SEGMENTAL BLOCK PAVEMENTS - OPTIMIZING THE JOINT WIDTH AND JOINT MATERIAL

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SUMMARY

Following a study of the mechanisms occurring within the bedding and the joints of segmental block pavements, it was realized that further work was needed to study the effects of various jointing materials and the effect of varying the joint width between individual segmental blocks. A method of evaluating the interface strength of the joints by extracting individual blocks was developed. A range of optimum widths and materials for the joints was identified. A site survey of precise joint widths was made to relate the optimum conditions determined by the experiments to the practical conditions achieved during construction.

1. INTRODUCTION

The individual blocks are rigid, yet the pavement as a whole responds in an elastic manner. It has been shown that the flexible response is accommodated by the material in the joints between individual blocks (1,2). Detailed studies (1) have identified flexible response in the joints as a mechanism to accommodate the interface stress, strain, shear and friction forces induced by loads applied either vertically or torsionally. In discussions of such concepts as "lock-up" - the development of the jointing material with weathering and application of loads (1,3,4) - it is recognized that if there is an improvement of the material in the joints around the blocks themselves then the pavement as a whole is more capable of supporting applied loads with less deformation. Reduced deformation results in either longer pavement life before the surface deformation becomes unacceptable and exceeds defined limits (2), or in the pavement structure being capable of supporting greater applied loads.

Attempts have been made to model segmental block pavements (5) and to study the effect of the improvements in the jointing material during a period of settling-in. The effective moduli of the support layers under the segmental blocks were determined by numerous Heavy Vehicle Simulator tests and other tests to obtain values with a high level of confidence (5). It has not yet been possible to use moduli with the same confidence level for the block layer because of the difficulty of determining the response value of the joints relative to the segmental-block paving-layer as a whole. Wide ranges of moduli values were used for the modelling (5) - to date these values were used in prediction modelling where the results could not be easily related to existing pavements.

The determination of usable effective moduli for the composite structure forming the block layer required a series of interrelated tests incorporating many techniques available at the National Institute for Transport and Road Research (NITRR). These techniques included a Heavy Vehicle Simulator, multidepth deflectometers, INSTRON traxial apparatus with a purpose-designed tray, specially developed extraction equipment and other instruments designed for studying the block layer under both laboratory and field conditions. The instruments and the methodology used are described and the data obtained are discussed.

2. PURPOSE

Since the joints around the blocks are so important to the pavement as a whole, the maximum and minimum joint width required determined. It was also necessary to determine and define the range of ideal jointing material and any restraints imposed upon it, such as moisture content and the required compaction technique. The study further sought to provide a simple method of evaluating both new and older existing block pavements with respect to the strength of the joints. The purpose of the evaluation method was to provide accurate input data for a prediction model for determining the effective field moduli of the insitu pavement.

3. CONSIDERATIONS

Various relationships for determing effective field moduli of the segmental block layer were first considered. These included:

1. Practical limits of joint width with respect to manufacturing tolerence, specified jointing sand particle size and site procedure.
2. Mean joint widths, determined by measurement, around individual blocks: standard deviations of individual joint widths, range of joint widths in a specified part of the pavement surface.
3. Consideration of the face of the blocks where joint width measurements are made since there was thought to be some variability in joint strength due to the physical shape of the block. For example, the response of the joint of the long face of a block may be different to that of the short face. In fully interlocking blocks (2) (S-A) different responses can be expected if measured either at the convex or concave tip of the plan geometry of the faces.
4. A relationship of joint strength to joint width irrespective of material used (Figure 1). Physical restrictions on the ingress of jointing material in tight joints reduce their effectiveness, and in the wide joints the moduli would apply to the jointing material

rather than the composite layer.

5. The relationship of the extraction force needed to pull an individual block out of its matrix to the vertical distance moved. In such a relationship a practical limit for this can be established, based either on the acceptable step between individual adjacent blocks, or on the allowable resilient deformation of an individual block relative to adjacent limits. This type of relationship is shown in Figure 2.

6. Figure 2 also shows a variable relationship of the frictional resistance within a joint as a function of the stress or density of the jointing material.

7. A relationship between

a) deflection; or

b) extraction force required to pull out a block; or

c) density of material in the joints; or

d) increase in pavement strength;

to the increase in joint strength.

Such relationships are given in Figure 3, which shows that the relationships are also affected by three moisture content conditions:

a) optimum moisture content

b) at wet of optimum and

c) at dry of optimum.

Rapid initial increases in joint strength would result if the materials were wet of optimum since with the typical joint widths of 2 - 5 mm (2) the water would assist compaction due to its lurication effect. However, the highest ultimate strength would be achieved at optimum moisture content. A gradual increase in strength could be expected as the moisture content drops below the optimum, but the ultimate strength would also be lower than when the moisture content is at optimum because the compaction of a mixture of cohesive and granular material requires some moisture (6).

4. FIELD MEASUREMENT OF JOINT WIDTH

Blocks are laid by a variety of methods to ensure their alignment and to provide a particular joint width.

Some contractors use rubber hammers to position the blocks as tightly as possible and others place them by hand thereby achieving more open joints.

An instrument was devised some years ago by a visiting scientist (Dr Shackel) which was used in a joint width survey. The instrument is called a "Shackelometer" after him and consists of a simple graduated cone which is pushed into the joints. Its simplicity and accuracy allow a great number of joint widths to be measured rapidly.

Pavements with blocks of various shapes (S-A, S-B and S-C (2)) were selected at random for surveys. Where units had a rectangular shape (S-C), measurements at the centre of each of the four faces were made and averaged. With the more complex shapes found in S-A and S-B blocks, measurements were made on the centre of each of face for averaging. Blocks were chosen in accordance with the established random selection procedure (7) and at least 5 blocks were measured before an average joint width was established for a particular pavement. The scatter of results obtained was surprising, and on a typical pavement laid to the best standards, joint widths were found to vary from 1 to 5 mm. This can be explained by the manufacturer's specifications and the need to correctly align the blocks by varying the joint widths. The specifications of the Concrete Masonry Association (CMA) and the Brick Development Association of South Africa (BDA), together with the draft manufacturing specifications produced by the Bureau of Standards provide guideline specifications (8,9,10). These specifications allow that the width and length of concrete units to vary by $\pm$ 2 mm. The maximum variation between individual units can therefore be 4 mm, assuming adjacent blocks with these extreme dimensions. With fired clay units the specifications allow a wide tolerance since the manufacturing technique is currently less precise. For this product the length can vary by $\pm$ 3 - 4 mm. Hence in extreme cases adjacent units could be 8 mm apart. The joint width in a pavement, calculated by the average measurements of the faces of at least 5 blocks chosen at random, is therefore not likely to be less than, say, 2 mm for any particular pavement to allow true alignment from end to end.

5. DISCUSSION OF FIELD JOINT WIDTHS

Results of field joint width measurements showed that even in a pavement constructed to provide the tightest joints there was a typical scatter of results from 1 - 4 mm. By averaging all the results obtained in the manner described above an average joint width of 2,35 mm was calculated. In typical pavements laid by hand packing the blocks the average joint width was 3,15 mm, and in both brick and concrete pavements laid with widely varying joint widths the average width was also 3,15 mm.

The above data suggest that a joint width specification of less than 2,35 mm is impractical.

Since the joints have such an important stress-transfer function in the pavement, properly constructed joints are essential. It should be possible to fill the joints with jointing material and compact it by suitable techniques such as vibration. The practical minimum average joint width is therefore 2,25 mm as measured by the above method.

With a minimum specified joint width of 2,25 mm, the joints should become adequately filled with sand (2). Figure 4 shows the grading envelope of recommended material. The largest particles allowed are 1,18 mm. In order to allow such material to enter the joints an individual absolute minimum joint width 1,25 mm is required.

The oldest known extensive areas of segmental block paving in South Africa are the Chatsworth residential streets in Natal. The blocks have been used by normal street traffic, including trucks and busses, for over 20 years. Apart from surface deformations occuring in some areas due to poor construction methods of the subbase and settlement of the subgrade, the pavement is performing very satisfactorily.

There was no cracking of the blocks which would be the result of very tight joints which allow adjacent units to come into physical contact with each other and induce spalling. The average joint width was 4,5 mm and a sample of the jointing material was found to comply with the grading envelope specified in RP/9/81(2) and shown in Figure 4. Figure 4 also shows an Australian bedding and jointing sand grading envelope and a recommended improved grading envelope (discussed below).

6. EXTRACTION INSTRUMENT FOR WITHDRAWING INDIVIDUAL BLOCKS

An extraction instrument was designed to evaluate the interface stresses, shear and strain within the joints only. In order to eliminate the effects of the bedding sand and the sublayers under the blocks, the instrument was required to pull an individual block from its matrix without affecting the surrounding blocks. In this way the effect of the resistance to extraction would apply to the joints only. It is appreciated that in practise a load applied to the pavement would induce stresses initially in a downward direction within the joints, but no accurate measure of the effect of the joints only could be obtained from such applied loads. The extraction force measured by the instrument induced by lifting was considered to be identical in magnitude (except for the effects of gravity) to a downward load. The instrument provided an effective yet simple means of identifying actual stress within the joints occuring under a variety of simulated loading conditions.

The instrument comprised a containing ring within which the vertically applied lifting device can be positioned. A hand-operated hydraulic jack provided the constant force needed to extract individual blocks selected. As the test had to be non-destructive, individual blocks were pulled out by sticking a surface plate with a welded, threaded bolt head to the upper surface of the block. After the block had been extracted the plate was easily removed with a chisel. This instrument is simple and portable, and allows a variety of pavements to be evaluated.

7. RESULTS AND DISCUSSION OF EXTRACTION TESTS

Numerous extraction tests were carried out on a variety of pavements with various block thicknesses and joint widths. It was found that for individual pavements there is considerable scatter of the results. With some pavements, especially where the extraction force was low, the extraction results were similar for several blocks removed. The oldest pavements tested were at Chatsworth, Natal, where the main estate roads have served their purpose for more than 20 years. Whereas the extraction forces varied considerably from block to block, the lowest extraction force recorded was considerably higher than that found at any other place. It is therefore concluded that if jointing material is used which contains some cohesive material as recommended ((2) and Figure 4), and as found in the Chatsworth pavements (where 100 per cent finer by weight, passed the No. 28 US sieve, 96 per cent passed the No. 48 sieve, 91 per cent the 100 sieve and 90 per cent the 200 sieve), there will be a long-term improvement in extraction resistance. Jointing material used in pavements where the lowest extraction forces were recorded contained no cohesive material and often consisted of sand of a single particle size.

The results suggest the specification of a minimum extraction force for a structural pavement where the joints have the important function of stress transfer. From the results obtained so far with the extraction instrument a minimum acceptable extraction force of 1 kN is proposed. It is hoped that by laboratory experiments with the extraction instrument on a variety of jointing methods and materials, this minimum extraction force can be increased above 1 kN to a minimum of 3 kN, if possible. The tests are described below. An increase in extraction force also increases the field elastic modulus of the block layer, thereby requiring less foundation material in the sublayers to support the same load. By this means the proper jointing material can significantly improve the performance of a block pavement. Since the jointing sand represents a very small part of a block pavement structure, a better quality could be used without unduly increasing the cost.

8. LABORATORY TESTS WITH EXTRACTION INSTRUMENT

There were many stages involved in determining the effective elastic moduli of block pavements. One stage is to simulate construction with a variety of joint widths and jointing material in a laboratory. In order to study joints, a tray was designed and constructed into which a few blocks bedded on bedding sand and jointed with jointing material could be placed. The tray was mounted on a vibrating table and, by various methods of kentledge loading, construction techniques were simulated. The instrument has been described elsewhere (11). Two relationships were considered to have bearing on the investigations. The first relationship is shown in Figure 5, where some optimum joint width for the type of jointing material could be determined. Where joints were tighter than suggested by the relationship, insufficient jointing material was introduced into the joints and effectively compacted to enable the full stress potential of the jointing material to be achieved. Where the joints where wider than the optimum range, the jointing material sheared more readily since the interface friction (i.e. the friction between the jointing material and the vertical face of the block in the joint) was not utilized as effectively as possible. An aspect of this relationship is also shown in general terms in Figure 1.

The other relationship considers the amount of jointing material around an individual block. Since there is an optimum joint width for a particular material, and the material is needed to provide the flexible response of the block layer of a segmental block pavement, it follows that the greater the amount of jointing mate-

rial used effectively, the greater will be its stress-potential. The quantity of material in the joints can be increased (without increasing the joint width beyond its optimum range) by

1. choosing a joint width at the widest end of the optimum range;
2. increasing the thickness of the block to provide a deeper joint;
3. taking away any surface chamfer to allow the joint to be as full as possible;
4. using a geometric shape (plan view) which provides the longest edge profile of the blocks (such as an S-A shape).

It is not practical, however, to use all these four methods to provide the maximum effective jointing material. Is is obviously possible to choose the widest joint possible (ie 1) above) within the optimum range for the jointing material used, but this may not be readily adopted by site staff laying the blocks. The increase in block thickness proposed in 2. above is obviously not a cheap solution since with proper structural balance (5) in the total pavement design a small improvement in the strength (or possibly thickness) of supporting material under the blocks would be as effective as thicker blocks. Handling thicker and hence heavier blocks is more difficult and could affect the costs of the completed pavement. In some cases blocks are made without surface chamfers, but most units have them to allow easier handling. (Units without chamfers tend to cut the hands, especially when many units are laid in each shift.) Chamfers allow surface levels to be less precise and can easily accommodate up to 2 mm difference between one block and the next. The chamfers tend to hide these differences in levels from the naked eye. They also add to the overall aesthetic appearance of the pavement. Since chamfers are typically only 3 mm deep the loss of jointing material by chamfering the units is minimal. An easy way of increasing jointing material in structural pavements is to choose a fully interlocking unit of the most complex shape possible (as suggested in 4.) above).

Various tray tests were done in the laboratory. Six types of jointing sand were chosen from those currently used by contractors when laying blocks. The grading analysis of these sands is shown in Figure 6. Several other jointing materials were immediately rejected since they were either :

1. of too great a particle size to enter and effectively fill the joint, or
2. they contained no cohesive content needed to allow the joints to become pressurized (i.e. internally stressed) due to the pore water pressures on the elongated particles.

The jointing materials that provided the greatest extraction forces fell within the recommended grading envelope shown in Figure 4.

Many tests were conducted with various acceptable jointing materials. For the sands numbered 1, 3, 4 & 5 a range of joint widths showed a greater resistance to extraction.

An important relationship was discovered when the effect of moisture content on the extraction force was studied. It can be seen in Figure 7 that it is critical to keep the moisture content of the jointing material to 2 % or less. The sand types 4 & 5 used in the study were found to provide the best resistance to extraction and hence the best improvement in the strength of the block layer. From the data obtained, it was found that the optimum range of joint widths was 2 mm - 5 mm. (This confirms the general joint widths suggested by manufactures and by previous research). Figure 4 shows how the recommendation for jointing material can be improved.

9. RELATING THE TRAY TESTS TO SITE CONSTRUCTION METHODS

The method of compacting the blocks into the bedding sand and vibrating and compacting the jointing material between the blocks in the tray test involved the use of a vibrating table. Two arbitrary vibration times were initially chosen, namely 6 seconds and 20 seconds. The 6-second period was thought to represent a well constructed pavement where several passes would have been made by a plate vibrator. The 20-second period was thought to provide a very well compacted segmental block layer. As the tests progressed it became obvious that the 6-second period made little improvement to the compaction of joint material, although it did allow the joint to fill. After 20 seconds of vibration some significant increases in withdrawal forces were noted. The tray tests were initially carried out with substantially dry jointing material whose moisture content was similar to that of material used in full-scale construction of segmental block pavements.

A relationship therefore exists between an increase in joint strength and vibration time. When the optimum jointing material was found in accordance with the requirements described above the ideal method was sought to compact it within the joints.

To relate the vibration needed to compact jointing material to its maximum resistance to extraction as discovered in the tray tests to that required by the plate vibrators used in pavement construction, involved using the extraction instrument on a site. Several blocks were extracted after various numbers of passes with the type of plate vibrator used for construction. It was found that a minimum of 3 passes with a typical operating speed of 3 - 4 km/h were required. The usual one or two passes currently made on site gave a lower extraction force than desirable. Vibrations caused by trafficking in time help to produce the optimum conditions. This is part of the reason for the improvement in carrying capacity that occurs with time in segmental block pavements. This is known as either the settling-in period (1,5) or the "lock-up" (3,4).

The tray tests therefore provided information to define the following with a high degree of confidence, which can be immediately applied in practise :

1. The grading envelope for jointing materials within which the ideal materials would be

classified (Figure 4).

2. The range of joint widths within which the full structural response of the composite components of the segmental block layer are optimum (2 - 5 mm).

3. A moisture content of 2 per cent and less in the jointing material during the construction.

4. The best compaction method for developing maximum joint strength : a minimum of 3 passes with the small plate vibrators used on site.

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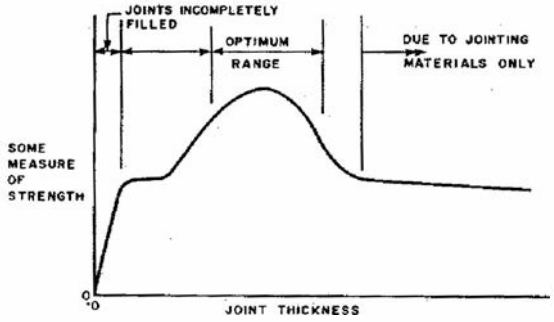


FIGURE 1 *GENERAL RELATIONSHIP OF STRENGTH OF JOINTS WITH RESPECT TO THICKNESS*

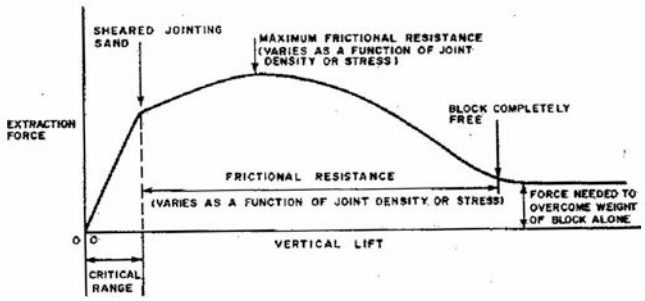


FIGURE 2 *GENERAL RELATIONSHIP OF EXTRACTION FORCE TO THE VERTICAL LIFT*

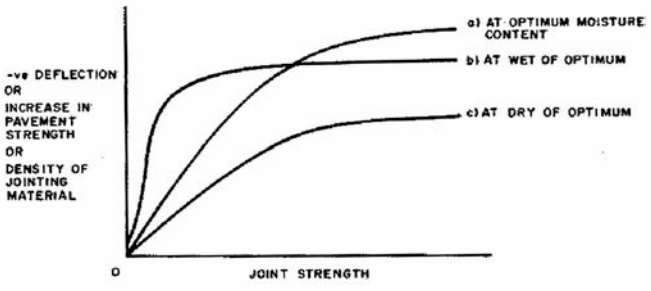


FIGURE 3 *VARIOUS RELATIONSHIPS WITH RESPECT TO JOINT STRENGTH*

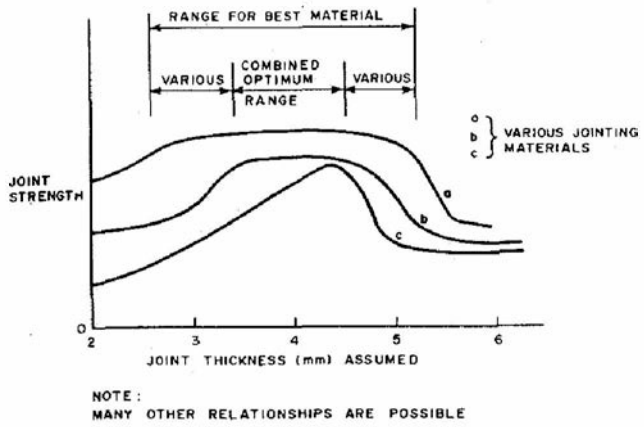


FIGURE 5 *RELATIONSHIP OF JOINT WIDTH / JOINTING MATERIAL / JOINT STRENGTH*

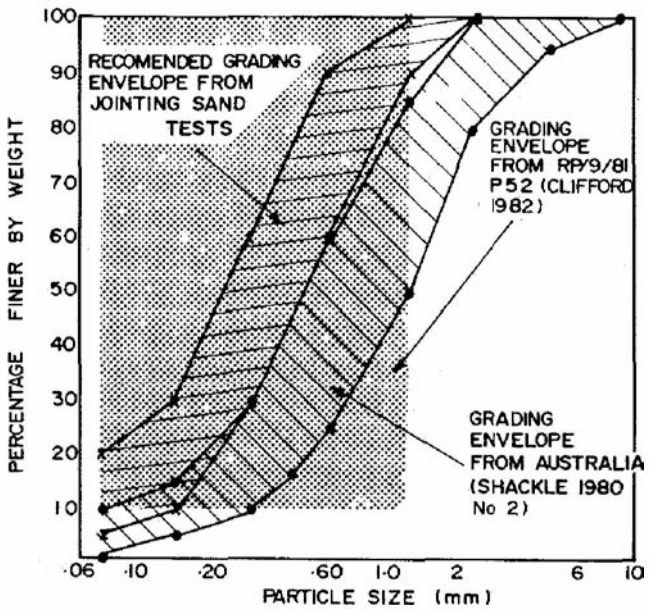


FIGURE 4
ENVELOPES OF JOINTING SAND

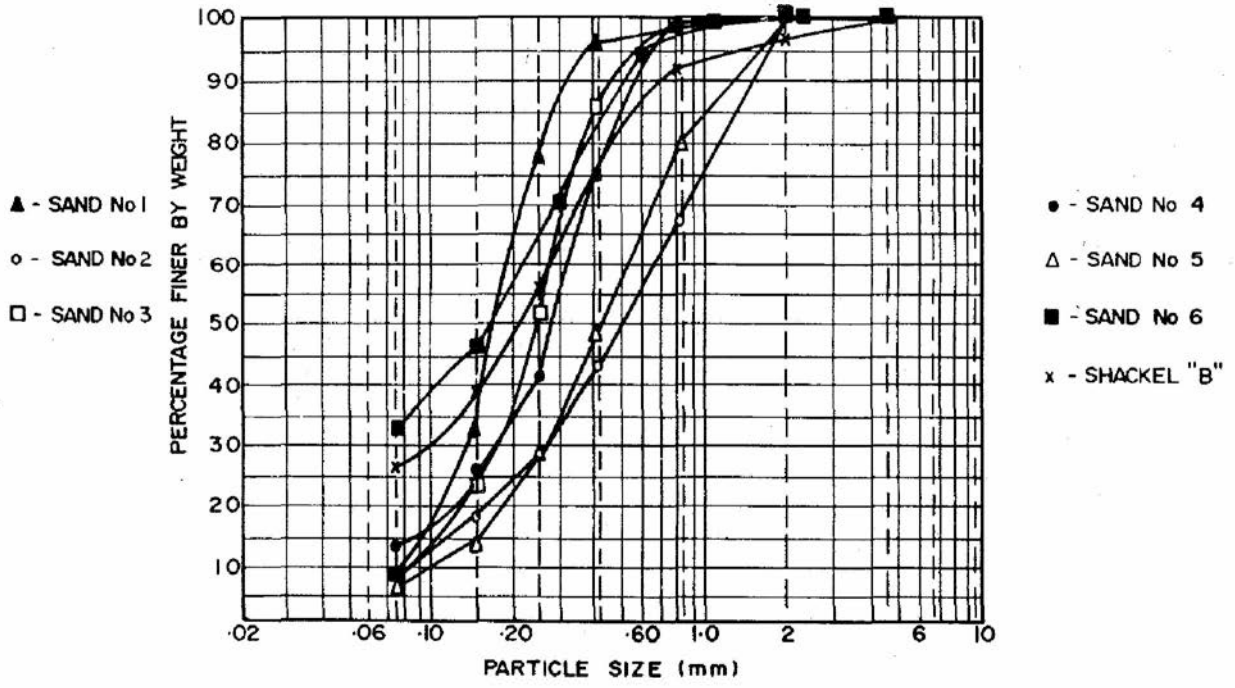


FIGURE 6
PARTICLE SIZE DISTRIBUTION OF SIX SANDS USED FOR JOINTING TESTS TOGETHER WITH SAND SHACKEL "B"

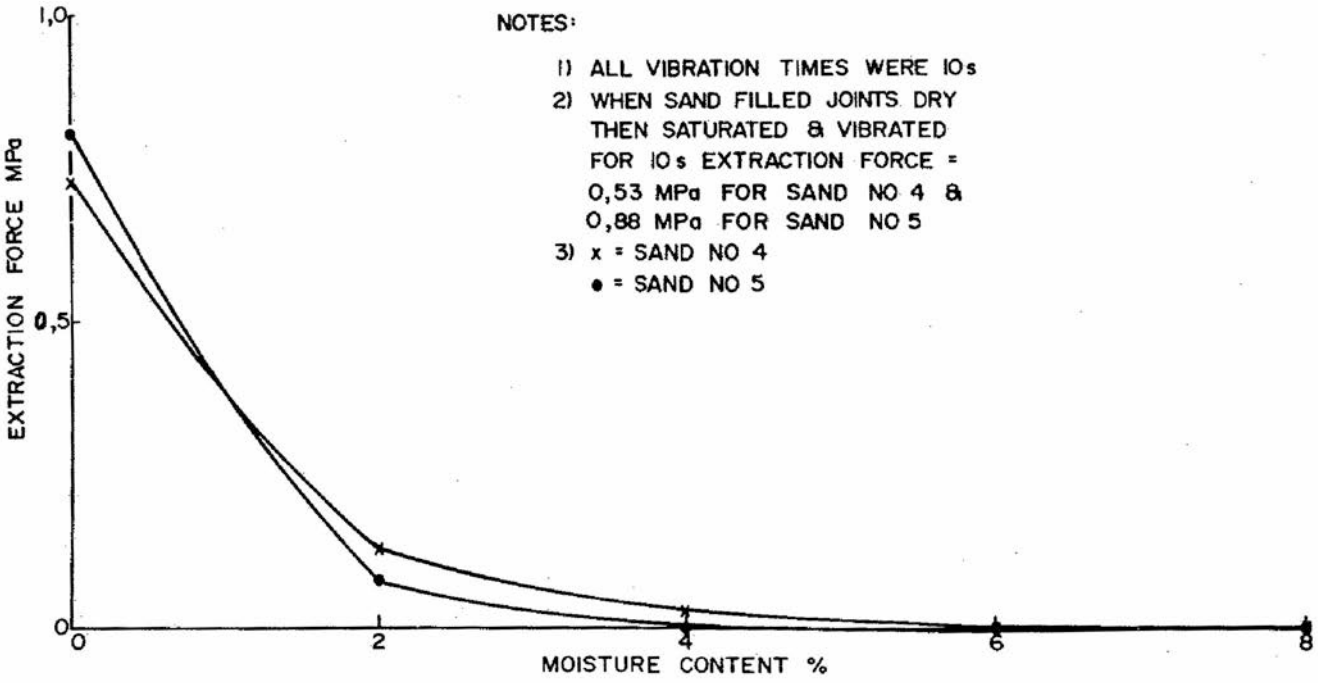


FIGURE 7

EFFECT OF MOISTURE CONTENT ON EXTRACTION FORCE