SOME FACTORS AFFECTING SUCCESS AND DISTRESS IN SEGMENTAL CONCRETE BLOCK PAVEMENTS IN AUSTRALIA

A. R. Pearson
Executive Director
Concrete Masonry Association of Australia
and
J. R. Hodgkinson
Senior Engineer, Roads and Pavements
Cement & Concrete Association of Australia

SUMMARY

Segmental concrete block paving has been in use in Australia for approximately fifteen years. It's application has ranged from pedestrian areas to roads and streets to heavy duty industrial pavements. Factors affecting the construction and performance of segmental concrete block pavements include site investigation, assessing design loads, thickness design, materials selection, construction practice and supervision.

This paper discusses important aspects of materials selection and construction quality with an emphasis on practical applications. A number of Australian projects are referenced to illustrate aspects of construction quality which have affected success and distress. Several types of projects are discussed to emphasise the universality of construction guides and specifications to minimise distress. The paper also discusses the question of construction supervision and its role in the overall quality of the project.

1 . INTRODUCTION

Since the mid 1970's segmental concrete block paving has been used in a wide range of road and industrial applications in Australia. By 1980 total national usage had reached about 2,000,000m^2 per year, and by the mid 1980's usage had risen to about 7,000,000m^2.

In the large majority of this inventory performance has been good. However, there are documented instances where this is not the case. The basic intention of this paper is to identify the key issues which have affected the success or problems in Australian segmental concrete block pavements.

Much discussion in the past has centred on the development of design models and thickness design procedures. The success of a pavement is equally, if not more dependent on other factors, such as adequate site investigation, the selection of materials and construction practice. This is not to deny the importance of adequate thickness. However, in many cases where distress has occurred, there has been an inclination to investigate alleged lack of thickness as a primary source of distress to the detriment of other contributory factors.

As a result of experience in Australia over 15 years and by reference to difficulties which are known to have occurred, contrasts between success and distress are illustrated. Discussion includes site investigation, estimating loads, selection of materials, construction practice, detailing and supervision.

It can be rightly argued that many of these factors apply equally to other forms of pavement construction. However the authors are aware of perceptions that the surface layer of paving blocks may be able to compensate for deficiencies in the underlying pavement structure. This paper emphasise the fact that the performance of the pavement will be no better than the total quality of design and construction.

Supervision is all too frequently seen in terms of its construction cost only. The authors are of the firm view that experience has demonstrated that the cost and disruption to operations caused by distress resulting from lack of supervision is far greater than the cost of supervision in the first instance.

2. PAVEMENT STRUCTURE

Segmental concrete block pavements usually consist of three layers: surface, basecourse and subgrade. On low-strength soils a further layer ie sub-base or an improved subgrade/working platform, may be required. The layers are described as follows and as shown in Figure 1.

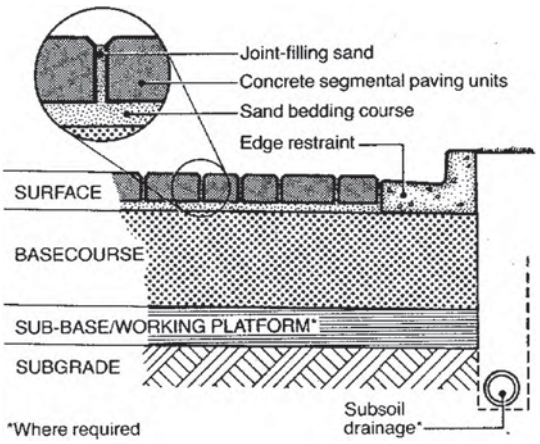

Figure 1 *Interlocking Concrete Pavement Structure*

Surface The surface layer comprises the segmental concrete paving units, a sand bedding course and edge restraints. Gaps, usually referred to as 'joints', between paving units are completely filled with a fine joint-filling sand.

Basecourse The basecourse consists of one or more layers of either high-quality unbound or cement-modified fine crushed rock or natural gravel, or a cement-bound crushed rock or gravel.

Sub-Base/Working Platform With low-strength subgrade soils, a sub-base of stabilised subgrade or other material may be required to provide a firm stable platform on which to construct the basecourse.

Subgrade The subgrade is the prepared insitu soil or fill on which the pavement is constructed.

The construction of a segmental concrete block pavement should not be approached in the expectation that the layer of paving units will compensate for deficiencies in the construction of underlying layers. The effort applied to preparation of the subgrade and construction of the basecourse will be critical to the performance of the pavement.

3. SITE INVESTIGATION

In designing a new pavement the following parameters need investigation in relation to the site:

- Site survey,
- Soil investigation,
- Drainage.

The time devoted to site investigation will of course vary according to the size and status of individual projects and previous experience. However, to meet the design and performance objectives, each of the above areas warrants some consideration.

3.1 Site Survey

Local site conditions that will influence the pavement design include:

- climatic conditions in the region, particularly rainfall,
- the ground-water level and its seasonal influence, ie flood or tidal conditions,
- the soil profile; the nature of the insitu material and its depth.

3.2 Soil Investigation

It is the low strength of most natural soils which requires the construction of a pavement in the first instance. An investigation should be made of the characteristics and the strength of the soil on which the pavement is to be constructed.

The calculation of the thickness of pavement layers requires an accurate assessment of the subgrade strength. The California Bearing Ratio (CBR) is the most commonly used measure of this subgrade strength in Australia. Whilst there remains some technical debate on assigning CBR values for design, most designers use a CBR value based on a soaked laboratory specimen. This is considered to be the best means of simulating long term moisture conditions in the subgrade over the design period.

The soil investigation should be sufficiently extensive to allow soils of differing strengths and properties to be identified. The assigning of an average soil strength based on too few samples can lead to under-designed pavements.

This is particularly so in large industrial pavements, where the site may have been used as a fill repository for various types of waste material over a period. Therefore, it is important to investigate both sufficient locations and the depth of the soil.

Three known problem instances are as follows:

- On one 20ha site, square in shape, only two samples were taken, at diagonally opposite corners. One showed a CBR of 2 of the other 20. Design was based on an average of 10. In-service distress occurred within one year. Subsequent investigations showed that 95% of the site had a CBR of 2.
- One large industrial site had been used for night soil disposal and then filled with rubble. The history of the site was not investigated in detail and soil boreholes were only shallow. Designs were based on a CBR of 7. Again when early distress occurred the underlying material was identified and a design CBR of about 2 should have been used.
- Similar to the last example a site had been used for disposing of old newspapers and the initial depth of sampling did not show this.

The point to be made from the above is that the additional cost of a more thorough site investigation would have been far less than the cost of remedial investigation and pavement rehabilitation, not to mention the economic impact on the operation of the facility.

3.3 Drainage

Segmental concrete block pavements, particularly in their early life, are not waterproof. Water can permeate through the joints between blocks into the sand bedding, and basecourse. Both surface and sub-surface drainage of segmental concrete block pavements should be designed and installed as thoroughly as for other pavements.

The water inside the pavement should be given somewhere to drain away.

Two specific aspects of draining segmental concrete block pavements are:

- The sand bedding is usually relatively free draining. To permit water to drain into pavement perimeter gullies the detail shown in Figure 2 has been very successful in Australia.

- To ensure that the surface drains freely where chamfered blocks are used, the pavers should finish above side channels or surface inlets to avoid ponding as shown in Figure 3.

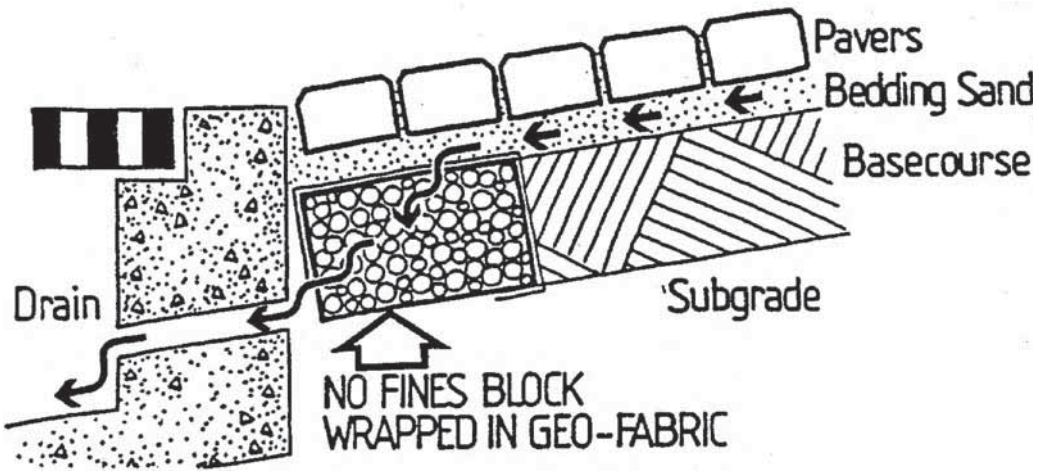

Figure 2 *'No fines' block in basecourse layer*

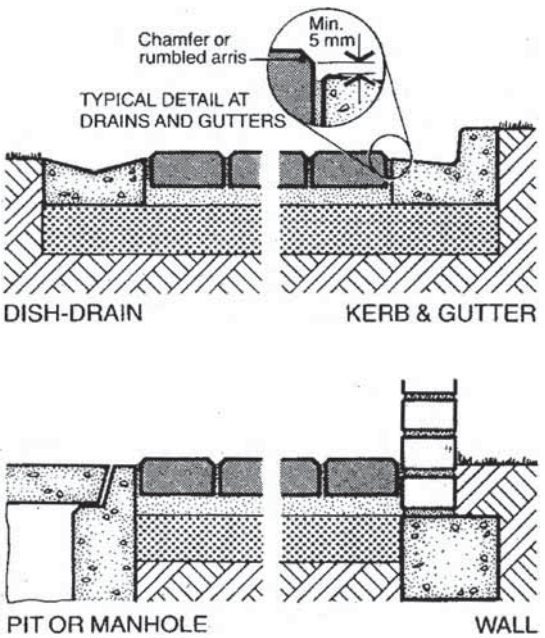

Figure 3 *Detail at channels or surface inlets*

4. ESTIMATING LOADS

One of the key factors which has a direct bearing on pavement design and performance is the estimation of frequencies and magnitudes of applied loads. The following factors have contributed both to the success (where thoroughly evaluated) and difficulty (where incomplete data is available) of Australian segmental concrete block pavements.

4.1 Residential and Highly Trafficked Streets

Pavements can be built before or after housing construction. In a new residential development the trucks used to supply building materials can constitute up to one quarter of all heavy commercial vehicles which will use the pavement. When placed in service the predominant large vehicle will be for garbage collection. For both these situations and in many of the narrow contemporary carriageway widths, these vehicles can track over the same path in each direction - the so-called 'double-tracking'.

Careful evaluation of these loads is vital to the good performance of the pavement.

If it is expected that commercial vehicle usage will grow in time, allowance should be made in the form of an annual cumulative growth factor.

4.2 Industrial Pavements

There is considerable potential for underestimating the magnitude of applied loads in these areas. The authors are aware of many instances where enquiries have been received concerning the design of 'truck yards'. It has then become evident that the trucks are carrying shipping containers which will then be handled by large forklift or similar vehicles themselves weighing between 35 and 45 tonnes. The combined weight of the container and handling vehicle is up to 80 tonnes - all of which is effectively carried on one axle when lifting the container or in braking and turning movements. This is nearly twice the all-up weight of a fully loaded road truck. In the same 'truck yard' containers will often be stacked 4-high. Four very closely spaced container pads occur at intersections of rows of containers leading to very high loads.

In designing industrial pavement two load estimation factors should be kept in mind:

- The full range of vehicles and related loads and container stacking loads which will be used in the facility should be listed at design stage,
- Where during design there is a change in the type of vehicle to be used, particularly materials handling vehicles, this should be communicated to the designer.

In relation to the latter point, one large container handling yard showed distress in the form of rutting early in its life. The designer had received a written specification for the design vehicle and had designed the pavement accordingly. During the design phase the operating organisation decided to use another vehicle which weighed 50 per cent more than the original design vehicle - but did not advise the designer. As a result and from the day the pavement was commissioned, the pavement received regular usage of loads 50 per cent greater than expected.

5. PAVEMENT MATERIALS

5.1 General

A pavement is only as good as its constituent materials. To ensure good performance in a segmental concrete block pavement, it is essential to use good quality materials in the surface and basecourse layers. It should not be assumed that a layer of interlocking paving units can compensate for, or in some way bridge over, a poorly prepared basecourse or subgrade, or a basecourse built using inferior quality or poorly compacted materials.

Segmental Paving Units

All countries, including Australia, which use segmental concrete paving units have developed manufacturing standards for the paving units which are appropriate for the conditions of usage in the respective countries. Australian specifications are set out in detail in Reference (9). Recommendations as to suitable shapes, thicknesses and laying patterns are available in Reference (3) for road pavements and Reference (7) for industrial pavements.

5.2 Basecourse Material

In general, unbound materials for segmental concrete block pavements should comply with local requirements for a basecourse for an asphalt-surfaced pavement. The material may be a fine crushed rock or natural gravel which meets the specifications for basecourse construction issued by the relevant State or Local Government road authority.

For the purpose of this paper unbound basecourse material is divided into two categories: Class A, 20-mm nominal maximum aggregate size; Class B, 20-mm or 40-mm nominal maximum aggregate size. The properties of each are shown in **Table 1.**

Table 1 *Properties of Unbound Basecourse Materials*

	Class A	Class B	
Maximum nominal aggregate size (mm)	20	20	40
% Passing			
50.0-mm sieve			100
37.5-mm sieve	-	-	95-100
26.5-mm sieve	100	100	80-90
19.0-mm sieve	95-100	95 -100	69-83
13.2-mm sieve	78-92	78-92	56-74
9.5-mm sieve	68-83	69-83	44-64
4.75-mm sieve	44-64	44-64	29-49
2.36-mm sieve	29-47	30-48	21-37
425-micron sieve	12-20	14-22	10-17
75-micron sieve	2-6	6-10	5-8
Liquid Limit (max)	20	23	23
Plasticity Index (max)	6	8	8
Los Angeles Test % Loss (max)	40	50	50
CBR after soaking at 98% modified Maximum Dry Density (min)	100	80	80

Cement-Bound Material

Cement-bound materials are designed to have sufficient strength (stiffness) to allow this property to be taken into account in pavement thickness design. For high traffic-loads and low-strength soils, reductions in basecourse thickness result from the use of cement-bound materials.

In areas of high rainfall or where subgrade moisture level and water tables are consistently high, cement-bound materials offer improved performance by comparison with unbound materials, as they are less susceptible to the effects of ingress of moisture. Due to the segmental nature of the surface layer of concrete block pavements, the prevention of upwards reflection cracking from a cement-bound basecourse is not a design criterion.

Recommended cements for cement-modified or cement-bound basecourses to suit normal conditions are either Type A (normal) portland cement complying with AS 1315, or blended cements complying with AS 1317. Where aggressive groundwaters may be present, the use of Type D (sulphate-resisting) portland cement complying with AS 1315 is recommended.

The strength of the cement-bound basecourse material as measured by a 7-day unconfined-compressive-strength test should be uniform and not less than 3 MPa.

Lesser Quality Materials

Most agencies which govern the building of public roads have materials specifications which meet the above guidelines and which will produce good results.

However, there have been instances where lesser quality materials have been used and where inferior performance has been noted in industrial projects. Where knowledge has been gained of the history of such projects it has been more often the case that the initial material specification was satisfactory but that the specifications were either not enforced or allowed to be changed to what appeared to be less-costly materials which in a very short time led to distress and remedial works which cost far more than the initial material savings. The chief offending areas were materials with high plasticity index values and which were not capable of achieving the required CBR value when placed in the pavement.

5.3 Bedding and Jointing Sands

Although fulfilling a primary role of a construction expedient the quality and construction aspects of these materials have a vital impact on the performance of the pavement. The materials specifications are set out in detail in References (3) and (5). One common fault with segmental block pavements is to use the bedding sand as joint filling sand - again in the expectation that some construction cost saving will be available.

When properly constructed there will be a nominal gap of about 3 mm between paving units. For a typical bedding sand up to 20 per cent will have a grain size of about 2 mm and larger. Such sand will present difficulties in being able to fully fill these gaps. Where the gaps are not fully filled the interlock between paving units will be incomplete, the pavers can move about slightly under traffic and corner spalling and rotation of pavers leading to significant surface deformation will occur.

6. LAYING THE SURFACE

The surface of a segmental block pavement includes the bedding sand, pavers and filling sand.

Every effort should be made to accurately trim the basecourse to ensure an even thickness of bedding sand and that its layer thickness is as thin as can be sensibly controlled in the field, ie about 25-30 mm when compacted. The practice of filling up hollows in the basecourse by bedding sand remains unfortunately a cause of differential bedding compaction which is very soon reflected in surface deformation under traffic.

Like all other forms of pavement construction the planning and execution of segmental paver laying requires techniques peculiar to it. Construction practice in Australia, in common with other countries, the practice of laying the surfacing is set out in detail in References (3) and (5) and is not discussed in detail here. The process is shown schematically in Figure (4).

Whereas the actual skills are not difficult and do not take long to acquire, what is important is that those involved in building or specifying these pavements need to recognise that there are particular techniques for them and that success depends on their faithful execution.

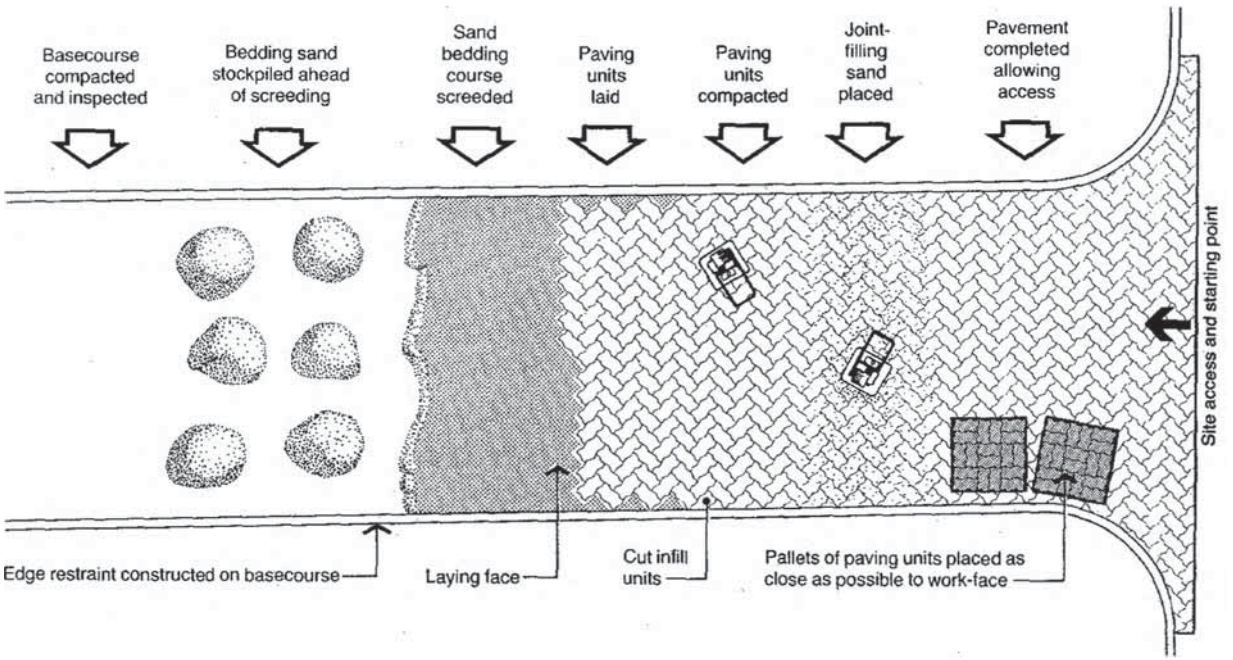

Figure 4: *Typical Site Layout/Construction Sequence*

These techniques include:

- Planning the work,
- Selecting a start line,
- Establishing a good working face,
- Progressive compaction of bedding and filling joints,
- Progressive checking of the alignment of the laying face,
- Working around penetrations,
- End of day procedures.

Common faults include:

- Laying pavers too tightly,
- Not progressively compacting the bedding sand and filling joints leading to surface deformation,
- Poor end-of-day arrangements leading to bumps at the line of discontinuity.

7. SUPERVISION

If one overriding observation could be made as to the cause of the difference between success and problems, it would have to be supervision. Constant and suitably qualified or experienced supervision is all too often seen only in terms of a cost against construction. The number of occasions where the cause of distress has been simplistically laid at the door of thickness design is large. As reported by Rollings (2) 'A great deal of effort is often expended on pavement thickness design. In actual fact, failure in the field is most often associated with poor construction practice, inadequate materials or both. A sophisticated design, poorly executed with improper control over materials is doomed to failure whereas a mediocre design well built using appropriate materials will probably perform admirably.'

Further, the cost of remedial works arising from inadequate supervision is invariably much higher than the apparent cost savings from the absence of such supervision.

As an example is the case of culs-de-sac in housing estates in two Australian cities. In each case the soil and traffic conditions were very similar and the pavements constructed in advance of building constructions. After some 16 years service one estate has negligible visible pavement distress. In the other case massive surface deformations occurred within a few months of pavement construction.

In the latter case, site investigation yielded three contributing factors; the subgrade profile was very uneven, in some areas the actual basecourse thickness was zero compared with specified values in the range 150-200 mm and the completed surface was some 25 mm below the lip of drainage pits preventing the runoff of rainwater.

In the successful project every stage of construction was inspected during and on completion of it. The inspectors were suitably experienced civil road inspectors. Materials were inspected at every stage of construction. In the unsuccessful case there were many days when there was no supervision at all and where construction proceeded to a further stage without any inspection or testing of the previous stage. One whole cul-de-sac had to have the whole pavement removed and reconstructed. The initial basecourse material became so contaminated with subgrade materia! during the excavation that it could not be re-used. The 'absent' supervision costs would have been in hundreds of dollars - the remedial works actually cost thousands.

In private sector projects the very successful projects have resulted where the consultancy or design/construct agency was involved in the whole project, investigation, design and construction and where individuals with experience in soils and pavements engineering were associated with it. Many problems have been directly attributable to a lack of continuity between 'design' and 'construction' supervision where there has been no direct communication between designer and constructor.

With particular reference to major industrial projects it is ironic that vast sums are spent on warehouse and materials handling facilities and plant because 'we cant afford to work without them'. But one factor which probably contributes at least as much to the operational profitability of the facility - the pavement - frequently receives little or no adequate supervision on the grounds that 'we really cannot afford to have it'.

S. CONCLUSION

This paper has taken an overview of key factors associated with and differentiating good and inferior performance in segmental concrete block pavements over many millions of square metres in Australia over the last decade or so. Thickness design per se is important and the authors do not suggest any interpretation of this paper to the contrary.

However, the sum total of experience suggests that many other factors can have a greater contributory role to success or otherwise than the statement that the pavement was too thin. Site investigation, evaluating all design loads, drainage, materials selection and relevant construction practice are all integral to success.

Drawing of all these factors together is the element of supervision at all stages of the project. Adequate supervision has invariably been one of the largest preventive maintenance measures in the construction and performance of these pavements.

1. ROURKE, JT - *Case Study of Distressed Roads Culs-de-sac in a New Residential Estate;* Proceedings - International Workshop on Interlocking Concrete Pavements, Melbourne, Australia, 1986.

2. ROLLINGS, RS - *Evaluation of Block Pavement Design Procedures;* Proceedings - International Workshop on Interlocking Concrete Pavements, Melbourne, Australia, 1986.

3. *INTERLOCKING CONCRETE ROAD PA VEMENTS A Guide to Design and Construction;* Cement and Concrete Association of Australia, 1986.

4. *CONSTRUCTION OF CONCRETE BLOCK PAVING;* Cement and Concrete Association of New Zealand, 1990.

5. *GUIDE SPECIFICATION FOR CONSTRUCTION OF INTERLOCKING CONCRETE ROAD PAVEMENTS;* Cement and Concrete Association of Australia, 1986.

6. SHACKEL, B and PEARSON, A - *The Application of Concrete Segmental Paving in Municipal Engineering:* Sixth National Local Government Engineering Conference, Hobart, Australia, August 1991.

7. SHACKEL, B - *The Optimal Design of Road and Industrial Pavements using Micro Computers;* Proceedings ENGSOFT Conference, London, July 1985.

8. SHACKEL, B - *Design and Construction of Interlocking Concrete Block Pavements;* Elsevier Applied Science, 1990.

9. *SPECIFIC A TION FOR CONCRETE SEGMENTAL PA VING UNITS;* Concrete Masonry Association of Australia.