LAYING COURSE SAND FOR CONCRETE BLOCK PAVING

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Introduction

It is common practice throughout the world to lay concrete paving blocks on sand or grit, to form a regulating and bedding layer. Laying blocks on mortar has been reported, but is rare. (I)

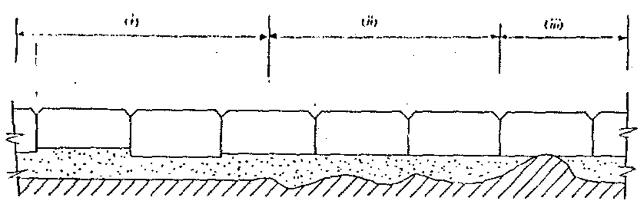
In practice, the average thickness of the compacted laying course is between 20 and 70mm. A 50mm mean thickness is the most frequently specified in the U.K.

The purposes of the laying course are illustrated in Figure 1 and are to allow the creation of a level running surface to the pavement, by:

i) catering for variations in block thicknesses.

ii) smoothing-out irregularities in the levels of the layer immediately beneath the laying course.

iii) providing a uniform support for individual blocks, without any 'hard-spots' that could result in high local stress causing damage to blocks.



Originally in the U.K., a clean, sharp sand, containing less than 3%, passing the 75um sieve was recommended. (II) Later a more detailed specification giving a full grading envelope was published. (III) These recommendations are shown in Table 1, together with the limits proposed for BS 6717: Part 3. (IV) which are broader. No reasons have been given for these recommendations, but they have been generally satisfactory in practice. A reason given by Lilley (V), for recommending sands with a low silt/clay content was as a construction expedient. 'Dirty' sands are easy to screed to a level surface, making th achievement of a good final running surface the pavement difficult. The more detailed grading envelope, Ref.III, was intended to ensure more continuous sand grading, while tl later broadening of the envelope, Ref. IV., to allow contractors a greater choice of san(

Historically, no attempt has been made to drá water from the laying course, although part : of BS 6717 (IV) will include a recommendatior to do this. There is a practical problem ir providing this drainage and at the same time ensuring that the laying course is still retained beneath the blocks.

This paper is a report on a problem that has arisen on a few sites in parts of England. I must be emphasised that the problem has to da been limited to five or six sites, all carryi heavy, channelized traffic and in the North-West of the country. With the growing use o concrete paving blocks in heavily trafficked pavements, and the identification of the problem, the authors believe there is a need to have a more comprehensive specification fo laying course materials.

THE PROBLEM

The identified sites have all been at bus stations which, some 1 to 3 years after openi to traffic, developed faults, described as 'Elephant Footprints'. These develop in the wheel-tracks, are not continuous ruts, but elliptical shaped depressions, with their maj axis along the length of the track. A typic depression is less than ½ metre wide by ¾ to metre long, with its centre up to 50mm (the laying course depth) below original pavement level. Examination of the levels of the blocks, in the paving surrounding these depressions, does not show any blocks to have risen, which is taken as evidence that the sa beneath the depressed blocks had not been displaced sideways. All the sites on which investigations have been made, the blocks are used as an over-lay to an existing pavement, some with a concrete surface and the majority with an asphalt surface. Excavation of bloc showed that these bases were sound, not deformed significantly and having a closed surface, which would not have allowed loss of sand. Examination of the precast concrete kerbs, showed these were also in good conditi and effective as edge restraints. The proble has been found in both pavements laid with shaped and rectangular blocks.

On the first site examined in detail, rectangular blocks had been used, laid in a herringbone pattern. There was a light coloured deposit on the block surfaces, near the chamfers. At that stage of the investigation a hypothesis was suggested, as follows:-

"Sand grains of the laying course were breaking down (degrading) under a large number of repeated stresses, caused by the double-deck buses using the site. Degradation was such that a high percentage of the sand grains became as fine as silt which was then squeezed through the joints, in the form of a paste".

As no reports of a similar problem had been found from anywhere else in the world, the hypothesis was originally treated with scepticism.

FORMS OF INVESTIGATION

SITE STUDIES: The first stage of site investigations was to take sand from the original failure site by lifting blocks from near the bottom of a 'footprint' and carrying out a sieve analysis. This showed the sand to be much finer than specified and containing a very high proportion of material finer than 75µm, which gave some support to the theory. The amount of fine material measured this way would have under-estimated any degradation, as a considerable quantity of the finest material would have already been lost. Tests were made of sands taken from sites carrying similar traffic, which were much older and performing well. Sands were obtained from beneath wheel tracks and areas where there had been little or no traffic. Comparing gradings of the samples indicated little change had occurred. The sands were from river borne deposits and predominantly silica.

Having obtained this circumstantial evidence, supporting the hypothesis, literature surveys and practical tests were made, to obtain a better understanding of the subject and find a means of identifying unsuitable sands. The two methods of identifying sands was to consider using geological descriptions and/or the development of a simple physical test. It is also necessary to build up some understanding of the factors that could influence degradation. Degradation may not only depend upon the 'hardness' of the sand grains, but also its original grading, particle shape, amount and frequency of applied loads, the extent of interlock and possibly the moisture content of the sand and even the stiffness of the layer beneath the sand.

So far, degradation has been limited to laying courses formed of triassic and limestone sands, which are freely available in the north-west and midlands regions of England. With the present state of knowledge, relying on a geological description of a sand does not s to provide an adequate method of identifyi suspect sands, as those from some other geo logical source may also be unsuitable but r yet found.

THEORETCIAL STUDY

As stated earlier, no previous report descr ing this form of failure has been found, bu there has been considerable work on the degradation of unbound roadbase materials, Le and Zakari (VI) define degradation as, "the reduction in size of particles which occur the process of laying and compaction and as consequence of traffic action in associatio with weathering processes in the pavement l Although intended to describe a different l of a pavement, this definition is considere ideal for describing the phenomenon occurri with laying courses.

There are many ways by which degradation co be measured, change of grading, increase in amount of material passing a certain sieve size, increase in specific surface area, or measuring the energy required to degrade a sand to a certain level (VII).

Having considered the various possibilities reliance has been placed on measuring the increase in the percentage passing a sieve sieves after placing samples in a simple ba mill, operated for a fixed time. Before describing the test in detail, it is first necessary to consider factors likely to cau degradation.

PARTICLE GRADING AND SHAPE: Consider a uniformly graded material made of spherical particles; high contact loads will be deve oped, as illustrated in Figure 2. It can shown that if the particle diameter is halv the number of contact points will increase a square law and therefore the load at individual contact points reduced in a simila proportion. From this it is implicit that fine sand is preferable.

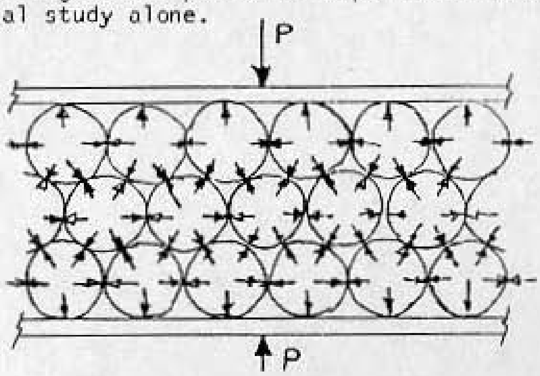
It is also axiomatic that a well graded material, made up of spherical grains, woul have a greater number of points of contact than a single size material, the ideal mate being one where every grain had contact ove 100% of its surface. Theoretically, this would be a material with a grading curve fo lowing the equation proposed by Fuller and Thompson (VIII), as follows:

Percentage passing any sieve

$$= 100\sqrt{\frac{\text{The aperture size of that sieve.}}{\text{The size of the larges particle.}}}$$

In addition to the grading having a major effect on the stress generated at particle contact points, particle shape will also have an influence.

Theoretically a material made entirely of single size cubes, placed against each other would form good laying course for resisting degradation. It can be seen, therefore, although a Fuller curve would seem to be the best grading for a laying course material composed of spherical particles, the reverse would be true for a subic material. Natural materials are made of a host of particles of different and irregular shapes and it was, therefore, thought to be unrealistic to reach reliable conclusions on the effects of grading and/or particle shape from a theoretical study alone.



PARTICLE HARDNESS: From the theoretical considerations and the generally excellent performance of heavily trafficked concrete block pavement, the authors have concluded that any of the factors considered concerning grading and particle shape are of second order importance and the prime concern is to avoid the use of materials made up of particles which can break down to sizes small enough to be able to be forced, under pressure, through joints between blocks or into the interstices of any underlying layer. Obviously the size of these pressures is important, increasing with traffic loads and decreasing with improvement of block interlock.

SITE INVESTIGATION

The part of the paper describes a detailed investigation of one of the sites exhibiting the problem of 'Elephant Footprints'.

General description of the site and the investigation

The concrete block paving was constructed over an existing carriageway which had been a major route through the town centre. A dual carriageway was built allowing the original road to be made into a two-way bus route, forming part of a bus station, adjacent to a new shopping precinct.

In parts of the area, the existing road levels were suitable to directly receive the blocks and laying course, but in others they had to be built up. The block paving construction followed normal practice, which had been use very successfully on many other bus stations After some 18 months of use, dperessions appeared in the surface of the paving. With the co-operation of the employing authoritie the cause of these was investigated by carefully lifting the blocks and the laying cour to expose the roadbase.

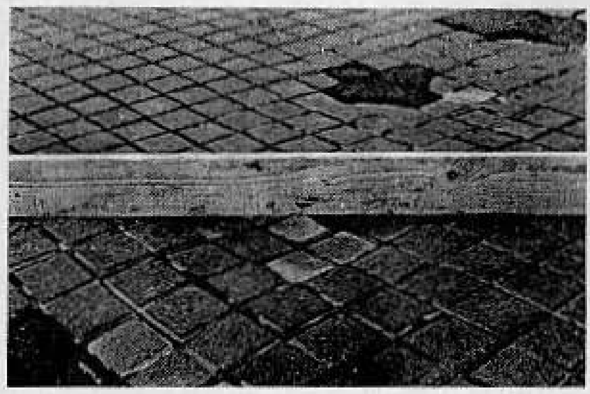
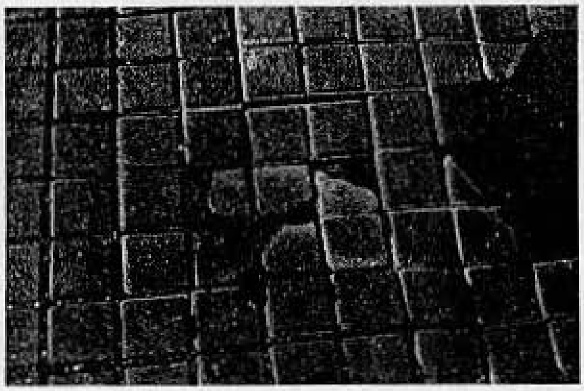
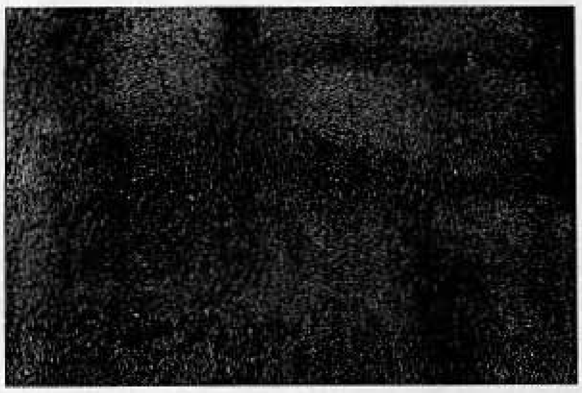


Figure 4 is a close view of one of the depressions, showing typical opening of the joints.

A specific appearance of the joints associated with this type of failure is fine sand extruding from the joints (Figure 5) and/or in most instances staining around the edges of the blocks, as shown in Figure 6.





The blocks were removed carefully and individually without disturbing the laying course, which was found to be hard and well compacted. Depressions in the laying course reflected depressions in the surface. The sand was also seen to be stained to a dark colour in the location of the joints of blocks, see Figure 7.

The sand was then removed and found to be formed into a biscuit-like structure, individual sand grains being bonded together. Awa from the joints the sand was found to be its original colour, but towards the bottom of t layer further staining was observed. Sample were sent away for further analyses.

Finally all the sand was removed to expose t roadbase which was found to be sound and not deformed.

For the purpose of comparison, another area which could not have carried any traffic was lifted and samples of the laying course sent for testing.

The sands from the trafficked areas were muc finer than specified and than that from the untrafficked area. Any sieve analysis of sand from beneath a depression would not acc ately show the total amount of 'fines', as material extruded through the joints would have been lost.

<u>Conclusions from the site investigation</u>

This investigation gave considerable support to the original hypothesis and therefore a need to be able to identify suspect material Other investigations carried out in a simila way have shown that not all depressions deve oping in the surface of a block pavement are due to sand degradation. Some failures are due to faults in the roadbase, an example of which is shown in Figure 8.

<u>Analysis of results</u> It is not possible to demonstrate what actually had happened to the laying course sand, but there seems to be ample evidence to support the theory of sand degradation.

INTERPRETATION OF RESULTS

<u>Original Gradings:</u> Of the 47 tested, all of which had been or were proposed to be use as a laying course, 38% were finer than the grading envelope recommended in Reference (I at at least one sieve size. Comparing the actual gradings with the slightly broader recommendations given in Reference (IV), onl increased the number of sands fully complyin with the recommendations by 3, (6%). After being subjected to the degradation in the ba mills, the sands finer than the original recommendations had been increased by 22%. Th number finer than the extended recommendatio had been increased by 25%.

Considering the coarse side of the grading limits, 15% of the samples were outside the recommendations on at least one sieve size. After being subjected to milling, none of the samples were coarser than the recommende limits.

One sample, as supplied, failed to comply with the limits; on one sieve size it was too coarse and on another too fine.

The sieve analyses tests indicate that sands complying completely with current recommendations are not readily obtainable in the U.K. and that there is a trend for the sands to be generally finer than specified. Of 47 sands, as supplied, only four had more than 3% material finer than 75um, two less than 1% in excess and two 2.5% in excess of the 3% maximum recommended. The sand with 5.5% material passing the 75um sieve had been used on one of the sites where 'elephant footprints' had developed within 18 months of carrying very heavy bus traffic. This sand degraded very severely in the ball-mill, the amount passing the 75um sieve increasing to 11.6%.

Shackel (XI) reported that blocks laid on a laying course sand containing 20 to 25% clay, developed excessive rutting when the sand was flooded, and clay pumped through the joints. It was also reported that where the laying course is free of clay, deformation was not excessive, even when the laying course is saturated. Shackel was not concerned with sand degradation, but he did find that pavement failure could result from an excess of fine material in the laying course and the risk was greatest when the laying course was saturated.

If it is assumed that the sands actually tested give a good representation of those used nationally, in practice the initial sands grading does not appear to be of paramount importance, as long as the silt/clay content is low. Although the evidence is still circumstantial, the resistance of the laying course material to degradation does appear important and the development of a test justified.

<u>SETTING ACCEPTANCE LEVELS</u> The hypothesis appears proven and the use of a degradable laying course must be avoided. It seems logical to place a maximum limit on the increase of material passing, say the 300um, 150um and/or the 75um sieves, after degradation in the ball-mill. The maximum increases in percentages passing these particular sieves, proposed by the authors, are 75um, 2%, resulting in a total maximum of 5%, 150um, 5% (total maximum 15%) and 300um, 15% (total maximum 50%). The rate of degradation in the field will not only depend upon the physical properties of the sand, but also the weight and volume of traffic. Assuming a pavement life of 20 years is desired, it is very probable that even the most degradeable sand tested would perform well under lightly trafficked conditions. As an interim measure, it is recommended that any block pavement designed to carry, say more than 1.5 million standard axles, should have the laying course tested, as outlined above, and if it degrades beyond the limits suggested, the sand should not be used.

RECOMMENDATIONS FOR FUTURE WORK

A potential problem has been identified by the authors of this paper which could result in the poor long-term performance of more heavily trafficked block pavements. The authors find it difficult to believe that similar problems have not occurred anywhere else in the world and would like to hear from anyone that now believes that they could have had a failure caused by laying course degradation.

To be able to set better levels for the suitability of various laying course materials, considerably more research is needed. One simple way of undertaking such a study is to measure the change of laying course gradings, with time, on pavements carrying measured traffic flows and weights. Ideal sites would be the entrance and exits of docks or other similar industrial installations.

DEVELOPMENT OF A TEST METHOD

Having considered various possibilities, the decision was made to adopt a simple empirical test to measure sand hardness. Possibilities examined were the making of sieve analyses before and after carrying out some form of compaction test, for example, the Standard Compaction Test 3 from BS 1924. (IX) Finally a simple ball-mill test was chosen. This was favoured for several reasons; it did not appear to be sensitive to operator technique and would therefore be reproducible; answers could be available within a working day, once the sample had been dried; all tests could be made in triplicate almost as quickly as singly, reducing the risk of errors and also providing a guide on reproducibility of the method; the equipment was low cost and readily available.

At the initial stage of development it had not been decided whether comparison of gradings, before and after degradation would best be made by comparing the overall change in the shape of grading curves, or by comparing changes on just one or two sieve sizes. In practice, the latter has been chosen.

<u>Outline of test method</u>

i). Obtain a representative sample, weighing at least 1 kg.

ii). Dry the sample for 24 hours or to a constant weight in a thermostatically controlled oven set to run at 105 to 110°C.

iii). Obtain three sub-samples, each weighing approximately 200g. by passing the main sample several times through a riffle box.

iv) Carry out a sieve analysis on each sub-sample, in accordance with BS 812 (X)

v) Place each sub-sample in a porcelain jar of 1 litre nominal capacity (Figure 9), together with two 25mm diameter steel ball bearings.

vi) Place each jar on a bottle roller, so that they rotate at a speed of 50rpm for six hours.

vii) Repeat the sieve analysis on each sub-sample.

viii) Report the mean of each of the three sieve analyses before and after degradation.

At the time of writing this report, the Cement and Concrete Association laboratories had tested 47 sand samples in this way. Similar tests had been made of 30 sand samples by the laboratories of Marshalls Mono Ltd.

The early samples tested by the Cement and Concrete Association were not sub-sampled by riffling, and considerable differences in sets of sieve analyses were found. Riffling to obtain the sub-samples greatly reduced these differences and probably improved the repeatability of the test.

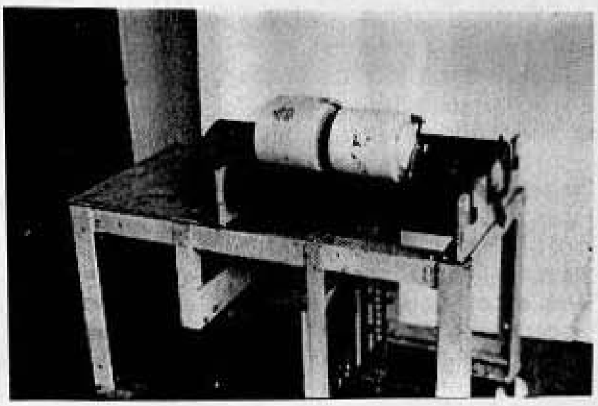


TABLE I Recommended grading limits for laying course sand

BS Sieve	Percentage	Passing
Ref. No.	(III)	(IV)
5mm	90-100	90-100
2.36mm	75-100	75-100
1.18mm	55- 90	55- 90
600um	35- 59	35- 70
300um	8- 30	8- 35
150um	0- 10	0- 10
75um	0- 3	0- 3

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