AKINMUSURU, J. O., AKINBOLADE, J. A. and ODIGIE, D. O.
University of Ife, Ife-Ife, Nigeria

Bearing Capacity Tests on Fiber-Reinforced Soil

Essais de force portante sur des sols renforcés par des fibres

The use of synthetic and other man-made fabrics for soil improvement is oftentimes not within common reach in developing countries due to inavailability of high grade material and high cost of suitable imported fabrics. Work is currently being undertaken aimed at utilising locally available material to achieve similar objectives. The results of laboratory model tests presented are on bearing capacity experiments on a dry sand reinforced with a locally obtainable rope fiber material and also layers of crushed rock. Parameters studied were the influence on the bearing capacity of a square footing of vertical spacings of reinforcement layers, depths below the footing of the first layer and number of layers. A comparative study of the two materials used showed that although bearing capacities with crushed rock layers were improved by a factor of about two, experiments with the rope fiber material indicated that improvement factors could be as high as three. This was shown to be due to the tensile strength of the rope material as against zero in the case of the crushed rock.

L'utilisation de textiles synthétiques n'est généralement pas à la portée des pays en voie de développement du fait du coût élevé des textiles importés. Le but de ce travail est d'utiliser à la place des matériaux locaux. Les essais présentés sont relatifs à du sable sec renforcé avec des fibres locales, ainsi que des couches de gravier concassé. On a étudié l'influence des paramètres suivants sur la force portante d'une semelle carrée: espacement entre les couches de renforcement, profondeur de la première couche de renforcement sous la semelle et nombre de couches. Une étude comparative des deux matériaux montre que bien que les forces portantes avec des couches de gravier concassé aient été améliorées par un facteur de deux, les essais faits avec les fibres ont montré que le facteur d'amélioration pouvait aller jusqu'à trois. On a pu montrer que ceci était dû à la résistance à la traction des fibres, comparée à zéro dans le cas du gravier concassé.

INTRODUCTION

The application of the reinforced earth technology is fast becoming very popular among designers of retaining structures in developed countries. A lot of encouragement however still needs to be given to the application of the technique in the less developed countries as the benefits of lower cost of construction in both time and money is more relevant in these countries. Incidentally, however, the use of reinforced earth in construction is very native in the local construction of some of those countries. In Nigeria as in many developing countries, the use is commonplace in many village constructions. Rope fibers and bamboo sheets are used to strengthen rural road bases and the soil below low-cost low-rise buildings. Vertically arranged rectangular grids of bamboo sheets and stalks of palm branches are also used as the central core around which mud walls are built because of the resulting higher strengths and resistance to cracks and crack propagation that such composite walls possess.

Since the pioneering work of Vidal (14, 15), much work has been done by many researchers (3 - 13) on the analysis, design, testing, and construction of reinforced earth structures. Although much of this work relates to earth retaining structures, it has been shown (3, 5, 6) that the reinforced soil technology is also applicable to bearing capacity problems. The need to channel local technology in developing countries to the design and construction of low-cost highway and housing projects cannot be overemphasised (2) and an earlier work of the authors (3) is an attempt in this direction. It was mainly research into the use of local rope fibers to reinforce granular soils. The problem with the use of such fibers is that they are biodegradable and therefore are prone to being unsuitable in housing or road design projects. As the water table in the soil rises above the level of the strip reinforcements, the strips become weakened. Also, they are prone to termite attack. This paper aims at exploring the suitability of an alternative type of reinforcement that would be non-biodegradable and yet be low-cost. In place of rope fibers therefore, crushed rock has been used and a comparison is being made of its efficiency as compared with the rope materials.

LABORATORY - SCALE MODEL EXPERIMENTS

The model tests were performed in a square-based wooden box 1.0m wide with a depth of 0.7m. The soil material was unformly graded dry sand passing through British Standard (B.S.) No. 14 sieve and retained on B.S. No. 200 sieve; D_{50} = 0.43mm and D_{10} = 0.14mm; specific gravity = 2.70. The method of sand compaction resulted in a constant density of 1,700 kg/m^3 and a friction angle of 38^o. For the crushed rock material, the gradation was also uniform, the partide sizes varying between 5mm and 20mm. The gradation curves are shown in Fig. 1

The rope reinforcement material has been described elsewhere (3). It was used in strips that were 10mm wide and 0.03mm thick, the tensile strength being 80N/mm^2 and the angle of soil-tie friction 12^o. The model footing was a 100mm square-sided steel plate 13mm thick. The geometry of the test arrangements for

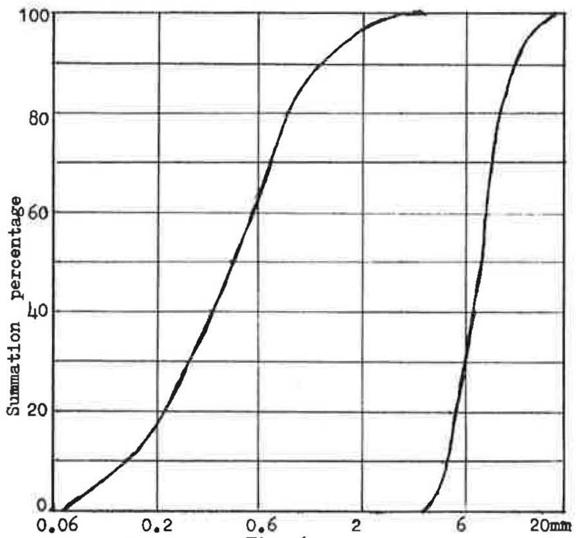

Fig. 1

both types of tests - with rope fiber and crushed rock reinforcements - are shown in Fig. 2. The method of soil placement and the loading arrangements have been described elsewhere (3) and so also is the method for estimating the ultimate bearing capacity in each test (1).

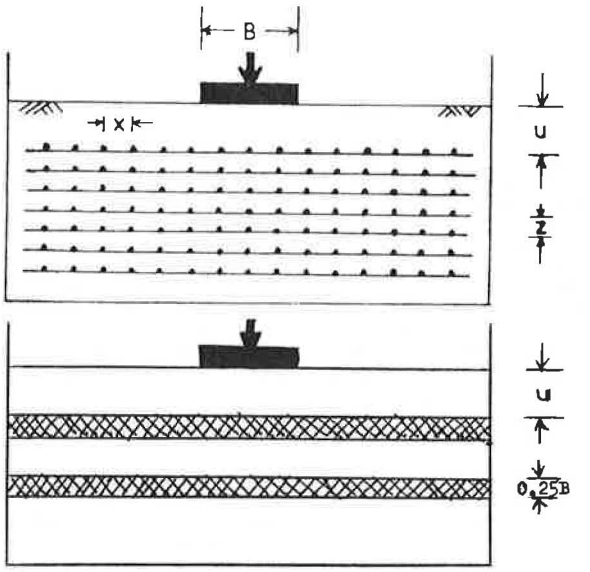

Fig. 2 Geometry of the bearing capacity test series.

The reinforcing strips were almost as long as the 1.0m sides of the smooth bed of compacted sand arranged in horizontal square grids in directions parallel to the sides of the footing and the box. In each test, all the strips in one direction were first laid and those in the other direction were then laid on top. The middle strip in each direction of each layer always passed directly under the center of the footing. In the case of reinforcement with crushed rock, the gravels were spread evenly at predetermined horizontal locations within the soil mass ensuring that the thickness of each gravel layer was 25mm, that is 0.25B, B being the width of the footing. The ultimate bearing capacity q_o of the unreinforced soil was found to be 91 kN/m^2. This was used as comparator for all subsequent tests. A bearing capacity efficiency was defined for the purpose as the ratio of q, the ultimate bearing capacity of the reinforced soil, to q_o. The tests performed were to determine how the ratio q/q_o was affected by the various parameters being examined.

EXPERIMENTAL RESULTS

Crushed Rock Reinforcements

Three series of tests were performed to examine how the bearing capacity efficiency is influenced by the depth of the topmost layer below the footing base, the vertical spacings between layers and the number of layers.

(a) Depth of top layer below footing:- It has been shown before (3) that irrespective of the number of layers involved, the trend of the effect of depth of top layer below the footing base is qualitatively the same. The influence of this parameter on the capacity efficiency is shown in the typical graph in Fig. 3 for N = 1. The peak of the curve was obtained for the situation when the gravel layer was on top of the sand mass and directly below the footing (u = 0). The efficiency is generally high up to u = 0.25B. (Note that the thickness of gravel layer effectively makes the surface of the soil below the layer an extra 0.25B below the footing.)

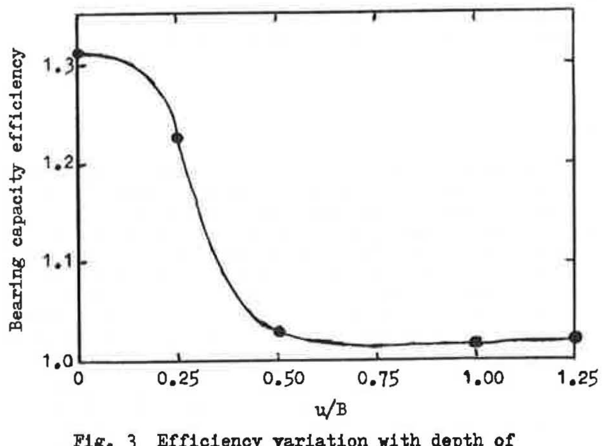

Fig. 3 Efficiency variation with depth of first layer (N = 1)

It was observed that the failure patterns of the soil-gravel mass below the footing were different for u = 0 and for other u - values. With the gravel in direct contract with the footing, failure was by punching of the gravel immediately below the footing into the sand below. With other u - values, there was squeezing of the sand immediately below the footing and above the gravel layer. The resulting effect of these on the settlement characteristics (not shown) was that footing settlement - to - failure for sand in contact with the footing was much compared with the u = 0 case. In this latter case, there was an initially high increase in the load supported with very little settlement. The post-yield behavior was however that of a brittle medium, the ultimate bearing capacity being little more than that at the end of the linear (elastic) portion of the load-displacement curve.

(b) Vertical spacings between layers:- The influence of vertical spacings between layers of reinforcement on bearing capacities is shown in the typical curve in Fig. 4 for N = 3 and u = 0.25B. For z - values up to 0.25B, the efficiency was approximately constant showing that under the first layer of reinforcement, block action took place with the sand and gravels acting as a single entity. With higher z-values, the layers became

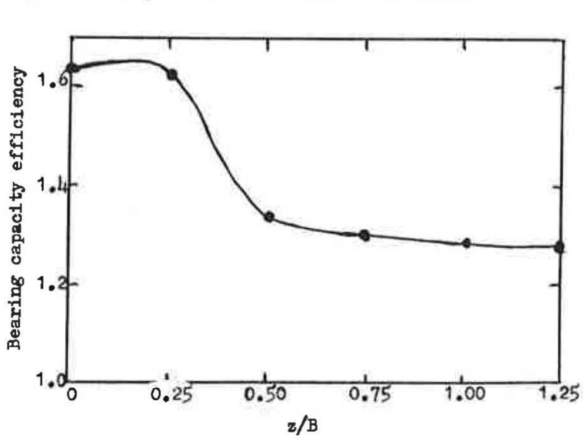

Fig. 4 Efficiency variation with vertical spacing between layers (u = 0.25B, N=3)

sufficiently far apart to enable the shearing of the sand in-between layers. The behavior of the composite soil thus approached that with only one layer of reinforcement as the lower layers became farther and farther away from the zone of influence of the footing. Thus, with z increasing infinitely, the efficiency approached the level of that of the footing when supported on one layer (Fig. 3).

(c) Number of layers:- The influence of the number of layers on bearing capacity efficiency in turn depends on the location of the topmost layer, as described above. Thus, two sets of tests were performed in this series, with u = 0 and u = 0.25B. The results are shown together in Fig. 5. It is clear from these curves that the u = 0 condition gives higher efficiencies than u > 0.

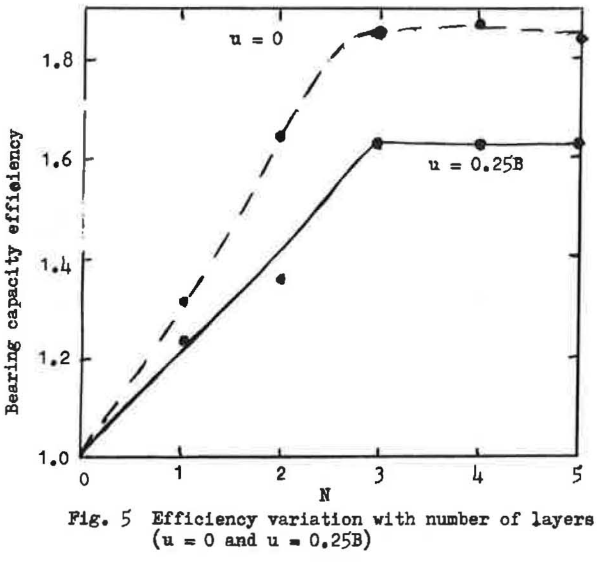

Fig. 5 Efficiency variation with number of layers (u = 0 and u = 0.25B)

However, irrespective of the value of u, it is apparent that little change occured in efficiency after the use of three layers indicating that the addition of more layers of reinforcement after the third does not contribute to bearing capacity improvement.

Rope Fiber Reinforcements

Along the same lines as the crushed rock reinforcement tests, the results of three series of tests are reported herein.

(a) Depth of top layer below footing:- A typical curve is shown for z = 0.5B, N = 5 and horizontal spacings between strips, x = 0.5B in Fig. 6. The peak of the curve was obtained at u = 0.5B. For u-values up to 0.5B, there was a slight increase due to the fact that

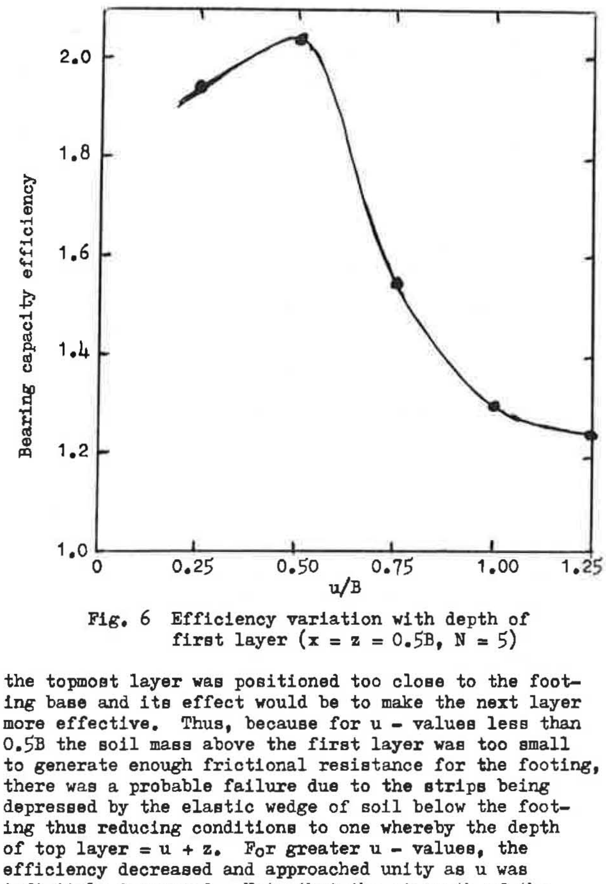

Fig. 6 Efficiency variation with depth of first layer (x = z = 0.5B, N = 5)

the topmost layer was positioned too close to the footing base and its effect would be to make the next layer more effective. Thus, because for u - values less than 0.5B the soil mass above the first layer was too small to generate enough frictional resistance for the footing, there was a probable failure due to the strips being depressed by the elastic wedge of soil below the footing thus reducing conditions to one whereby the depth of top layer = u + z. For greater u - values, the efficiency decreased and approached unity as u was infinitely increased. Note that the strength of the strips was always achieved through their tensile strength whereas for the gravels with no tensile strength, this was achieved through the compressive strength of each gravel and through the intergranular contact stresses.

(b) Vertical spacing between layers:- Typical results of the variation of bearing capacity efficiency with z are shown in Fig. 7 for many values of horizontal spacings x between strips. The behavior is similar to that of crushed rock reinforcements described above (Fig. 4). For z greater than B, very little capacity improvement was achieved for all x-values because of the magnitude of z. In the behaviors for gravel and strip reinforcements, the results with strips that can be compared with those of gravels would be for x = 0 when all strips are placed side by side with no spacing between them.

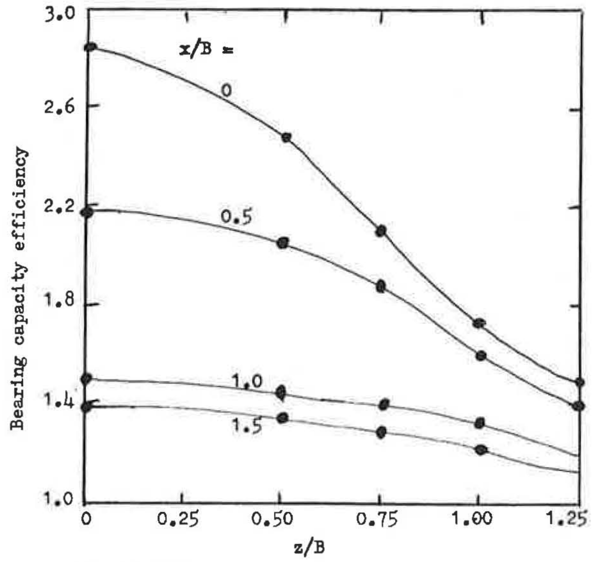

Fig. 7 Efficiency variation with vertical spacing between layers (u = 0.5B, N = 5)

It has been shown by Binquet and Lee (6) that three modes of footing failure can be identified depending on u and z: for high u - values, soil shear would take place completely above the layers of reinforcement. For low u but with few strips or with short ties irrespective of number of layers, failure is more by strip pullout. For low u, many layers and long strips, failure is more likely by fracture of the upper layers of strips. In the experiments, it was observed that for z less than 0.5B, block action of the soil - tie composite was evident. For high z up to z = B, tie break was observed but for z in excess of B, tie pullout resulted.

(c) Number of layers:- Unlike with gravels, the strips had no compressive strength and therefore, with u = 0, the behavio was as an unreinforced soil mass. With reasoning similar to that of results from gravel reinforcement, it is evident in Fig. 8 that the addition of more layers after the third does not contribute much to the bearing capacity improvement.

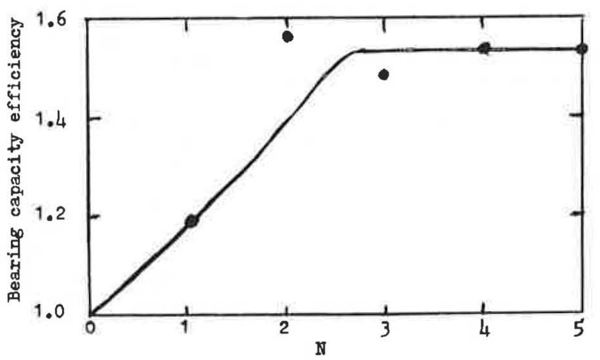

Fig. 8 Efficiency variation with number of layers (u = 0.5B, x = z = 0.5B)

CONCLUSIONS

Results obtained from using the two types of reinforcements indicate that some bearing capacity improvement is obtained with the use of the reinforcement materials, the degree of improvement depending on depth below the footing of the first layer, vertical spacings between layers and number of layers of reinforcement. Fig. 7 also shows that bearing capacity efficiency also depends on the horizontal spacings between strips of fiber reinforcements. It was shown that depending on the arrangement of the reinforcements, improvement in capacity values by a factor of up to three times that of the unreinforced soil can be obtained with the rope fiber material . However, the improvement factor with the crushed rock was not more than two.

A comparison of the results show similar behaviors with crushed rock and rope fiber reinforcements used in the sand. However, it is worth noting that the mechanisms of behavior are different. With strip reinforcements, strength is derived entirely from the tensile strength of the reinforcements material which in turns governs the maximum soil-tie frictional resistance that can exist on the strip surfaces. With crushed rock, strength is derived from the compressive strength of the reinforcement as well as the intergranular contact stresses. Observation at the end of each test with the crushed rock indicates that the strength that could normally be derived from the rock material per se is grossly undermined by the fact that the sand above and below the gravels are forced into the voids in the gravel, thereby causing stress release in the sand, and also that no appreciable soil - gravel friction is achievable (because there is no continuity in the gravel material) especially when compared with the strips. The problem of stress release in the sand does not exist with strip reinforcements.

It appears that the problem pointed out in the earlier work of the authors (3) concerning the biodegradable nature of the rope strips is not helped much by replacing the strips with gravels. To achieve the goal then of using locally obtainable raw materials as reinforcement material, an alternative high tensile strength strip material that is locally available is still required provided it is not biodegradable. Alternatively, the quest for determining what locally available methods and materials can be used to treat the rope fiber reinforcements to render them waterproof and free from insect attack is still much alive.

REFERENCES

(1) Akinmusuru, J.O., "A Method of Estimating Foundation Ultimate Capacity," Soils and Foundations, (Tokyo, 1982).

(2) Akinmusuru, J.O. and Adebayo, I.O., "Fiber Reinforced Earth Blocks," Journal of the Construction Division, ASCE, Vol. 107, No. CO3, Proc. Paper 16517, (New York, 1981), 487-496

(3) Akinmusuru, J.O. and Akinbolade, J.A., "Stability of Loaded Footings on Reinforced Soil," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT6, Proc. Paper 16320, (New York, 1981), 819-827.

(4) Al - Hussaini, M. and Perry, E.B., "Field Experiment of Reinforced Earth Wall," Journal of the Geotechnical Engineering Division, ASCE, Vol. 104, No. GT3, Proc. Paper 13596, (New York, 1978), 307-321.

(5) Binquet, J. and Lee, K.L., "Bearing Capacity Tests on Reinforced Earth Slabs," Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT12,

Proc. Paper 11792, (New York, 1975), 1241-1255.

(6) Binquet, J. and Lee, K.L., "Bearing Capacity Analysis of Reinforced Earth Slabs," Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT12, Proc. Paper 11793, (New York, 1975), 1257-1276.

(7) Lee, K.L., Adams, B.D. and Vagneron, J.J., "Reinforced Earth Retaining Walls," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 99, No. SM10, Proc. Paper 10068, (New York, 1973), 745-764.

(8) Micheal, B.J., "Earth Reinforcement, New Methods and Uses," Civil Engineering, ASCE, Vol. 49, No. 1, (New York, 1979), 51-57

(9) Price, D.I., "Reinforced Earth," Ground Engineering, Vol.8, No. 2, (Brentwood, 1975) 19-24.

(10) Richardson, G.N. and Lee, K.L., "Seismic Design of Reinforced Earth Walls," Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT2, Proc. Paper 11143, (New York, 1975), 167-188.

(11) Richardson, G.N. and Lee, K.L., "Seismic Testing of Reinforced Earth Walls," Journal of the Geotechnical Engineering Division, ASCE, Vol. 103, No. GT1, Proc. Paper 12696, (New York, 1977), 1-17.

(12) Schlosser, F. and Long, N.T., "Recent Results in French Research on Reinforced Earth," Journal of the Construction Division, ASCE, Vol. 100, No. CO3, Proc. Paper 10800, (New York, 1974), 223-237.

(13) Tinubu, A.O., "Reinforced Earth - A Literature Review and Laboratory Study," thesis presented to Clemson University in partial fulfillment of the requirements for the degree of Master of Science, (1976), 51pp.

(14) Vidal, H., "La Terre Armee," Annales de l'Institut Technique de Batiment et des Travaux Publics, (Paris, 1966), 888-936.

(15) Vidal, H., "The Principle of Reinforced Earth," Highway Research Record, No. 282, (Washington, 1969), 1-16.