BEDDING SANDS FOR CONCRETE BLOCK PAVEMENTS SUBJECT TO HEAVY CHANNELISED LOADING

by

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Summary
In critical cases of channelised, heavy loading, a number of failures of concrete block paving, particularly in wet climates, have been attributed to the use of unsuitable bedding sands. The functions of the laying course are listed, the requirements of a bedding sand to fulfill these functions are stated and specifications for bedding sands are discussed. The mechanism of pavement failure is outlined. North American research into laying course performance is introduced and limited test data are presented for three types of bedding sand. It is concluded that the aditional cost of a top quality bedding sand for critical loading conditions represents worthwhile insurance against the consequences of pavement failure.

INTRODUCTION

Interlocking concrete block pavements are widely used, in many countries, to support traffic and heavy, industrial loads. For a variety of reasons, the pavers are laid on a thin laying course of bedding sand. In the past, little attention was paid to the quality of the sand used. Generally, if a sand was suitable for making concrete, it was accepted as a bedding sand. Paving contractors require sand to be locally available at low cost and are generally little concerned with detailed specifications. For pavements supporting light loads, concrete sands have often been used successfully. In critical cases of heavy, channelised loading of structural, concrete block pavements, particularly in wet climates, a small number of failures have been attributed to the use of unsuitable bedding sands.[1][2] Such failures are costly in terms of reconstruction, litigation and damage to the image of concrete block pavements to support traffic and industrial loads. The additional cost, to obtain a first class bedding sand for critical aplications, is negligible compared to the cost of failure and should be considered as worthwhile insurance. The requirement to be able to identify such first class bedding sands has led to a re-examination of the criteria by which bedding sands are specified.

LAYING COURSE

The sand laying course is considered[3] to be an essential element, in a concrete block pavement, which facilitates placing the pavers. However, in the case of structural pavements supporting heavy loads, it can also be a potential source of weakness.

Functions

The main functions of the laying course are:

- to provide an even surface on which to lay the blocks
- to accommodate accepted tolerances in the finished surface level of the base
- to accommodate the manufacturing tolerances in block thickness
- to provide uniform support for the blocks and to avoid stress concentrations which could cause damage to the blocks
- to fill the lower part of the joint spaces between adjacent blocks in order to develop interlock

Requirements

In order to fulfil these functions, the bedding sand should:

- be readily available at reasonable cost
- be easily screeded to a uniform thickness
- be easily compacted
- be free-draining
- not be frost-susceptible
- be able to enter the joints between blocks
- be resistant to mechanical degradation

Specifications

Performance of laying course sands is thought to depend on a number of factors, including:

- the thickness of the laying course
- the grading of the sand
- the angularity of the sand particles
- the moisture content of the sand during compaction and in service
- the geological origin of the sand

Specifications have usually consisted of a grading envelope and a statement to the effect that any clean, sharp sand, suitable for making concrete, could be used. The increasing use of block pavements to support heavy loading has led to consideration of a more detailed specification for bedding sands under critical loading conditions. As vertical deformation of the bedding sand occurs under load, it is desirable that the laying course thickness not be excessive. The actual thickness will be influenced by the tolerance of the underlying base and by the manufacturing tolerance of the pavers. After compaction, the laying course should not be less than 25mm thick at any point.

Sand grading

Typical sand grading envelopes from Australia and the U.K. are shown in Figure 1. Other gradings have been developed in the United States and these are summarised in Table 1. In the Netherlands, particularly for mechanical laying, a coaser mixture of sand and fine gravel, having an upper size limit of 8mm, is generally used, but in that case many of the particles will be too large to enter a 2 to 5mm wide joint. In most other countries an upper size limit of 5mm is specified.

Fines

Bedding and grading envelopes generally allow between three and ten per cent of particles finer than 75μm. In areas where frost action occurs, it is considered desirable not to permit particles finer than 75μm. Knapton[4] has shown that 75 micron diameter particles will be transported by water flowing through a laying course at a velocity of 50mm/sec and that 25 micron diameter particles will be transported at a flow rate of 6mm/sec. Thus it is important also to exclude particles finer than 75μm when specifying bedding sands where pumping conditions (water and repeated heavy load applications) may be expected.

Particle shape

Provided that bedding sand is not lost from beneath the pavers, it has been shown[3] that minimum rutting of the pavement will be achieved by the use of angular sands, due to their high angle of internal friction. Experimental results[3] indicate that minimum rutting will occur if the bedding sand has an angle of internal friction of 40° or higher. However, it has been suggested[5] that rutting is primarily due to loss of bedding sand. Analysis of the failure of a small number of block pavements subjected to heavy, channelised traffic, lead to the conclusion that the angular bedding sands, manufactured from crushed rock, were the cause of failure.[2] Replacement of the 'crushed rock' sand with a naturally occurring silica sand and elimination of particles finer than 75μm resolved the problem. Although the manufactured sand was very stable at the laying moisture content, when saturated it fluidised under load, producing fines which went into suspension and were washed away causing failure.

Degradation

Lilley and Dowson[1] have indicated that the most important property of a bedding sand is the ability of the constituent particles not to break down under repeated loading. Sand degradation can be tested by measuring fines generated by 18 000 revolutions in a ceramic bottle with and without water. When tested wet, the most resistant sands show less than 2% increase in particles finer than 75μm, whereas the most fragile can exhibit values as high as 25%. Those sands least resistant to degradation often have very high angles of internal friction. Dowson[6] has suggested that for heavy duty applications, the increase in the percentage of sand particles passing the 600μm, 300μm and 150μm sieves should be limited to 10, 8 and 5 respectively.

Geological origin

It would be expected that sands consisting of hard constituent minerals would be most resistant to degradation and would perform well as bedding sands. It would also be expected that spherical sand grains would be less likely to break down under repeated loading than would irregularly shaped grains having weak asperities. Naturally occurring sands may have been produced by weathering of igneous, sedimentary or metamorphic rocks. Similarly, manufactured sands may be produced by crushing rock of all types. Knapton[4] has reviewed the geology of bedding sands and

has concluded that it is not just the mineral composition of the grains which is important, but also their geological history. For example, in sands produced by crushing sandstone, the particles formed may consist of two or more sub-grains cemented together by chemical action when the sandstone was formed. The bonds between the sub-grains may break down under load. For critical applications of repeated, heavy, channelised traffic in the presence of water, Knapton recommends the use of naturally occurring quartz sands with no particles finer than 75μm. Crushed granite contains quartz, feldspars (potassium, sodium and calcium, aluminium silicates) and micas. Quartz is hard and exhibits no cleavage planes. Feldspar is almost as hard as quartz, is less stable chemically and has two cleavage planes. Micas are relatively soft minerals and exhibit perfect basal cleavage, splitting into thin, flat sheets. Sand formed by crushing granite will thus be expected to be less resistant to mechanical degradation than a pure quartz sand. In Canada, screenings from the quarrying of limestone are often used as bedding sands. They consist almost entirely of calcite, a very soft mineral. Most of the particles are flat or elongated, having weak asperities which fracture easily. This material can be produced to meet specified gradings and has a very high angle of internal friction.

Pavement failures

Interest in the properties of bedding sands for structural, concrete block pavements arose out of two investigations of failures of such pavements under heavy, channelised traffic. The first investigation, reported by Lilley and Dowson[1] in 1988, concerned five or six sites in the North-West of England, all at bus stations. The problem became evident in the form of elliptical depressions oriented with their major axes along the wheel paths and generally 75cm to 1m long and less than 50cm wide. The depth at the centre of the depressions was 50mm, which corresponds to the original thickness of the laying course. None of the surrounding blocks had risen and it was therefore concluded that the bedding sand had not been displaced laterally. A light coloured deposit on the block surface near the joints suggested that the sand grains were being broken down to silt size by traffic stresses. It was hypothesized that the silt sized particles formed a paste with water entering the pavement and that this paste was squeezed out through the joints. It was noted that bedding sands in successful block pavements supporting similar heavy, channelised bus traffic, consisted almost exclusively of naturally occurring silica sand.

The second failure investigation concerned a high-profile project in Seattle, where 3000 square metres of streets, including two intersections, were surfaced with granite pavers. Heavy rain occurred shortly before the pavement was opened to channelised bus traffic; within hours the pavement began to rut excessively and bedding sand was observed being pumped out through the joints. The original bedding sand was a crushed granite having 13% finer than 75μm and selected on the basis of having the highest California Bearing Ratio of the candidate sands. This was replaced with a naturally occurring silica sand containing virtually no particles finer than 75 microns and with most particles within the range

500μm to 3mm. As a precaution the joints in the re-constructed pavement surface were sealed against the ingress of water, using a proprietary pre-polymer sealant.

Traffic
The failures described all occurred in areas subjected to channelised, heavy loads. In these circumstances every wheel load is applied in the same wheel path, whereas on a standard 3.75m wide road lane there is some lateral distribution of wheel loading. In U.K. practice, where traffic is channelised the estimated design traffic figure is multiplied by three before calculating the required pavement thickness. This is to allow for the increase in the concentration of loads on a particular wheel path.

Climate
The failures described occurred in North-West England and in the Pacific North-West of the United States. Both of these areas receive significant rainfall and rain water entering the pavement was a contributory factor in these failures. Although joint sealing of concrete block pavements is not considered necessary for all applications, there are a number of special cases in which it should be used. In cases similar to those reviewed, in which there is channelisation of heavy vehicle loads, the application of a joint sealant to the newly constructed pavement is recommended in order to minimize ingress of water. It should be emphasized that joint sealing is to be used as an adjunct to the proper selection of a bedding sand suited to severe loading conditions. Details of an elastomer, developed for airfield concrete block pavements subjected to jet-blast and suitable for the stabilisation of jointing sand have been given by Emery.[7]

Mechanism
The failures described above have three components:-

- an unsuitable, manufactured sand whose particles break down into fines under repeated loading
- channelised, heavy traffic loading
- ingress of rain water

The mechanism of the failures is that under the effects of repeated application of heavy loads, the sand particles broke down into fines which, in England, formed a slurry in the rain water which had entered the laying course through the joints and, in the United States, went into suspension. Pressure generated by further wheel loads caused the slurry to be squeezed out through the joints and the suspension to be ejected by pumping. In all cases the resulting loss of material caused rutting in the wheelpaths which, at the limit, was equal to the original compacted thickness of the laying course, i.e. 30 to 50mm, which significantly exceeds acceptable values of pavement deformation.

BEDDING SAND RESEARCH
In response to the pavement failures described,a programme of research into North American laying course sands was initiated. Samples of approximately forty laying course sands have been

obtained from different sources in Canada and the United States. Physical and mechanical properties have been measured and selected sands are being used in trial, laboratory pavements loaded vertically, at 5Hz through a 300mm diameter steel plate. The loading sequence is shown in Table 2. If this loading sequence is completed without producing more than 13mm permanent vertical deformation, the pavement is flooded to the top of the pavers and loading at 40kN continued at 5Hz for a further two million cycles or until prior failure. Figure 2 shows the load-deformation relationship for limestone screenings and for crushed granite during the flooded phase of the tests. Limestone screenings were pumped out through the joints and a permanent vertical deformation of 8mm was reached after one million wet cycles, whereas the crushed granite had reached a deformation of only 6mm after two million cycles. Table 3 shows particle size distributions for dry samples of limestone screenings, crushed granite and natural silica sand before and after the mechanical degradation test. It can be seen that neither the granite nor the limestone meet the criteria proposed by Dowson.
Relationships will be sought between the performance of the trial pavements under load and the measured properties of the bedding sands.

CONCLUSIONS

1. The performance of the laying course of an interlocking concrete block pavement can be critical where channelised, heavy traffic is supported.
2. Under heavy, channelised traffic, the ability of the bedding sand to resist mechanical degradation and control of the fines content appear to be more important than particle angularity.
3. The additional cost to secure a first class bedding sand for pavements subjected to critical loading is small and should be regarded as a worthwhile insurance against the costs incurred due to pavement failure.

ACKNOWLEDGEMENTS

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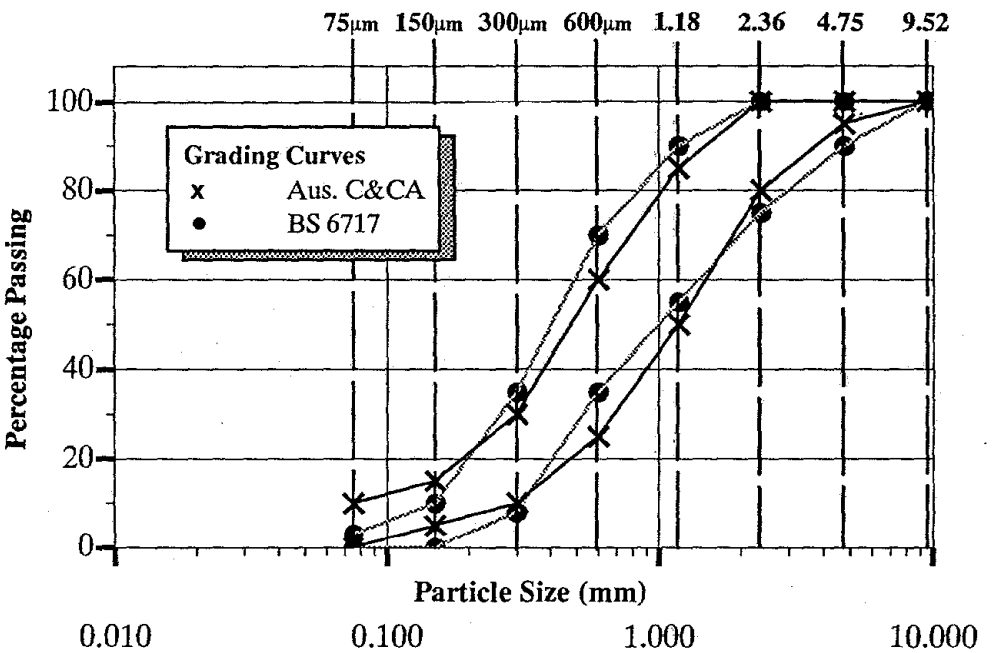

Figure 1 — Bedding Sand Grading Envelopes

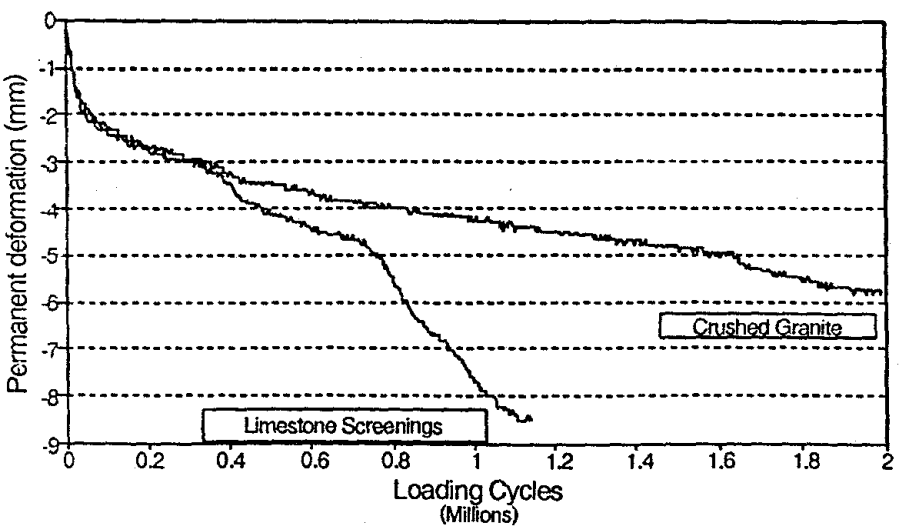

Figure 2 — Load versus deformation, flooded pavement

	ASTM	NCMA	C of E	BS 6717	Aus. C&CA
9.5mm	100	100	100	100	100
4.75mm	95–100	95–100	80–100	90–100	95–100
2.36mm	80–100	80–100	60–90	75–100	80–100
1.18mm	50–85	50–85	25–70	55–90	50–85
600μm	25–60	*Not Specified*	10–35	35–70	25–60
300μm	10–30	10–30	5–20	8–35	10–30
150μm	2–10	5–15	0–10	0–10	5–15
75μm	*Not Specified*	0–10	0–5	0–3	0–10

Table 1 — Bedding sand grading envelopes

Load (kN)	Actual Cycles	Equiv. Cycles	Hours
10	56 000	219	3.11
20	48 000	3 000	2.67
30	24 000	7 584	1.33
40	2 000 000	2 000 000	111.11
50	412 000	1 005 859	22.89
60	200 000	1 012 500	11.11
70	108 000	1 012 922	6.00
Total	2 848 000	5 042 084	158.22

Table 2 — Test pavement loading sequence

	Barmin Silica Sand		North Bay Crushed Granite		Elginburg Limestone Screenings	
Sieve	Before	After	Before	After	Before	After
4mm	100	100	97.4	98.0	74.0	77.7
2mm	98.7	98.7	81.1	90.6	46.2	54.5
1mm	54.0	60.0	66.2	86.6	29.0	38.2
500μm	32.0	33.1	49.9	78.2	18.7	31.3
250μm	9.9	14.2	30.4	54.1	13.1	26.0
125μm	1.2	2.9	16.0	30.3	9.3	21.8
63μm	0	1.1	9.0	16.8	6.8	18.9

Table 3 — Grading before and after degradation by Lilley & Dowson test