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Review of Design Criteria and Performance of Block Pavements in Gauteng

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First a brief overview is given of the evaluation of performance and the factors that need to be considered. Thereafter, the experimental design matrix according to which sections were selected, is presented. The performance of these sections is evaluated, and this is related to the pavement structure. A discussion of the findings together with guidelines for improved structural performance is presented and finally, conclusions are drawn.

It is found that the design guide is adequate and pavements constructed according to this guide gave satisfactory performance. Guidelines are also given to address factors that result in unsatisfactory performance, such as poor surface and subsurface drainage, loss of jointing sand and details at kerbs and manholes.

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TECHNICAL PAPER - DESIGN CRITERIA

REVIEW OF DESIGN CRITERIA AND PERFORMANCE OF BLOCK PAVEMENTS IN GAUTENG

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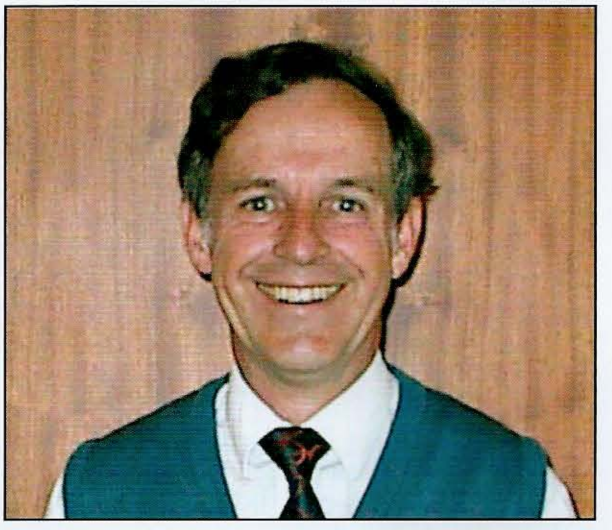
ABBREVIATED CV - PROF. ALEX VISSER



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SYNOPSIS

The structural design guide for block pavements UTG2:1987, which was based on accelerated testing, has been in use for some 15 years. It was therefore time to evaluate the performance of pavements designed in accordance with these guidelines. The aim of this paper is to present the results of a limited evaluation of the structural performance in Gauteng, to highlight potential problem areas and to recommend changes to the structural design and construction techniques where warranted. First a brief overview is given of the evaluation of performance and the factors that need to be considered. Thereafter the experimental design matrix according to which the sections were selected, is presented. The performance of these sections is evaluated and this is related to the pavement structure. A discussion of the findings together with guidelines for improved structural performance is presented and finally conclusions are drawn. It was found that the design guide is adequate and pavements constructed according to this guide gave satisfactory performance. Guidelines are also given to address factors that result in unsatisfactory performance, such as poor surface and subsurface drainage, loss of jointing sand and details at kerbs and manholes.

INTRODUCTION

The use of blocks for paving roads can be traced back thousands of years, and pavements constructed 2 000 years ago by the Romans using stone setts are still in use today. Stone setts used as ballast in the unladen sailing ships travelling from Europe were used for paving in Cape Town as early as the 1700's. Improved mechanisation and modern production facilities resulted in the use of concrete block paving being introduced into South Africa in about 1972, using the prior experience of small paving elements.

After extensive field experiments and laboratory studies standard specifications for materials and laying were published in 1984 (SABS, 1984). Structural design guidelines for South African conditions are contained in Draft UTG2:1987, "Structural design of segmental block pavements for southern Africa". Design guidelines prepared by the Concrete Manufacturers Association (1999) still make use of these original structural designs.

It has been some 15 years since the structural design guidelines were prepared, and a significant number of projects have been constructed according to these guidelines. A need was identified in the block paving industry to evaluate the structural performance of block pavements and to identify potential deficiencies.

The aim of this paper is to present the results of a limited evaluation in Gauteng of the structural performance, to highlight potential problem areas and to recommend changes to the structural design and construction techniques where warranted. First a brief overview is given of the evaluation of performance and the factors that need to be considered. Thereafter the experimental

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design matrix used in the research is presented. The performance of these sections is evaluated and this is related to the pavement structure. A discussion of the findings together with guidelines for improved structural performance is presented and finally conclusions are drawn.

FACTORS OF IMPORTANCE IN STRUCTURAL EVALUATION

Structural composition

The accepted structural terminology used in South Africa is shown in Figure 1. Blocks are placed on the bedding sand layer and jointing sand is vibrated into the joints between the blocks. This jointing sand is important for "locking up" the blocks and for reducing water penetration into the underlying layers. Note that the properties of the bedding sand and jointing sand are different (UTG2:1987).

In South Africa the layer beneath the bedding sand is the subbase, and this conforms to the terminology used with concrete pavements. It differs from asphalt surfaced pavements where the layer below the asphalt surfacing is the base. Although Shackel (1990) suggests that in the urban environment a granular subbase should be used to facilitate access to underground services, stabilised subbases are necessary for heavier trafficked routes or where water infiltration is likely to result in pumping or softening of the granular layers.

Selected layers are placed to ensure adequate protection of the in-situ or subgrade materials. The number of layers and quality would depend on the properties of the in-situ material that needs to be protected.

Performance evaluation

The purpose of any pavement is to provide a service to the user. Functional requirements are therefore paramount in evaluating a pavement, but structural issues often impinge on the functional performance. Although noise generation and skid resistance of block paving are two important functional considerations, they are not affected by structural aspects, and will therefore not be considered. The functional requirements that are affected by structural considerations are riding quality, rut formation and local depressions resulting in surface drainage problems.

Riding quality is the most commonly used objective measure of functional performance. On urban roads and parking areas where speeds are low the riding quality is not as important as on rural roads where road unevenness has been shown to affect vehicle operating costs.

Rut formation and local depressions have a negative impact on the user, particularly pedestrians, as ponding water is tricky to traverse, and passing vehicles could spray water onto pedestrians. Both rutting and local depressions could be related to structural inadequacy.

EXPERIMENTAL PROGRAMME

As-built information and traffic carried are invariably difficult to obtain on private facilities, as the core business of such organisations is not to manage their road infrastructure. Consequently stratification, as shown in Table 1 based on the age of the pavement and the type of traffic, was used. Such stratification was expected to give a broad enough range of the important factors that affect pavement performance. Note that all the facilities were in the Gauteng area, which thus excluded evaluation of climate.

The average riding quality of a site was determined by means of a MERLIN device (Machine for Evaluating Roughness using Low cost INstrumentation), which allows measurements in restricted areas where normal vehicle speeds are unattainable (Cundill, 1989). The MERLIN is made up of a steel frame 1,8m long, with a wheel at one end, a support at the other, and a probe midway between them, as shown in Figure 2. The probe rests on the surface, and is connected to a moving arm with a pointer at the end, which moves over a chart. The MERLIN is pushed by hand, and the position of the pointer on the chart is recorded at successive positions. This chart is then processed and the results related to standard measures of roughness through a correlation.

At each site a visual inspection defining the severity of distress and the extent of occurrence was performed. This gave an overall impression of performance. In areas that performed well and ones where the performance was less than satisfactory, based on the visual inspection, an evaluation of the in-situ bearing capacity was performed by means of the Dynamic Cone Penetrometer (DCP). In addition to the in-situ strength, layer thicknesses were also defined from this test (Kleyn and Savage, 1982).

EVALUATION OF PERFORMANCE

Riding quality

It is well known that block pavements provide a high level of riding quality. The average riding quality of the seven sites ranged from a present serviceability index (PSI) of 3.1 to 3.7. This may be compared with the terminal level of 2.5 PSI on freeways. These measurements were taken in the wheelpaths and thus do not reflect the severity of local distress or distress outside the wheelpaths, such as heaving or shoving. The high level of riding quality makes block paving suitable for rural roads, and this has been proven by the good performance of an experimental section on the Pietermaritzburg bypass (Knoesen, 2000).

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Structural capacity

The oldest section evaluated was a service road at the Botanical Gardens, Pretoria, which was about 30 years old. 60mm interlocking pavers were used. It was estimated that this was an ER traffic class, as it only carries an occasional light vehicle. There were isolated areas with severe deformation, heave and consequent drainage problems. For a road of this traffic class UTG2:1987 requires a minimum CBR of 10 below the pavers in a moderate climatic region. The positions where severe rutting and deformation had taken place had in-situ CBR values of 4 to a depth of 160 mm below the sand and less than 10 to a depth of 500 mm. At positions where the performance was satisfactory the in-situ CBR values were better than the design values. This indicates that the design recommendations are adequate. It should however be borne in mind that a high level of field compaction must be achieved to limit local settlement which invariably results in drainage problems, rather than just considering the CBR.

For pavements in a moderate climate with a granular subbase UTG2:1987 requires a G5 material, which has a minimum CBR of 45. For increasing traffic classes the thickness of the subbase layer increases, from 100 mm for less than 0.2 million E80s, 125 mm for between 0.2 and 0.8 million E80s, and 150 mm for 0.8 to 3 million E80s. The strength of the layer below the subbase should be a minimum CBR of 15.

The Belle Ombre bus terminal is about 12 years old, was built with 80 mm G-blocks and it was estimated to have carried about 3 million E80s. At a location where severe turning movements take place there are signs of block breakage and poor drainage. This is shown in Figure 3. The DCP results at this location showed that the in-situ CBR to a depth of 170 mm below the sand was 28 or less, and to a depth of 420 mm was 10. It is not clear whether the deformation and soaking occurred because of the weak material, or whether the weak material resulted from the soaking. However, it is clear that the material at this location was substandard as the G5 classification is based on a soaked laboratory CBR. The large deformations then resulted in the blocks breaking. The locations, which performed well, fulfilled the structural design requirements.

At Fedsure Industrial Park, which was 13 years old, built with 80 mm G-blocks, and which had carried an estimated 1 million E80s, the pavement was generally performing well. There was slight rutting of a few millimetres, but this would be expected. At an isolated location near a water feature there was a depression, leading to ponding water. The upper 130 mm had an in-situ CBR of 35, which was marginal compared with the design requirements. The in-situ layer had a CBR of 19, which was adequate. The origin of the deformation was the subbase layer, and this situation may be aggravated with future traffic. Over the remainder of the site the design criteria were fulfilled.

Graphite Park is about 9 years old, was built with 80 mm G-blocks and has carried about 0.4 million E80s. The site was located next to a river and the surrounding area drains through the site. Because of the surface water flow there is a significant loss of jointing sand. There is also widespread heaving and rutting. There is little evidence of block breakage, probably because of the relatively light traffic. At 5 of the 6 test points the subbase strength was less than a CBR of 45, and at one test point the CBR to a depth of 280 mm below the sand was 4. There is poor drainage and the quality of the pavement structure is inadequate as evidenced by the rutting and deformations. The design requirements are thus confirmed.

West Manor is a relatively new facility, as it is only 3 years old, was built with 60 mm G-blocks and has carried less than 0.1 million E80s. There is moderate rutting at this site, some heaving and significant loss of jointing sand. The 150 mm subbase had an in-situ CBR less than 25, and the subgrade had a CBR of 4 to 6. The fact that this facility has carried relatively little traffic has led to only moderate distress. Judging from the structural capacity significant further distress and deterioration can be anticipated in future. This would include fracturing of the blocks.

The last site with a granular subbase that was evaluated was the Tuscany Office Park. This facility was 4 years old, was constructed with 60 mm Cottage Stone pavers (type S-C or non-interlocking pavers) and has carried less than 0.1 million E80. Visually this is by far the worst site, as drainage problems, major deformation, heave and loss of jointing sand was found over most of the site as may be seen in Figure 4. This is attributed to the loss of jointing sand due to the base movement and aggravated by the type S-C paver. Similar experience with this type of paver has been found at other sites and all have started with poor support conditions or the use of this type of paver for relatively heavy traffic. The size and shape of the pavers also facilitate pumping of the bedding and jointing sand, which leads to loss of integrity and low spots where ponding water accelerates the deterioration. Unlike the fully interlocking paving blocks, Cottage Stone type "S-C" are unforgiving, in that any weakness, whether by design or construction, in the underlying layers, will lead to rapid unwanted deterioration. A lack of maintenance was contributing to the deterioration, as in some areas the pavement structure was adequate as determined from the in-situ CBR. However, in areas where the upper 300 mm of the granular material had an in-situ CBR of less than 10, the deterioration was more severe.

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Only one facility was constructed with a cemented subbase, namely Schurveberg Road. This road carries heavy truck traffic and it was estimated that it had carried about 1 million E80s during its life of 5 years. It would probably have a design life of 4 million E80s. The UTG2:1987 design for such a facility would be 80 mm type S-A pavers, 200 mm C4 cemented subbase on material with an in-situ strength of 15. From the DCP testing it appears that this design was followed, although the subgrade strength was much higher than the minimum required. This road is performing well and little deterioration is noticeable. At one test point there was some deformation, and the CBR of the upper 140 mm was 38, and to a depth of 420 mm it was 13. Without an in-depth investigation as to the cause, it is only possible to speculate that the loss of strength was caused by poor mixing at the time of construction, or from carbonation, which reduces the cementing action as the cement reverts to calcium carbonate. This result does however show that the structural design is adequate.

DISCUSSION OF RESULTS AND FURTHER OBSERVATIONS

The structural guidelines have been shown to be adequate. However, at many sites the paving is the last construction activity, and there are regular reports that at that time funds budgeted for paving have been expended on the earlier construction activities. The paving contractor is then placed under pressure to provide a facility with an insufficient budget. It has been shown that an inadequate pavement structure invariably leads to the blocks breaking, and the block supplier is then accused of providing inferior materials. Consultants and contractors should ensure that pavement structures are as recommended in the structural guidelines. If a subcontractor completes the earthworks, the quality may be validated by means of the Dynamic Cone Penetrometer (DCP) before placement of the blocks is started.

It is re-assuring that the design guidelines as contained in UTG2:1987 generally lead to good performance in the Gauteng region. Conversely, poorer quality materials, affected by substandard drainage, invariably result in poor performance. It is however likely that these materials, if kept dry, would be able to provide adequate support based on observations at a number of other sites. Provision of adequate drainage is therefore of paramount importance.

The Concrete Manufacturers Association has provided guidelines for ensuring successful surface and subsurface drainage. Longitudinal fall should be at least 1% whereas transverse fall should be at least 2%. Special care must be taken in backfilling and compacting trenches as even limited settlement of inadequately compacted material could cause local depressions and water ingress into the underlying layers when flat slopes are used. To counter the effects of poor compaction, the use of foamed concrete or flowable fill, which fills all the voids around a pipe, are effective and economic means of trench reinstatement.

Although block pavements are effective in shedding water, there is a potential for water seeping into the underlying layers when the pavement is new and has not yet achieved lock-up, or when the jointing sand is washed out or blown away through the action of wind or moving vehicles. Any water will then flow through the bedding sand towards the lower areas. These are invariably at kerbs. Unless provision is made for the water to drain through the kerb, as shown in Figure 5, ponding will occur with a consequent softening and weakening of the underlying materials and possible pumping. This situation was found at a water feature at Fedsure Industrial Park. It should be standard design practice to provide lateral outlets of 25 mm diameter plastic pipes, plugged with geofabric to prevent fines from being washed out, at between 1 and 5 m centres.

At the majority of sites that were studied, and also others that were visited, the loss of jointing sand has been a major problem. This loss is attributed to compaction after opening to traffic, or through the removal by traffic, wind or water. At most sites where block paving is used the core business of the client is not to manage pavements. Maintenance therefore receives no attention, and this leads to significant deterioration. Construction contracts should include a period of up to one year during which time, normally at three monthly intervals, the site is resanded. Resanding beyond the maintenance period provides scope for a small contractor to provide this service to property developers and other owners on an annual basis.

Another problem, which has been noticed, is the detailing of the blocks both at the kerb and at manholes or drainage catchpits. Invariably the blocks at kerbs have to be cut to provide the correct pattern. Often cement grout is used to fill in the voids adjacent to the fixed structure. This grout tends to shrink and over time the pieces break out under the action of climate, water flow and traffic, leaving a void. This then becomes a perfect place for water ingress into the underlying layers. The solution to this problem is to use a gutter shape where the water flow is in the gutter. Blocks are placed slightly above the level of the gutter to ensure drainage even when there is settlement of the pavement structure. This should also be standard practice at catchpits. In addition, since drainage catchpits are at a low point, there should be 25 mm diameter drainage holes at the top of the subbase level the same manner as at the kerbs. Catchpits and manhole covers should receive special attention and a reinforced concrete or

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module should be placed as shown in Figure 6. Attempting to use blocks and grout has been shown to be completely ineffective for these situations.

CONCLUSIONS AND RECOMMENDATIONS

The primary aim of this paper was to evaluate the structural design guidelines presented in UTG2:1987 by means of the performance of pavements that have been in service over a number of years in Gauteng. Pavements constructed in accordance with the guidelines performed well. Based on the limited evaluation there is no need to modify the structural design guidelines.

There were, however, factors contributing to unsatisfactory performance. These include:

- Poor quality control during construction – this can be remedied by use of the Dynamic Cone Penetrometer before the pavers are laid.
- Inadequate surface drainage overall, or local settlement as a result of poor backfilling of trenches – the solution is adequate slope, and the use of non-compactable materials such as flowable fill or foamed concrete for backfilling around pipes.
- Special care should be taken to prevent water saturation of the underlying layers by ensuring subsurface drainage at kerbs or catchpits by means of weep holes.
- The loss of jointing sand, with the consequent water ingress and loss of lock-up, should be rectified. During the maintenance period this is the responsibility of the contractor provided it is included in the contract, and subsequently by specialist maintenance contractors.
- Block size and details at obstructions such as kerbs and manholes should be designed to prevent the ingress of water into the underlying layers or to create a future maintenance workload through erosion.

ACKNOWLEDGEMENTS

A final year civil engineering student at the University of Pretoria, Mr Stephan Jooste, carried out this investigation and his inputs are gratefully acknowledged. The assistance received from members of the Concrete Manufacturers Association in identifying suitable sites and providing design information is appreciated.

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Table 1. Experimental design matrix of block pavements tested

AGE	LIGHT TRAFFIC	HEAVY TRAFFIC
less than 6 years	West Manor Building, Sandton	Schurveberg Rd, Laudium
	Tuscany Office Park, Rivonia	
6 to 10 years	Graphite Park, Strijdom Park	Federated Indus. Park, Midrand
more than 10 years	Botanical Gardens, Silverton	Belle Ombre, Pretoria

AGE LIGHT TRAFFIC HEAVY TRAFFIC less than 6 years West Manor Building, Sandton Schurveberg Rd, Laudium Tuscany Office Park, Rivonia 6 to 10 years Graphite Park, Strijdom Park Federated Indus. Park, Midrand more than 10 years Botanical Gardens, Silverton Belle Ombre, Pretoria

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Figure 1. Terminology used for the block pavement structure (UTG2:1987)

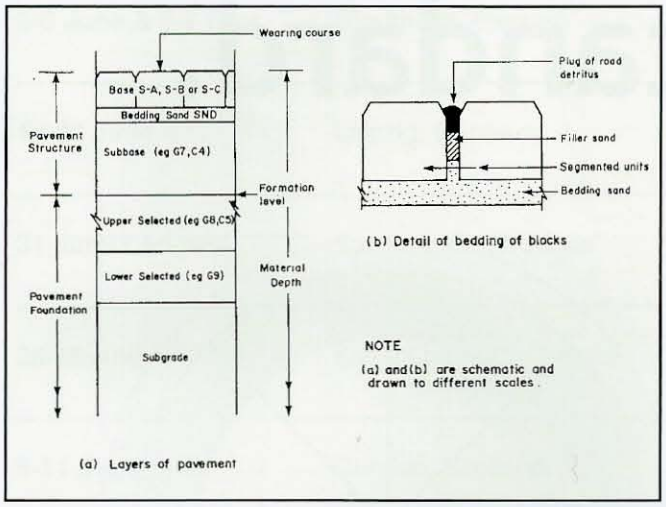

Figure 2. The MERLIN road roughness measuring device (Cundill, 1989)

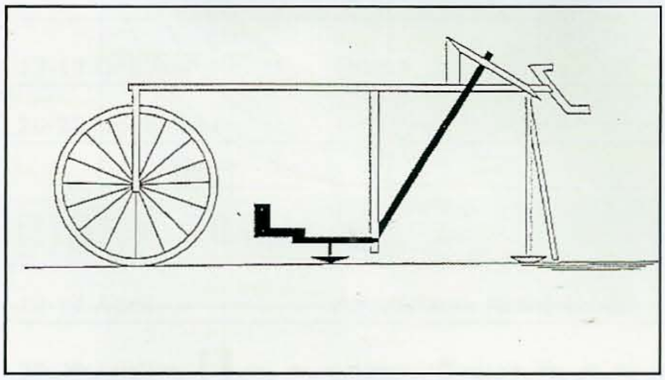

Figure 3. Deteriorated block paving at Belle Ombre bus depot

Figure 4. Badly deteriorated block pavement on weak structure

Figure 5. Details of subsurface drainage at kerbs

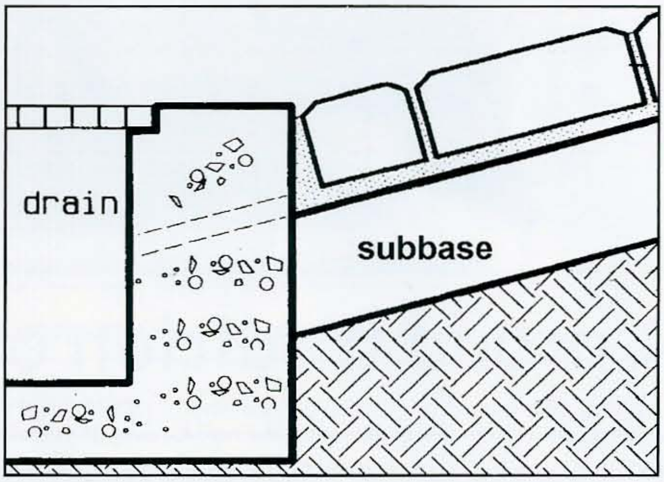

Figure 6. Details at manholes or drainage catchpit (CMA, 1998)