the location of the steel edge restraint. Cutting and removing the excess asphalt ensures the highest compacted material adjacent to the concrete pavers and steel edge restraint.

**Norwegian Airports** – The experience at several Norwegian airports positively answers the question on the success of concrete pavers in winter climates, de-icing chemicals, and snowplows. Snow plows and de-icing chemicals have been used regularly with little or no damage to the pavers at Trondheim, Kristiansand, Stavanger, Sola NATO base, and Oslo International Airport (all airports are located above 58° north latitude). All projects used urethane to stabilize the joint sand. This material has performed well with no maintenance.

Trondheim constructed 27,000m² next to a new terminal in 1994. A high quality aggregate base supports approximately 50 movements per day at seven gates from B737, B767, DC-8, and A320 traffic. The base and soil subgrade fills have experienced some differential settlement, which underscores the need to use stabilized bases when aircraft loads exceed 45,500 kN. The concrete pavers have endured under steel snowplow blades (11)(12).

Kristiansand airport rehabilitated existing asphalt with a 6,650m² inlay of concrete pavers in 1991. The pavement sees 15 to 20 B737s per day. Steel snowplow blades and glycol are used on the pavement to remove snow and ice (12) with no adverse results.

Braathens Airlines, Norway’s domestic air carrier has 7,500m² at the entrance to their Heavy Maintenance Hangar for servicing some 20 B737s at Stavanger airport (12). Next to Stavanger airport is the Sola NATO base. Since 1989, it has maintained an annual rehabilitation program of replacing worn PCC taxiway pavement with concrete pavers for F-16s, C-130s, and rescue helicopters (13).

In 1991, Oslo Fornebu International Airport rehabilitated 8 asphalt stands (1,248m²) for B737s with an inlay of concrete pavers under the landing gear. This was an inexpensive, fast solution to static indentation in the asphalt. All work was done at night, 3 nights per stand. In addition, the paver areas help the pilots know where to park. A similar inlay of concrete pavers was done for parking of NATO military aircraft elsewhere at Oslo airport (14).

**Hong Kong** – Airfield pavements at Hong Kong’s new international airport consist of two runways and associated taxiways leading to parking aprons for passenger aircraft, cargo, maintenance areas, and business aviation. Pavements are designed for use by current aircraft and have sufficient structural

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**Figure 8. Edge restraint detail for overlay/inlay.**

2 lifts of FAA P-401 asphalt
Joint sealant
13mm dia. x 300mm long galvanized steel spikes 600mm on center
75mm x 75mm x 5mm galvanized steel angle
80mm thick concrete pavers
25 - 40mm bedding sand
Asphalt

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capacity to support future aircraft weighing up to 770 t. When fully operational, the airport will serve over 35 million passengers and handle over 3 million tonnes of cargo annually.

Construction of the airside infrastructure began in May 1995. At the end of 1998, over 3.7 million m² of airfield pavement were in place. This consists of 2.6 million m² of asphalt pavements for the two runways and the taxiway system, 700,000 m² of concrete pavement for aircraft parking stands, and 400,000 m² of interlocking concrete pavement in apron areas and cargo loading areas. The interlocking concrete pavement represents the largest single installation in an airfield, as well as the state-of-the-art in its design and construction (15).

Interlocking concrete pavement was selected in areas where rigid PCC pavement could not tolerate expected settlement. Concrete pavers also offered resistance to creep and static indentation, resistance to rutting, fuel spills, and to concentrated loads from cargo handling and service equipment, ease of repair should settlement occur, and reduction of gate closure times.

A review of difficulties on past interlocking concrete pavement projects indicated that they were likely due to inadequate specifications, or failure to enforce specific workmanship and tolerances during construction. By implementing rigorous specifications and by closely monitoring the construction, past mistakes were avoided. (Similarly, the development of asphalt and concrete pavements has moved, and continues to move, through a similar process of refinement.)

The pavement thickness was determined using a one-for-one substitution of the concrete pavers and bedding sand for asphalt. The crushed rock base immediately below the bedding sand had 3% percent cement added to reduce elastic deformation. Reports of trials of asphalt bases and asphalt-stabilized bases show that if the elastic deformation is maintained below 1.5mm, the occurrence of spalling, cracked pavers, and FOD are greatly reduced.

Some shrinkage or movement cracks will inevitably occur in the cement-stabilized base over time. Cracks could result in a place for the bedding sand to wash or migrate downwards, as happened at DFW. The resulting loss of support under the pavers would then result in failure. To mitigate this, a geotextile was placed over the cement-stabilized base course and secured with a bitumen tack coat. Additional bitumen was applied and allowed to soak into the geotextile. This bitumen-rich layer helped seal cracks in the CTB course and bound lower layers of sand with the geotextile and base.

Numerous problems are attributed to poor quality or excessive thickness of the bedding sand under concrete pavers; the sand can be placed with variable thickness and density, it breaks down, compacts unevenly, or is lost into cracks and joints. To avoid repeating past errors, the project specifications were written to ensure a uniform thin sand layer while specifying a clean, strong, well-graded material. A compacted thickness of 20 mm was specified following successful application at Cairns Airport.

Sand gradation for the bedding material met the specifications for gradation and hardness. It is essential that the material passing the 75mm sieve be held to less than 3%. It should be held below this amount after testing for resistance to degradation with a variation of the Micro Deval abrasion test known as the Lilley-Dowson Bottle Rolling Test (16). The on-site dredged marine sand was found to be ex-tremely durable when tested using the Bottle Rolling Test. The percentage passing the 75mm sieve occasionally increased to 2%, but this easily met the maximum requirement of no more than 3% passing and other specified limits as recommended in the ICPI guide (2).

The Airport Authority used dentated pavers laid in herringbone pattern. The Authority put the onus on the contractor to propose methods for dimensional control of the pavers during manufacture so that joint widths were consistent during installation. The specification also required that the contractor mathematically model the effect of his proposed plan for control of dimensional tolerances. This confirmed that the joint spacing criterion (1.5mm to 4mm) in the specification would be achieved.

Full depth concrete curb edge restraints up to 1.5m deep were specified. These occurred mainly at the high side of the paving while the low points were restrained with drainage channels. At the low points, 32mm diameter weep holes were cast into the wall of the drainage channel at 1m centers at the
level of the bedding sand to aid in the drainage of the bedding sand. This is considered good practice to dissipate excess water and reduce the chance of pore pressure build-up in the bedding sand (15). To ensure that the bedding sand was not washed away through the weep holes, the geotextile continued up the face of the drainage channel to 10mm below the surface.

With over 400,000 m² to be laid at an average of 1,000 m² per day, it was necessary to use mechanical installation equipment. See Figures 9 and 10. To maintain a continuous herringbone pattern, the pavers were hand-stacked in layers on pallets in the factory in the required herringbone pattern. (Where labor costs are higher in other parts of the world, hand stacking is uneconomical. Rather, each layer is manufactured in a ready-to-install herringbone pattern.) Two stack-bonded pavers were placed in diagonally opposite corners to help in the locating and laying of the cluster. When the cluster was laid, the corner pavers were removed and the clusters were locked together as shown in Figure 11.

Mechanical installation was done using three laying machines. Following training of site personnel and some further development of the machines, laying rates of 500 m² per day were easily achieved with each. The pavers where seated into the bedding sand using a 350kg plate compactor on a rubber pad that transmitted a compactive force of 0.08 MPa. This is a similar force to traditional, smaller 22kN force plate compactors. The larger plate area enabled faster and more consistent compaction.

Paver installation usually began against at a concrete curb. Special hand-laid edge pavers and manufactured half units were used to start the herringbone pattern. Cut pavers were applied at the closing...
edges, around pits and manholes, and at changes in direction of the pattern. Diamond saw cutting ensured a clean, smooth face, as well as uniform joints and contact areas. All cut pavers were larger than 25% of the whole unit. Cut faces were always chamfered to replicate whole pavers. Random checks of a 1m² area for every 250m of pavement were made to confirm the specified joint spacing.

One problem occurred when the joint sand stabilization material was applied. Pavements left unsealed for long periods in dusty areas developed a layer of silt in the joints. This effectively prevented the sealer from soaking into the joints resulting in a skin on the surface which had to be removed by high-pressure water spraying.

A low-viscosity elastomeric pre-polymer stabilized the sand in the joints. Penetration of the sealer into the joints averaged between 20mm and 30mm. Higher penetration was avoided because if it occurred near the bedding sand weep hole, the geotextile over the weep holes would clog and become ineffective. While there is little performance history, the joint sand stabilizer is expected to last at least 10 years.

With the opening of the new Hong Kong Airport on July 6, 1998, the interlocking concrete pavement came into service under frequent heavy aircraft loads. At the time of writing this paper, no load-related failures were evident.

**Conclusion**

As with asphalt and concrete, specifications for interlocking concrete pavements for airfields will be subject to continual refinement. However, after 15 years of experience, the critical aspects of design, specifications, and construction with concrete pavers have been addressed. The projects represented in this paper highlight the learning process engineers have gone through to develop industry-accepted standards. This increases the confidence by airport pavement engineers and operators in the use of interlocking concrete pavements. Further confidence and more precise structural design methods could be gained by the testing at the FAA National Airport Pavement Test Facility. An FAA Advisory Circular (AC) on interlocking concrete pavements would also confirm this cost-effective pavement by synthesizing the literature and experience from other federal agencies, airport authorities, and airfield pavement engineers. It would support AIP projects, thereby facilitating realization of construction cost savings and/or reduced interruptions to airport operations.

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