AN EVALUATION OF TYPICAL CONCRETE BLOCK PAVEMENT FAILURES IN SOUTH AFRICA

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Summary:

It is always a natural tendency for proponents of a product, system or technology to emphasize a focus on successes and conveniently to ignore the areas of less success or of outright failur However, it is common cause that more lessons can be learnt from analysing mistakes than from eulog sing about successes.

In the case of precast concrete block paving, where there has been a failure in an industri pavement or roadway, distress is most evident in the paving block surface but it is seldom t fault of the blocks. If the pavement structure is properly designed at the outset, and if t structural earthworks are constructed correctly to specifications, then the risk of future perfo mance problems are reduced to a minimum.

In spite of the fact that, in South Africa, where National Codes of Practice and Standards are n available for design and construction guidance and that manuals, guidelines and design publicatio have been issued by the various local associations and research institutions, there still appears be an inadequate understanding of the basic principles and characteristics of concrete block pavi technology. This manifests itself not only in the fact that some pavement designs are total inadequate for their intended use but conversely others are completely overdesigned, resulting uneconomical use of the system.

This paper presents case studies of three projects, each of which had a different problem caus pavement failure. The paper will illustrate that, in the precast concrete paving industry in So Africa, there are still an alarming number of designers, specifiers, users, manufacturers, and c tractors who do not understand the basic principles of concrete block paving technology.

CASE I

Heavy Vehicle "Truck-Inn"

1) Introduction:

This project involved the development of a rest area for heavy truck drivers in the Northern Transvaal region of South Africa incorporating a parking area with fuel, ablutions and refreshment facilities. The paved area is 3500 square metres in extent and 80 mm thick grey coloured precast concrete interlocking type blocks were used.

A firm of Consulting Engineers were appointed to design, prepare a specification and subsequently to supervise the work.

2) Soils Investigation.

An investigation into the natural soils occurring in the area was carried out and it was established that the site is situated on recent colluvial and pedogenic gravels overlying granitic bedrock belonging to the basement complex.

The natural soil profile consist of coarse, medium and fine, rounded and sub-rounded vein quartz gravels, loosely packed in a matrix of moist to wet, light grey silty sand. The layer extends down to approximately 0,7 m bel the surface and is of colluvial origin.

The colluvium is underlain by dense to ve dense hardpan ferricrete in a sparse matrix light grey silty sand. This layer is app rently impermeable and was the cause of t presence of a perched water table at rand locations on the site.

The ferricrete overlies the pebble marker whi consists of coarse, medium and fine rounded a sub-rounded quartz gravels, loosely packed in matrix of moist to wet, light grey silty sand

3) Extent of Failure.

Work was completed in November 1986 and so after the "truck inn" was opened to traffic t paving started showing signs of failure, whi very rapidly deteriorated beyond acceptab norms.

The mode of failure were typical and includ inter alia

i) Rutting where traffic is concentrated alo specific routes, particularly in areas whi were subjected to high traffic volumes.

ii) Chipping and spalling of the pavers in op areas where vehicles turn and manouvre.

iii) Elastic deformation of the surface under the wheel loads.

iv) Rotation and subsequent creep of the blocks in the badly affected areas.

v) Opening up of joints thus destroying shear transfer between the blocks.

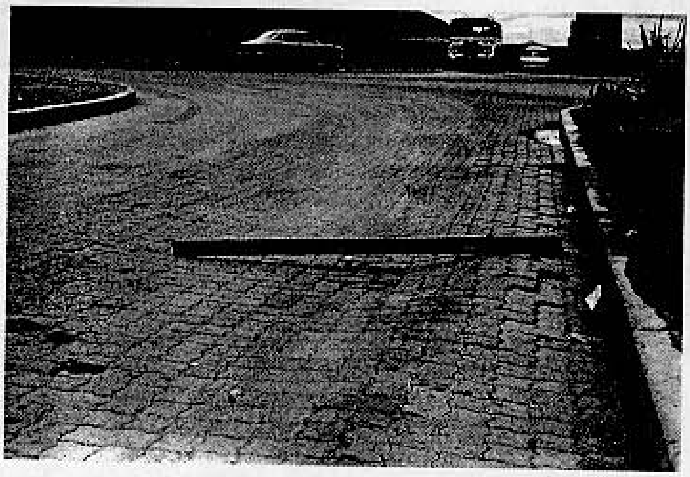


Figure (1) Extent of Failure

4) Failure Investigation.

Several independent firms of Engineering Geologists and Soil Testing Laboratories representing the various different interested parties were called in to carry out investigations into the likely cause of failure.

The testing consisted of

i) Excavating test holes and describing each horizon of the soil profile in terms of six standard descriptors namely moisture condition, colour, consistency, structure, soil type and origin in accordance with procedures advocated by Jennings et al (1973).(1)

ii) Grading analysis and Atterberg limit tests.

iii) Mod AASHTO tests to establish CBR/UCS values of the structured layers.

iv) Grading analyses of the bedding sands and the filler sands.

v) Compressive strengths of the blocks.

5) Evaluation of Test Results.

On completion of the in situ investigation and the laboratory tests a comparison was made of the findings with the original design which had been carried out in accordance with the CSIR design manuals RP 9/84 "Structural design of segmental block pavements for Southern Africa" (2).

The following criteria were used:
Road category = B (Important with a h
level of service)
Traffic class = E2 - E3
Axle loading = 80 kN up to 12 x 10 re
titions over 20 years.
In the comparison the main differences betwe
the "specified" criteria and the "as
constructed" criteria were as shown in Table

The strength of the blocks was specified as
minimum of 25 MPA at 28 days and subsequ
testing verified that the actual streng
substantially exceeded this minimum requi
ment.

Although the grading of the bedding sands we
not ideal the deviation was considered not
be of sufficient significance as a factor
establishing the reason for failure.

An observation made during the investigati
which is also considered to be a significa
factor in the failure of the pavement was th
a perched water table was present. The ear
works sub-structure was saturated over most
the pavement. No provision had been made
the design for dealing with the subsurfa
water.

6) Reasons for Failure.

A re-analysis made of the original desi
showed that the proposed sub-structure to t
paved area would have been structural
adequate for the anticipated loading cond
tions, had they been constructed accordingly.

The grading of the slopes of the surface were
nowhere less than 3,5% and thus provided ad
quate falls for draining surface water.

The strength of the blocks, the thickness
bedding sand and the laying pattern were withi
acceptable standards.

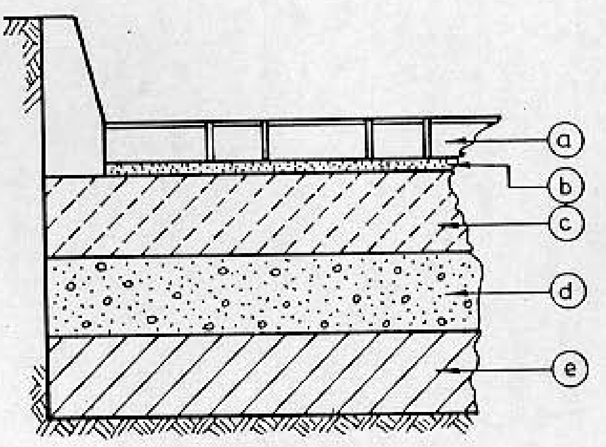
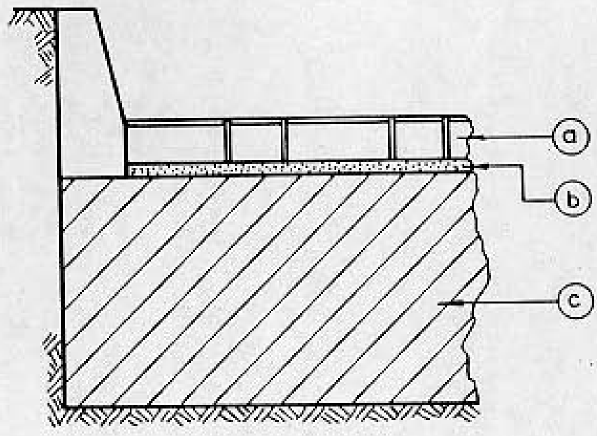
However the standard of workmanship in co
structing the sub-surface earthworks was bel
even marginal limits. This together with th
inferior materials used in the fill under th
pavement and further aggravated by the fac
that no sub-surface drainage was allowed fo
resulted in a complete breakdown of the inte
grity of the pavement.

Although the paving sub-contractor had origi
nally been held responsible for the failure
ultimate blame had to be shared between th
earthworks contractor for faulty workmanshi
and the Consulting Engineers for inadequat
supervision of the works.

7) Remedial Measures.

Based on the 3 basic principles, that:-

-Remedial measures were urgently required.

AS SPECIFIED	AS CONSTRUCTED
	

As specified:

a) 80 mm interlocking concrete pavers
b) 25 mm bedding sand
c) 150 Stabilized natural gravel sub-base compacted to 95% mod AASHTO
d) 150 selected natural gravel sub-base layer compacted to 93% mod AASHTO
e) 150 mm thick in-situ sub-grade material scarified and re-compacted to 93% mod AASHTO

As constructed:

a) 80 mm interlocking concrete pavers
b) 20 mm bedding sand
c) Moist light grey, dense micaceous slightly clayey fine sand-fill. Compacted to 93% mod AASHO

Material Properties

	c	d	e
Min CBR @ 98% Mod AASHO density	80%	30%	10%
Max Liquid limit	25	35	-
Max linear shrinkage	30%	5%	-
Max plasticity index	7	10	12
Group index value	80%	30%	10%
Max size of aggregate	-	-	-
After compaction	37 mm	63 mm	100 mm

	c
Min CBR @ 98% Mod AASHO	10
Max Liquid Limit	37
Max linear shrinkage	8%
Max platicity index	5 to 21
Max size of aggregate After compaction	120 mm

TABLE 1 - COMPARISON BETWEEN SPECIFIED AND CONSTRUCTED CRITERIA.

- Disruptions to operations at the inn would occur during remedial work, but had to be kept to a minimum

- The client could not be expected to pay for any fruitless expenditure.

The following recommendations were made:

i) All of the paving had to be lifted and stockpiled for re-use. It was estimated that approximately 80% of the 3400 square metres would be suitable for re-use after it had been properly cleaned.

ii) The bedding sand layer and 150 mm sub-base layer had to be removed and discarded.

iii) The remaining selected subgrade layer to be trimmed to level and compacted to AASHTO density.

iv) Suitable selected gravel had to imported, stabilized with 4% cement, compacted to 95% mod AASHTO density to form 150 mm sub-base.

v) Paving had to be re-laid on new bedding sand and filling sand vibrated into joints. Both bedding and filling sand had to confor to relevant grading specifications.

vi) The total area was to be sub divided into sections and repaired in a sequence approved by the client.

vii) Further investigations should be undertaken to ascertain whether or not a sub-surface drainage system was necessary.

8) Assessment.

The authors are of the opinion that the sub-standard materials and construction methods used were the main cause for the paving distress.

On this particular contract it was necessary to dispel an attitude that the use of segmental block paving should have been able to withstand the applied loads despite the inadequacy of the sub-structure construction. This unfortunately is an attitude which is far too often present amongst specifiers and users of block pavements.

CASE 2

Road Motor Transport Bus Report.

1) Introduction.

The new depot, situated near Johannesburg, is the maintenance nerve centre for the commuter busses operating to outlying towns in the district. It was constructed during the latter part of 1985 and the first six months of 1986.

The pavement surfacing on this project required the supply and laying of 10000 sq. metres of interlocking precast concrete paving.

The client body used its in-house engineering staff to design, specify and supervise the project.

A sub-contract for the paving was awarded to a block manufacturing company by the main Civil Engineering Contractor. The sub-contract was undertaken during the period from January 1986 to July 1986. A paving sub-contractor was engaged by the manufacturer of the blocks to do the laying on an earthworks base prepared by others.

2. Extent of Failure.

Approximately 6 months after the depot had been opened to traffic, rutting occurred at the entrances to the workshop where the most intense trafficking takes place. In general, deflections measured in the surface of the paving were in the order of 30 mm in depth. However, it was noticeable that in one area in particular, the damage was more severe and deflection of up to 100 mm were present (see figure 2). This particular area was approximately 450 sq. m. in extent and was further distinguishable from the general pavement by red clayey material which was being squeezed through the joints in the blocks.

The design originally specified by the client Engineers for this important structure only required "the existing earthworks to be graded and compacted to 93% Mod. AASHTO with a minimum CBR value of 10" - a particularly vague specification.

Figure (2) Photograph showing severe deflection in pavement.

The construction of layers below this had been carried out in a previous terracing contract where the specification called for the compaction of the material to 43% Mod. AASHTO. Subsequent tests showed that this would achieve average CBR values of 27%. No other foundation layers were specified.

The expected loading conditions were as follows:

(i) Heavy busses - approximately 25 T gross weight
(ii) Axle loads would not be greater than 8 kN
(iii) Expected design life of 20 years.
(iv) Axle repetitions +/- 500 000
(v) The busses would have a slow, rolling action on the area

Before being able to lay any blocks, it transpired that the Paving Contractor had been instructed to make up earthworks levels on the majority of the pavement area. With the material at his disposal which was approved by the Supervising Engineer, he was able to achieve the following standards from four samples tested of the completed sub-surface layer, after it had been compacted to 93% Mod. AASHTO.

CBR values 25
20
20
45
---
110 therefore, Ave = 27
for a layer thickness of 150 mm

However, it transpired that the red material had also been imported by the Contractor once the supply of the other material had been exhausted. This was also tested and approved by the Engineer as having achieved the compaction requirement of 93% Mod. AASHTO.

3. Failure Investigation.

The client, through the Main contractor, requested that the block manufacturer investigate the problem and effect repairs as soon as possible.

The investigation entailed the following:
i) test holes dug in the pavement and profiled.
ii) samples of materials taken for laboratory testing
iii) consideration of the original design and specification
iv) consideration of the sequence and standard of construction activities

Samples of the material which was present in the area of severe rutting were tested in a soils laboratory and a summary of test results are shown in Table 2.

The material was described as moist, red, very soft, silty clay weathered diabase (lava).

4. Reasons for Failure.

The most obvious reason for pavement failure was the injudicious importation of the red clay material in the isolated area of most severe rutting.

However, it can be concluded that the original specifications of the sub-surface layers included in the paving contract and in the previous terracing contract were inadequate for the loading requirements.

It is particularly significant that, if the inferior red material had not been imported, the whole pavement would still have distorted by up to 30mm.

5. Remedial Measures.

The Engineers specified that remedial measures had to be carried out in the area of severe rutting only. These measures were as follows:

(i) Uplifting blocks and setting aside for re-use.
(ii) Excavate 150mm of insitu material and cart to spoil.
(iii) Rip and scarify sub-grade over depth of 150mm level and compact to 93% Mod. AASHTO.
(iv) Form sub-base 150mm thick with imported crusher run. Level and compact to 95% Mod. AASHTO.
(v) Supply and spread bedding sand and screed to level.
(vi) Clean and re-lay usable existing blocks including sweeping fine sand into joints and compact.

	ACTUAL	SPECIFIED
i) Liquid limit	62	-
ii) Plasticity index	21	12
iii) Linear shrinkage	8	-
iv) Grading modulus	0,32	min 1.00
v) Mix dry density	1715	-
vi) Optimum moisture content	16	-
vii) CBR at 100% Mod. AASHTO	3	20
at 95% Mod. AASHTO	3	20
at 90% Mod. AASHTO	2	-

Table 2 Results of laboratory tests on typica[l] sample of red material.

It is particularly interesting to note that t[he] above specification represents an upgrading the pavement design previously specified in that items (iii) and (iv) were added by t[he] Engineers. The client therefore agreed to p[ay] for these items. This was tantamount to admi[t]ting that the original pavement design was n[ot] up to standard.

It is further interesting to note that althou[gh] rutting had also occurred in other areas of pavement, the client body ruled that the d[is]tortions would not impair the serviceability the paving and that no further remedial m[ea]sures would be necessary.

6. Assessment.

The Authors are of the opinion that the fail[ure] highlighted by the severely damaged area then by a subsequent investigation into remainder of the pavement indicates a compl[ete] lack of understanding of the behaviour of [seg]mental block paving by all concerned, es[pe]cially when one takes into consideration intensity of loading to which it was to subjected.

The failure also highlights the fact that though Engineers are employed to supervise construction of pavements, there is a dist[inct] lack of appreciation for the importance of function, so as to ensure the success of serviceability and life of a precast conc[rete] paved area.

CASE 3

A Petrol Filling Station.

1. Introduction.

As part of a national campaign to upgrade standard of the outlets for its products o[ne of] the major oil companies in South Africa l[et a] contract for building improvements and court re-construction at one of its fi[lling] stations in the Orange Free State.

The filling station is located adjacent major shopping complex and is constantly [sub]jected to high volume traffic.

The forecourt had previously been paved using 80 mm grey "SF2" type concrete blocks. The paved area had been in use for several years and had performed satisfactorily under traffic.

The purpose of re-vamping the forecourt was to substitute coloured rectangular blocks (Type S - C) to suit a specific pattern which had been adopted nation-wide by the Oil Company in order to project a standardised corporate image to the public.

The services of a Consulting Engineer were not retained for this project and a paving contract was let to the contracts division of a major block manufacturing company in South Africa.

The scope of the work included the following:

i) Lift and store existing blocks on site.
ii) Remove 100 mm existing base-coarse material (crushed rock).
iii) Install new 100 mm layer of crusher run.
iv) Set barrier kerbs.
v) Relay area using a blend of terra-cotta and charcoal coloured rectangular blocks in a specific pattern, of colours.

In order to cater for the expected upsurge in trafficking during the Christmas season, an extremely tight construction programme had to be adhered to and the entire contract involving 1200 sq. m. had to be completed in 2 weeks during December 1986.

2) Extent of Failure.

Immediately upon completion of the work it was evident from a visual inspection that the paved area would not meet the aesthetic standards set either by the client or by the Contracting Company's management. However a detailed inspection was made one month after completion and the following defects were reported:-

i) The surface texture of the blocks was inconsistant (from very smooth to rough).
ii) Several blocks were chipped and broken in half.
iii) The alignment of the blocks was very poor.
iv) The joint widths varied from 0 mm to 12 mm.
v) Blocks were porous, losing colour, delaminating on the surface and the corners were chipped.
vi) There were signs of rutting and evidence of subsidence.

Soils Investigation.

To investigate the settlement which had taken place five test holes were excavated at the site and a typical profile (section) of the side of the test hole, is shown in figure 4.

An examination of this profile revealed that the re-establishment of the base course had not met the minimum thickness of 100 mm specified and it was concluded that this had contribut to the surface distortion that had taken plac

Figure (3) Photograph showing typical defects

Samples of the decomposed dolerite and the cl were analysed in the laboratory and a summa of the average results were as shown in tab 3.

TEST	LAYER 1	LAYER 2	LAYER 3
Liquid limit	23	29	64
Plasticity	5	9	30
Linear Shrinkage	2,2	3,3	14,4
Percentage Passing 0.075 sieve	5	8	62
CBR @ 95% compacted density	72	64	0
Optimum moisture content	5,5	9,2	18,5

Table (3) - Results of Laboratory tests on various layers (see figure 4).

Using the above criteria a check was made c the design and it was concluded that provide the base coarse layer was increased to th minimum thickness of 100 mm as originally spe cified the pavement would be able to suppor the loading conditions imposed by the traffic.

4) Aesthetic Deficiencies.

Representative samples of the precast concret blocks were submitted for scrunity and speci mens sent to a laboratory for physical an chemical testing.

The results were compared with the standard laid down in the specification for Precas Concrete Paving blocks as proposed by th Concrete Masonry Association of South Afric (3), and S.A.B.S. 1058 (4).

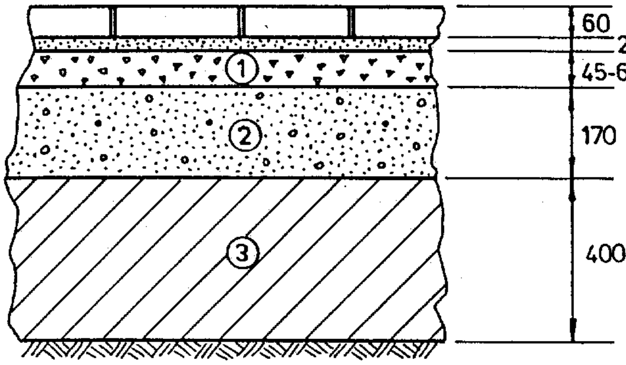


Figure (4) - Typical profile of test hole

The following is a report of the findings:

(i) Age of blocks: 28 days.
(ii) Appearance: 20% of the blocks examined had chips exceeding 15 mm in maximum dimension and covering more than 3% in the periphery of the intended exposed surface.
(iii) Shape Dimensions: 36% of the blocks exceeded the allowable tolerance of plus/minus 2 mm in their geometric shape.
(iv) Thickness: 45% of the specimens measured exceeded a tolerance of 3 mm.
(v) Chamfers: All the specimens met the requirement that the area of the wearing surface shall be at least 70% of the gross area but the arrises of the chamfers were not sharp and in some blocks the chamfers were hardly discernible at a all.
(vi) Compressive strength (specified 25 MPa ave). The compressive strengths varied between 26 MPa and 54,3 MPa with an average strength of 28,3 MPa.
(vii) Resistance to fading: In addition to large visual variations in colour none of the blocks could achieve the minimum fading value of 3 compared with an unexposed specimen in accordance with SABS test method 182. (5)

From the above it was clear that the blocks supplied by the Manufacturer to the site were completely unacceptable and were the cause of poor alignment and irregular joint spacing of the blocks, as observed in the completed pavement.

6) Remedial Measures.

The entire contract was condemned by the manufacturer's management and the following remedial measures instituted.

(i) Blocks uplifted and removed from site.
(ii) Existing base coarse material removed.
(iii) A 100 mm thick layer of crusher-run (base coarse) relaid, and compacted to 98% mod AASHTO.
(iv) 25 mm layer of bedding sand imported.
(vi) New 60 mm coloured blocks, manufactured in accordance with CMA specifications, laid.

The cost of the remedial work was borne jointly by the block manufacturer and the paving contractor who had failed to reject the defective blocks when they had been delivered to site, and who had failed to construct the sub-base to specification.

7) Assessment.

In arriving at a conclusion as to why the original pavement was not a success the following factors were agreed upon by the authors.

(i) Neither the block manufacturers nor the paving contractor's staff had a sufficiently clear perception of the clients needs, for an aesthetically acceptable pavement.

(ii) Due to the tight construction schedule short cuts were resorted to and quality of product and workmanship were overlooked.

(iii) There also was insufficient understanding of the technical input required to ensure that the pavement would function for the purpose for which it was intended.

Conclusion:

As is required of any other engineering structure an elemental block pavement must conform to certain laws of physics in order to function in the manner for which it was originally intended.

The relevant principles and criteria of these laws are found inter alia in:

(i) The theory and practice of soil mechanics.

(ii) The basic principles of the strength of materials.

(iii) The theory of structures.

(iv) The testing and laboratory analysis of materials.

(v) The technology of dry mix concrete.

(vi) The theory and practice of hydraulics.

Furthermore due to its exposure to constant visual examination a paved area should conform to specific aesthetic standards including shape, colour, texture and patterns.

It is therefore clear that the success of any paved area will depend upon the professional skills of the designer, specifier and contractor who have been engaged to provide the client or end-user with a surface he needs for his particular application.

Complete failure of the project will as a rule not be the direct result of only one of the elements mentioned above being defective, but rather a combination of such defects.

For a user to expect perfection in all the physical, mechanical and aesthetic aspects making up a pavement would not only be unrealistic but would also be totally uneconomical.

Therefore as is illustrated in the above case studies the failure of a block pavement may in the one case be due to the non-conformance of certain individual elements that would make up a perfect surface, and yet in another case the non-conformance of these same elements would be perfectly acceptable for the purpose for which it is intended.

The level of knowledge and understanding of the purpose for which a block pavement is to be used is of vital importance at the conceptual stage, and it is important for the success of any pavement that the architect, engineer, manufacturer, and the contractor are all fully aware of the intended use of the proposed paved surface.

<u>References.</u>

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2) Clifford J.M. RP/9/84 Structural Design of Segmental block pavements for Southern Africa.

3) Concrete Masonry Association (S.A.) Precast Concrete Paving Blocks - Specification.

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5) South African Bureau of Standards - S.A.B.S. Test Method 182.