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USE OF BAMBOO AND COIR FOR REINFORCEMENT — AN APPROACH

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ABSTRACT

All over the world , the Civil Engineers are in search of new competitive construction materials which can suitably and effectively be used to face many challenges that have cropped up with time. Even though Geosynthetics are suitable to the actual needs, they have not been much used in many developing countries like India. The prohibiting reason for this is the high cost and non-availability of the synthetic fibers. Here natural fibres are considered as a prospective Geotextile. In this paper, a three-dimensional nonlinear finite element analysis of a model foundation considering the frictional aspect of the natural fibres like coir and bamboo, which are used as reinforcement is proposed.

INTRODUCTION

The introduction of geotextiles in the Engineering field wide open the possibilities of new techniques, design and construction methods especially in geotechnical engineering. The development of this branch of Civil Engineering is more or less based on *synthetic materials or chemical fibres . These geotextiles are basically fibrous materials, even* though the related products do not have fibrous appearance. They are generally long, flexible, thin (with small area of cross section) and with high tensile strength . These characteristics are essential for good contact with the soil particles and the resulting stress transfer by friction. Even though the technique is suitable for the actual needs, Geotextiles have not been much used in many developing countries like India. Prohibiting reason for this are high cost and non-availability of synthetic fibres. Hence it is high time to think about other alternative which are cheaper and readily available. One of the answer is natural fibres like coir, jute, bamboo etc.. The natural fibres can very well be used in applications like erosion control, separation, filtration and reinforcement where the required life span is short. Some of the potential use of natural fibres in geotechnical Engineering can be seen elsewhere. [1].

Even though the natural fibres are one of the prospective alternative to geosynthetics, detailed analytical studies such as powerful FEM, taking into consideration the frictional resistance of fibres are still in primitive stage. It is clear beyond doubt that the friction between soil and fibres plays an important role in the proper functioning of geotextiles. With better understanding of the behaviour of these material, its functions and applications in the actual geotechnical engineering problems, we can make use of these natural fibres as a suitable alternative for geosynthetics. In this paper a three-dimensional non-linear finite element analysis of a model foundation considering the frictional aspect of the natural fibres like coir and bamboo which are used as reinforcement is proposed and some of the results are verified using available experimental results.

The three dimensional nonlinear Finite Element Analysis has been developed[2] *paying individual attention to modeling the soil, fibres and the interface* between the two. For modeling the interface behaviour, a three dimensional, nonlinear soil - reinforcement- interface friction element has been developed, which is specially suited to represent the friction (including adhesion) between soil and reinforcement, especially when the latter is in the form of rods or strips. A general purpose Finite Element Program - NOSFIN - is modified and the newly developed interface element is implemented with it. A parametric study has been done to study the influence of some select parameters on the behaviour of composite earth system as a whole under the load.

SYSTEM ANALYSED

Model foundation selected consists of a sand bed of dimensions 1000 x 1000 x 500mm, prepared in a tank loaded by a footing in steel of dimensions 200 x 200 x 18 mm. [Fig. 1]. *The soil used is river sand filled in layers and compacted to get a unit weight of 16.75* x10^6 N/mm^3. The basic reinforcing material used for the study is bamboo strips, either alone or with coir ropes glued on it, to improve the frictional properties. Unless otherwise specified, the section of reinforcement used is 10 x 5 mm (50mm^2). A symmetrical pattern of reinforcement (referred to as crosses here) was selected for the studies to maintain the perfect symmetry of the system, and the analysis was confined to a quarter, even though in the present case theoretically one-eighth of the system would have sufficed.

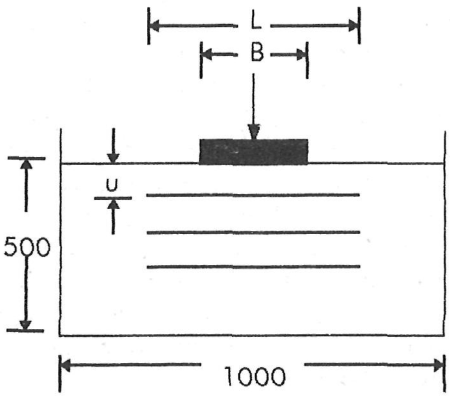

Fig. 1. Schematic Representation of Model Set-up

The Finite Element mesh consists of nonlinear bricks to represent soil and 4 linear bricks to model the footing. Four 8-noded interface elements are used to represent the interface between the footing and the soil. By trial and error, the interface thickness is chosen as 3mm and normal stiffness k_n is given a value of $100 N/mm^3$, so that there is no interpenetration of the nodes. The vertical displacements of the bottom nodes of the soil and also the displacement across the boundary nodes are arrested. Similarly the displacement of the nodes across the symmetrical vertical planes passing through the center are arrested. All the initial stress due to gravity are considered as per the at-rest condition. The incremental method [3] of non-linear analyses is used and the loads are applied in 8 increments. (In most of the cases the total loads applied for different increments in the analysis are 1, 2, 3.5, 5, 7, 8.5, 10 and 11kN.)

In the reinforced cases three dimensional truss elements are used to model the reinforcements. The truss elements are treated as linear elements. The newly formulated three-dimensional line interface elements (Fig. 2) are used to model the soil- reinforcement interfaces. The width of the interface is taken as the lateral dimension of the reinforcement. During loading if the soil element is found to fail in shear, the same is noted, but no changes are effected and the element is allowed to follow the hyperbolic relation[4] as before, in keeping with the nonlinear elastic formulation of the problem. If during loading the interface fails in shear (slip) the value of shear stiffness in the element is reduced to small value. If tensile condition develop across the interface elements, both shear and normal stresses are assigned small values, as per usual practice found in the literature.

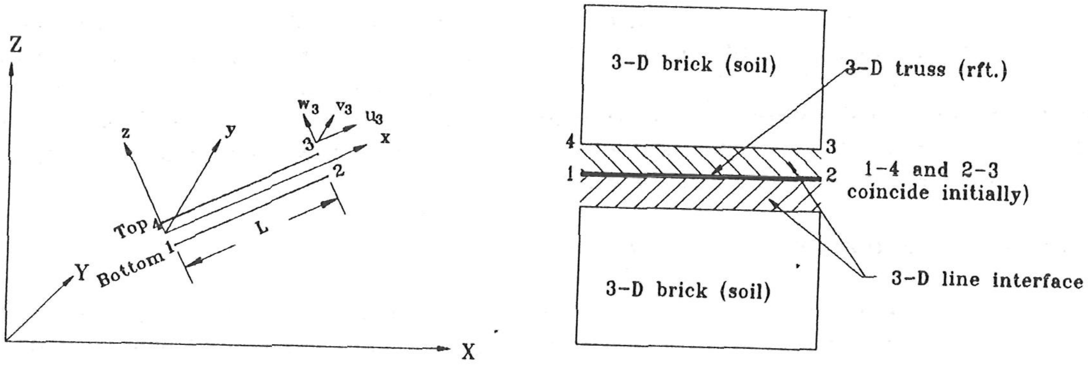

Fig. 2. 3D Line Interface Element

Based on some preliminary studies an extensive and systematic parametric study has been conducted. Reinforced earth being a composite material the properties of both the reinforcement and the soil have their own influence on the behaviour of the system. Here, in this study, the influence of the material of reinforcement, quantity and the disposition of reinforcement are considered.

Material of Reinforcement

The effectiveness of reinforcement is basically due to the higher modulus of material constituting the reinforcements, but limited by the roughness of the surface of the reinforcements. Here three materials have been tried whose modulii differ vastly. The material tried are steel, bamboo and coir. The analysis has been done with and without considering interface also. The reinforcing pattern used is one layer of reinforcement having a length of 2B and consists of three crosses, placed at a depth of 0.5B from the surface. It can be seen from the Fig. 3 that even though steel is having much higher value of E, the analysis with bamboo gives a fairly close result as that of steel as a result of the interface. Analysis with coir shows the least effect due to its very low E, notwithstanding higher roughness. Analysis without interface always showed lesser settlements as would be expected on account of the increased rigidity of the system than those with interface.

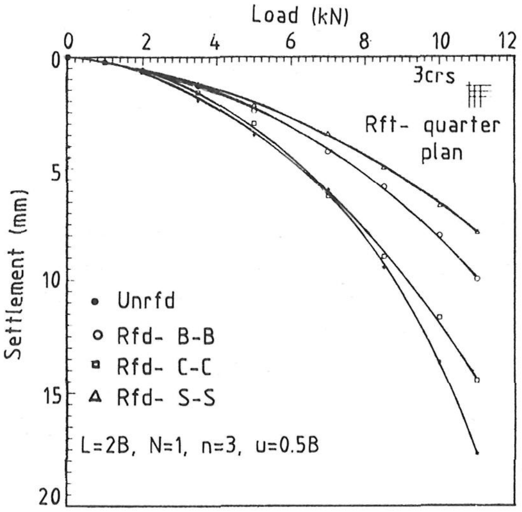

Fig. 3

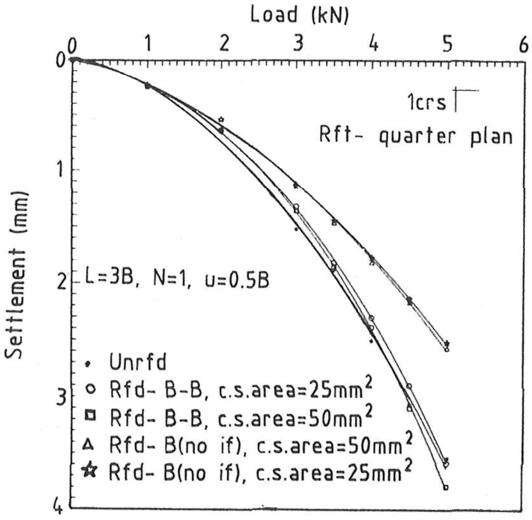

Fig. 4

Studies were also conducted to know the influence of the area of cross section of the member used as reinforcements. Two cross section were tried with and without interfaces as shown in Fig. 4. Here the material used was one cross of bamboo strip having length 3B placed at 0.5B from the top. The load stages applied were 1, 2, 3, 3.5, 4, 4.5 and 5kN. It is found that the lesser the area of cross section higher the effect, possibly due to the reduction in the bending stiffness of the rods.

Quantity and Disposition of Reinforcement

The material used for these studies, unless otherwise specified, is bamboo with coir ropes perfectly bonded to it on the surface (represented as B-C). For the purpose of comparison, and to give a quantitative representation of the results, a term "Reinforcement ratio" is defined as

$$R_r\ (\%) = \frac{\text{Total volume of all reinforcements}}{B^3} \times 100\ .$$

The denominator in the above expression roughly stands for the volume of the bulb of pressure under square footing. The effect of the following parameters have been studied.

Depth of reinforcement

Fig. 5 shows the variation of settlement according to the position of the reinforcement. Reinforcement placed very close to the footing ($u = 0.25B$) shows more settlement than others. This may be due to the fact that the normal stress at this level is initially very low and there may not be sufficient friction developed to transfer the load to the reinforcement properly. (It may be noted in this context that once shear failure (slip) of interface occurs, the element is not allowed to recoup and hence it may continue to act as a plane of weakness.) In the same way, it is found that the single reinforcement (cross) placed at a depth of more than 0.75B is not very helpful. The possible reason for this is the fact that the deformations at this level are too nominal to produce sufficient relative movement, on which depends the development of frictional resistance. In general it is observed that if one layer of reinforcement (R_r = 0.75) only is used, the optimum position of the same is at a depth of 0.5B from the base of the footing.

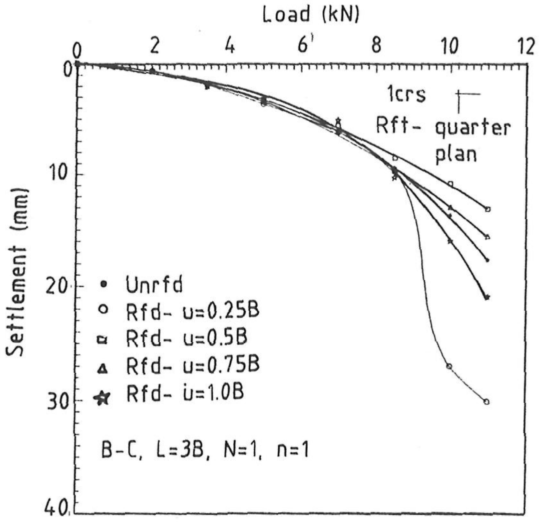

Fig. 5

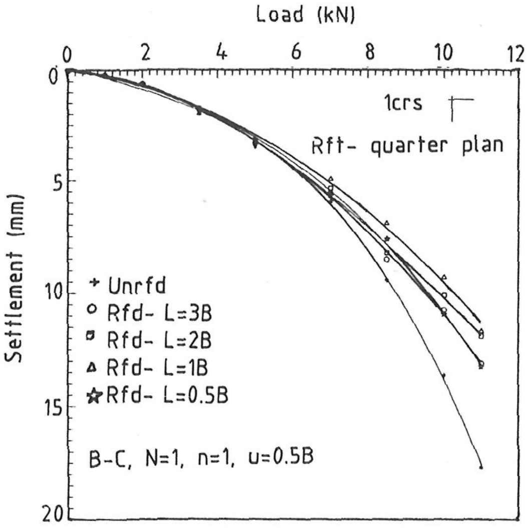

Fig. 6

Length of reinforcement

In order to get an answer to the question to what extend of the medium under the footing should be reinforced, which would be effective in reducing the settlements, four lengths of reinforcements were tried in the analyses and the results are presented in the Fig. 6. From the figures it can be seen that a reinforcing length more than 2B is not much effective, especially when we consider the quantity of the material input. In most of the load stages, the percentage reduction in settlements are less than with reinforcements whose length exceed 2B. It is found that the effect of the reinforcement in restraining settlement is the highest from those which are placed within the footing boundaries. The contribution of the extended lengths of reinforcement beyond the footing periphery is of a secondary order. Generally a reinforcing length of B to 2B (R_r = 0.25 to 0.5) can be recommended based on the results of the analyses.

Number of reinforcement bars

Analyses have been conducted to study the influence of the number of reinforcing bars in one layer. Two sets of studies have been carried out, one using a reinforcement length of B and the other using a length of 2B (Fig. 7). In both cases the number of reinforcements are increased by adding one cross to each to the starting case with one cross. In this manner the maximum number of cross used for a length of 2B is 4 and that for a length of B, is 3. For the case L = 2B, the maximum reduction in settlement is obtained for three crosses (R_r = 1.5) of the reinforcement followed by two crosses (R_r =1.0). The reduction of settlement with four crosses of reinforcement is slightly less than the above two cases. A similar trend is seen in the cases under L = B, in which two crosses (R_r = 0. 5) represent the most effective case. Comparing the cases of L = 2B with three crosses (R_r = 1.5) and L = B with three crosses (R_r = 0.5), the former, representing a higher material input, is *found to be more effective.*

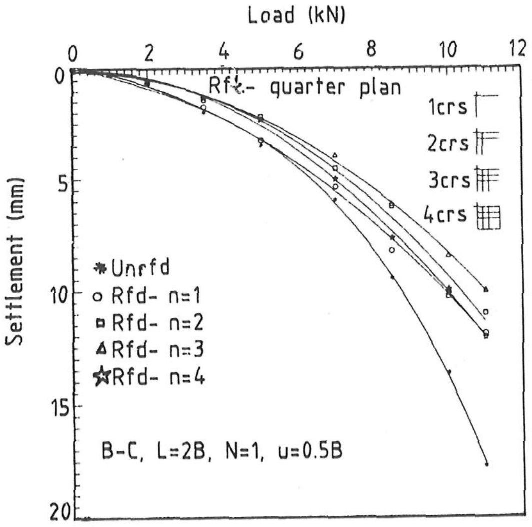

Fig. 7

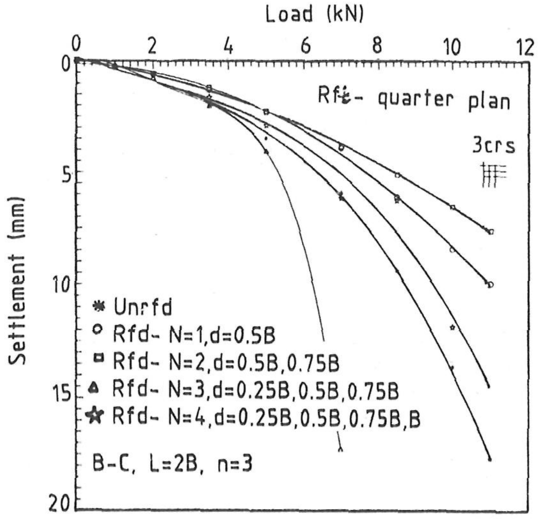

Fig. 8

Number of layers of reinforcement

To understand the behaviour of the reinforced soil system under the variation of the number of layers of reinforcement, two sets of analyses were conducted. Fig. 8 shows the results of the analyses for the case L = 2B and n = 3 (number of crosses). Similarly a set of *analysis have been conducted for L = B and n = 2. The number of layers were increased in* steps of one starting from one and reaching four. It can be seen from figure that the introduction of a layer of reinforcement at a depth of 0.25B from the surface increases the settlement considerably, negating the purpose of reinforcement as far as the settlements are concerned. In both the series, the effectiveness of reinforcement is reduced for the case of N = 4, when compared with material input.

EXPERIMENTAL VERIFICATION

Some of the salient cases analysed have been verified using the results of the experimental investigation conducted by Prasanna[5]. The comparison between the experimental results and the theoretical predictions are shown in Fig. 9(a) - (d). The size of the testing tank, (same as the size of the sand bed), the footing and the reinforcements used in the test are the same as those assumed in the analysis and comparison have been made on the settlements, measured by dial gauges, in the test. The agreement is found to be good in all the *cases compared. The author was associated with all phases of these experimental* investigations starting with the stage of planning.

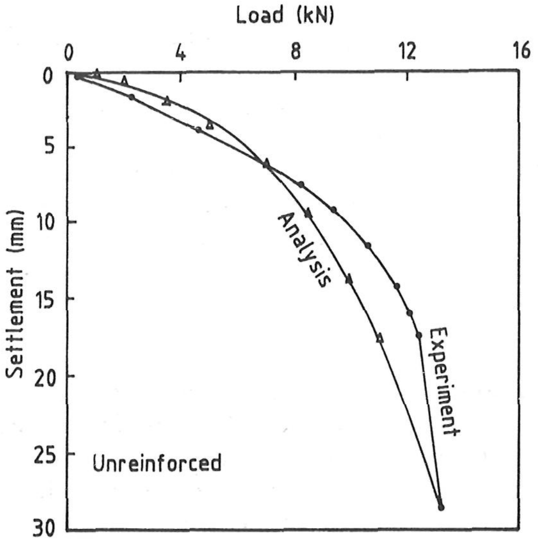

Fig. 9 (a)

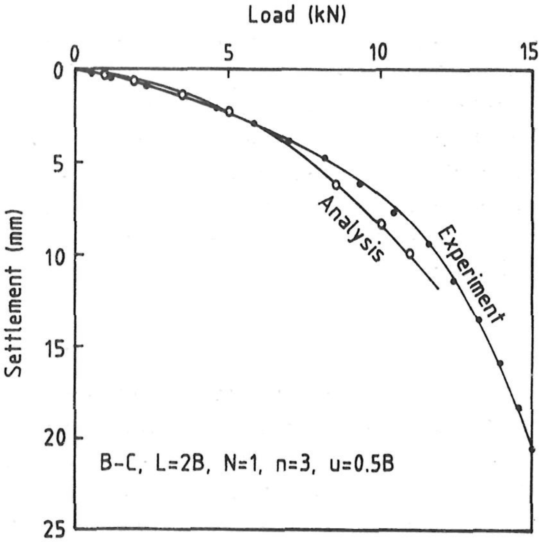

Fig. 9 (b)

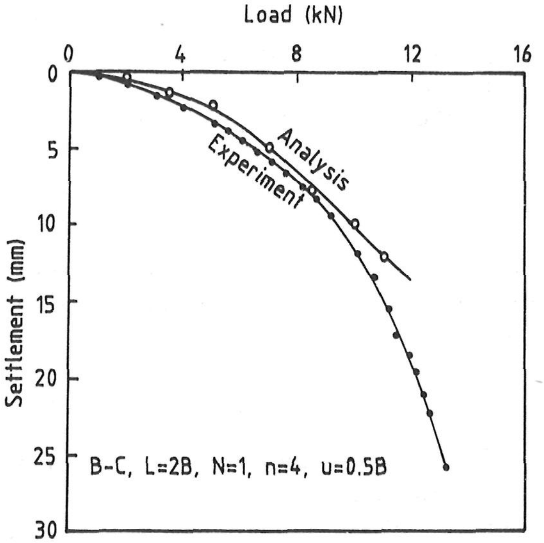

Fig. 9 (c)

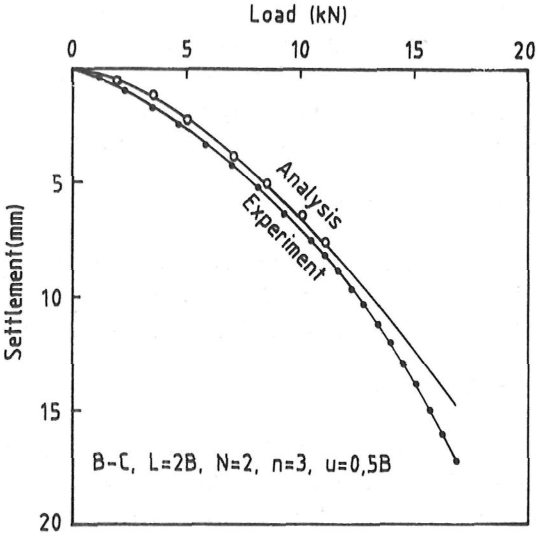

Fig. 9 (d)

CONCLUSION

The studies essentially involve the use of bamboo splinters as the reinforcing material. It is also practically attractive considering its low cost against high strength of material. Winding bamboo splinters with thin coir rope (ensuring no slip between them) in practical installations can considerably improve its frictional characteristics which can ensure a higher fraction of its strength to be realized in practice. The cross sectional area of the bamboo reinforcement used in these studies works out to 0.125% of the plan area of footing.

From the studies it has been found that the reinforcements placed very near to the top surface can produce negative results. The ideal position is to start the reinforcement at a depth equal to approximately one fourth to half the footing width from the top (i.e., between u = 0.25B and 0.5B). Reinforcements placed at depth of more than 0.75B is found to be not beneficial in reducing settlements. Regarding the length of reinforcement, it is found that a length of B to 2B is ideal. Reinforcing strips with smaller sectional area gives better results on account of the increased surface area for the same cross sectional area. Settlement is found to decrease with increasing number of layers of reinforcement. Taking into account the aspect of material input, reinforcements in 3 or 4 layer over a depth of B from surface appear to be the optimum.

The interfaces elements are necessary in modeling the systems such as reinforced earth, without which the analysis leads to exaggerated results. In most of the cases, analysis without interface elements leads to overestimation of the performance of the system. The modulus of elasticity of the material of the reinforcement and the surface characteristics of reinforcement together govern the behaviour of the reinforced earth system under load. Even though the aim of parametric studies has not been projecting bamboo strips as an ideal form of reinforcement in loose cohesionless soils, one cannot help mentioning that the same is indeed a viable form of reinforcement in such soils, at any rate for temporary and semi-permanent structures, considering its performance against factors such as cost and availability. Winding bamboo splinters firmly with thin coir ropes is an attractive proposition which can considerably improve its frictional characteristics and ensure a higher fraction of its inherent strength to be realised in practice.

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