DEVELOPMENTS IN MACHINE INSTALLATION OF CONCRETE BLOCK PAVING

CHRIS HODSON, MANAGING DIRECTOR, XENEX INTERNATIONAL
Russells End, Bromsberrow, Ledbury, Herefordshire, HR8 1PB, UK
TEL +44 1531 650027 FAX +44 1531 650028
E-Mail xenex@hodsons.com
COLIN ROBINSON, RMC CONCRETE PRODUCTS (UK) LTD., UK

ABSTRACT

The paper considers current pressures and opportunities in markets for machine installation of concrete block paving in the UK and other countries. New developments are examined in laying machines and innovations in site support to enable optimum efficiency. The influence of paver designs on laying efficiency and structural performance is discussed and recent comparative trials on 4 paver designs summarised. An important case study project, comprising an airport pavement in Hakodate, Japan, is then described to illustrate the practical implementation of the developments previously considered.

1. DEVELOPING THE MARKET FOR MACHINE LAID BLOCK PAVING

Machine installation offers much faster laying rates than manual techniques, with consequent reductions in labour levels, costs and project duration, making it particularly useful for larger fast-track projects and to minimise operational down-time. However, in a number of countries, including the UK, machine installation of block paving was introduced over 15 years ago but failed to demonstrate sufficient benefits to ensure its expansion and continuing use at that time. In the UK today, a new initiative by manufacturers and trade associations has reawakened interest. This is supported by independent evidence on the cost-competitiveness of machine laid concrete block paving compared with in-situ concrete and asphalt pavements. In addition, European laws (EU Directives) are now in place which, in practice, will limit the scope of manual installation of block paving and it is anticipated that similar legislation will be increasingly found in other countries. As a result, in many parts of the world, market conditions are now ready for the adoption of machine laid block paving. In order to maximise this opportunity, all aspects of machine installation and the procedures connected with it should be reviewed and innovations introduced where possible to ensure that the mechanised process is as efficient as possible.

2. IMPROVEMENTS TO LAYING MACHINES

Machine laying is achieved with either hydraulically operated clamps to contain and lift ‘clusters’ of blocks, effectively as an articulated unit, or vacuum systems which attach to the top of each block lifting groups of blocks as individual items. Clamps are simpler and quicker to operate but are more suited to blocks with better interlock preventing them from falling out of the ‘cluster’ formations in which they are delivered to site. Vacuum systems do not rely on interlock and may be needed for block designs which do not inherently interlock.

Both clamp and vacuum systems are available on dedicated machines designed specifically for block laying to give good visibility and site manoeuvrability: examples are shown in Photos 1 and 2. Alternatively, both systems can be fitted to some general site equipment for more occasional use, although these are usually less efficient. Sometimes, manually operated trolley clamps are also used, although these do not provide a satisfactory alternative to powered machines. Compared with a laying rate of about 50m2 per man-day for hand laying, dedicated powered machines can easily achieve 400-600m2 per day on most suitable projects.

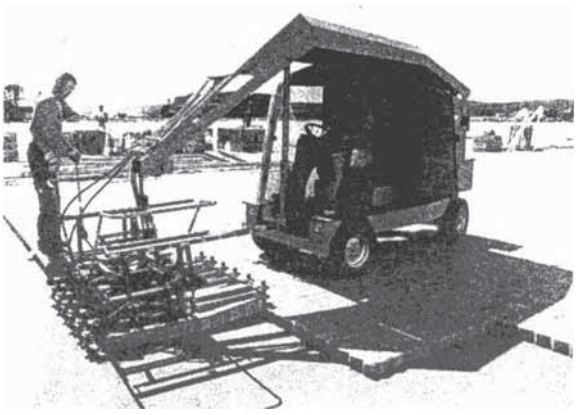


Photo 1. Dedicated Laying Machine.

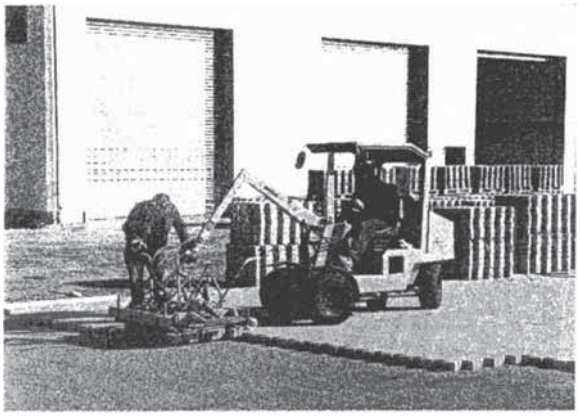


Photo 2. Dedicated Laying Machine.

Powered laying machine manufacturers have recently added optional hydraulic rotators for laying clamps, allowing the driver/operator far more positional control than in the past. This development is particularly useful for one man operation, without the need for a second operative manipulating the clamp. One man operation is most effectively achieved with paver designs which provide fully dentated interlock for accurate location of paver clusters and offers real cost-effective possibilities for use of machine laying on smaller projects. Other recent improvements have been introduced on dedicated laying machines including automated sequential clamp operation, simplifying operator controls, and “pushing off’ devices to ensure that pavers touching the laying face drop into place.

3. SITE SUPPORT FOR MACHINE INSTALLATION

To make the most of machine laying, good overall site management and planning are essential, preferably incorporating mechanisation of other related site activities. For example, the use of asphalt laying machines to place and screed the laying course material is becoming more common, particularly as older machines, no longer usable for asphalt, may well be suitable for this purpose. Other mechanised sand screeding techniques are also used to speed up the preparation process ready for machine laying of pavers. During block installation, stock piling of pavers close to the laying face is an important consideration to allow the laying machines to operate at their optimum rates with limited travel. Here it is important to concentrate the dedicated machines on laying, not carrying “clusters” over long distances. However, once block laying of an area is complete, the dedicated machines can be released for other activities. Attachments to dedicated laying machines are already available for the brushing-in of jointing sand and development work is under way for machine mounted equipment for the application of joint material stabilising sealants.

4. DEDICATED PAVER DESIGNS FOR MACHINE LAYING

Various proprietary block paving systems are available designed specifically for machine laying. These are generally based on non-rectangular formats - such as Y, L or X shaped systems - with dentations applied to give greater interlock, so that they stay in place when lifted by simple clamps. Such pavers are installed in ‘clusters’ exactly as supplied to site, in contrast to rectangle based designs requiring manual block relocation to ‘stitch’ laid clusters together. The latest generation of fully interlocking pavers combines an X shape with a heavily dentated laying face, as shown in Photo 3. Here blocks can only be installed vertically, rather than from the side with most other systems. Contractor experience in several countries has shown that consistent accuracy of joint widths and laying lines is effectively in-built, as shown in Photo 4. This reduces supervision and quality control requirements, while ‘cluster effect’ (over-wide or straight joints between clusters) is eliminated without any reduction in laying rates.

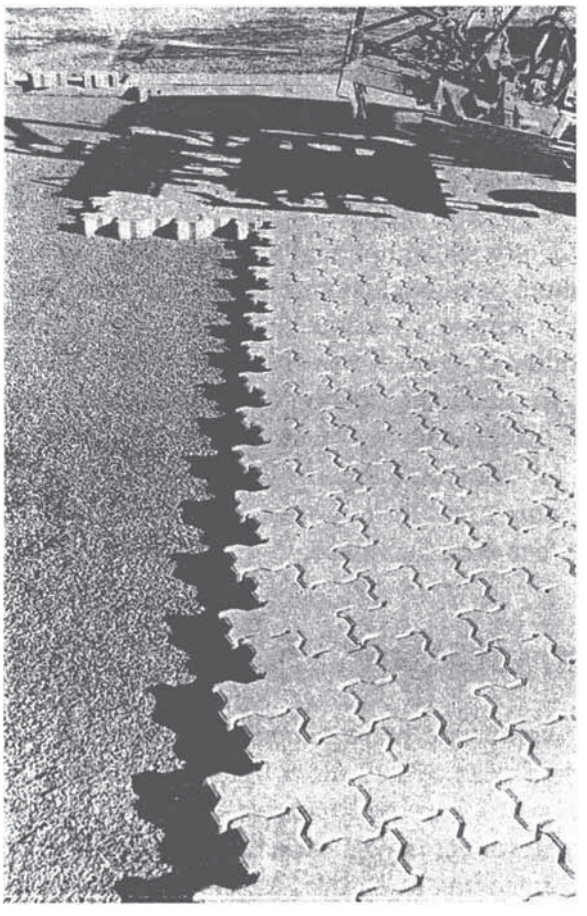


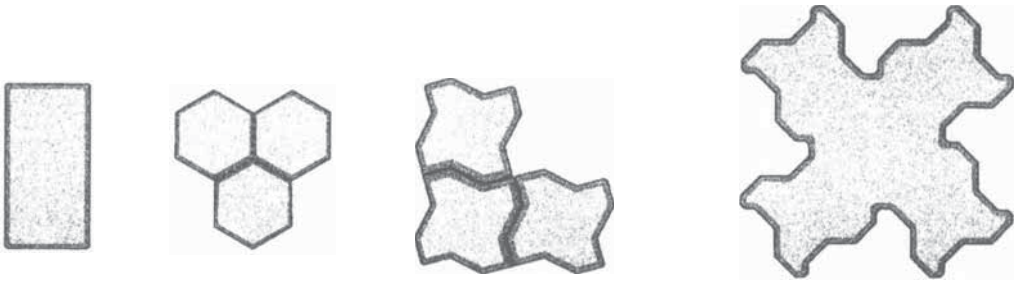
Photo 3. X-shaped Pavers Offer a Heavily Dentated Profile for Positive Location.



Photo 4.Maintenance of Straight Laying Lines and Consistent Joints.

5. COMPARATIVE STRUCTURAL PERFORMANCE OF PAVER DESIGNS

The effects of paver shape on performance of machine laid pavers have previously been examined by Hodson and Emery [1], particularly in terms of geometric assessment. However, recent comparative trials carried out at the University of Newcastle, UK, using the NUROLF rolling load facility provide a practical demonstration of performance benefits related to some paver shapes specifically designed for machine laying. Trial results are recorded in 'A Report on the Performance of Pavers for Mechanical Installation' [2]. For these tests, four pavers commonly used in machine installation were selected as shown in Figure 1. The 'footprint' areas of the pavers are listed in Table 1.



Type I Type Y Type L Type X

Figure 1. Machine Laid Paver Types Tested

Table 1. Comparison of Paver 'Footprint' Areas

Paver Type:	Area ('000 mm2):	Ratio (to rectangular):
I (rectangle)	20	1
Y	26.25	1.3
L	38	1.9
X	63.28	3.16

Pavers were laid in consecutive areas 2.5m square on the following construction:

80mm thick pavers
30mm laying course material
150mm lean concrete road base material
250mm D.Tp. Type 1 granular sub-base material

Each of the paver types was subjected to channelised full scale wheel loading up to 130,000 cumulative standard axles with the NUROLF facility, shown in Photo 5. During its load cycle, NUROLF applies a vertical wheel load of 7000kgf through its offside wheel to the centre of the test area (Photo 6). It commences a cycle at one end of the site, accelerates linearly over the full test site and decelerates at the end. In so doing, it applies a horizontal force of 700kgf, always in the same direction, to the pavement. The combination of 7000kgf vertical load and 700kgf horizontal load represents the heaviest loading to which a pavement would be subjected. To simulate the most adverse combination of traffic and climate the test area remained saturated during testing. At intervals, detailed surveys of the trial areas were carried out using a set of 20 Linear Voltage Displacement Transducers connected to a local computer. At the end of the trafficking trials, pull-out tests were executed with a rig which allowed the applied force and displacement of the paver to be measured. Neighbouring pavers were held in place by application of the test equipment's reaction load.



Photo 5. Trial Paver Areas at the NUROLF Facility

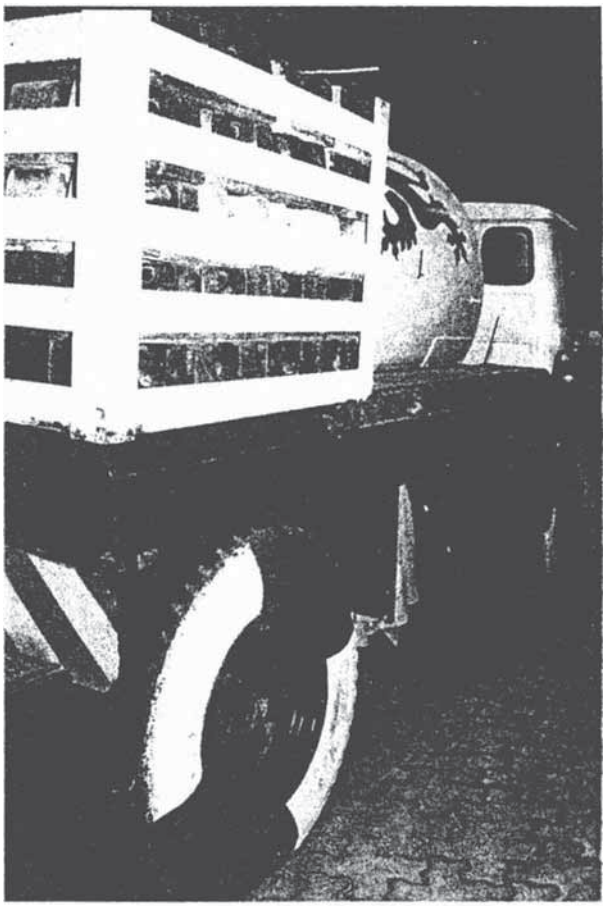


Photo 6. Heavily Loaded Rear Wheel of NUROLF

Firstly, the trials clearly demonstrated the capabilities of larger pavers, such as Type X, to withstand substantial loading and trafficking without breakage. Considerable data was collected during the trials and summary results for maximum rut depth (Table 2) and pull-out forces developed at a displacement of 1.5mm (Table 3) are included here. The pavement base was designed to ensure that it remained undeformed, yet allowed sufficient elastic deflection for the pavers to demonstrate their interlocking properties. The deformations measured are all a result of the laying course material having either degraded or migrated which is dependent upon the stresses imposed. Therefore, these deformations are a measure of the stress attenuation achieved by each of the test paver areas. From Tables 2 and 3 it can be seen that the type X paver develops greater interlock, provides enhanced resistance to vertical loads and achieves greater levels of stress attenuation. This can be interpreted in terms of the type X paver providing extended design life, with resultant lower whole-of-life cost, or particular suitability for heavy duty applications, such as channelised traffic.

Table 2. Maximum Rut Depth Developed in the Test (at 130,000 c.s.a.).

Paver Type:	Deformation (mm):
I (rectangle)	3.3
Y	3.2
L	3.0
X	2.8

Table 3. Pull-out Forces at 1.5mm Deformation

Paver Type:	Pull-out Force (kN):
I (rectangle)	11.6/12.8
Y	9.3
L	11.6
X	13.4/14.0

6. CASE STUDY - MACHINE INSTALLATION AT HAKODATE AIRPORT

Many of the techniques described above have been utilised during the recently completed construction of an air-side pavement at Hakodate Airport, Hokkaido, Japan. This was the first known use of interlocking concrete pavers for an airport pavement in Japan and provides a particularly interesting case study of the latest machine laying techniques. A summary of a report supplied to the authors by Ueda Co., Ltd., manufacturers and installers of the concrete pavers used, now follows.

Hakodate Airport opened in 1961 and in 1997 it handled over 2,420,000 passengers and 10,600 aircraft operations (takeoffs and landings). The runway was extended to 3,000m in April 1999 and the airport now services 16 domestic destinations and one international route. A variety of large aircraft, including the Boeing 777-300, which exceeds 70 meters in length, transit the airport. In response to increasing demand for air traffic and a shifting of the airport facilities' mission requirements, various upgrades and expansions to the terminal area, including the apron stand, have come under consideration. One such project was the upgrade and refurbishing of the ground service equipment (GSE) passageway, an area totalling 3,800 m2 (190m x 20m).

When originally constructed, the GSE passageway was topped with an asphalt pavement. However, since trafficking by airport vehicles was causing increasing rutting and unevenness, it was concluded that resurfacing with asphalt would not be appropriate. Two alternative materials, a cement concrete pavement and an interlocking concrete pavement, were considered. In the end, the interlocking concrete pavement was selected based on two strengths: 1) GSE passageway closures could be localised and then quickly reopened, as work was restricted to night hours (8:00 p.m. - 7:00 a.m.) in which the passageway was not in use; 2) follow-on maintenance requirements would be minimal. Due to the very tight time constraints under which the actual construction had to be conducted, it was decided to seek improved efficiency by using paver laying machines in lieu of conventional manual laying.
With nominal dimensions of 337.5mm by 112.5mm, the XeneX pavers (shown in Figure 2) selected for this project were larger than typical interlocking concrete pavers. The unique XeneX design combines a heavily dentated profile with an X shape to generate superior interlock and provide enhanced resistance to both horizontal and vertical loading. A herringbone pattern with a 45-degree offset was employed to achieve maximum resistance to turning and braking forces. The XeneX pavers also have the advantage of being easy to install in manufactured clusters of approximately Im^2 using the simplest of clamping systems. When lifted, the XeneX pavers lock together to prevent displacement, further easing and accelerating installation.

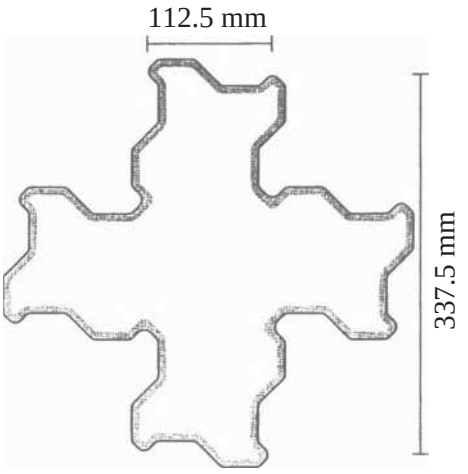


Figure 2. Plan of the XeneX Paver

The quality of the bedding and joint sand and the care taken with its application have a direct effect on the stability and long-term performance of any interlocking concrete pavement. Therefore, the sand selection process went well beyond simple size gradation considerations. To ensure the pavement would realise its full potential, rigorous preliminary testing included, for example, an impact compaction test to identify sand that could withstand anticipated load factors. Only high-grade natural sand that passed this test was used for bedding and joint sand. The relationship between moisture content and unit weight was also investigated. This relationship yielded an optimum sand moisture content upon which quality control parameters could be established. Bedding sand moisture content was correspondingly adjusted at a ready-mix concrete plant adjacent to the airport, and the treated bedding sand was stored in bags. The bags could then be opened on an as-needed basis and applied using an asphalt finisher (Photos 7 and 8). Optimum workability of the joint sand was achieved by drying it at a nearby asphalt plant and then trucking it to the construction site on a just-in-time basis for application.

To avoid hindering airport operations, the GSE passageway was divided into 10 construction sections. Construction was confined to a single section at a time, and work could not advance to the next section until the previous section was completed. In each section the existing pavement was removed, a new base formed and the paver pavement laid. Due to this segmented approach, the project took longer than one might expect if only the 3,430m^2 surface area was considered. The segmented work also resulted in increased costs. This also meant that the asphalt finisher could not be used to full effect when spreading and screeding the bedding sand. Nevertheless, the bedding sand's compacted density reached 81% and its levelness was outstanding. It can therefore be assumed that asphalt finishers will prove to be very effective in projects dealing with large surface areas and will effectively minimise the amount of manual finishing labour required. Furthermore, in cases where the base course is to be asphalt-stabilized, using an asphalt finisher to lay down both the base course and the bedding sand will increase the machinery’s effective working day ratio.

The pavers were installed using a dedicated, powered installation machine with hydraulic clamp (Photo 9). This could accommodate Im^2 “clusters” of pavers for each operation. Optimum laying rates for this arrangement were not achieved due to the sectional nature of the work. After the paver installation was completed in a section, the surface was covered

with a buffer mat to prevent spalling and compacted with a 7-ton vibrating roller (Photo 10). Through previous testing it had been determined that a nearly complete compaction could be achieved with one back-and-forth pass of the roller in non-vibrating mode and three back-and-forth passes in vibrating mode; a procedure followed for this project. The pavement surface height was measured at each survey point before and after compaction to determine the degree of bedding sand settling. In addition, a paver was removed after the final rolling compaction and the bedding sand density was measured. As with the earlier testing, little additional settling was noted in the bedding sand upon the third pass with the roller and its average density was found to be 94%. The pavement was therefore deemed stable.The actual filling of the joints was done with a laying machine-mounted fill brush (Photo 11).

Sealant stabilisation of the joint sand after final compaction is a vital element of any airport interlocking pavement construction. A urethane prepolymer sealant, Resiblock 22, was selected for this project. This was chosen due to its excellent resistance to oil and fuel, its ability to retain its flexibility in almost any type of weather, and its proven performance in projects overseas. The sealant was applied during days in which the temperature remained over 50C and the weather was fine. Spread manually, it was applied evenly at a controlled rate of 2 $1/m^2$ using a squeegee-type mop, and special care was taken to work it into the joint areas (Photo 12).

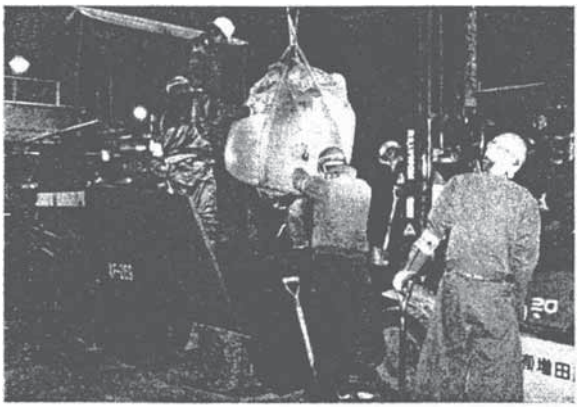


Photo 7. Loading Bagged Sand into the Asphalt Finisher.



Photo 8. Installing the Laying Course.

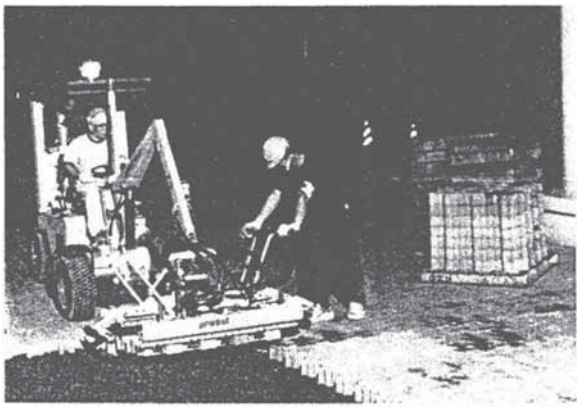


Photo 9. Machine Laying the XeneX Pavers.

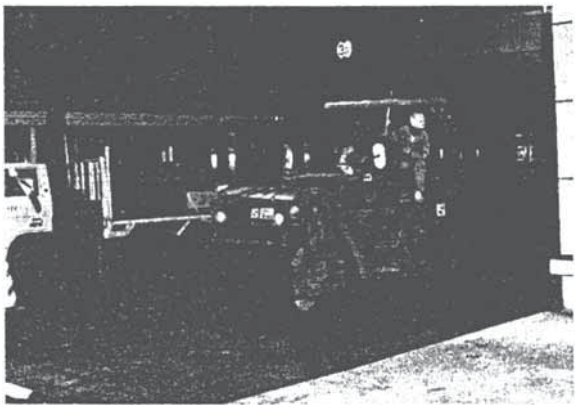


Photo 10. The Vibrating Roller in Operation.

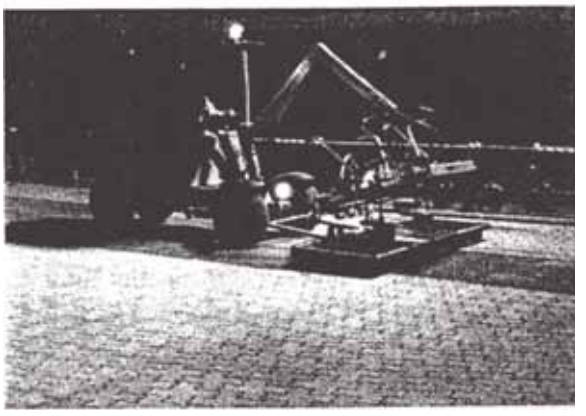


Photo 11. Machine Mounted Brushing -in Equipment.



Photo 12. Applying the Joint Sealant.

In this project, the use of interlocking pavers to resurface the GSE passageway presented an interesting contradiction. On the one hand, the work could be performed during the limited night hours, making pavers a tailor-made solution. On the other hand, because ongoing use of the passageway mandated dividing the site into small, distinct work sections, the work conditions prevented the project from demonstrating the full potential of paver pavement construction. Little time has elapsed since the project's completion, making an in-depth performance evaluation impossible. However as of today the following conclusions can be drawn.

1. The construction of an interlocking concrete pavement can accommodate almost any time constraints.
2. With sufficient compaction, a newly constructed pavement can be opened to use immediately.
3. Asphalt finishers can be used effectively to spread and screed bedding sand. However, the need for a piece of equipment with a smaller footprint clearly exists.
4. The laying machine performed as expected and proved functional in small work areas.
5. A ready-mix concrete plant is an ideal facility for preparing bedding sand with optimal moisture content. However, a mobile mixer can also be used. It cannot be over stressed how important controlling bedding sand moisture content is to the pavement's durability.
6. A large vibrating roller is almost a necessity to ensure the pavement's durability and to achieve a good finish with surface regularity.
7. The XeneX pavers used in this project is are suitable for machine laying and demonstrate superior interlock. It is also expected that maintenance costs will be reduced.
8. Unlike cement concrete or asphalt pavements, XeneX pavers provide eye-pleasing variety to the pavement surface.
9. The importance of proper edge restraints is paramount. In this project, two types of temporary restraints were employed, steel angles and square logs, and both were found to be fully functional.
10. Buffer mats were found far superior to a covering of joint sand when compacting with the large vibrating roller, both in terms of minimising spalling and reducing the need for follow-on labour.

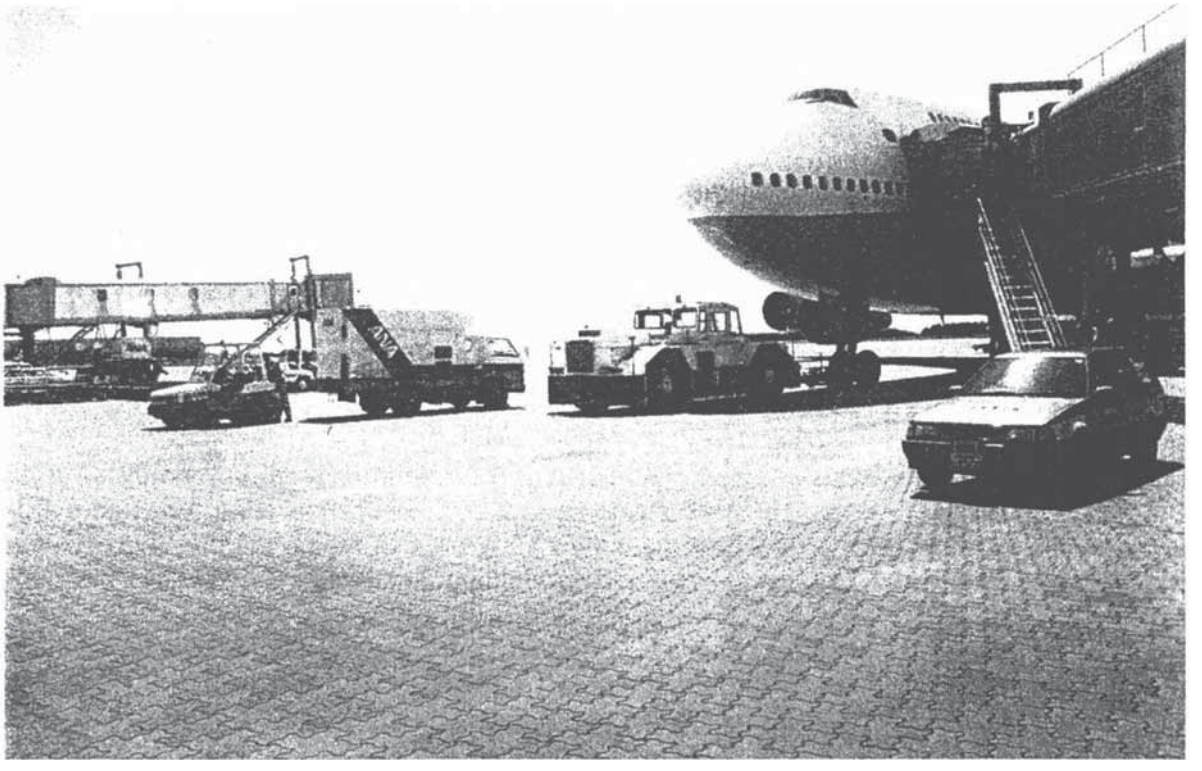


Photo 13. Completed GSE Passageway Pavement in use.

An interlocking concrete pavement proved very suitable to the various restraints that this project involved. Although work was limited to short nighttime hours, it was still possible to reopen work sections the following morning in such a way that airport operations were not hindered. Thus, the project demonstrated machine installed interlocking concrete pavers' tremendous suitability to projects involving tight work restrictions. In addition to airports, these pavers can clearly be used on roads and in other applications where the construction site's ongoing use must be considered. It has also been proven that the XeneX interlocking concrete paver system is suitable for mechanical installation. It is further expected that these pavers will demonstrate superior interlock and outstanding resistance to both horizontal and vertical loading. The system should therefore be considered suitable for other airport GSE passageway, apron, and taxiway pavement projects, as well as for roads and container yards subject to heavy vehicle traffic. With rapid machine installation now a reality, interlocking concrete pavements will also demonstrate genuine advantages where the pavement is being newly constructed.

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1. Hodson, C. and Emery, J. (1996) Advances in Mechanically Laid Pavers, Proceedings of the 5th International Conference on Concrete Block Paving, pp.225-235.

2. Knapton, J. (2000) A Report on the Performance of Pavers for Mechanical Installation, University of Newcastle upon Tyne, UK.