PREDICTING THE PERFORMANCE OF BEDDING SANDS

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SUMMARY

A programme of research, designed to examine correlation between simple physical and mechanical properties of sands and the performance of concrete block paving in which they constitute the layingcourse, is described. The role and requirements of the bedding sand are presented and specifications aimed at meeting these requirements are discussed. Details of the approach to testing of the sands and of the laboratory test pavements are given, together with preliminary results of tests so far completed. Modifications made to the structure of the test pavement, following completion of the first test, are outlined and the intended future course of the testing is indicated.

INTRODUCTION

It is general practice to lay concrete pavers on a bedding course of sand having a strictly limited content finer than 75 microns. 'Although the bedding course is an essential feature of concrete block paving, in the case of pavements supporting heavy loads, it is also a potential source of weakness. A small number of failures, of concrete block pavements subjected to heavy channelized traffic, have led to the conclusion that a more comprehensive specification for laying course materials is required [1].

RESEARCH OBJECTIVES

The objectives of the work described in the paper are:

- to measure a series of physical and mechanical properties of a range of bedding sands
- to use those sands as the bedding course of a test pavement subjected to dynamic loading representative of traffic
- to seek a correlation between simple physical and mechanical properties of the sand and its performance in the test pavement under load
- to provide a simple testing procedure to enable unsuitable bedding sands to be rejected

ROLE OF THE BEDDING SAND

The role of the laying course or bedding sand has been discussed by a number of authors [1], [2], [3]. Its main functions are:

to fill the lower part of the joint spaces between adjacent blocks in order to develop interlock

- to provide uniform support for the blocks and to avoid stress concentrations which could cause damage to the blocks
- to provide an even surface on which to lay the blocks
- to accommodate the manufacturing tolerances in block thickness
- to accommodate accepted tolerances in sub-base surface level

REQUIREMENTS OF THE BEDDING SAND

As has been pointed out [4] the sand laying course is included in a block pavement as a construction expedient. Although it fulfils the roles indicated above and also contributes to the distribution of stresses applied to the pavement, it can also be the source of vertical deformation which appears as rutting of the pavement. The requirements of the laying course sand include the following; it 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 TO MEET THESE REQUIREMENTS

It has been stated [4] that three factors relating to the sand have an influence on the performance of the laying course under a trafficked block pavement. These are:

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

To these it is suggested that the hardness of the sand minerals should be added.

Block pavements to carry vehicle loads have been laid in Europe for as long as there have been vehicles to run on them. However, it is only since this technology has spread, to countries where it has not been traditionally used, that the need for specifications has made itself felt. A further contributing factor in the increasing use of concrete block paving to support heavy industrial and traffic loads. Untill recently, statements such as “a clean, sharp sand containing less than 3% passing the 75 μm sieve” “any sand suitable for making concrete” were felt to be sufficient.

THICKNESS

The most commonly specified thickness for the laying course has been 50mm after compaction. As a result of concern that the laying course was a major contributor to rutting, in Australian practice

uncompacted layer thickness of 30mm is now specified. Thus, after compaction, the layer thickness will be 20 to 25mm. In current U.K practice [5] a compacted thickness of 50mm is still specified where the tolerance on the sub-base surface level is ± 20mm. Where better tolerances are achieved the thickness may be reduced to 30mm but in no circumstances is to be less than 25mm thick at any point.

GRADING

In the Netherlands a coarser mixture, of sand and fine gravel, having an upper limit of 8mm is generally used, but in this case many of the particles will be too large to enter a 3 to 5mm joint. In most other countries a limit of 5mm is specified.

The Australian Cement and Concrete Association appears to have been one of the first, in 1980, to specify a grading envelope for laying course sands. This is shown in Figure 1 and corresponds to a typical well-graded 5mm sand suitable for concrete manufacture [2], In Britain, the Cement and Concrete Association (now the British Cement Association) also produced a grading envelope in 1983 and with minor modifications this was incorporated into a British standard [5] in 1989. This is also shown in Figure 1. It will be noted that the essential difference between these two specifications is in the amount of material finer than 150 pm which is permitted. In North America the National Concrete Masonry Association grading has been developed from the ASTM C-33 grading for fine aggregate for concrete [6]. The Portland Cement Association recommends the Australian C&CA grading and the U.S. Army Corps of Engineers has developed its own grading envelope. At the Dallas/Fort Worth Airport, the ASTM grading was specified, but with zero passing the 75μm sieve [7] These gradings are summarized in Table 1. In countries where frost action is of concern, there is a trend to eliminate particles finer than 75 microns. This also has the advantage of depriving the sand of silt-size particles which would be liable to go into suspension if pumping conditions occurred.

It has often been argued that the grading envelope should be as wide as possible so that as many sands as possible should be acceptable without the need for additional washing and screening. However, the cost of the laying course represents a small proportion of the total pavement cost. Where concrete block pavements are used to support channelized, heavy vehicle loads, the performance of the bedding sand may be critical. In these cases, if the pavement fails, the additional costs of reconstruction and possible litigation are such that the expenses incurred in obtaining a first class bedding sand would be negligible. The higher cost of the better sand could be considered an insurance against failure.

MOISTURE CONTENT

Specifications for the condition of the bedding sand often include statements such as:“The moisture content of the laying course should be as uniform as possible” and “the material should be moist without being saturated” [5], Others have suggested a target moisture content of 6% [4] or a range of 6 to 8% [8]. On a recent large airport paving project in the United States, the specifications stated that the moisture content of the laying course sand “shall have a uniform moisture content within 2% of the optimum moisture content” [7].

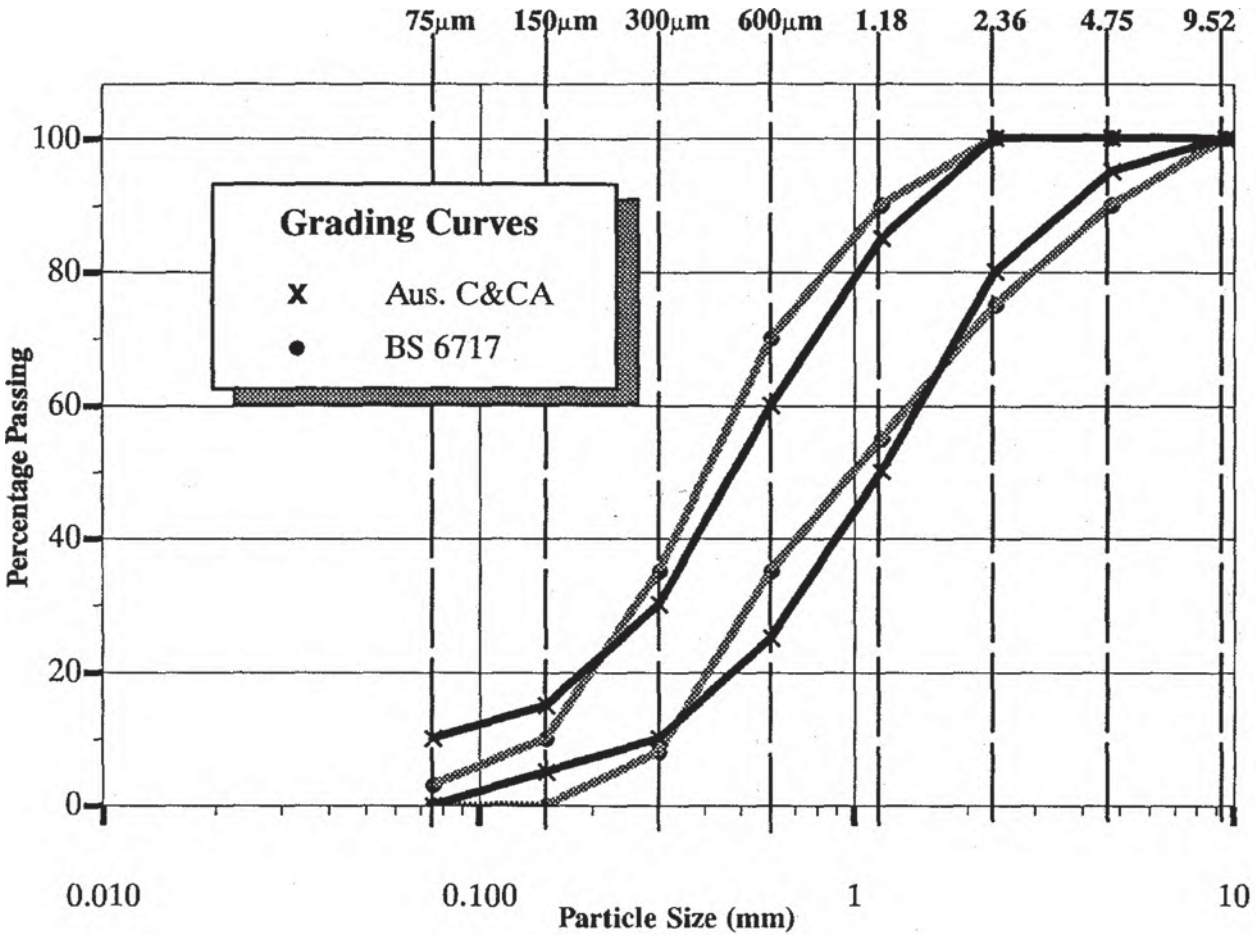


Figure 1 — Bedding Sand Grading Envelope

Miller-Cook [8] has shown that the loose thickness of screeded sand needs to be between 25 and 42% thicker than the desired thickness after compaction, for sand gradings typically used and for a moisture content in the range of 6 to 8%. Lilley [9] has indicated that, as the amount of bulking depends on both grading and moisture content, neither should be allowed to vary very much. It has been suggested by Seddon [10] that, for maximum compaction, the sand should be either dry or saturated. As Lilley [9] has remarked, this is not desirable in practice as, in either of these conditions the sand would be nearly fully compacted prior to vibration and, in consequence, little sand would be able to enter the bottom of the joints, as it must do for interlock to be developed.

ANGLE OF INTERNAL FRICTION

Work done in South Africa [2] showed that the amount of rutting of a concrete block pavement under the heavy vehicle simulator was related to the angle of internal friction of the laying course sand. The results suggest that a friction angle of greater than 40° would be desirable to minimize rutting. However, it has also been suggested [9] that rutting under concrete block paving is primarily due to loss of bedding sand. If the laying course is held in place by the sub-base, the blocks and the edge restraint,

it has been pointed out [9] that the structural properties of the sand should not be of prime importance. As yet the angle of internal friction has not been mentioned in sand specifications, but the requirement that the sand particles be angular would normally lead to a high value of friction angle.

	ASTM	NCMA	CofE	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 Specifed*	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 Specifed*	0-10	0-5	0-3	0-10

Thble 1 — Bedding sand grading envelopes

TESTING PROGRAMME

SAND TESTING

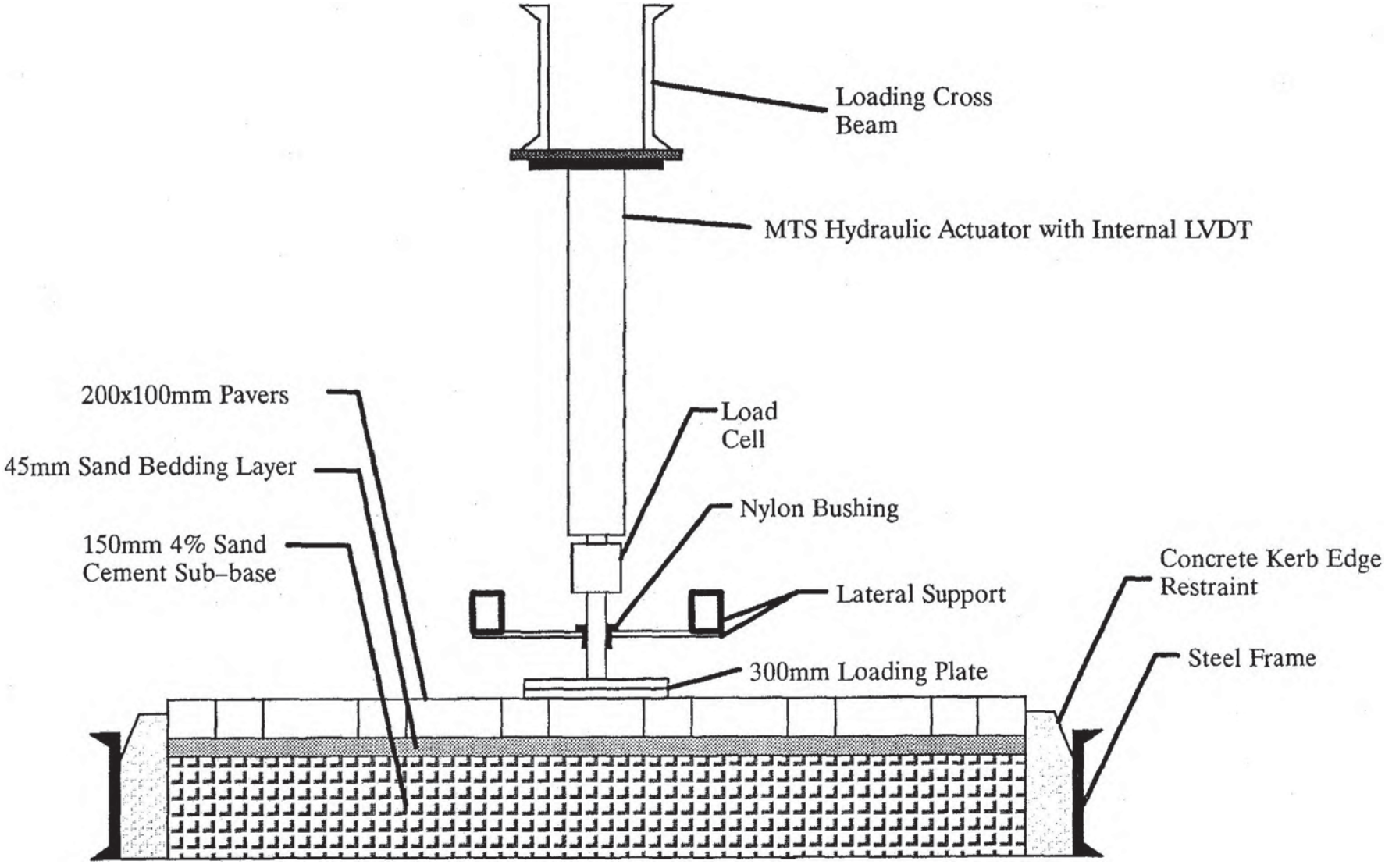
The programme of testing of sand properties consists of the following elements:

1. Particle size distribution by wet sieving
2. Moisture content - dry density relationship
3. Permeability by constant head test
4. Degradation by the method of Lilley and Dowson [1]
5. Friction angle and shear strength, dry and saturated, by 60 x 60mm shear box
6. Mineralogy by X-ray diffraction and petrographic analysis
7. Photography of fines under microscope

To date, a mixture of American and British test standards have been used.

TEST PAVEMENT

The second part of the testing involves the use of different sands in test pavements constructed in the laboratory. The original test pavement structure is shown in Figure 2. A 150mm thick sub-base of sand-cement containing 4% of cement was constructed over a polythene sheet placed directly on the concrete floor of the laboratory. This was restrained laterally by 300 x 150mm kerbs located within a


Loading Cross Beam
MTS Hydraulic Actuator with Internal LVDT
200x100mm Pavers
45mm Sand Bedding Layer
150mm 4% Sand Cement Sub-base
Load Cell
Nylon Bushing
Lateral Support
300mm Loading Plate
Concrete Kerb Edge Restraint
Steel Frame

steel frame. The sand was screeded on the sub-base to a loose thickness of 45mm, and 80mm thick rectangular pavers were hand laid on the bedding layer and vibrated into place using a small vibrating plate compactor. Dry sand having a maximum particle size of 1.18mm was brushed and vibrated into the joints. The testing of this pavement will be discussed later. It proved to be a very strong pavement which resisted loads extremely well. However, in order to obtain useful performance data concerning bedding sands it became evident that more flexibility had to be introduced into the pavement structure to allow vertical deformation to occur. The modified structure of the test pavement is shown, in isometric view, in Figure 3, from which it can be seen that a simulated subgrade layer made up of a combination of neoprene rubber and foam neoprene has been incorporated into the pavement structure. This simulates a subgrade having a California Bearing Ratio in the range five to six. The second change made to increase flexibility is the substitution of a crushed rock sub-base for the previous soil-cement. The material used is known as Ontario granular A' and is the highest quality of crushed rock specified by the Ontario Ministry of Uansport for road construction within the province. The grading of granular 'A' material is shown in Table 2. This material was placed and compacted in three lifts of 50mm finished thickness using a vibrating plate compactor.

Sieve Size	26.5mm	19.0mm	13.2mm	9.5 mm	4.75mm	1.18mm	300μm	150μm	75 μm
% Passing	100	85-100	65-90	50-73	35-55	15-40	5-22	*N/A*	2-8

Table 2 — Granular W grading

Sand Placement

In the present work, the bedding sand was initially placed at a moisture content equal to the optimum value obtained in the standard Proctor compaction test, in this case 10.5%. It was found that when the pavers, which had been carefully placed on this laying course with a 3mm joint spacing, were vibrated, they experienced considerable lateral movement with consequent loss of bond. They did not penetrate into the sand to generate the first phase of interlock. Clearly the combination of the high moisture content of the sand and the relative rigidity of the underlying sand-cement did not permit the sand to rise up between the pavers as desired; also the sand would have been in a relatively compact state as laid at this moisture content. Experiments with vibratory compaction at different moisture contents led to a choice of 6% as the optimal value.

It seems clear that there are good reasons to specify a uniform moisture content in the range of 6 to 8%.

Loading

The test pavement was loaded at its mid-point through a 300mm diameter rigid steel loading plate bearing on a thin sheet of hard neoprene to ensure uniformity of contact. The load was applied through a computer-controlled MTS loading system as a sinusoidal pulse at a frequency of 5Hz. Initially 12 000 cycles were applied at loads of 20kN and 30kN, then approximately two million cycles were applied at 40kN, the wheel load corresponding to a standard axle load of 80kN. As this loading produced negligible vertical deformation, the load was increased progressively in 10kN increments to 70kN at which value a further 1.26 million cycles were applied. Loading was then stopped and pull-out tests

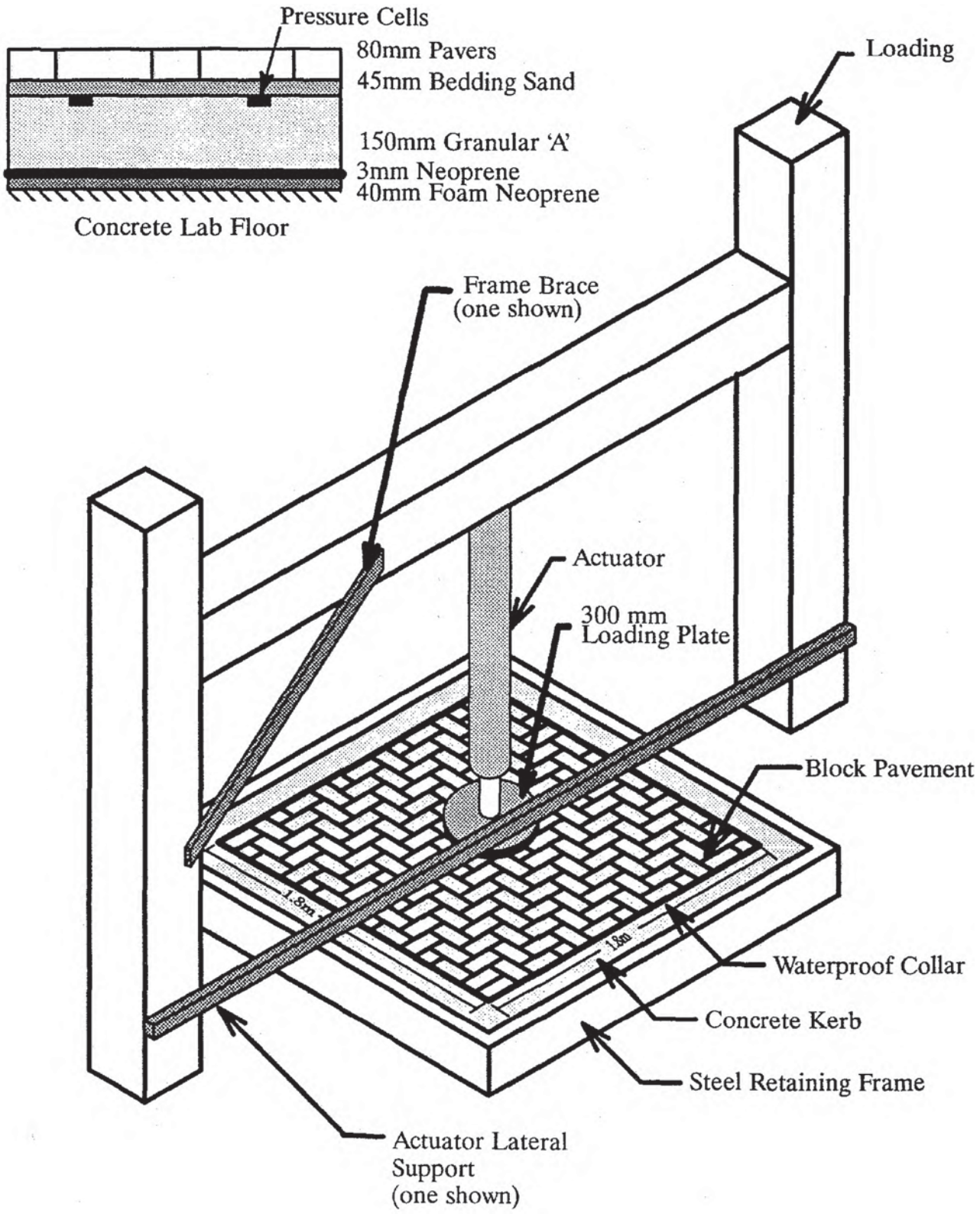


Figure 3 Modified Test Bed Isometric View

conducted on pavers in which anchors had previously been embedded. Through the gaps thus created in the pavement seventy litres of water were introduced. It was discovered that the polythene sheet,intended to enable the pavement to be saturated, had been damaged during construction and that, in consequence, some of the water added was lost. The blocks pulled out were replaced and a further 2.9 million load cycles applied at loads increasing from 40kN to 70kN. Details of the loading are given in Table 3. Total permanent vertical deformation at the end of loading was less than one millimetre. It was concluded that the initial pavement structure was too stiff to permit significant vertical deformation to occur within the range of loads applied. Accordingly, as previously described, the structure was redesigned to make it more flexible. At the time of writing, no tests with the new pavement structure have yet been completed.

Initial bedding sand moisture content 6%.			Load applied through 300mm diameter plate.
Stage	**Load (kN)**	**No. of Cycles**	**Notes**
0	20	1 000	Verification of loading control software
1	20	12 000	Start of Phase I.
2	30	12 000	
3	40	1 975 000	End of Phase I. 2M cycles applied
4	50	612 000	Start of of Phase II.
5	60	776 000	
6	70	1 264 000	End of Phase II. 2.652M cycles applied
7	40	876 000	Wet ~ 70 1 of water added through pull outs.
8	50	444 000	Wet
9	60	416 000	Wet
10	70	1 188 000	End of wet test, 2.924M cycles applied
		7 576 000	Total cycles applied
Final bedding sand moisture content 4%			Pavement dismantled after Stage 10.

Table 3 — Details of Loading, Test No. 1

SAND TESTING RESULTS

Data the for six sands tested to date are summarized in Thble 4.

DEGRADATION

It can be seen that most of the sands tested did not break down significantly when subjected to the degradation test in a dry state, but that appreciably more degradation occurred when the test was performed wet. Tvo particular sands are worthy of note, first the sand used at the Dallas/Fort Worth airport was exceptionally resistant to degradation. 70% of this sand consists of minerals having a

Moh's hardness equal to or greater than six. The second is the NCR sand which consists of limestone screenings. It will be noted that these are composed entirely of soft minerals having a Moh's hardness of three or less and that the breakdown in the degradation test, both dry and wet is excessive.

ANGLE OF SHEARING RESISTANCE

The angle of internal friction of the sands is being measured in a standard 60 x 60mm shear box. For the Sweets sand used in the first test pavement a peak value of internal friction of 46° and an ultimate value of 40' have been observed for the sand in a dry condition. The actual value of internal friction mobilized will be a function of the density and moisture content of the sand.

PERMEABILITY

The permeability of the sands was measured in a constant head permeameter. The values obtained, for the sands tested so far, are within the range 2 to 17x 10^{-4} m/s as would be expected for clean sands.

MINERALOGY

In order to test the hypothesis that the mineralogical composition of the sands could be an important factor in their performance as the laying course of a concrete block pavement, X-ray diffraction and petrographic analysis techniques were used to identify the constituent minerals. Each sand was mixed into a petrographic epoxy and allowed to set. Thin sections were then cut, polished and mounted on slides for microscopic examination. The constituent minerals were identified and the percentage by volume of each was determined by the point count method. The shape of each grain was identified as angular, subrounded, or rounded.

Sample Name	**Sieve Testing**				**Perme-ability**	**Mineralogy**					
	%	**%< 63 µm**			**@20 °C**					**Shape**	
	<1 mm	**Init**	**Mill**	**Wet Mill**	**m/s**	**Quartz (7)**	**Feldspar (6)**	**Calcite (3)**	**Other (<6)**	**Angular**	**Rounded**
Alyea's Rd. Pit	96.4	3.6	4.4	7.6	2.34 x 10^{-4}	10	11	71	1	46	54
D/FW Airport	57.1	1.2	1.3	2.9	4.2 x 10^{-4}	59	22	4	0	7	93
NCR	55.2	9.3	15.5	23.9	*N/A*	2	2	93	0	49	51
Sierra Pit	70.0	3.2	3.7	6.3	4.58 x 10^{-4}	18	38	32	7	14	86
Tait Rd. Pit	*N/A*	6.2	6.5	8.7	2.05 x 10^{-4}	10	10	71	1	14	86
Sweets (Wall)	34.5	4.6	5.6	8.8	1.65 x 10^{-3}	22	22	39	3	29	71

Table 4 — Some properties of sands tested

FUTURE TESTING

The number of sands to be tested is to be increased to a minimum of twenty-five. It is intended that these should be representative of the full spectrum of sands likely to be considered for use in the laying course of concrete block pavements throughout North America. To the extent possible, U.S. test standards will be used. The Los Angeles abrasion test will be included as other work on aggregates [11] has suggested that an index combining degradation and abrasion test numbers can be useful.

From the sands tested, a smaller number will be selected to represent good, bad and intermediate properties. These will be used as the laying course in test pavements subjected to dynamic plate loading. A waterproof bituminous seal and collar will be incorporated in the modified test pavement so that the tests can be carried out with the laying course flooded. In addition, Pressure cells will be installed immediately beneath the laying course. Correlation will be sought between sand properties and performance in the test pavement.

CONCLUSIONS

1. A programme of tests, designed to examine the effects of the physical and mechanical properties of sands on their performance as the laying course in concrete block pavements, has been described.

2. The role of the bedding sand and current laying course specifications have been discussed.

3. Results of the limited testing carried out to date have been presented and the proposed direction of further testing has been outlined.

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