A behavioural Study on Two Layered Flexible Pavement Reinforced with Coconut Coir Mat

Bibha Das Saikia[1], Biplab Gogoi[2] and Krishna Gogoi[3]

[1] Department of Civil Engineering, The Assam Royal Global University, Ghy-35, Assam, India
bibhadassaikia@gmail.com
[2] Department of Civil Engineering, The Assam Royal Global University, Ghy-35, Assam, India
biplabgogoi20@gmail.com
[3] Department of Civil Engineering, Assam Engineering College, Ghy-13, Assam, India
bgogoi@rgu.ac

Abstract. It is often necessitated to stabilize and reinforce the structurally unsound soil to bear the traffic load. Different types of sustainable materials are being increasingly used in highway engineering to facilitate rapid construction and to ensure better performance. In the present study a series of plate load tests were conducted on a two layered flexible pavement system (field model) consisting of a locally available sand sub-grade layer of eighty cm thickness and an aggregate WBM layer of varying thickness of ten cm, fifteen cm and twenty cm respectively. In the interface between the sand sub-grade layer and the WBM layer of the pavement system, locally available coconut coir mat as geo-textile reinforcement material was placed either in single layer or in double layers. These tests were conducted on the above materials with and without coconut coir mat to find the reinforcing effect imparted by coconut coir mat. The values of modulus of sub-grade reaction (K), the modulus of elasticity (E) and the ultimate bearing capacity (q_u) were determined from the plate load test results for all the test bed conditions Finally, for all the three different thicknesses of WBM layers the percentage change in K, E and q_u values using coconut coir mat (both for single layer and double layer) with respect to the corresponding values without coconut mat was calculated and it was observed that the fifteen cm WBM layer over the sub-grade with double layer coconut coir mat gives the maximum percentage variation.

Keywords: Two Layered Flexible Pavement, Geo-Textile Reinforcement, Coconut Coir Mat, Plate Load Test.

1 Introduction

Now a days, the use of geosynthetic materials as an alternative improvement technique for embankments and roads construction is a trending approach. This method has been used in embankments and earth retaining structures construction as a sustainable cost effective method alternate to conventional methods. Furthermore, under some situations roads are to be constructed rapidly over a very soft sub grade and to fulfill the required strength and settlement criteria, the subgrade should be stabilized with suitable method like the use of geotextile material. Various researchers investigate the effect of geotextiles in soil subgrade for enhancing the geotechnical properties. Researchers namely , Binquet et al. (1975), Brown and Poulos (1981), Varghese and Jose (1989), Kumar and Sathyamurthy (1993), Guha(1995), Srivastava et al. (1995), Kumar et al. (2005) etc. did some work in this domain. In the present study a series of plate load tests were performed on a two layered flexible pavement system (field model) consisting of locally available soil and aggregate with different combination; reinforced by locally available coconut coir mat as geo-textile material to observe the reinforcing effect imparted by the coconut coir mat.

2 Test Program

2.1 Material Characterization

The material used in the experimental program are-

1. Sandy soil, for the purpose of preparing sub grade
2. Aggregate, which acts as WBM construction material
3. Coconut coir mat, which acts as reinforcing material.

The soil used to perform as sub grade was collected from the bank of the river Brahmaputra at Narengi, Guwahati, Assam. Various laboratory tests i.e. Grain size distribution, Specific gravity, Modified Proctor and CBR test were performed as per Indian standard code to determine the properties of sub grade soil which are given in(Table 1)

Table 1. Properties of sub grade soil

Sl No	Property	Test value
1	Uniformity coefficient, C_u	1.93
2	Curvature coefficient, C_c	0.92
3	Effective size, D_{10} (mm)	0.15
4	Specific gravity, G	2.67
5	Optimum moisture content (%)	15.87
6	Maximum dry density (gm/cc)	1.73
7	Laboratory Soaked CBR value (%)	11.72
8	Laboratory unsoaked CBR value (%)	21.22

The tests conducted on aggregate to judge their suitability as the WBM construction material were: grain size distribution test, specific gravity test, Los Angeles abrasion test, aggregate impact test, flakiness index test and water absorption test. The test results are shown in Table. 2. The size of the aggregate was 63mm and down, which is preferably used in Water Bound Macadam (WBM) road construction.

Table 2. Properties of aggregate

Sl No	Property	Test value
1	Specific gravity, G	2.77
2	Abrasion value (%)	29.30
3	Impact value (%)	20.22
4	Flakiness index value (%)	9.52

5	Water absorption value (%)	0.88

The reinforcing material used in the test program was coconut coir mat (woven type). Out of different types of coconut coir geo textiles available in the market (Rao et. al. (1988)), type C coconut coir mat was selected in the present study. An image of type C coconut coir mat is shown in Fig.1. The properties of coir geotextiles for different types are shown in Table 3.

Fig. 1. View of type C coconut coir mat

Table 3. Properties of coir geotextile (Rao et al. (1988))

Coir geo-textile	Mass per unit area (gsm)	Tensile strength (kN/m)	Tensile strain at failure (%)
Type B	610	11.45	25.42
Type C	1335	31.50	42.00
Type D	750	2.76	31.67

2.2 Test set up

The field model plate load tests using 30 cm diameter steel plate were carried out to find the values of modulus of sub-grade reaction (K), the modulus of elasticity (E) and the ultimate bearing capacity (q_u).For this purpose, a test pit of size 3.60m x 1.50m x 0.80 m depth was excavated and filled by Brahmaputra sand in layers (15 cm thick) and compacted by ramming. Compaction was done to have a dry density in the range of 1.66 gm/cc to 1.8gm/cc i.e. the sub grade was kept at its optimum moisture content 15.87% and within a field density range of 1.93 gm/cc to 2.09 gm/cc. Coconut coir mat was placed at the interface depending upon the test bed condition. Next WBM layers were laid using the locally available coarse aggregates, which falls in the category of grading-II. As per the standard specification and code of practice for water bound macadam, IRC:19 (2005), screening materials type-A were used to fill up pores of the aggregates The WBM was constructed as per the guidelines given in the above code of practice (Fig.2).

In order to study the reinforcement and separation function of coconut coir mat, thickness of WBM layers over the sub grade was varied from 10cm to 20cm in steps of 5cm and the coconut coir mat in each case was placed at the interface either in single layer or in double layer. For comparison of the test results the tests were also performed without providing the coconut coir mat at the interface and above the sub grade layer only.

The two layered flexible pavement sections were constructed at different bed conditions as given in Table 4; above which the plate load tests were conducted.

Table 4. Various bed conditions for Plate load test and its designation

Designation	Test bed condition
A	80cm depth Brahmaputra sand as sub grade
B	10cm WBM over sub grade without coconut coir
C	10 cm WBM over sub grade with single layer coconut coir
D	10 cm WBM over sub grade with double layer coconut coir
E	15cm WBM over sub grade without coconut coir
F	15cm WBM over sub grade with single layer coconut coir
G	15cm WBM over sub grade with double layer coconut coir
H	20cm WBM over sub grade without coconut coir
I	20cm WBM over sub grade with single layer coconut coir
J	20cm WBM over sub grade with double layer coconut coir

2(a) 2(b) 2(c)

Fig. 2. Test set up: (a) test pit (b) test bed prepared with coconut coir mat (c) test bed ready for experiment

The entire plate load test set up is shown in Fig. 3. The plate load tests were carried out as per the specification of IS: 1888 (1982). The vertical load was applied by the hydraulic jack of capacity 10 tones. The load was measured by a proving ring attached to the hydraulic jack and connected to the test plate through the loading column. The two supports of the reference beam or datum rod were placed over firm ground, fixed with three dial gauges making an angle of 120^0, on the top of the test plate to measure its settlement. The loads were gradually applied in small increments by hydraulic jack and the resulting deformations were noted from dial gauges for the purpose of drawing the entire load settlement curve.

In the plate load test, the load to the soil was applied in cumulative equal increments up to 1kg/cm^2 one fifth of the estimated ultimate bearing capacity, whichever was less. In the present study, 1kg/cm^2 load increment was used. The final settlement was observed each increment of load after an interval of one hour to the nearest 0.02 mm/minute. A minimum seating pressure of 70 kg/cm^2 was applied and removed before starting the next test. From the load-settlement data, graphs were then plotted.

3(a) 3(b) 3(c)

Fig. 3. Plate load test set up: (a) complete loading arrangement (b) dial gauge set up (c) hydraulic jack

3 Test Results

3.1 Failure Patterns

Radial Cracks and large settlements were observed when the subgrade consists of Brahmaputra sand only. Use of Coconut coir mat restricts the radial cracks and large settlements. Partially circular cracks were observed at the time of failure using the WBM layer with coconut coir mat. (Fig.4)

4(a) 4(b) 4(c)

Fig. 4. Failure pattern for different combination of testing: (a) only sand sub grade (b) aggregate layer above sub grade without coconut coir mat (b) Aggregate layer above sub grade with coconut coir mat

3.2 Load Settlement Curve

Load - settlement curves were plotted for each test bed condition. A typical load settlement curve for the test bed condition A is shown in Fig 5. Similar curves were obtained for all the test bed conditions. The failure loads for the different test bed conditions were determined from the load-settlement curves by double tangent method as shown in Fig.5.

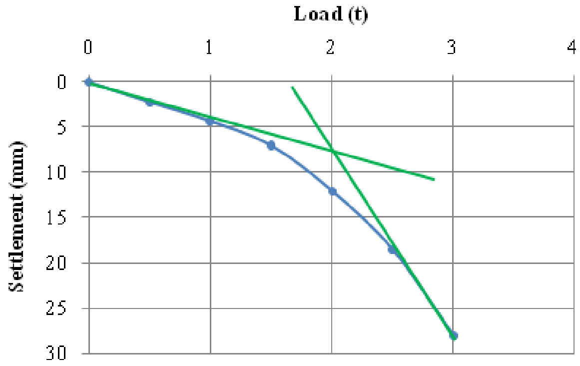

Fig. 5. Load settlement curve for the test bed condition A

3.3 Determination of modulus of Sub grade reaction (K)

Modulus of Sub-grade reaction was determined by using the method described by Khanna And Justo (2001).

As for example, for test bed condition A, from the load settlement curve for Brahmaputra soil, the load value (P) corresponding to mean settlement value of Δ=0.125 cm is determined= 0.308t =308 kg.
Unit load P_1= 308/ (Π/4 x 30^2) kg/cm^2
Modulus of Subgrade reaction K_1 for 30 cm diameter Plate = P_1/ Δ =3.49 kg/cm^3
Modulus of Subgrade reaction K for standard plate of 75 cm diameter Plate
= (3.49 x 30)/ 75 kg/cm^3 =1.39 kg/cm^3.

Similarly the modulus of Subgrade reaction for different test bed conditions were determined as tabulated in Table - 5.

3.4 Determination of modulus of elasticity (E)

Values of stresses and strains are calculated from the plate load test results for each case to draw stress-strain curves. The modulus of elasticity, E was determined from the linear portion of the stress-strain curves within 2% strain.

For example, from the linear portion of the stress-train curve for the test bed condition A, E = (1.41/1.17) kg/cm^2 =1.21 kg/cm^2 (Fig. 6).

Similarly the values of E were determined for all the test bed conditions as shown in Table. 5.

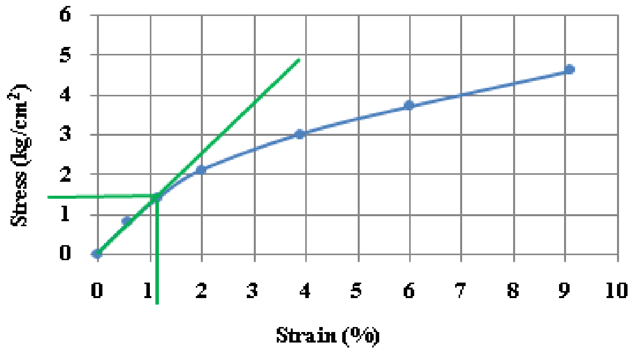

Fig. 6. Stress-strain curves for the test bed condition A

3.4 Determination of ultimate bearing capacity (q_u)

The ultimate bearing capacity (q_u) was determined by double tangent method. For example, for test bed condition A, the ultimate load= 2.0 ton = 2000 kg (Fig 5).
Therefore the ultimate bearing capacity (q_u) = 2000/ (Π/4 x 30^2) kg/cm^2 = 2.83 kg/cm^2
Similarly for different test bed conditions the ultimate bearing capacity (q_u) values were determined which are tabulated in Table. 5.

Table 5. Values of K, E, q_u for different test bed conditions

Test bed condition	Modulus of sub-grade reaction (K) value (kg/cm^3)	Modulus of elasticity (E) value (kg/cm^2)	Ultimate bearing capacity (q_u) (kg/cm^2)
A	1.39	1.21	2.83
B	1.62	1.41	3.40
C	1.71	1.49	3.71
D	1.80	1.59	4.10
E	1.50	1.18	3.25
F	1.86	1.48	3.68
G	2.11	1.68	4.24
H	2.13	1.75	5.23
I	2.36	1.99	5.38
J	2.61	2.14	5.52

4 Discussion

The values of the modulus of sub-grade reaction (K), the modulus of elasticity (E) and the ultimate bearing capacity (q_u) of various pavement sections with and without coconut coir mat; indicate that the inclusion of coconut coir mat adds strength to the subgrade.

Table 5 shows that the test bed having 20cm WBM over sub grade with double layer coconut mat gives the maximum modulus of sub-grade reaction (K), modulus of elasticity (E) and ultimate bearing capacity (q_u) values of 2.61 kg/cm^3, 2.14 kg/cm^2 and 5.52 kg/cm^2 respectively .

Again the percentage change in modulus of sub-grade reaction (K), modulus of elasticity (E) and ultimate bearing capacity (q_u) values using coconut coir mat with respect to the corresponding values without coconut coir mat were determined as shown in Tables 6, 7 and 8. It is observed that 15 cm WBM over subgrade with double layer coconut coir mat gives the maximum percentage increase in each case.

Table 6. Percentage change in modulus of sub-grade reaction (K) values with coconut coir mat

WBM layer thickness	% change in K value with single layer coconut coir	% change in K value with double layer coconut coir
10 cm	5.56	11.11
15 cm	24.00	40.67
20 cm	10.80	22.53

Table 7. Percentage change in modulus of elasticity (E) values with coconut coir mat

WBM layer thickness	% change in E value with single layer coconut coir	% change in E value with double layer coconut coir
10 cm	5.67	17.77
15 cm	25.42	42.37
20 cm	13.71	22.29

Table 8. Percentage change in and ultimate bearing capacity (q_u) values with coconut coir mat

WBM layer thickness	% change in q_u value with single layer coconut coir	% change in q_u value with double layer coconut coir
10 cm	9.12	20.59
15 cm	13.23	30.46
20 cm	2.87	5.54

5 Conclusions

The behavioural study on two layered flexible pavement reinforced with coconut coir mat with the help of plate load test indicates that the presence of coconut coir mat in between Brahmaputra soil sub grade layer and locally available aggregate WBM layer enhance the engineering properties under investigation i.e. the modulus of sub-grade reaction (K), the modulus of elasticity (E) and the ultimate bearing capacity (q_u). When 20cm WBM layer was placed over sub grade with double layer coconut mat gives the maximum K, E and q_u values of 2.61 kg/cm^3, 2.14 kg/cm^2 and 5.52 kg/cm^2 respectively. Again when 15cm WBM layer was placed over sub grade with double layer coconut mat gives maximum percentage change in K, E and q_u values with respect to the corresponding values without coconut coir mat. Therefore it can be concluded that 15cm WBM over sub grade with double layer coconut coir mat gives the maximum benefit. However, this study can be further extended towards different test bed conditions considering other Geotechnical parameters also.

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