THE INFLUENCE AND EFFECTS OF WATER IN LAYING COURSE MATERIAL IN CONCRETE BLOCK PAVING CONSTRUCTION

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ABSTRACT
The progress of water through the sand laying course has not been proven, but it has been a common understanding by block makers, researchers and users, that the water enters through the joint, either by incomplete joint filling or by deflection of the construction greater than 1mm, causing interlock failure.

For fine sand to move and be deposited on the upper surface of the block, there has to be a mechanism of moving fine material within the sand mass itself. Parallels have been drawn with the transportation of naturally occurring sand in the ground.

All this work generally deals with thick layers of different soils with fluid motions, in a gravitational field that originated from, or is influenced by, variations in density within the fluid characterised by the term stratified flow. Two-layered systems represent the simplest case of stratified flow. In the case of block pavements, the laying course is in a very thin layer, generally not exceeding 70mm and held between two rigid plates of the concrete block paving and the roadbase.

In order for water to move from one point to another, two conditions must be met. Firstly, there must be a difference in the hydraulic head between two points and secondly, the sand between the two points must be permeable enough to allow the movement of water. Sand contains relatively large pores compared with clay. At saturation all the pores are filled with water. Saturated flow depends on the rate or ease of water movement and the size and configuration of pores.

1 SAND INVESTIGATION

1.1 Sand Categories

As sands for laying course material have been characterised by particle size distribution, the relative grading limits are used to demonstrate the predominate size. The particle size distribution for sand to be used a laying course material, has been taken from BS 7533-3[1] and has been reproduced in Table 1.

Table 1. Particle size distribution for different categories of sand

Sieve Size	Percentage Passing Each Sieve				
	Category 1A	Category 1B	Category II	Category III	Category IV
5mm	90-100	90-100	90-100	89-100	89-100
2,36mm	75-100	75-100	75-100	65-100	65-100
1,18mm	55-90	55-90	55-90	45-100	45-100
600µm	35-65	35-65	35-65	25-80	25-80
300µm	10-45	10-45	10-45	5-48	5-48
150µm	0-10	0-10	0-10	0-15	0-15
75µm	0,3 max.	0-0,5	0-1,5	0-3	0-5

1.2 Void content

From this it is possible to examine the packing effect of the particles and to obtain the void content. It is impracticable to express air content of the sand on a weight basis, so air is usually given as a percentage of the total volume of the sand and can be expressed from the following equation:-

$$\frac{100\ Va}{Vs+Vm+Va}$$

where Vs = volume of sand
Vm = volume of water
Va = volume of air

The volume of occupied air and water (liquid) in sand is often referred to as the void. The sum of the two volumes expressed as a percentage of the total volume of the sand is known as the porosity and is calculated from :-

$$\frac{100(\ Va + Vm\ )}{Vs+\ Vm + Va}$$

The ratio of the sum of the air and water volumes to the volume of the solid component is called the void ratio and is expressed as :-

$$\frac{Vm+Va}{Vs}$$

1.3 Packing aspects

When constructing pavements using concrete blocks, the particles arrange themselves in this layer and will be referred to as the sand structure. The sand structure will depend on :

- the size, shape and surface roughness of the individual particles
- the range of particle size

The state of packing of the sand can be visualised in several ways, an example is given. Table 2

Table 2 Packing of sand particles

Effect of packing	Loose	Dense
Distance between particles	Furthest apart	close together
Void space	Maximum	minimum
Density	Minimum	maximum
Particle contact	Least	most
Freedom of movement of particles	Most	least

In all problems of three-dimensional packing of spheres of equal diameter, much importance must be attached to the relative volume of the space between the spheres. Barnes[2] states that the typical values of porosity lie within the limits of 35 - 50% with the lowest porosity and greatest density produced for :-

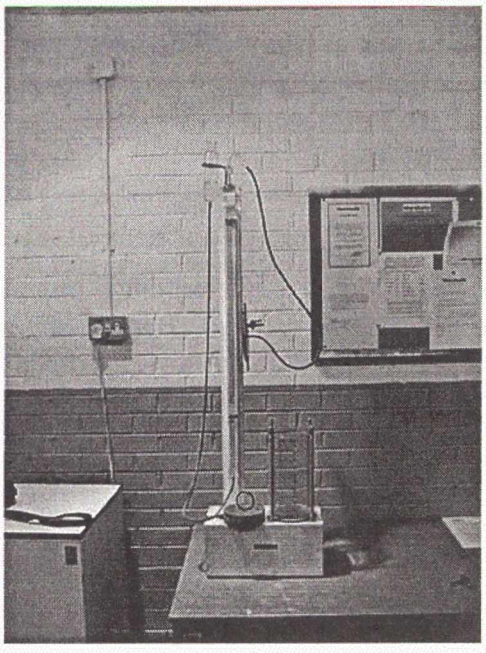
- larger particle sizes
- a greater range of particles sizes
- more equi-dimensional particles
- smoother particle

In the case of loose packing the percentage porosity is 47.6% with a void ratio of 0.91 and for close packing the percentage porosity is 26% with a void ratio of 0.35. Dowson[3] in his paper on Mix Design, where packing of particles forms the basis of his design procedures, produced the following details to include a co-ordination number and a diameter of the central sphere. The co-ordination number is the number of spheres that touch in a configuration. The diameter number of the central sphere is approximately three-quarters of the surrounding spheres

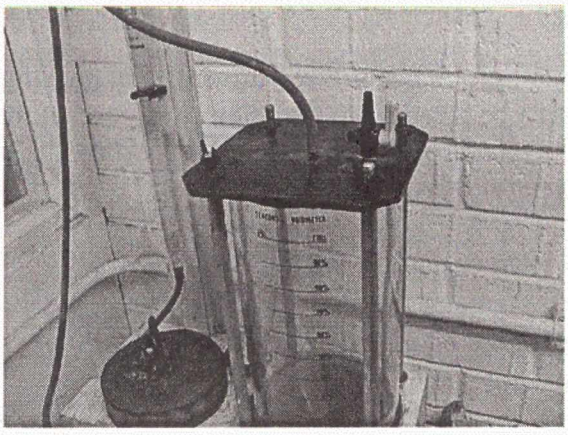
1.4 Void content measurement

The porosity and void content in granular material can be calculated from the relative density, however, the method detailed in BS1337-4[4] is mainly used for laboratory research and compaction control and can take several days to complete the test.

There is a simpler test method which was developed by the Building Research Station and Jencons (Scientific) Ltd, which involves a manometer to measure the entrapped air. The apparatus consists of a calibrated jar, into which the sand sample is compacted by dropping a 3 kilogram weight onto the loose sand. The jar is sealed with the metal plate, which has a venting valve, and a rubber tube connects the top of the calibrated tube and the plate. The valve is opened and the water level in the glass reservoir, which is calibrated and graduated, is checked to be at the correct level. The valve is closed and the small reservoir is lowered to the level of the bottom of the jar. Equilibrium of the water column is reached when the pressure of the air in the system plus the pressure due to the height of the water column is equal to atmospheric pressure. The amount of air in the sample is measured off the calibrated scale. As the volume of air above the sample is constant, variations in the distance that the water in the column falls, is directly related to the air in the sample. The apparatus is shown in Photograph 1 with a close up photograph of the metal lid with the connecting tube and the valve shown in Photograph2.



Photograph 1 General view of apparatus



Photograph 2 Close up of sealing metal with connection and valve.

Using Category 1A sand for void content evaluation, the test was carried out on the sand as received using the Jencon Void Meter.

To observe the effects of moisture in the sand on the void content of sea dredged material, tests were carried out using different water content levels. In each case the void was measured after the sand was compacted . The results are given in Table 3.

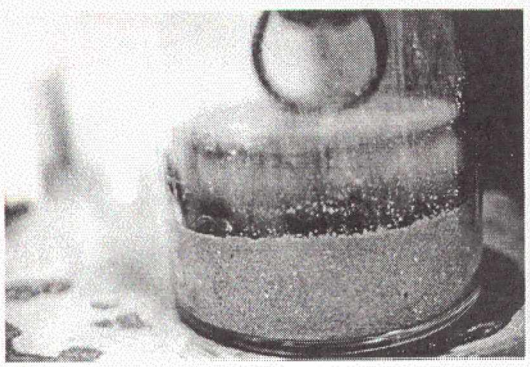
Table 3 Void measurements on different water contents

Blend	% water	% void
as received	5	31
as received	10	25
as received*	15	14

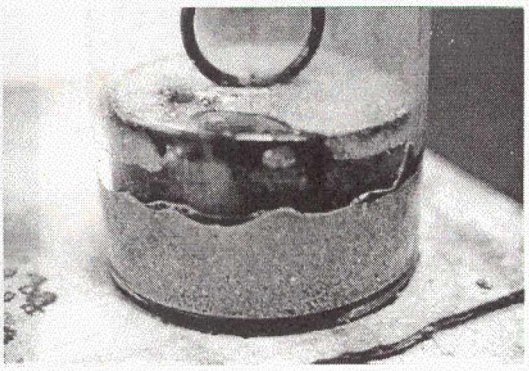
In the last test, with the water content at 15% of the dry weight, free water was drawn upwards and settled on the sand top. To measure the free water, a pre-weighed absorbent tissue was used to adsorb the water and the wet tissue was weighed. The amount of free water was 17 grams.

This action of extracting the water from the sand using low suction gave an indication that water can be removed from the laying course material. Unlike the void test procedure, where the volume of the sand is approximately 3 litres, the test was repeated using the standard procedure weight for compaction in the void test on a sample to achieve compacted sand approximately 30mm thick.

Category 1A sand was used and water was added to the sand in 5% increments to observe when free water appeared on the top of the sand. Photograph 3 illustrates the compaction of the sand using the weight. After each test the sand was removed from the jar and mixed with further water before being returned to the jar and re-compacted. The sand was compacted. There was no visible water on the side of the jar between the walls and the weight until 15% water had been added. Photograph 4 show clear water above the sand and in the gap.

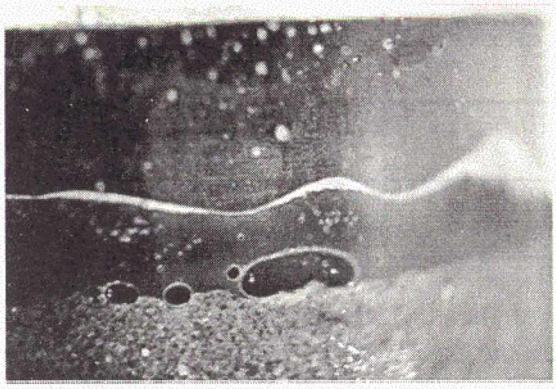


Photograph 3 Compaction of sand

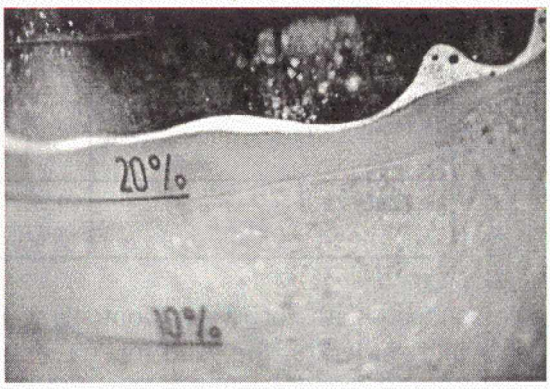


Photograph 4 Free water separation from sand

Pressure was applied to the sand through the weight by hand and it was possible to force air from within the sand material to the top and through the water. This is illustrated in Photograph 5 where various sized bubbles are visible. By maintaining the pressure on the sand surface, the water was observed for cleanliness and Photograph 6 illustrates little or no very fine particles in the water.



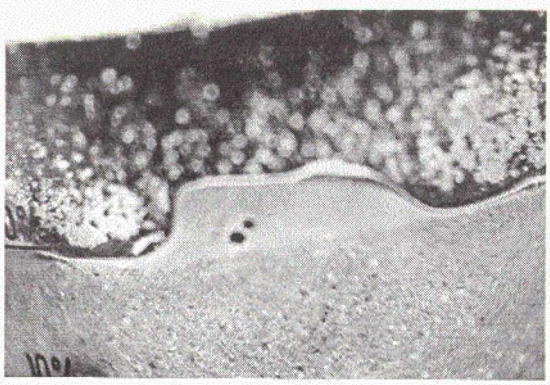
Photograph 5 Air bubbles being extruded from the sand



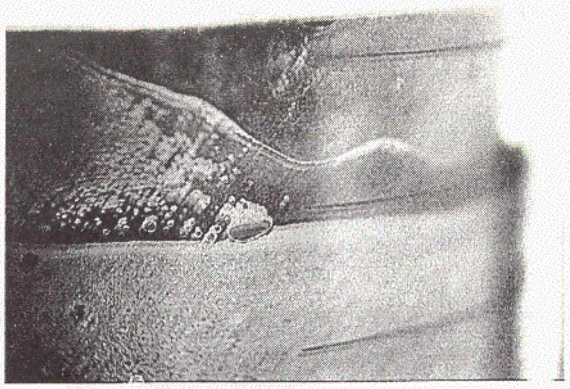
Photograph 6 Clear water above compacted sand

The test was repeated using a Category 3 sand with the silt content previously measured using the field settling test and found to be 4%. The sand was saturated to 15% moisture content and using the weight was compacted as before. Photograph 7 illustrates air being forced out together with the very fine particles and the water. Unlike the sea dredged sand, the particles have coloured the water.

By maintaining pressure to the sand as previously stated with the Category 3 sand, the sand and water action was observed to see if the fines in the sand would perform in a similar manner as the sea dredged sand. The very fine material of the Category 3 sand is moved to the top of the sand layer, as shown in Photograph 8 and is seen as a distinct layer.



Photograph 7 Example of fine sand and air in the free water



Photograph 8 Examples of fine material being moved with the water

2 CONCLUSIONS

Where Category 1A sand was used, the water flowed through the sand without observed fine sand particles being present. When Category 3 sand was used in a repeat of this experiment, the water flow exhibited the movement of fine particles.

From the void measurement reading obtained, the free space available between the grains is much higher than is required when free water is visible on the surface. From this work when the water content in the sand is approximately 15% of the dry weight of the sand, free water can be expressed using minimal pressure. To reach this critical point the water ingress level is relatively low as demonstrated in the small field trials where the saturation point of 15% was required.

Previous papers written by the author reference was made to the term 'Elephant Footprints', this is where there are surface depressions of approximately one metre diameter in an irregular pattern. The experimental work of observing water flow through sand has provided a theory of why this phenomena occurs. As the sand reaches the surface saturation point through the ingress of water and there is vibration through vehicle traversing the pavement, the sand settles and free water occupies the space between the underneath of the block and the upper layer of the laying course. This water after a period of time percolates back into the sand and under constant loading from vehicle slowly settles on to the remaining sand.

This theory can be further substantiated by observing the effects of bulking effect on compacted sand. The normal moisture content of laying course material is in the order of 5 to 10% and using the result from Table 3 for a given mass of sand the compacted height was 61mm and after the moisture content was increased to 15% this compacted mass occupied 54 mm height. This represents a reduction in height of 10% and in the investigations of Elephant Footprint the sand loss was in the same order. This depression of the surface was confirmed in the small field test where water was added to newly laid paving laying course and trafficked.

Again, from these experiments another theory can be substantiated for the fine particle which are deposited on the surface by the way water moves across the sand layer. The standard restricts the level of 75μm material. To substantiate this effect, when load was applied to a Category 3 sand using the Void Meter jar and compacted, at 15% water addition the free water brought the fine particles to the surface. This was also apparent in the vertical movement of water flow of the same sand. To determine the silt or 75μm content, there are several methods specified. Using the field settling method a Category 3 sand was tested and the result obtained was 4%. In the case of saturated sand it is similar to the field settling test. The field settling test requires the sand to be thoroughly mixed with water and then allowed to settle. We have a similar situation in practice where water enters the sand layer until the surface saturation point is passed. The Elephant Footprint theory and action begins to take place, during the time the load is imposed on the pavement. This layer causes the particles to be mobilised bringing the fine particles to the surface. These remain on the surface and when further water enters through the joint, the water and fine material are mobilised and at any point where water can enter or there is an ineffective joint between blocks this mixture will be deposited on the surface.

The performance of block paving is reliant on a sand layer to support the units and the joint between the blocks to restrict any water penetrating in to the sand laying course. It has been accepted practice that some water may penetrate into the laying course during the early stages of the pavement life, however becoming sealed by the action of detritus in the joint sand. For the detritus to be deposited on the surface of the sand jointing material, water borne dirt and dust is deposited on to the jointing sand. The jointing sand acts as a filter allowing some water through, dependent on the efficiency and effectiveness of the workmanship on filling the joints and leaving the ultra fine material on the joint surface. The effectiveness of the jointing between blocks requires further investigation.

REFERENCES

1. **BRITISH STANDARDS INSTITUTION** BS 7533 Part 3 Code of practice for laying concrete and clay pavers British Standards Institution London UK 1997

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3. **DOWSON A.J.** Mix design for block paving Proc. 1st Int.Conf. on Concrete Block Paving Newcastle UK 1980 pg 121-127

4. **BRITISH STANDARDS INSTITUTION** BS 1337 Part 4 British Standards Institution London UK 1997