FURTHER INVESTIGATION INTO SATURATED BEDDING SAND–INTERIM REPORT

A.J. Dowson
Marshall Building products
Halifax, Great Britain

Summary.
Following the Rome Conference where the author along with A A Lilley introduced the failure concept named as Elephant Footprints, the author has continued his investigation into the phenomenon of sand performance. New work was introduced to the conference in Oslo last year. This subject has now aroused interest all over the world.

Since Oslo, more experimental work on developing a test to identify potential sand at risk for special usage namely, channelised traffic over a rigid base. The test is becoming more acceptable and the paper describes this evaluation work of the Bottle Rolling Test.

Coupled with this work, investigation into on-site complaints has lead the research work to investigate the sand properties under water flow conditions.

On a site investigation, following a relaying of blocks with drainage at the sand layer where on the surface similar indentations occurred showed that the sand, which was homogeneous when laid has segregated into particle size layers where much of the very fine material has sunk to the bottom of the layer.

In the laboratory, with simple apparatus it was easy to demonstrate this separation, as supplied sand, material was separated in standard sieve sizes where the water flow characteristics were measured.

Introduction

At the Rome Conference in 1988, the author and Mr. Alan Lilley presented a paper entitled " Laying Course sand for Concrete Block Paving " and introduced the term Elephant Footprints. These were sites identified as having elliptical shaped depressions developed in the wheel track. The hypothesis suggested that the sand grains were being broken down, (degradation), under load of repeated traffic. Degradation was such that a high percentage of the sand grains became as fine as silt, which was then squeezed out through the joint, in the form of a paste. A test was suggested to be developed to identify sand which would not degrade in use.

From this paper, other researchers became interested and in New Zealand three papers were presented. K Hudson indicated the hardness of the sand was important and that the best was geologically recent alluvial river deposits, crushed and washed. Dr. A Beaty, following a research development based on the author's suggestion indicated that the Bottle Rolling Test concept should be used. Knapton and Cooke proposed limits on the fine material limiting the sand source to alluvim deposits.

In Washington in 1993 at the BIBM Conference, the author presented more developments in test sands and introduced the test called Bottle Rolling. Professor Knapton confirmed his thoughts on sand hardness and introduced the Electron Scanning Microscope method.

In 1994's Second International Workshop in Oslo, Knapton, Beaty and the author produced further papers on this subject and this paper continues with further development on sand and sand performance, in respect to sand degradation.

WATER PENETRATION EVALUATION

From the bottle rolling test it can be seen that, when tested saturated, the degradation of the sand is accelerated, so it is important that the water is restricted in entering the laying coarse sand and which is normally vulnerable in its early life.

Water penetration of pavements has been studied in the laboratory by many researchers and their conclusions are given below:
Clarke undertook trials in which water was sprinkled on to untrafficked concrete block paving and the surface run off was weighed and expressed as a percentage of the water applied (run off coefficient). He described the application for between 20 mm/hr and 55 mm/hr and showed that pavements with slopes of 5% and 2,5% had a run off coefficient of between 70% and 90% in all cases.Further work by Smith, in which trafficked pavement slopes 0,7% to 1,3% were

subjected to simulated rainfall intensities between 2 mm/hr and 30 mm/hr, showed that as the intensity of rainfall diminishes, the run off coefficient also diminishes. When the rainfall is 5 mm/hr or less, the rainfall coefficient is around 50% or less, so that several millimetres per hour penetrates the pavement.

During his tests, Smith observed that:
"Concrete block paving placed on a sand and gravel base, trafficked by automobiles, does not always have the joints filled over time with detritus (generating a high run off coefficient). The sealing action of sediment and detritus in the joints may be negative or even reversed by sucking and pumping action of automobile tyres on the concrete block paving."

From Clark and Smith, it can be concluded that concrete block paving designers should anticipate the percolation of sufficient rainfall through the joints of the pavers to reach a condition where the laying course material is affected by moisture. It may be that trafficking will impede the ingress of water but there is insufficient data available to rely on the detritus sealing hypothesis working with any degree of confidence. As an example of the danger inherent in relaying up on detritus sealing, consider Smith's conclusion in relation to a bus road. It is possible that the traffic may actually remove detritus, rather than deposit it. Therefore, there will always remain a possibility that such pavements may become well sealed between the wheel tracks and permeable in the wheel track, which will have an effect of amplifying the volume of water entering the laying course in the wheel track.

Taking the worse scenario, water will enter the laying course through the jointing sand, so the following test was carried out to examine water flow through both jointing sand and bedding course sand.

Fine grain particles can be transported by the movement of water passing through the sand. Siever, in his book "Sand", shows that water velocity and particle size can be transported is related by the following equation

$$U = kd^2$$

where U = velocity of water
k = constant
d = maximum grain diameter that can be transported

To examine the passage of water through sand will vary, depending on the particle distribution and to check the flow characteristic an apparatus was developed, as shown in appendix.

Taking a sample of dry sand, weigh out a representative sample of 1,2 kg, place a filter paper at the flat bottom and carefully compact the sand in the funnel. One litre of water is poured into the water container and through the gauze the water is allowed to sprinkle on to the top of the sand. The timer is started and when the water has stopped running through the sand the timer is stopped and the time is recorded.

Using the same source of material, gradings were prepared with various fractions removed and the test was carried out on these samples. In each case the time taken for the water to stop running through the sand was recorded.
The table shows the results;-

Test	Smallest fraction	Time (minutes)
1	75 µmm	15
2	150 µmm	14
3	300 µmm	5
4	600 µmm	2min 22 sec

To observe the effect of some moisture present, a sample was taken in the as delivered condition and was subjected to the same test method. This took 4 mimutes 30 seconds for the water to stop running through. The water that passed through was collected and this amounted to 750 ml . It was observed that the water was contaminated with fine particle unlike the dry sample there was no fine particles visible, when tested.

As part of the evaluation, the jointing sand was tested in a similar way and this took 5 minutes to pass through and the amount collected was 700 ml.

The test was repeated using only the filter paper in the funnel. The water was poured into the top funnel and the time measured for the water to pass through. The test was also repeated using Terram filter fabric as the filter. The results are

Type of filter	Time taken (minutes)
Standard paper	5 min 23 sec
Terram	9 sec
Terram 700	6 sec
Terram 4000	12 sec

It is obvious that the influence of the fabric or filter plays an important role in the speed in which the water passes through the sand. The test method was repeated using selected gradings and comparisons made with the time it takes to pass the water through.

Material condition	Type of filter	Time taken	Remarks
As delivered	filter paper	21 min 42 sec	Moisture 4.18%
		26 min 27 sec	
		27 min 28 sec	
As delivered	Terram 700	6 min 31 sec	
		6 min 51 sec	
		5 min 32 sec	
As delivered	Terram	5 min 25 sec	
		6 min 13 sec	
		5 min 19 sec	

From the previous work using standard filter paper, the test was repeated using selected gradings to observe the flow characteristics and the filter media was changed.

Material condition	Type of filter	Time taken
+75µmm to 5 mm	filter paper	19 min 32 sec
		17 min 04 sec
		15 min 37 sec
+ 150µmm to 5mm	filter paper	22 min 09 sec
		26 min 42 sec
		29 min 22 sec
+300µmm to 5mm	filter paper	6 min 33 sec
		8 min 52 sec
		5 min 38 sec
+600µmm to 5mm	filter paper	2 min 30 sec
		3 min 23 sec
		3 min 06 sec
+600µmm to 5mm	Terram	38 sec
		26 sec
		35 sec
	Terram 700	21 sec
		22 sec
		23 sec
	Terram 4000	32 sec
		35 sec
		35 sec

As one of the results appear to be inconsistant with the rest of the results, the test was carried out again with selected gradings and the results obtained were as follows

Material condition	Type of filter	Time taken
+75μmm to 5mm	filter paper	11 min 53 sec
		13 min 42 sec
		11 min 17 sec
+150μmm to 5mm	filter paper	9 min 21 sec
		10 min 51 sec
		10 min 16 sec

From all of the results of water flow there is a natural variation and this is mainly due to the way the particles of aggregate have packed down.

If water can penetrate through the jointing sand and the bedding sand, and sand is known to breakdown more readily under this condition, a comparision was made for the different fractions. Equivalent samples, with the different fraction removed, were bottled rolled to observe the effect of dry and saturated conditions.

The results of the percentage change in the respective sieves were

Sieve size	Sample					
	+600W	+600D	+300W	+300D	+150W	+150D
5	1,8	0,2	0,6	0,1	0,1	
2,36	13,6	0,7	3,0	0	0,3	
1,18	20,3	3,1	3,8	0,4	0,7	0,1
600			12,8	1,4	2,3	0,3
300					6,6	3,4
150						

Individual sizes of sand were removed and the samples were bottled rolled to see whether there was a particular sand fraction that broke down under this test regime. The results of the percentage increased were :-

Sieve size	As delivered	600μmm rem	300μmm rem	150μmm rem
5mm	0	0,2	2,0	0,4
2,36mm	0,5	0,9	3,0	1,2
1,18mm	1,9	1,2	4,4	2,1
600μmm	3,5		7,9	4,9
300μmm	11,3	9,0		17,3
150μmm	6,7	4,9	7,9	

The selection of sand is a very important factor, especially when we are dealing with pavements with a very high degree of channellised traffic. During the last twenty years specification for bedding sand has been evolving rapidly around the world. During this time, the practice in the United Kingdom has been to specify a good concreting sand. This has generally been sufficient specification, but failures occurring during periods of heavy rainfall and where there is a large amount of heavy channallised traffic, has led to a number of revisions.

The sand is a very important part of the structural integrity of the pavement. It is therefore a possible source of weakness in a pavement if not specified correctly.
Attributes of the bedding sand, which affect the performance of the pavement, have been discussed and the research carried out to identify a suitable testing programme to identify suitable sands.

Evaluation of the Bedding Sand Durability

For about 17 years, the author of this paper has spent time identifying which were good sands for bedding pavers on under high and channellised loads in areas of high rainfall. From this was developed the Bottle Rolling Test, which has been used as an indicator and now is being recommended as an acceptable test method as procedure for evaluation and selection of sand.

This test involves simple standard low cost equipment, unlike the latest means of identification using expensive Scanning Electronic Microscopy examinations. The SEM method has limitations as it does not quantify the limits of particles or particles with little or no fissure, or conglomerates of smaller particles.

One of the later recommendations was to specify sand by controlling the 75 μmm content and by simply surveying quarries or pits from their geological background without a qualitative test.

The Bottle Rolling test does not fully represent what happens in practice, but does apply load to an actual representative sample to cause breakdown of particles. It can be shown from this test method that sands can be identified for satisfactory use in heavy channellised areas as the table indicates:

LOCATION	CLASSIFICATION
Armthwaite, Carlise	good
Netherly Edge, Macclesfield	good
How Mill, Carlisle	good
Darlston, Carlisle	good
Blaydon on Tyne	good
Swavesey, Cambridge	good
Doncaster	good
St Ives	good
Corbridge	poor
Cleasby, Darlington	poor
Garstang, Lancs.	poor
Horwich	poor
Lechlade	poor
Tamworth	poor
Waddington, Clitheroe	poor

This list is for example only and is not definitive.

In all cases, when the sample is rolled saturated, the degradation is greater than when tested in a bone dry state.

Euston Bus Station in London is well known as a good example of block paving subjected to high volumes of bus traffic. It is estimated to have had over 17 million standard axles running over the surface in the last 17 years. Reconstruction has taken place and on examination of the base, the sand thickness varied between 40 and 100 mm and yet the surface profile remain level with no hint of surface depression. A sample of sand from the little or non traffic area has been obtained and was subject to the bottle rolling test.

The result of the test is:-

Sieve size	% increase after bottle rolling
5	0,1
2,36 mm	1,1
1,18 mm	4,9
600 µmm	8,9
300 µmm	9,7
150 µmm	5,2

The test was repeated with the sand saturated and bottled rolled for 6 hours and the result is :-

Sieve size	% increase after bottle rolling
5 mm	0
2,36 mm	0,1
1,18 mm	3,9
600 µmm	8,1
300 µmm	11,8
150 µmm	7,7

Considering the known record of performance of this sand, we are able to set limits for the increase in the grading change after bottle rolling.

The limits are :-

Sieve size	% increase
2,36 mm	3,0
1,18 mm	6,0
600 µmm	10,0
300 µmm	12,0
150 µmm	8,0

To reduce the time taken in dry bottle rolling the test method, could be modified to testing wet and the test could be reduced in time to a two hour test as the dry six hour test is similar to the two hour wet test. The limits on the increase on sieve sizes should be as the values given previously.

Appendix. Description of apparatus.

