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Bearing Capacity of High Density Polyethylene (HDPE) Reinforced Sand Using Plate Load Test

Er. Aly K[1], Prof. Stephen Joseph Nigli[2], Dr. Antony Balan[3]

1 Research Scholar, Karunya University, Coimbatore, T N and Executive Engineer, Local self Govt. dept. Kerala , India.
2 Professor & Head of Department of Civil Engg., College of Engineering, Trivandrum, Kerala, India (Retd.)
3 Former Professor, Karunya University, Coimbatore, T N and former Chairman, Central water Commission, India.

Abstract:
The work presented here is a study to examine the improvement in bearing capacity of coastal sand of Trivandrum, Kerala, India using high density polyethylene (HDPE) /woven fabric as reinforcement in discrete layers. The bearing capacity was evaluated using plate load test. The effect of reinforcement configurations like sheet reinforcement (sanded with adhesive, with adhesive and sheet alone) and strip reinforcement (single and grid pattern) are investigated. The test parameters chosen for the present study are, depth of topmost layer of reinforcement layer below footing, compacted density and number of layers of reinforcement etc. From the tests, it has been observed that sheet reinforcement is more effective than sheet sanded with adhesive and strip reinforcements. It is found that the synthetic adhesive gives no binding action at the interface of the reinforcement and soil. But it is to be noted that the sheet with adhesive dried has a marked influence on the bearing capacity especially at lower densities. The strip reinforcements in single pattern is considered to be a favorable choice for minimum reinforcement. The strip reinforcement in single or grid pattern gives sufficient improvement in strength.

Keywords: *Bearing Capacity, Reinforce Earth, Plate Load Test, River Sand, Geotextiles, HDPE, Strength Improvement, Bearing Capacity Ratio.*

I. Introduction

Recently, the world has witnessed a phenomenal increase in the use of man made materials in geotechnical construction activities like reinforcing of soil. And there had been a major growth in the interest in the subject because of research and developments in the universities and laboratories. Sometimes a foundation engineer faces many problems when low bearing capacity of soil exists at the site. For increasing the bearing of soil, ground improvement techniques like stabilisation, preloading, compaction, vibrofloatation and grouting etc. are used. The inclusion of reinforcement in the soil at a particular level is also a part of this technique. Many types of reinforcements such as G1 sheet or strip or mesh, coir rope, jute, pineapple leaves and geosynthetics are used. A large variety of petrobase synthetic fabrics, fiber glass fabrics and natural fabrics are tried in various projects. The polymers and composites like HDPE and LDPE were also used for the reinforcement. Nowadays this concept of reinforcing soil has been recognized as an emerging topic in geotechnical engineering field, as it contributes improvement in strength, reduction in cost and ease of construction coupled with basic simplicity.

II. Reinforced earth - concept

Reinforced soil is somewhat analogous to reinforced concrete as the reinforcement is bonded to the soil in the former while reinforcement is embedded in concrete in the later. However a direct comparison between the two situations is not completely valid. In reinforced concrete, the reinforcement is designed to carry the tensile forces in the structural element but in the reinforced soil a completely compressive stress field will be existing. The mode of action of reinforcement in soil is therefore not one of carrying developed teni1e stresses but of an isotropic reduction or suppression of one normal strain rates. The suppressive mechanism of reinforced soil described by Vidal shows individual soil partic1e tied together producing a form of pseudo cohesion (4) . The mechanism of increase in strength can be expressed either as a pseudo cohesion, in the case of tensile failure of the reinforcement or as an apparent increase in the internal angle of shearing resistance when bond failure prevails. As enhanced internal confining pressure may said to be responsible for both the modes of failure (1). According to Henri Vidal reinforced earth can be a competitive material in a certain number of examples like retaining walls, dams, vaults, slabs, piles, quay walls etc. but except for beams (5).

III. Theoretical Aspects

Limit equilibrium approach can be used to provide a general analysis of reinforced soil. It is assumed that there exists critical plane through the reinforced soil and that this plane bisects the reinforcement defining the plan area on the critical plane for each reinforcing member as AB and the force in each member at critical place as PR. The shear stress will be equal to (Tyx—PR Sin0)/ AS and normal stress = (Gy+PR Cos0)/As where 0 is the orientation of the reinforcement with vertical. Tyx - shear stress in y-x plane, Gy - normal stress in the y-direction fig 2.3.1. From these equations, it is evident that the reinforcement has increased the normal stress whereas it reduced the shear stress experienced by the soil. In other words the shear strength of the soil has been increased by the reinforcement. The increase in shear strength of cohisionless soils is given by J = PR (Cos øTan0 + Sin0)/As where ø = angle of internal friction (4). Basset and Last have considered a more general approach to the concepts of earth reinforcement by considering the modification of strain fields of soil caused by the addition of reinforcements. Fig3.1 shows conventional Mohr's circle of stress and corresponding Mohr's circle of strain rate. The effect of reinforcement is to restrict anisotropically one normal strain (E0), more can be evaluated considering modification to strain fields. The centres of strain circles represents (E1 + E3)/2=r/2 (volumetric stress rate) and (E1-E3)/2 = r/2 Max A&B represents planes across which E=0 and the direction to A&B are the corresponding direction of E0.

IV. Reinforcement chemistry

HDPE (high density polyethylene) fabric is available in woven and non woven forms of varying thickness in different colours. It has been grouped under polymers. Polymers are the products of combining large number of small molecular units called monomers by a chemical process known as polymerisation. It is a process by which molecules or groups of atoms are joined together to form long chain molecules. Natural materials such as bitumen, rubber and cellulose has this type of structure. There are two important types of polymerisation. In the first type, a substance consisting of a series of long chain polymerised molecules called thermoplas- tics is produced. All the chains of the molecules are separate and can slide over one another. In the second type, the chains become cross linked so that a solid material is produced which cannot be softened and which will not flow, such solids are called thermosetting polymers (18). High density polyethylene comes under the first category viz, thermoplastics. The standard properties of tested polymers are shown in Table 5.2.2

V. Experimental Investigation

5.1 Scope of the study

In the coastal regions of Kerala, the sand is deposited either by the action of wind and water or during flood. The sand in this area is found to be relatively fine, uniformly graded and is fairly loose. The sand has little or no cohesion and low bearing capacity. This type of sand if reinforced by some means can be improved in bearing capacity to enable the economical design and construction of sub structure or foundation suitable for the site. The present study was conducted by reinforcing the coastal sand with layers of woven high density polyethylene in sheet and strip form. It is available in large quantity in the form of empty cement bags. and was found to be a waste materials commercially available from construction industry, cheapest, and durable among the polymers.

5.2 Material Properties

5.2.1 Sand:

The fine, loose and uniformly graded coastal sand passing through 4.75mm IS sieve was used for the entire test programme. The test sand was obtained from Thumba, in Trivandrum district of Kerala, and the properties of which are shown in Table 5.2.1.

5.2.2 Reinforcement:

White sheet of woven high density polyethylene fabric (HOPE) 150cm x 150cm x 0.18mm size placed in discrete layers is used as the reinforcement. The strips are 10cm wide and 150cm length with a horizontal spacing of 30cm c/c. No spacers are used for the reinforcements. The edges are stiffened by end anchorages of eta plys 15mm x 3mm. The properties of reinforce- ments used are shown in Table 5.2.2.

5. 3. Experimental set up:

A standard reaction type loading plate load test set up was used for the entire test programme. The MS plate 30cm x 30cm x 2cm, 25t capacity hydraulic jack, 10t capacity proving ring, set of dial gauges forms the experiment set up. All the tests are carried out in a square masonry tank of 160cm x 160cm x 90cm inside dimensions. The inside of the tank is plastered with cement mortar 1:5. The tank was filled up to 75 cm height with sand placed in 15cm thick layers. (half the plate size) corpacted to the required density is obtained by placing weighed soil and using compacting effort of 7Kg weight with 20cm drop height. Densities of 1.55g/cc and 1.7 g/cc were achieved by 100 and 200 drops respectively. The deep sand beds will ensure homogeneous nature of the soil up to the required depths of placement of reinforcement. The test was conducted on reinforced and unreinforced sand beds. An initial seating pressure of 70g/cm2 was applied. The pressures are applied in ranges of 1.5t/m2 till the failure was imminent through the square plate placed on the surface of the sand bed. The corresponding settlements of model footing at four corners were measured using dial gauges fixed by independent magnetic bases, accurately. In the case of reinforced sand bed the appropriate reinforceements are placed at predetermined depth below the model footing. The test was repeated in the same manner for the unreinforced sand.

5.4 Test variables:

The following test parameters were varied to study their effect on bearing capacity of the sand bed.
1. Depth of the top most layer of reinforcement below model footing.
2. Number of layers of reinforcement.
3. Compacted density.

The reinforcement configurations chosen for the present study are:

1. Sheet type reinforcement
2. Sheet reinforcement sanded with synthetic adhesive.
3. Sheet reinforcement with synthetic adhesive (dried).
4. Strip reinforcement (single pattern)
5. Strip reinforcement (grid pattern)

In strip reinforcement, the horizontal spacing and vertical spacing are kept equal to plate size and half the plate size respectively viz 30cm c/c and 15cm c/c. In sheet reinforcements the vertical spacing was 15cm c/c. The synthetic adhesive used was fevicol with registered trade marks.

5. 5. Test Programme:

The pressure was increased at intervals of 1.5t/m^2 and corresponding settlements at four corners of the plate are determined using dial gauges for each pressure increment. Pressure settlement graphs of unreinforced sand are plotted from the observations. Similarly, the tests are repeated for reinforced sand by placing sheet reinforcement at required depth bellow model footing.

In the second phase of the test, sheet reinforcements sanded with synthetic adhesive were tried as in the previous case. The sheet reinforcement sanded with synthetic adhesive was placed at predetermined depth below footing.

In the third phase of the experiment, sheet reinforcements with synthetic adhesive (dried) are used as reinforcement as in the previous case for the predetermined depths of placement. The test was repeated for various test parameters, to study the effect of synthetic adhesive dried on sheet reinforcement improve bearing capacity of sand.

In the next stage, strip reinforcements both in single pattern and grid pattern are used for the test. The horizontal spacing of strips are kept equal to 30cm c/c. The alternate layers of the reinforcements are placed such that their directions are perpendicular to each other. In each of the above four cases, pressure settlement graph were plotted for all tests. The bearing capacities in each of the tests were determined at 5mm settlement of the plate and at 10mm settlement of plate for comparative study of the effect of reinforcements.

5.6. Test Results:

For convenience in analysing the data for various test parameters, a term known as bearing capacity ratio was defined. BCR = q_u / q_o

q_u - bearing capacity of reinforced sand. q_o - bearing capacity of unreinforced sand.

In this work q_u and q_o are defined at 5mm and 10mm settlements of the plate. Test results are shown in Table 5.6.1. The bearing capacity ratio at 10mm settlement of the plate is used for analysis. The bcr ratio of 5mm settlement is also considered for certain cases for a comparative study.

Eff. Size (mm) D10	Med grain size (mm) D50	D60 (mm)	Unifo. coeff Cu	Coeft. grad Cc	Emax	Emin	Sp.gravity G	Angle of internal friction (Degree)
0.5	0.65	0.7	1.4	1.02	0.78	0.48	2.6	40 (r=1.70g/cc) 38 (r=1.55g/cc)

Table . 5.2.1 Properties of test sand

Material	mean thickness (mm)	Unit wt (kg/m^2)	Tensile Srength (kg/cm^2)	modulus of elasticity ($kg/cm^{2)}$
Woven HDPE fabric	0.18	0.1	490	261

Table 5.2.2 Properties of Reinforcement

T No	r g/cc	U (cm)	U/B	N/ Type	% Vol Reft.	quf (t/m2)	BCR 5mm	qut (t/m2)	BCR 10mm
Unreinforced sand									
1	1.70				0	13.73		19.28	
2	1.55				0	11.48		16.13	
Sand Reinforced with HDPE sheet									
3	1.70	15.00	0.50	1 sheet	0.24	22.13	1.61	30.08	1.56
4	1.70	15.00	0.50	2 sheet	0.48	22.4	31.63	34.53	1.79
5	1.70	30.00	1.00	1 sheet	0.24	11.63	1.00	19.28	1.00
6	1.55	15.00	0.50	1 sheet	0.24	13.58	1.18	2l.38	1.33
7	1.55	15.00	0.50	2 sheet	0.48	14.63	1.27	22.28	1.38
8	1.55	22.50	0.75	2 sheet	0.48	10.88	1.00	17.93	1.11
9	1.55	37.50	1.25	1 sheet	0.24	11.18	1.00	16.13	1.00
Sand Reinforced with sheet coated with sand by adhesive									
10	1.55	15.00	0.50	1 sheet	0.24	13.13	1.14	16.88	1.05
11	1.55	15.00	0.50	2 sheet	0.48	14.63	1.27	22.43	1.39
12	1.55	22.50	0.75	2 sheet	0.48	13.28	1.16	19.88	1.23
Sand Reinforced with sheet with adhesive coating									
13	1.55	15.00	0.50	1 sheet	0.24	16.28	1.42	20.78	1.29
14	1.70	15.00	0.50	1 sheet	0.24	18.38	1.34	28.21	1.46
Sand Reinforced with strip (single pattern)									
15	1.55	15.00	0.50	1 strip	0.0085	11.33	1.00	16.73	1.04
16	1.55	15.00	0.50	2 strip	0.0169	13.13	1.14	18.68	1.16
Sand Reinforced with strip (grid pattern)									
17	1.55	15.00	0.50	1 grid	0.0169	12.23	1.07	17.48	1.08
18	1.55	15.00	0.50	2 grid	0.0330	13.13	1.14	20.18	1.25

Table 5.6.1 Bearing capacity and bearing capacity ratios at 5mm and 10mm settlement of the plate (L/B=5)

VI. Conclusions

After analysis and discussion of the test results, the following conclusions can be drawn.

1. The woven HDPE can be used as an effective reinforcement with fine sand and a definite

increase in bearing capacity may be possible with suitable treatment.

2. Bearing Capacity increases when depth of placement of top most layer of reinforcement equal to half the plate size and the effect is very small beyond this significant depth.
3. Increase in compacted density and number of layers results in considerable increase in bearing capacity when reinforcement is placed at significant depth.
4. The sheet reinforcement coated with sand by synthetic adhesive has no significant effect on improvement of bearing capacity of fine sand.
5. Sheet reinforcement if stiffened by impregnation using cheap resin can be used as a favorable choice, especially at lower densities.
6. Strip reinforcements do not seem to be very attractive for improving bearing capacity since they do not offer effective confinement.
7. The sheet reinforcements can be attempted for shallow foundations in low—cost construction particularly if the sheet is stiffened by suitable mechanism.
8. The same test can be further conducted on saturated soil, providing holes to allow for dessipation of pore water pressure, drainage, permeability etc.
9. The reinforcing action due to random reinforcing of sand can be studied for different percentage volume of the reinforcements.

VII. Scope for further studies

1. The present study was conducted on fine coastal sand. Further studies are therefore possible in the case of different sands, clays or lateritic soils.
2. It was noticed in the present study that effective restraint and friction were not mobilised by plain HDPE sheets. Improvement of these sheets by incorporation of stiff frame work and maximum roughness is possible. Further studies may be very fruitful.
3. The works presented here is at a compacted density of sand equal to 1.55 g/cc, or 1.7 g/cc and single and double layer reinforcement. Therefore studies can be conducted for higher compacted densities as well as number of layers.
4. The effect of reinforcement at depth less than significant depths can be studied for various layers of reinforcements.
5. In this study, length of reinforcements the horizontal and vertical spacings are kept constant. It is possible to extend the study for various spacings and lengths of reinforcement or strip size and geometric shape.
6. The effect due to alternate layers of grid and strip reinforcements can be attempted.
7. The present study was conducted using a square plate of 30cm x 30 cmx 2 cm size for a square footing. The results can be compared with that of various plate sizes as well as strip footings.
8. The reinforcing action due to random reinforcing of sand can be studied for different percentage volume of the reinforcements.

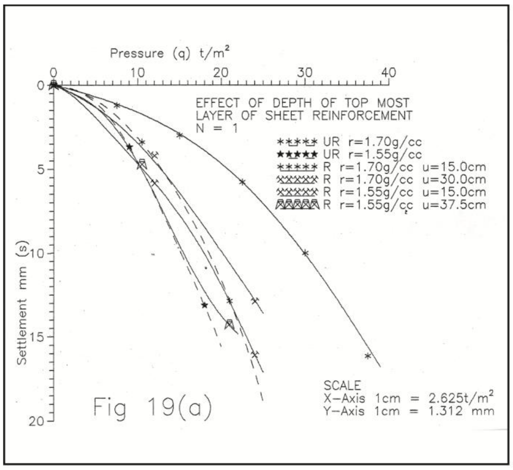

Fig 19(a)

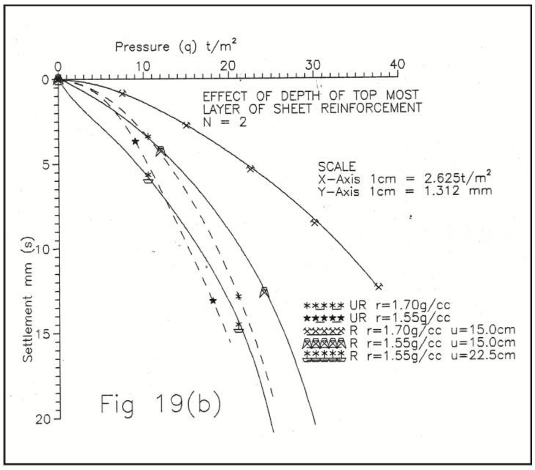

Fig 19(b)

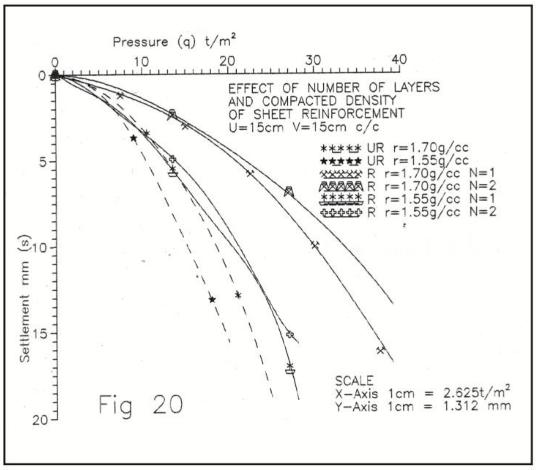

Fig 20

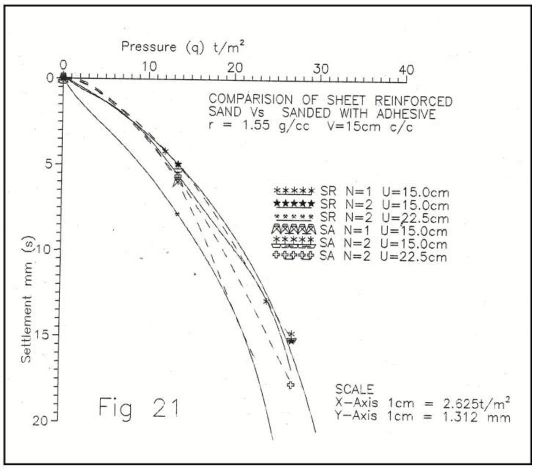

Fig 21

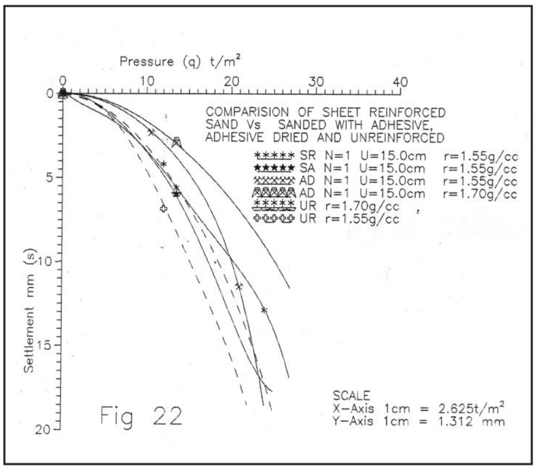

Fig 22

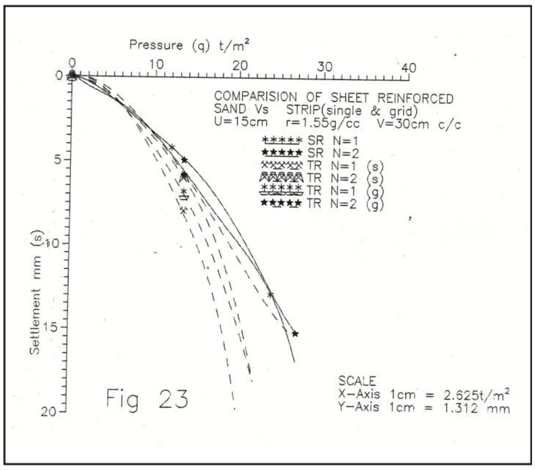

Fig 23

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