A SURVEY OF AUSTRALIAN CONTAINER PORT PAVEMENTS SURFACED WITH CONCRETE SEGMENTAL PAVING

Shackel, B., Pearson, A. and Holt, W.

School of Civil and Environmental Engineering, University of New South Wales, Queensland, Australia.

ABSTRACT

This paper presents a study of concrete block pavements (CBP) currently in service in four major ports along the Eastern seaboard of Australia. Eleven pavements built over a wide range of subgrades and fills were studied. Structural and service details of the pavements are given in the paper. The pavements had been in service for periods ranging up to about 20 years. Each of the pavements was designed for container handling operations. Loads ranged from those applied by front lift trucks, straddle carriers and transtainers to various heights of container stacking.

The study looked at factors influencing serviceability and maintenance. These factors included surface rutting and damage to pavers caused by traffic and container stacking, settlement movements and the choice of pavement and drainage details. An assessment of both the severity and extent of factors necessitating pavement maintenance is then presented. Finally, factors needing more emphasis during design and in the detailing of CBP for heavy industrial use are identified and discussed.

1. INTRODUCTION

Concrete block paving (CBP) has been used successfully in Australian ports for more than 20 years. Much of this experience has been summarized elsewhere (e.g. Shackel, 1982; Oldfield, 1992). Moreover, Australian ports were amongst the first Australian organizations to sponsor and collaborate in research into the effective use of CBP under heavy industrial loads (Shackel, 1986). Recently the Concrete Masonry Association of Australia (CMAA) decided to review the performance of CBP in several of the biggest ports in Australia to assist in developing new Australian Standards, Codes of Practice and Design Methods for CBP in industrial areas. This involved walkover inspections of major port pavements located on the Australian Eastern seaboard ands discussions with port engineers, design consultants and paving industry representatives. The pavements were representative of large container facilities.

All of the pavements were performing satisfactorily although the maintenance engineers in one port had expressed concerns about performance to the local paving industry. Nevertheless, as a result of the various inspections it became clear there were some common forms of distress in all the pavements. However, with one exception, this was not cause for concern by the pavement owners/operators because it was not severe enough to impact on pavement serviceability or maintenance costs.

In this paper, case histories for the various pavements studied are summarised and the forms and severity of the observed distress mechanisms are listed. The likely causes of the observed pavement distress modes are then discussed.

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It is important to note that no criticism of design or construction recommendations or procedures is intended or implied in any of the comments that follow. Rather, the paper seeks to identify common problems and, i*nter-alia*, to propose solutions to some of these.

2. CASE HISTORIES

2.1 Design

Discussions with various port engineers and design consultants showed that key design considerations for CBP included:

- The necessity of good surface drainage
- Reliability
- The need to achieve relatively flat stacking areas for containers.
- Ease of maintenance

Common design problems included:

- The need to construct pavements over low strength subgrades or poor quality fills
- Changes in the mode of operation or type of container handling vehicles that take place after construction
- The need to cope with ongoing settlement
- The choice of suitable pavement and drainage details

2.2 Pavement Details

Details of the 11 concrete segmental pavements used in the four facilities surveyed are summarised in Table 1. Although the precise design TEUs or load repetitions are not available for the various facilities it should be noted that for Facility A the expected traffic is only about half that expected in Facilities B, C and D but the stacking height of containers is slightly higher (4-high compared to 2 to 3-high elsewhere)

Table 1 shows that the most common type of basecourse was granular material such as crushed rock often modified by small amounts of cement to improve the plasticity. Only one pavement used cement-treated base and none of the pavements were based on the exclusive use of cement stabilized materials although this can often provide thinner and more economical pavements than where granular materials are chosen.

Several pavements (1, 3 and 11 in Table 1) used cement stabilized sub-bases beneath granular basecourses. This might be argued to be poor practice because it has the tendency to prevent water draining from the basecourse and, thereby, to impair the in-service performance of the base materials. In asphalt pavements this so-called “upside-down” design is often used to minimise shrinkage cracks in the sub-base reflecting through to the surface. Such a design is not, however, required in concrete block pavements. Rather, in respect of the base, the use of cement modification would have improved the plasticity but would not have rendered the base impermeable. Without provision for draining the base this is likely to have led to the pervious basecourses serving in wet conditions which would have been expected to have led to sub-optimal performance.

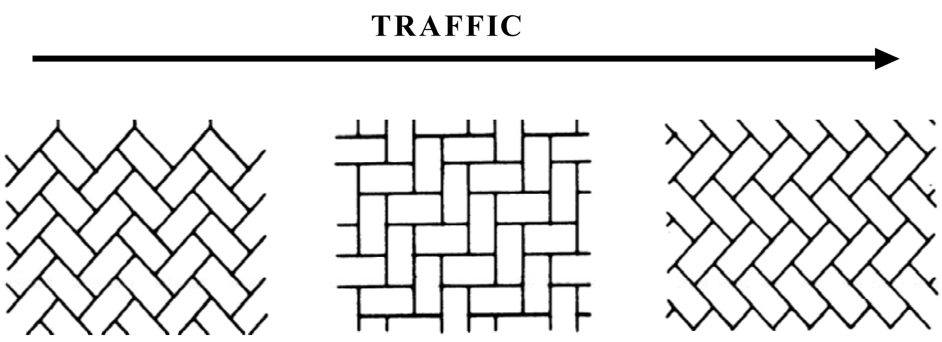
In all cases, the pavers comprised hand-layed 80mm thick shaped Category A pavers installed in herringbone pattern. It was observed that the orientation of the pattern with respect to the dominant direction of traffic was not always optimal. Tests have shown that the direction of the herringbone pattern has an influence on performance (Shackel, 1990). With reference to Figure 1, pattern (a) has been shown to be associated with less rutting than pattern (b).

This in turn performs better than pattern (c). In road pavements the bond orientation has any practical effect on in-service performance but should be considered for industrial pavements carrying heavy loads.

Table 1. Pavement Details and Thicknesses (mm).

FACILITY	**A**			**B**					**C**		**D**
Identification No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Operational Mode	FLT	SC + TT	SC + TT	SC + Trucks	SC + Trucks	SC + Trucks	SC	SC	SC	SC	SC
Pavers	80	80	80	80	80	80	80	80	80	80	80
Bedding Sand	25	30	25	20	20	20	20	20	30	30	20
Unbound Granular Base		280							200-250		140
Cement modified granular base	100		100	260	370	370	490	560			
Cement treated base										250	
Granular sub-base									150	170	
Cement treated sub-base	150		280								400
Granular working platform	100		100								
Fill materials	Sand Over Mud	Sand Over Mud	Sand Over Mud	-	-	Granula r	-	-	sand	sand	-
Subgrade CBR (%)	15-20	15-20	15-20	>25	>5	>25	>5	>5	16-25	16-25	15

SC = Straddle Carrier TT = Transtainer FLT = Front Lift Truck



(a) (b) (c)

Figure 1. Orientation of herringbone pattern relative to traffic with (a) best and (c) worst.

By referring to Figure 1 it may be seen that, for the pavement shown in Figure 2, the orientation of the herringbone pattern to the left of the drain with respect to the dominant direction of trafficking was the least advantageous possible. Here, rotation of the bond through 90º would have acted to reduce rutting under traffic caused by the transtainer. Inconsistently, the pattern show to the right of the drain in Figure 2 is optimally aligned for transtainers or straddle carriers moving along the container rows. Although the pavements were not specifically designed for transtainer operation this demonstrates the need to take care when establishing the orientation of laying patterns during design and construction and is discussed further below.

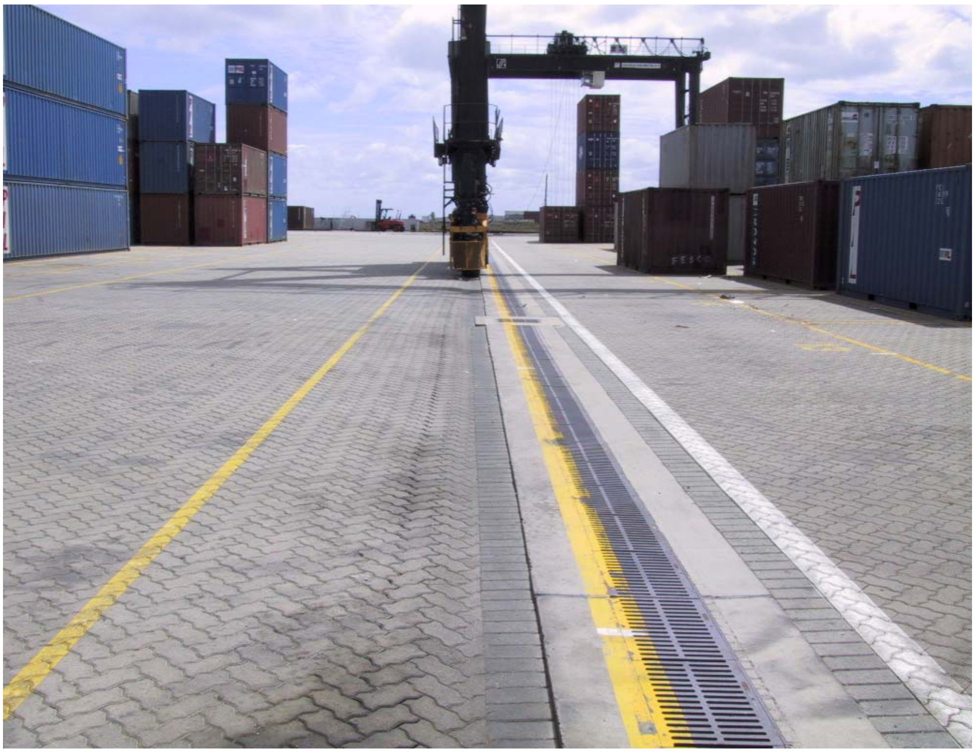


Figure 2. Pavement to right of drain is optimally orientated for straddle carriers whilst pavement to left is sub-optimal for the transtainer movements.

In many of the pavements studied the mode of operation was changed after the pavements entered service. This appears to be a common occurrence in container yard operation. In several facilities, the pavement was originally designed for front lift trucks but that, subsequently, the mode of operation was changed to straddle carriers. These two modes of container movement operate in different directions. This illustrates the need to consider orientation of patterns that will accommodate changes in the operational mode. If the mode of operation cannot be accurately forecast or is likely to change then it would be prudent to select orientation (b) in Figure 1 as the preferred direction of installing the pavers.

Table 2. Summary and Ranking of Distress for Ports A to D.

DISTRESS TYPE	EXTENT		SEVERITY		RANK
	Minor	Extensive	Mild	Severe	*
Settlement at Intrusions	C	A	C	A	+++
Damage to Intrusion Surrounds	B C	A	B	AC	++
Settlement at Edge restraints	B C	A D	B C	AD	+++
Damage to Edge Beams & Restraints	B S	A	B C	A	+
Pavement Rutting		A	B		+++
Pavement Subsidence	D	A	W	A	+++
Lipping of Pavers †	B		B		+
Cracking of Pavers in Trafficked Areas	B	D	B D		+
Damage to Pavers by Container Feet	B C D	A	B C D	A	+
Wear of Paver Surface	B C D	D	B C D		+

* Ranking in terms of effects on serviceability or maintenance costs

† Lipping was found only in areas that had been relifted/resurfaced

3. PAVEMENT DISTRESS

The principal forms of distress are summarised in Table 2 for all the port pavements studied (here +++ indicates a greater importance than +). This table sets out a subjective assessment of the extent and severity of each distress mode and a ranking of the distress modes in terms of their impacts on serviceability or maintenance costs.

From Table 2 it may be seen that some types of distress were common to all of the pavements. These included settlements and damage at restraints or intrusions and paver damage caused by container feet. However, it is important to note that, in most cases, the distress was largely cosmetic i.e. visible during inspection but having little or no impact on pavement serviceability. The principal distress modes are now discussed in detail.

3.1 Settlement Damage.

Settlement of the underlying fills was evident to a various degrees in all the pavements studied. Settlement could be distinguished from vehicle induced rutting because it was usually widespread rather than localised. Where pavements exhibited depressions these had often been patched with asphaltic concrete. This appears to be because maintenance engineers regard this as both quicker and cheaper than lifting and relaying the pavers

Often settlements were observed both in the body of the pavement and also next to intrusions such as drainage pits. The settlements in the main body of the pavements typically did not appear as ruts but, although localised, were more widespread. Without excavating the pavement it was not feasible to determine the precise cause of such depressions. However, the distress was indicative of differential settlement or the possible presence of mud lenses in the fill.

A problem in most of the facilities studied was differential movement between pits or drains and the pavement surface or between pavers and concrete slabs or wharf areas. Differential settlements between piled structures such as wharves and the adjacent pavements are almost inevitable unless the fills have been sufficiently preconsolidated by surcharging prior to pavement construction. However, pavers have the advantage that they may be easily lifted to allow the substructure to be corrected for settlement. The same pavers may then be re-installed. This is an alternative to the solution of simply overlaying with an asphaltic concrete ramp.

It was found that, in places, backfill to trenches comprised cement-stabilised crushed rock base overlying cement-stabilised sand sub-base. Such rigid forms of construction are likely to settle or deform differentially relative to the adjacent pavements. Furthermore, occasionally, the use of no-fines concrete sections 300 x 300mm or 300 x 240 mm have been specified along drains and around pits. This has been a common detail in CBP roadways but under heavy industrial loads It is unlikely that such no-fines drains will settle or respond to traffic in the same way as the adjacent structures or pavements.

In some areas, there was evidence of settlement along drainage lines suggesting that, in places, the backfill may have been insufficiently compacted. In this respect there does not appear to be much agreement about the best way to backfill trenches and both cement stabilized and unbound materials have been specified even within the one facility. Greater consistency in back-filling drainage lines is needed to obviate such problems.

In many instances differential settlements have occurred between paving and drainage pits. Ideally, pavement intrusions such as drainage pits need to be detailed to recognise that movements between the pit and pavement are inevitable.

In addition to settlement problems, pit surrounds have often been damaged by a combination of settlement and traffic. A common detail, adopted from road paving practice, in all the projects visited was to employ a soldier course of rectangular pavers around the pit. As for example shown in Figure 3, this detail does not perform well under heavy industrial loads or in areas of high settlement. In many places pavers had rotated and fractured and, in some instances, had been dislodged. New pit surround details, omitting the soldier course, need to be used for industrial segmental paving.

Figure 3. Damage to pit surrounds.

It appears that often compaction adjacent to pits in has been by Wacker Packer in contrast to the rollers used elsewhere on the pavements. This may have contributed to the differential movements observed at pits. This emphasizes the need to control both compaction and the choice of backfill materials adjacent to intrusions.

Soldier courses of rectangular pavers have also been used along slot drains and at yard entrances. Sometimes this has caused problems. For example, as shown in Figure 2, the soldier course may be seen to have been installed along the wheel path of a transtainer. This cannot be considered a good detail because, as noted above, it is documented (e.g. Shackel, 1990) that both rectangular pavers and stack bonds are associated with poor performance under traffic. Consequently pavers in the soldier course rotate and creep under traffic. Overall, based on this study it must be concluded that the use of pavement details developed for roads are not generally suitable for industrial pavements and more specific details need to be redesigned

During the various inspections it was noted that cracking of edge beams and restraints was fairly common. Better details for such beams and restraints and their foundations are clearly needed. Because the beams are usually very long and much of the damage is localised it may be appropriate to supplement the normal reinforcement in such beams with steel fibre reinforcement. This would also improve impact resistance.

3.2. Pavement Damage

The principal forms of pavement damage were traffic-induced ruts and cracking, lipping and damage to pavers caused by container stacking.

3.2.1 Rutting
Overall there was comparatively little rutting in any of the pavements visited. Where deformations were evident they were generally associated with localised differential settlement. One exception to this was observed where, as shown in Figure 2, extensive rutting had been caused by transtainer movements running parallel to a drain. As noted above, this was also an area in which differential settlement had occurred along the drain and the herringbone pattern of the pavers was orientated in the least advantageous direction relative to transtainer movements. Moreover, the wheel path of the transtainer ran parallel to a soldier course of rectangular pavers placed adjacent to the drain. For these reasons much of the deformation can be attributed to settlement and the detailing of the pavement rather than to traffic-induced rutting alone.

3.2.2 Cracking
In several of the pavements studied, cracking of the pavers was observed. In this respect, cracking was largely a cosmetic problem and did not affect the pavement serviceability. It was noted that cracking was most common in pavers laid over cement-stabilised bases. In some cases, however, the cracking was indicative of the pavements showing higher than expected transient deflections under traffic. Elsewhere, the cracking was more localised and appeared to be caused by a soft spot in the pavements sub-structure.

Whilst cracking is primarily an aesthetic problem it should be recognised that it may also be indicative of excessive transient deflections in the pavements caused by inadequate pavement thickness. Excessive deflection or deformation can also lead to damage at paver contact points.

3.2.3 Lipping
Lipping was not a widespread problem in any of the pavements inspected. Minor lipping was, however, observed in some areas of paving that had been reinstated. In the pavements studied, lipping had no impact on pavement serviceability

3.2.4 Paver Wear
Generally there was only slight wear to the pavers in any of the pavements inspected. Whilst wear was sufficient to expose some aggregate it was not significant enough to impact upon pavement serviceability. In other words the wear was largely an aesthetic phenomenon.

3.2.5 Damage by Container Feet
Worldwide it has been reported that no form of pavement including asphalt and reinforced concrete has proved immune to damage by containers. Indeed, in some European container yards such as the ECT, Rotterdam, it is common to eschew the use of any conventional surfacing and, instead, to use large sized crushed rock for container stacking. Judged by such criteria the damage observed in the Australian facilities was generally minor. The most severe example found during the study is illustrated in Figure 4.

Damage such as that shown in Figure 4 is largely cosmetic and can be completely and easily repaired if necessary, by removing and replacing just a small number of pavers. The sole impediment of serviceability is the tendency of the damaged areas to pond water. This, rather than the paver damage *per se,* provides the prime cause for maintenance to be required.

4. DISCUSSION

The container yards selected for study although those in Facility A were generally younger and were designed for only about half the numbers of container movements expected in the other ports.

They were all surfaced with 80mm category A pavers laid in herringbone bond and had similar modes of operation in terms of container handling machinery and axle loads although container stacking in Facility A was often 4-high compared to the 2 to 3-high stacking more common in elsewhere. In both Ports A and B the pavements were entirely located on reclaimed land with sand or granular fills overlying weak silts. On most of the sites the sub-surface drainage might fairly be described as nominal.

Figure 4. Damage caused by container stacking.

Overall, the pavements were performing satisfactorily. Whilst, for completeness, this paper details every form of pavement distress that was observed during the walkover inspections, many of these were essentially aesthetic i.e. they were visible to the trained eye but had little or no adverse impact on pavement serviceability or maintenance costs. In this respect, defects such as cracking, lipping or abrasion wear of pavers were of little practical concern. One possible exception to this was the paver damage caused by container corner posts. Here small areas were created where water may pond on the pavement. However, such damage was far less severe than that normally found in asphalt pavements and, as noted above, could easily be rectified by replacing the damaged pavers.

Despite the range of subgrade conditions and loads the various pavement designs summarised in Table 1 showed little evidence of traffic-induced deformation. Rather, the most significant form of distress was damage at drains or edges caused by differential settlement. Overall, there was relatively little pavement distress that could be attributed solely or directly to vehicle movements or to the choice of pavement type or thickness. However, there was occasional evidence of deformation along drainage lines and of localised soft spots in the pavements possibly due to inadequate compaction.

The problem of differential settlement between pavements and drains is that the pavement usually settles more than the drain. In this respect, the use of cement-stabilised sand as backfill surrounding the pit to the full depth of the drain largely overcomes the difficulty of achieving proper compaction adjacent to the drain.   Also, the inclusion of Plazadeck vertical drains between the pavement and the drainage structure minimises the chances of the pavement wetting up adjacent to the drain and, thereby, reduces the likelihood of settlement or traffic-induced deformation at the drain. Such details were observed to be performing well.

In one facility differential settlement problems were not confined to the immediate vicinity of drainage pits but tended to be more widespread. Accordingly it may be necessary to consider other treatments such as dynamic consolidation of the fill and/or the use of impact rollers to compact the subgrade. Both of these techniques have a proven history in the improvement of reclaimed land. Occasionally, pipe backfill materials do not appear to have been consistently matched to the adjacent pavements. Some differential movement adjacent to drains is, therefore, to be expected.

One common problem observed in all the facilities concerned the surface detailing of the paving at pits, drains or edge restraints. Here, following established good practice for CBP road pavements, rectangular pavers laid in soldier courses were used to form edge details. However, as noted above, these were not, in general, performing as well as the adjacent pavements. Details specific to heavy-duty paving need to be developed

Again, following good practice for CBP in roads, no-fines concrete drains have been installed along some drainage structures and around some pits in industrial pavements. It is not clear whether these details have contributed to the movements observed at such places. However, the suitability of no-fines inserts under high wheel loads, such as those applied by transtainers, needs to be reviewed.

This study suggests that there is a need for designers to be encouraged to give more attention to the orientation of herringbone laying patterns when very heavy wheel loads such as those applied by transtainers are to be carried. As noted above, a common situation is that the mode of operation may change after the pavement enters service e.g. from FLT movements to straddle carrier operations. In such cases, where a change in operation mode may occur, it would be best to choose Pattern (b) in Figure 1 rather than the more optimal pattern (a).

5. CONCLUSIONS

This study has shown that overall CBP pavements are performing well in Australian container ports. Thickness design does not appear to be an issue although, arguably, some economies might be achieved by encouraging a wider use of cement-stabilized base and sub-base materials. However, there is room for improvement in respect of the construction methods and choice of detailing so that maintenance costs are reduced.

The main conclusions of the study were:

- All pavements had been layed using shaped 80 mm Category A pavers installed in herringbone bond. No other shapes, thicknesses or patterns had been used except in edge details. In general the serviceability of these surfacing was high.
- Designers and specifiers appear not to understand the benefits of orientating herringbone patterns optimally to the traffic direction. Whilst the consequences of this are minor, more attention need to be paid to ensure that pattern orientations are chosen to minimize the likelihood of pavement distress.
- A variety of pavement materials had been used. Amongst these the use of cement-modified granular materials was the most common. These contained only sufficient cement to control the plasticity of the material. Surprisingly little use had been made of cement-stabilized materials despite the economic advantages these might be expected to yield.
- There was little or no traffic induced rutting in most of the facilities examined. Where rutting did occur it was of only mild severity.
- The most common form of pavement distress was localized areas of subsidence arising from differential settlement in the fills underlying many of the pavements. This, rather than traffic, was the most widespread cause of damage to the pavements.

- The most widespread problem was differential settlement adjacent to wharves, drainage pits or lines. Anecdotal evidence suggested that this was due to inadequate compaction of the backfill around such intrusions and, sometimes, to poor detailing of the pit structures.
- The second most common problem was damage to pit surrounds, edge beams and drains. This appears to be due to inadequate compaction and poor detailing of such areas.
- Where subsidence or settlement occurred it was more common for the pavement to be patched or overlaid by asphalt than for the pavers to be lifted and relayed. This appeared to reflect a view by maintenance engineers that repair to CBP was unnecessarily complicated or expensive.
- Details at edges, pits and drains that are customary in CBP roads have not, in general, performed well in heavy duty industrial pavements. In particular, soldier courses of rectangular pavers have not given good performance under heavy loads.
- The principal form of damage to pavers was cracking under container corner posts. Nowhere was there evidence of the structural integrity of the pavement being impaired but water often tended to pond at such locations. Usually the facility operators saw no need to repair this form of damage.
- In the oldest pavement studied there was widespread cracking of the pavers. This was, however, largely cosmetic and did not impair the pavement serviceability. The causes of this are likely to have been inadequate pavement thickness or the use of pavers of lower strength than those commonly specified today.
- Lipping was not widespread and appeared only to a minor degree in pavements which had been lifted and relayed during maintenance. This was normally not severe enough to require maintenance.
- There was minor evidence of abrasion wear in some older pavers. This was entirely cosmetic in nature and did not require replacement or repair. It is doubtful whether such pavers would meet current Australian Standards for abrasion resistance.

Overall, the pavements studied were performing satisfactorily. Nevertheless there was a widely held view that maintenance of CBP pavements was more complicated and expensive than it need be. Some of the causes of pavements distress are beyond the control of the pavement engineer but, rather require better attention to the uniformity and compaction of the fills and to better control and prediction of differential settlement. Nevertheless, .there is a need to prepare better design recommendations for industrial CBP than currently exist. Such recommendations should give attention to developing details for drains, pits and edge restraints that are specific to industrial traffic as there is evidence that current good practice for road applications of CBP do not always perform well under heavy wheel loads. More attention also needs to be paid to design recommendations that minimise the consequences of differential settlements within industrial pavements. This includes the choice of the pavement sub-structure, trench backfilling and the methods used to compact fill and subgrade materials. Greater attention to sub-surface drains may also be warranted.

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Shackel, B., Pearson, A. and Holt, W.

School of Civil and Environmental Engineering, University of New South Wales, Queensland, Australia.

CURRICULUM VITAE
Brian Shackel

Professor Brian Shackel worked in road, municipal and bridge engineering before taking an appointment at the University of New South Wales, Sydney, Australia where he was Head of the Department of Geotechnical Engineering and Director of the Munro Centre in the School of Civil Engineering before accepting his current visiting appointment.

He joined the National Institute for Transport and Road Research, CSIR, South Africa, as Senior Chief Research Officer whilst on extended leave from his university post. and has held numerous appointments as a guest or visiting professor to institutions including the Technical Universities of Vienna, Delft and Copenhagen, the Danish Road Institute and Tokyo and Nihon Universities, Japan

Dr. Shackel has lectured on pavement design and construction in 22 countries worldwide including repeated visits to Europe, the USA, Canada and South Africa. His book "The Design and Construction of Interlocking Concrete Block Pavements" has been translated into Japanese, German and and Hungarian. Further books are in preparation.