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Footing load tests on single and group of stone columns

Le chargement de fondation essaie sur le seul et le groupe de colonnes de pierre

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ABSTRACT
For an essential facility of a thermal power plant located along the eastern coast of India, ground improvement using rammed stone columns have been carried out. Vertical footing load tests on single and three column groups were conducted to assess the improvement in the sub-surface condition after installation of stone columns. This paper describes series of footing load tests and the results. The observed load settlement behavior of the improved ground has also been presented. Behavior of single and group of stone columns have been compared and criteria adopted for arriving at desired factor of safety based on the settlement observed, has also been discussed.

RÉSUMÉ
Pour une facilité essentielle d'une plante de pouvoir thermique a localisé le long de la côte d'est d'Inde, l'utilisation d'amélioration de sol a enfoncé les colonnes de pierre ont été exécuté. Le chargement vertical de fondation essaie sur le seul et les groupes trois colonnes ont été dirigé pour évaluer l'amélioration dans la condition de sous-sol après l'installation de colonnes de pierre. Ce papier décrit le feuilleton de fondation de tests de chargement et les résultats. Le comportement observé de règlement de chargement du sol amélioré a été aussi présenté. Le comportement de seul et le groupe de colonnes de pierre a été comparé de le et les critères ont adopté pour arriver au facteur désiré de sûreté basée sur le règlement observé, a été aussi discuté.

1 INTRODUCTION

The sea water make up pipe lines for the power project have been routed through one of the embankments of the flood diversion drain. This embankment with a crest width of 8m, side slopes of 1:3 and height varying from 3.5 to 4.0m; serves as the left embankment of the diversion drain and also supports an all weather road with sea water and effluent discharge pipe lines buried within. Soft marine clay was found to be underlying this embankment in certain stretches of diversion drain (about 1.6km). Ground improvement with rammed stone columns have been carried out in this stretch of embankment to improve the bearing capacity of the soil and also to simultaneously improve the stability of the embankment and to reduce the residual settlements so that the above facilities including the embankment shall stand safely and perform satisfactorily throughout their life time. From construction point of view this stretch of embankment has been divided into two packages each of 800m length.

2 SUBSURFACE CONDITION

Few boreholes carried out earlier for sea water transmission line adjoining the embankment are available and also additional four boreholes and field vane shear strength tests were carried out along the stretch of the embankment under consideration. The subsurface investigation revealed soft to very soft, blackish to grayish marine clay with/ without sea shells of thickness varying from about 4 to 10m under a thin layer of blackish clay with sand. The standard penetration test (SPT) 'N' value obtained in marine clay strata varies from less than 1 to 2. Due to presence of occasional sea shells in this layer, some of the vane shear strength data was found to be erratic, however, on an average field vane shear strength may be taken as 6 kN/m^2 in this layer. This marine clay layer is underlain by yellowish stiff to very stiff silty clay with SPT 'N' value varying from 17 to 29 or higher. Laboratory tests on soil samples collected from marine clay strata indicated cohesion value varying from 5 to 12 kN/m^2, liquid limit from 69 to 84%, plastic limit 25 to 32% and field moisture content from 40 to 68%. Ground water table was very close to the ground level and most of the stretch used to get inundated during monsoon prior to embankment construction.

3 STABILITY ANALYSIS

Stability analysis of embankment with and without stone columns was carried out using slope stability software 'SLOPE/W' of Geoslope International Ltd. Factor of safety without stone column reinforcement was 0.536. For short term stability, the reinforced ground was modeled as 900mm diameter vertical columns of stones with density of 22 kN/m^3 and angle of internal friction $\varphi_s = 46^0$ at centre to centre spacing of 4m confined by soft marine clay with un-drained cohesion of 6kN/m^2. The factor of safety was found to be 1.135 (Fig. 1). Considering the embankment load application to enforce settlement and quick drainage path provided by stone columns for consolidation, long term safety factor would definitely be more than the value estimated as above. Accordingly, stone columns at 4m c/c in triangular grid with an area replacement ratio of 4.59% were considered. Thus the c/c spacing of stone columns and hence the area replacement ratio for this case are out of the generally adopted range. Hence, it was imperative to carry out field tests on stone columns to ascertain the improvement in the founding strata of embankment.

The safe load carrying capacity of a single stone column and its tributary area was estimated as 365kN and the ultimate load as 1009kN. The ultimate bearing capacity of improved ground under effective area of each column works out to be 74kN/m2 as against the ultimate bearing capacity of 34kN/m^2 of founding strata without ground improvement. Total settlement of untreated ground with 4 and 9m thick marine clay strata was estimated as 641 and 950mm respectively at the centre of the embankment and that of ground reinforced with stone columns was 565 and 835mm respectively. Thus, with stone column reinforcement, there is a reduction of only about 12% in settlement which is low because of low area replacement ratio.

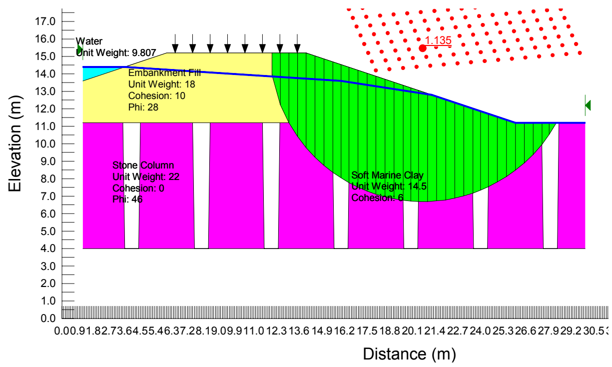

Figure 1. Stability Analysis of Embankment with Stone Column Reinforcement.

4 STONE COLUMN CONSTRUCTION

The stone columns of 760mm diameter nominally bored and rammed to 900mm diameter were installed at site. Stone columns were constructed by ramming granular materials into the pre-bored holes in stages using a heavy falling weight of 7kN from a height of 1.1m. Triangular pattern with 4.0m c/c spacing was adopted. It was specified that the stone columns shall be terminated once the boring has extended by about 30cm into the stiff yellowish silty clay layer. The consumption of material per column was used as a control parameter based on 900mm diameter stone column.

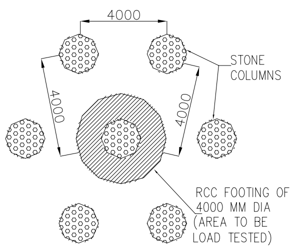

Figure 2. Plan of Load Test on Single Column

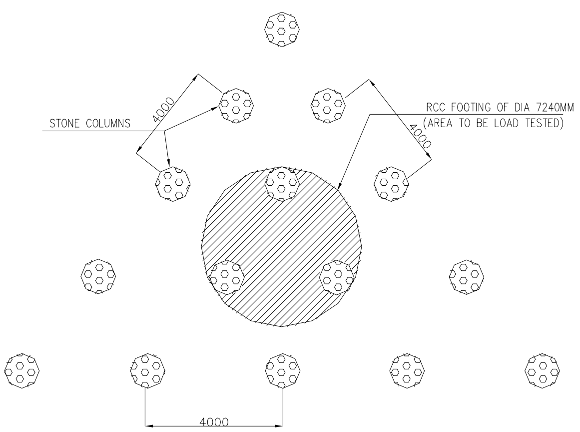

Figure 3. Plan of Load Test on Group of Three Columns

After reaching the termination depth, an initial charge of 1.5m was poured into the pre-bored cased hole and was rammed at least 10 times. Then the second charge of 1.5m was given, casing was lifted by 1m and rammed so that the height of compacted aggregate of second charge is reduced by about 0.5m. Third charge of 1.5m again was given and compacted by giving required no. of blows so as to compact the aggregate and height was reduced by 0.5m. The process was repeated till the column is constructed to the required height. No. of blows of rammer for each lift was 18 to 20 blows to compact the stone aggregates by 0.5m. About 80% of the stone aggregate used was of particle size ranging from 20 to 63mm, well graded.

5 TESTING PROGRAMME

Load testing of stone columns using footing was adopted so as to apply the load over an area larger than the cross-sectional area of a column. This is because applying the load over an area greater than the stone column increases the vertical and lateral stresses in the surrounding soft soil and it also reflects the in-situ condition. The footing load tests on a single as well as on a group of three columns, were performed at the trial site to evaluate the load settlement behavior of the stone columns, shear strength of the composite stone column reinforced ground and to verify the adequacy of the overall construction process. The test sites were close to the embankment within 20m away from the edge of the embankment. The initial soil conditions at each of these test sites was established by conducting field vane shear tests at 1.5m intervals in a borehole at each test site.

For three-column group, 15 stone columns were constructed in the prescribed pattern and 7 columns for the single column test as shown in Figs. 2 & 3. For all types of load tests a compacted blanket of 300mm thickness consisting of medium to coarse sand was spread over each test area before commencement of the load tests. A reinforced concrete footing of appropriate size and thickness was constructed on the sand blanket. The diameter of the RCC footing in case of single column was equal to the spacing of stone columns (i.e. 4m) with center of the footing coinciding with the center of the column. In case of three-column test, the diameter of the concrete footing was 1.81 times the spacing of the columns (i.e. 7.3m) with its center coinciding with the center of the three columns laid in a triangular pattern. The test load was corresponding to a pressure intensity of 150 kN/m^2 on the footing for single and three-column group, which corresponds to a surcharge load of 1885kN and 6100kN including self weight of footing for single and group column test respectively. The test load was applied on the stone columns through the footing in stages using kentledge and the arrangement was generally as shown in Fig. 4. For group testing, test load required huge kentledge. Also, because of large diameter of footing, about 13 m long girders were employed to support the dead load which was finally supported on the ground over wide area on all the four sides of the test pit.

Initially, it was planned to carry out one single and one group of stone column test in each package. However, as seen from Fig. 5, load-settlement behavior of first single column tests of both packages (SA and SB), are distinctly different and inconsistent, as a result it was not possible to take a view on these test results at that time. Therefore it was decided to carry out two additional single column tests one in each package (ASA and ASB).

6 TEST RESULTS & INTERPRETATION

The load settlement behavior of the improved ground as observed for single and group column tests have been presented separately through Figs. 5 and 6 and depth of termination (L), no. of days between installation and testing, consumption have also been shown in above figures. 'L' in the figure indicates termination depth, days indicate the number of days after which the test was conducted after installation of the stone column and the percentage (%) indicates the excess consumption of stones above the theoretical estimate for 900mm diameter.

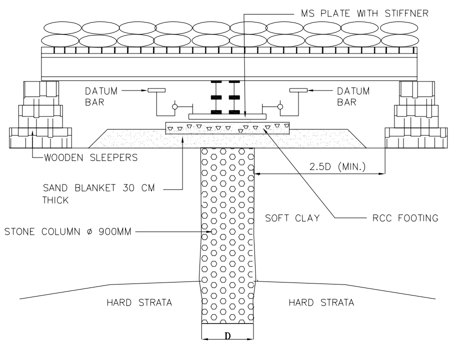

Figure 4. Typical Load Test Arrangement on Single Column

For single column tests, the termination depths varied from 5 to 12m and the tests were conducted after a minimum period of 26 days after installation. One of the load tests on single column was conducted by cyclic loading with an aim to eliminate seating settlement, if any. It can be seen that three of the four single column tests exhibited similar behavior. The very first test (SA) conducted showed hardly any appreciable settlement till 1100kN load beyond which settlement was rapid. The stone column (ASA) with 4.9m length, exhibited similar behavior with other two, but the rate of settlement decreased significantly beyond 1250kN and exhibited very low settlement till about 2100kN. The ultimate load by tangent method works to be 800kN for SB, 800kN for ASA and 1270kN for ASB and the corresponding settlements are 23mm, 38mm and 65mm respectively. The load intensity expected at the base and centre of embankment was 70kN/m^2. Accordingly, for a factor of safety of 1.5, the load corresponding to 1.5 times the pressure intensity works out to 1130kN excluding self weight of footing. Ignoring result of test SA, it can be seen that the settlements of footing corresponding to the above load are 50, 53 and 62mm for the balance three tests. Thus, with a factor of safety of 1.5, the settlements observed are very much within the generally permissible limits for a flexible structure such as an embankment (as per Indian Road Congress (IRC75-1979), for highway embankments the permissible total post construction settlement of 300 to 600mm and differential settlement of 50mm in 30m length may be considered).

Results of tests carried out on group of three stone columns are presented through Fig.6. It is evident that the test of package B has exhibited a better behavior and has a termination depth of only 6.8m, whereas the test for package A has a termination length of 10.9m. Both the test results show that initially for a load of 1000kN to 1500kN, there is hardly any settlement and then the settlement increases. The stone columns had around 20% excess consumption and the tests were conducted after slightly more than 100 days of installation. Thus, practically, both the tests differ only in length of columns and the group having shorter length (about 37%) exhibited better performance. In this case, for a factor of safety of 1.5, the load corresponding to 1.5 times the pressure intensity is 3500kN excluding self weight of footing. The settlements of footing are 34 and 88 mm, which are within permissible limits.

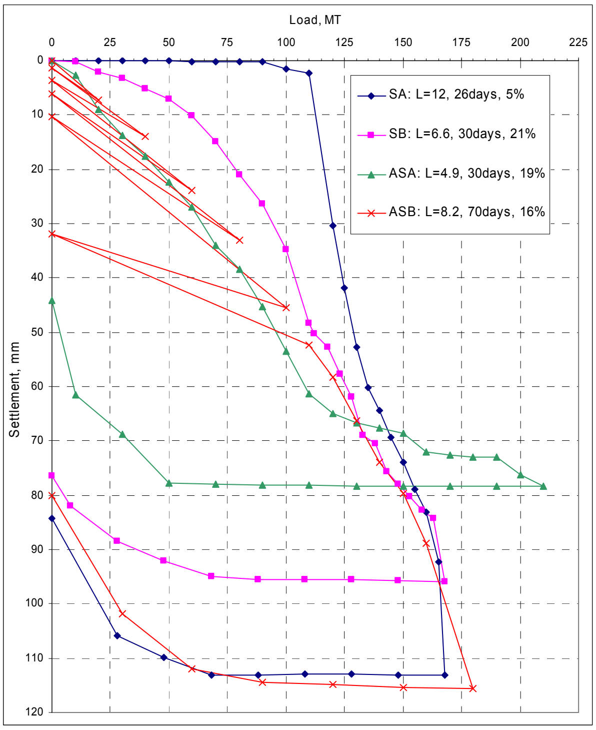

Figure 5. Load-Settlement Curve for Single Column Load Tests

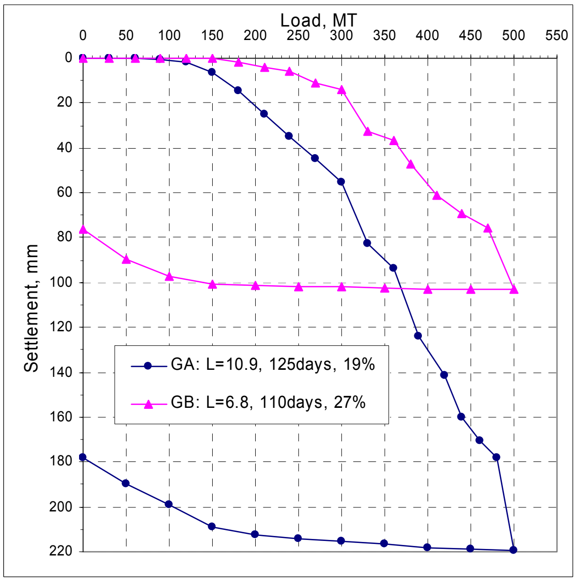

Figure 6. Load-Settlement Curve for Three Column Load Tests

If certain parameters of stone columns of single column load test SB (L=6.6m, 30days, 21%) and three column load test GB (L=6.8m, 110 days, 27%) are compared (Fig. 7), it can be seen that the termination depth and percentage consumption of stone columns are comparable, however, number of days after installation the test was carried out, are different. The ultimate load works out to be about 800kN for the single column test and the corresponding settlement is about 23mm and for three column test, the ultimate load is about 3450kN and the corresponding settlement is about 34mm. Thus, in group case ultimate load per column is 1150kN which is higher (about 40%) than the single column case. Thus an isolated single column compared to a group of columns has a slightly lesser ultimate load capacity per column in a group. This may be due to the fact that as surrounding columns are added to form a group, the interior columns are confined by the surrounding columns and the reinforced ground. The ultimate load for second group test GB works out to be 3660kN and the corresponding settlement is 100mm. From group test results, the ultimate bearing capacity of improved ground works out to be 83 and 88kN/m^2.

Thus, it appears that the performance of the stone columns in group is better than single column test although settlements are slightly higher. The larger bearing area in group test which simulates the site condition, together with the additional support of the stone column results in less bulging and a greater ultimate load capacity. The observed settlements are acceptable for the embankment; hence the required factor of safety for the improved ground has been achieved.

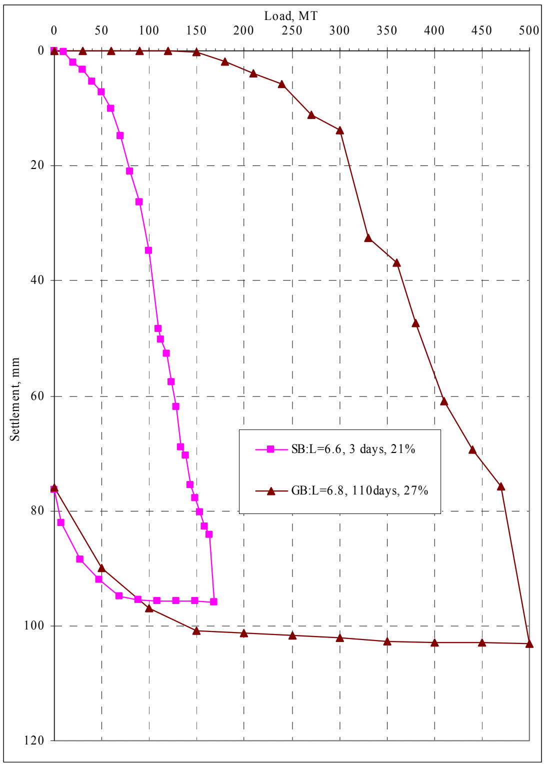

Figure 7. Comparison of Load-Settlement Behavior of Single & Group Column Load Tests

7 CONCLUSION

Behavior of single and group of stone columns have been presented. Criteria adopted for arriving at required factor of safety based on the settlement observed has been presented.

Although the spacing of stone columns and hence the area replacement ratio were high in this case the slope stability analysis carried out with stone column reinforced ground model, gave confidence to go ahead with the improvement pattern.

Single and group of stone columns have performed satisfactorily during the testing and desired factor of safety has been achieved, however, without the group load testing certain decisions regarding stability would not have been possible. Performance of stone columns in group test have been found to better than single column test.

As load test data on stone columns is scanty in literature, it is felt that the results of footing load tests carried out on single and group of stone columns, presented in this paper would be useful to practicing engineers.

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