GRAVEL PILES: CONSTRUCTION AND FIELD TESTING

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ABSTRACT

Construction methodology for installation of gravel piles by the non-displacement technique (i.e. boring method) is discussed in this paper. Two case studies are also presented. The first one illustrates successful application in loose sandy strata at a site in the Indo-Gangetic Alluvium. At this site, 400 mm dia stone columns were used to improve the soil beneath 22 m dia tanks. Load tests using different spacings between trial stone columns was used to optimize the design. The second case study relates to stone columns installed in a marine clay in coastal Andhra Pradesh.

BEHAVIOUR OF GRAVEL PILES

Introduction : Rammed stone columns or gravel piles are widely used to improve weak ground. The technique has been developed in India as an economical alternative to vibro-compaction. In practice, it performs best for large loaded areas. Examples are large diameter liquid storage tanks, raft foundation, long retaining walls etc.

The stone columns can successfully improve the soil bearing capacity and reduce foundation settlements. It also accelerates the rate of settlement with the result that a major part of the total settlement may occur during the construction period or hydro-testing period (in case of storage tanks).

Basic Concept : Conceptually, a gravel pile may be treated as a pile of low stiffness (Ranjan, 1988). These piles are individually not capable of transferring the loads to deeper competent bearing stratum. However, when a large area is developed by providing several stone columns in a pre-determined pattern, the composite ground effectively supports the load. Under actual loading conditions, the applied load is distributed between the gravel pile and the surrounding soils. The gravel pile acts as a reinforcing medium as well as a drainage medium.

Behaviour Under Load : The load carried by the gravel pile is resisted by interfacial shear between stone aggregates and soft soil and in end bearing (Ranjan, 1988, Rao, 1992). The lateral stress mobilized in the gravel pile will be resisted by lateral compressive strength of the soil. If the strength of the soil is less than the lateral stress in the column then the column will fail by bulging. As per the various researchers, the critical length of stone column varies from 3D to 5D. The function of stone column is two fold i.e. to act as reinforcing media and the other as drainage media. The passive pressures developed due to loading of treated ground offers resistance to the bulging of the gravel piles and thus contributes to its load carrying capacity. When the entire area is developed by providing gravel piles , the soil in the inter-space also contribute to load carrying capacity.

Yield Strength : Precise mathematical analysis for estimation of yield strength of stone column foundation system is very complicated and difficult. The available mathematical solutions for theoretical prediction of behaviour are for stone columns in clays. These solutions consider the improvement achieved by the drainage and consequent consolidation of the soils. Mitchell and Katti (1981) and Ranjan (1988) describe a procedure for computing the improvement achieved and have related it to a settlement reduction ratio. However no procedure is available for computation of improved bearing capacity of sands.

As a result, some semi-empirical approaches have been developed and adopted. These have been found to be satisfactory, based on load tests as well as observations of the behaviour of structures constructed on such foundation systems.

Stone column derives its support mainly from owing four components (Bhandari & Nayak 1984) :

a) resistance offered by the surrounding soil against lateral deformation (bulging) of stone column under axial load,

b) bearing support provided by soil in between the stone columns,

c) increased resistance to lateral deformation due to surcharge on the surrounding soil,

d) increased capacity from components (a) to (c) above, resulting from dissipation of excess pore water pressure through stone columns which act as drainage paths.

The ultimate capacity of stone columns is governed by the maximum confining pressure provided by the surrounding clay. It ranges between 25 to 50 times the undrained shear strength. For rammed stone columns in uncased boreholes, Datye (1982) recommends a value of 40 times undrained shear strength of the clay.

Broms (1987) states that the bearing capacity of soft clays reduces during installation due to remoulding of the clay. The shear strength and bearing c rapidly increase after installation and increase with time due to pore water pressure dissipation.

Peripheral Restrainment : For best efficiency, peripheral restrainment (Ranjan and Rao, 1986, Rao et al, 1991) of the stone columns is essential. This may be done by providing additional rows of stone columns outside the loaded area. An alternative method is to provide skirted granular piles.

CONSTRUCTION TECHNIQUE

Short, small diameter stone columns can be installed using simple augers (Sundaram & Gupta, 1994). For large diameter stone columns (400 to 1000 mm dia are commonly used), the borehole is made by either using a bailer or direct mud circulation (DMC) chisel or by rotary drilling method. The sides of the hole can be retained either by using casing or bentonite slurry (Bhandari, 1986).

In sandy soils, ground improvement is achieved by compaction of the sand and the increase in overall density of the soil mass. Drainage does not play an important role in the ground improvement process. Therefore, use of bentonite slurry in case of sandy deposits will not adversely affect the performance of the stone columns.

In clayey strata where boring is done using bailer or DMC method, a bentonite slurry of thin consistency is usually circulated. In practice a 5 percent suspension of bentonite is circulated. The boring period is about 2 to 4 hours and within this time, the formation of the soil cake on the wall is minimal. The contamination of the stone metal due to the bentonite, although it does occur, is small and within acceptable limits.

After boring to the required level, 75 mm down stone aggregate may be placed in the borehole in layers of about 0.5 to 0.8 m. The aggregates used should be in suitable proportion of 75 mm, 40 mm, 20 mm and 10 mm down aggregate, properly graded. A 0.2 to 0.4 m thick charge of sand may be placed above the gravel.

Compaction should be done using a down-the-hole rammer. The weight of the rammer should be carefully selected depending upon borehole diameter and soil conditions. Typical weight of rammer is about 600 to 1200 kg for borehole diameters of 400 to 600 mm.

Each charge of gravel should be compacted by the rammer. The height of fall may be kept about 2 to 3 m. Careful controlled compaction should be done to ensure that the borehole does not collapse. Each layer should be compacted till a set is obtained. The criteria for set is usually defined at site after monitoring a few trial stone columns. The quantity of aggregate used for the first few gravel piles should be compared with the theoretical volume of the borehole. The aggregate consumed for the trial gravel piles may then be taken as guideline for further work.

Over the gravel piles, a 200 mm thick blanket layer/levelling course may be laid. The blanket should be composed of well graded aggregate, 75 mm down, blinded with sand. It should be thoroughly compacted using a heavy roller. Specifications for compaction may be similar to that for WBM for roads. Foundations may then be constructed bearing on this blanket layer.

Trial Stone Columns : To assess the behaviour in the field, trial stone columns should be installed and load tested. Load testing on single column as well as on a group of three stone columns is usually conducted. For the case of clayey soils, the load testing is done after installing surrounding stone columns for peripheral restrainment and for better drainage. However, in case of sandy soils, it may be sufficient to load test the area between the columns since the compaction of the soils between the columns also takes place during the ramming process.

A 200 mm thick levelling course of 75 mm down stone aggregate blinded with sand should be placed on top of the trial stone columns and these may be load tested as per IS:1888. Load testing on trial stone columns with different spacings can be used to optimise the design. Fig.1 shows test arrangement for single column load test. Fig 2 is a photograph showing test arrangement using kentledge.

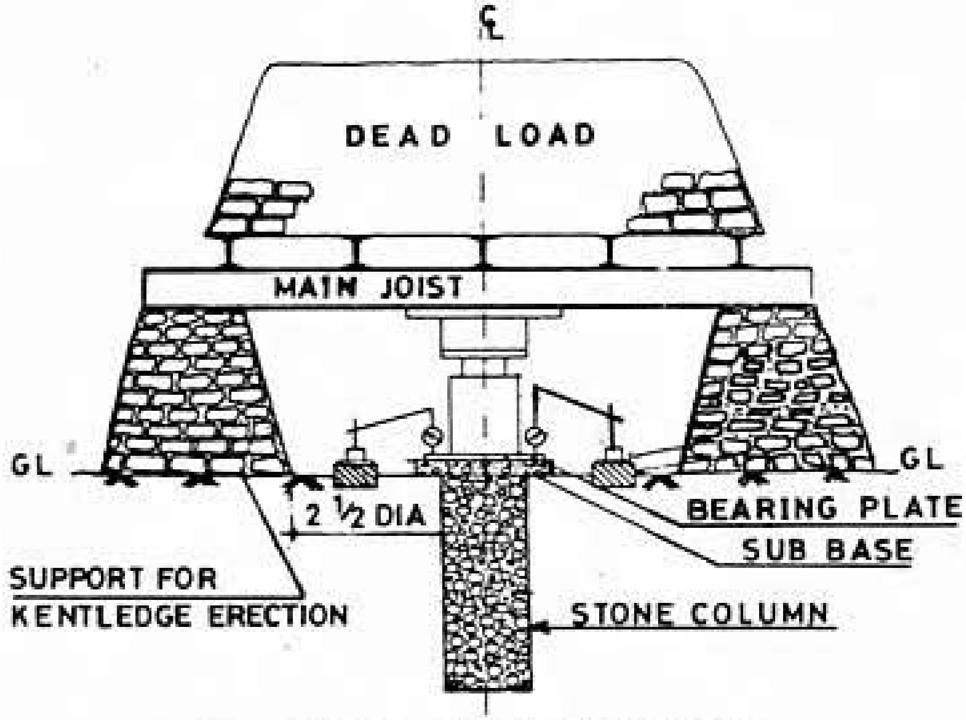

FIG. 1: TYPICAL ARRANGEMENT FOR SINGLE STONE COLUMN LOAD TEST

Fig. 2 : LOAD TEST ARRANGEMENT FOR SINGLE STONE COLUMN LOAD TEST (KENTLEDGE SYSTEM)

Acceptance Criteria : The basic concepts for any ground improvement technique are as follows :-

a) The in-situ strength of the soil and allowable loading intensity for the unimproved soils at proposed foundation level should be determined.

b) As per the structural requirements, the value of allowable loading intensity at foundation level for the modified ground should be determined.

c) Based upon strata conditions and engineering judgment, diameter and length of stone columns should be selected.

d) Trial stone columns should be provided at site as a group in triangular pattern.

e) Load test should be conducted over the area covered by the stone columns so as to determine the load settlement curve to work out allowable loading intensity Cone penetration testing may also be conducted to confirm the extent of improvement achieved.

f) The allowable loading intensity on improved ground should be compared with the target value.

g) The spacing and diameter of stone columns may be modified, if required, if the improved allowable loading intensity is less than the required values.

h) The above steps are experimental work for planning/design. After confirmation of all parameters, the working stone columns/gravel piles may be installed.

i) After providing stone columns/gravel piles in the actual area of proposed structures, load test and/or cone penetration test should also be conducted to reconfirm the bearing capacity achieved and the effectiveness of improvement The frequency of such tests may be one to two tests for each segment of improved area.

CASE STUDY-I

Load Testing and performance evaluation of gravel piles installed at a project site near the bank of River Yamuna at Delhi is discussed here. At this site, three 22 m dia, 10 m high steel tanks were planned. The stratigraphy at the site consisted of fine sand, locally called "Yamuna Sand". The sand is loose to about 8 to 10 m depth and medium dense below Groundwater was met at about 2.9 m depth. The site stratigraphy is illustrated in Fig.3.

The net applied pressure on the soil due to the load on the tank was about 10.5 T/sq.m. On the periphery of the tank, due to stress concentration and hoop stresses, the pressure is about 12.5 T/sq.m.

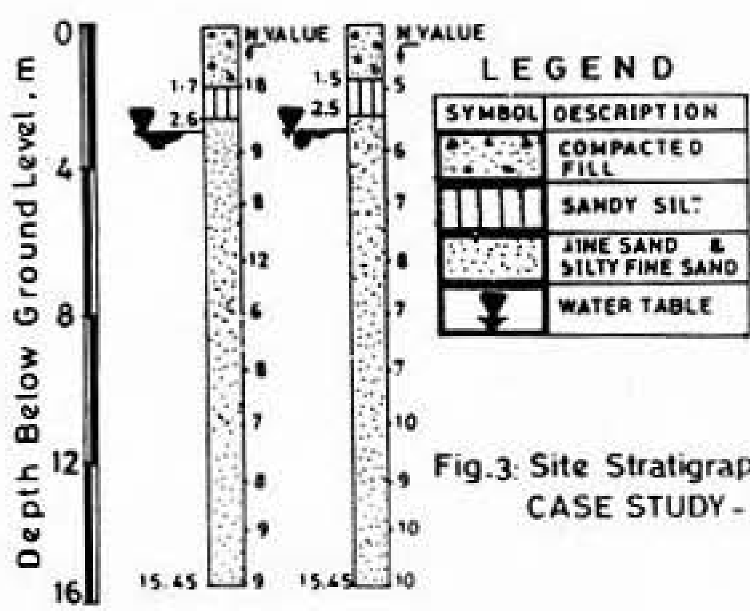

Fig.3: Site Stratigraphy
CASE STUDY - 1

It was decided to install 400 mm diameter 12 m long rammed stone columns to improve the soil so as to ensure a safe soil bearing pressure of 12 T/sq.m. Trial stone columns were installed at spacings of 1.2 m, 1.5 m and 1.8 m. Boring was done by the DMC method. A surface casing of about 2 m length was used. A thin (5 percent) bentonite slurry was circulated to maintain the borehole stable. The stone aggregate (40 mm, 20 mm and 10 mm, mixed, graded) and coarse sand were placed in 1 m high layer. Ramming was done using a 600 kg hammer falling through a height of 3 to 3.5 m. Ramming was done on the gravel layer. The set criterion developed from field observations was as follows:

(1) Apply minimum 25 blows on the gravel layer.

(2) Record penetration of the gravel for every 5 blows.

(3) If the set (lowering of level of gravel) is more than 2 cm for 5 blows, ram the gravel further by giving 5 more blows and check the set obtained.

(4) If the set for 5 blows is less than 2 cm, the next charge of sand and gravel may be poured.

Fig.4 presents a comparison of dynamic cone penetration tests before and after improvement. The extent of improvement achieved indicates the compaction of the sand that has been taken place between the stone columns.

Fig.5 presents results of a plate load tests on unimproved ground. A 100 cm x 100 cm size test plate was used to conduct the test. Figs.6 presents results of load test on group of stone columns for the different spacings selected. Fig.7 presents results of load tests on single stone column.

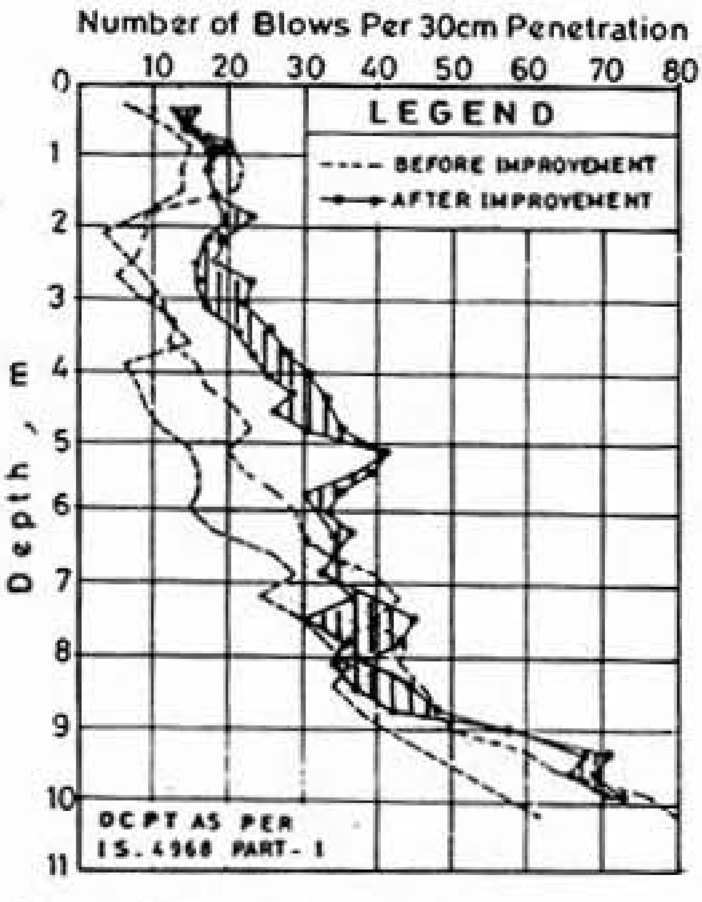

Fig-4 : DYNAMIC CONE PENETRATION TEST BFORE AND AFTER IMPROVEMENT CASE STUDY - I

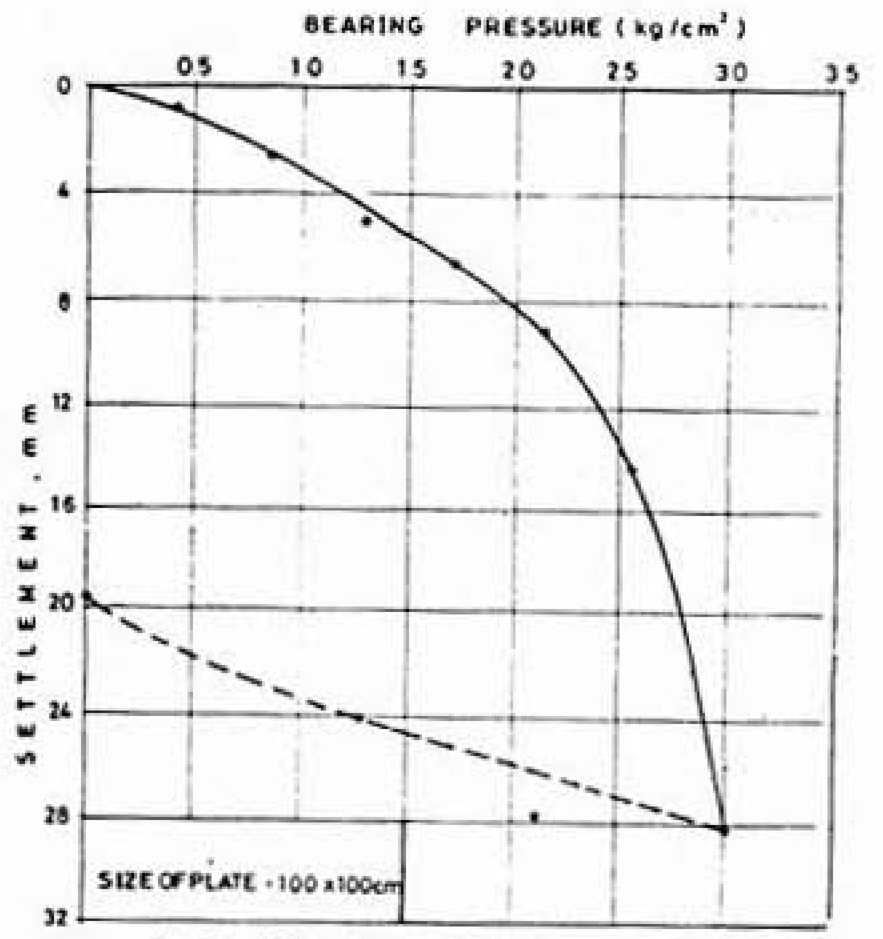

Fig.5. Plate Load Test on Unimproved Ground CASE STUDY No-I

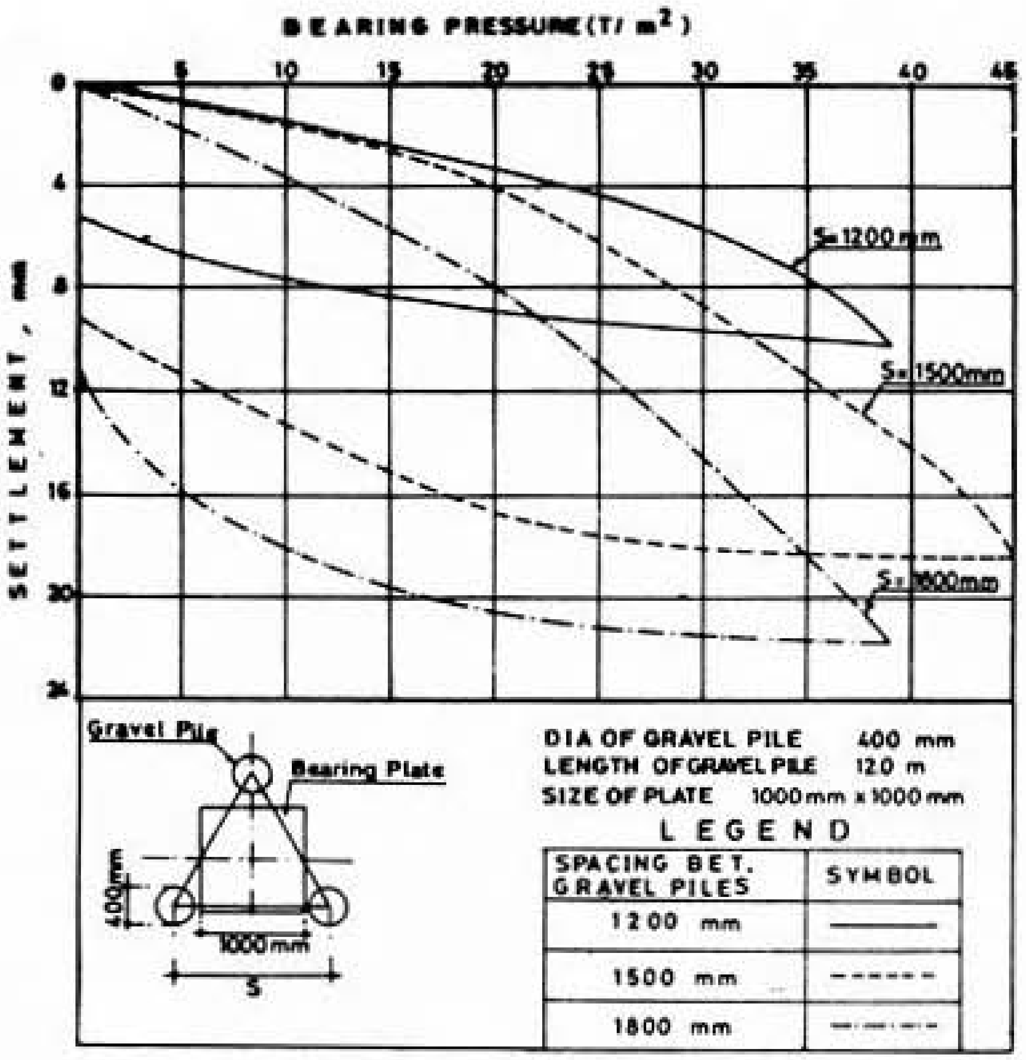

Fig No: 6 Load Settlement Behaviour of Improved Ground
CASE STUDY- I

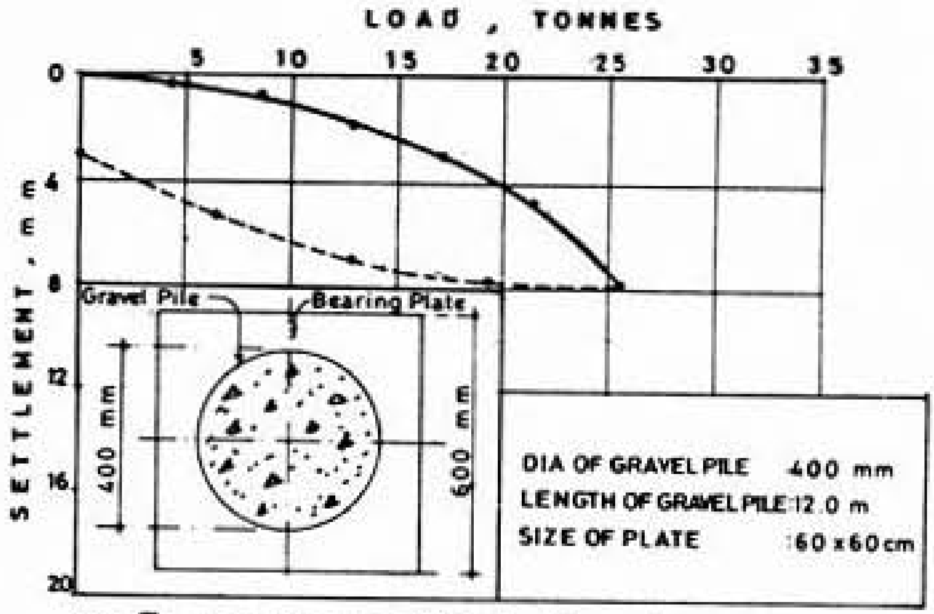

Fig-7: Load Test on Single Stone Column
CASE STUDY - I

Table-1 summarizes the results of the load tests -

TABLE-1 : RESULTS OF PLATE LOAD TESTS ON IMPROVED GROUND

Spacing Between Gravel Piles, m	Measured Settlement, mm under applied Bearing Pressure of				
	8 T/sq.m.	10 T/sq.m.	12 T/sq.m.	15 T/sq.m.	20 T/sq.m.
1.2	1.2	1.6	2.0	2.5	3.5
1.5	1.3	1.6	2.2	2.7	4.1
1.8	3.0	3.4	4.2	5.8	8.2
Unimproved Ground	3.0	3.4	4.2	5.8	8.5

The above results suggest that for centre to centre spacing of 1.8 m between the gravel piles, the improvement achieved is not significant. Further, the 1.5 m spacing between the gravel piles appears to yield optimum compaction. The reduction of the spacing to 1.2 m does not yield any significant advantage.

The final design and installation was done maintaining a 1.6 m spacing in the central portion of the tank and 1.4 m spacing in the periphery. Two rows within the tank area and two rows outside the tank area had the reduced spacing of 1.4 m. A triangular grid pattern built up a hexagonal layout as illustrated on fig.8 was used.

Recently, a hydrotest was conducted on one of the tanks. The tank shell settled by about 20 mm under a 10 m water height, thereby indicating successful ground improvement.

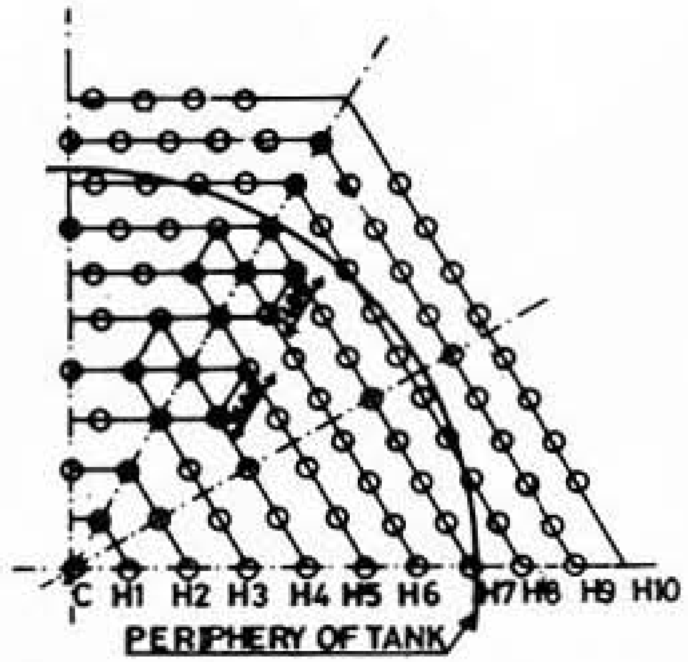

FIG-8 : LAYOUT OF STONE COLUMNS FOR 22 m DIA TANK

CASE STUDY-II

A 65 m diameter and 15 m high tank was planned to be installed in a coastal area in eastern Andhra Pradesh. The tank is placed on a 1m thick compacted gravel pad. The loading intensity on the soil is expected to be about 12.15 T/sq.m. The site stratigraphy is illustrated on Fig.9.

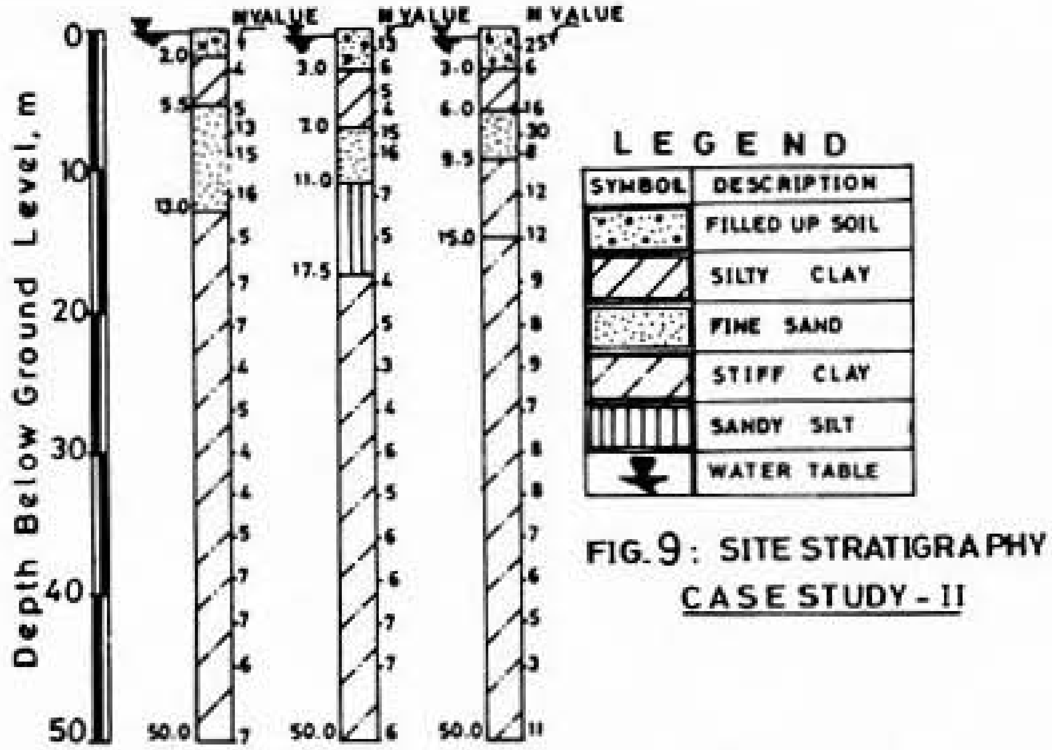

FIG. 9 : SITE STRATIGRAPHY CASE STUDY - II

Based on the field and laboratory test results, Table-2 presents the average profile selected for design.

TABLE - 2 : DESIGN SOIL PROFILE

Depth, m From	to	Description	Range of N-Values observed	Design N-Value	Shear Parameters c t/sq.m.	ø degrees	Compression index
0	2	Silty clay with sand seams	25-28	25	10	0	0.35
2	6	Stiff Silty clay	2-11	7	5	0	0.45
6	10	Medium dense Fine sand	13-32	23	0	34	-
10	50	Firm to Stiff clay	5-8	6	4	0	0.35

Based on the above parameters and other data the consolidation settlement at tank centre was computed as 1220 mm and that the edge of the tank was computed as 760 mm.

It was decided to provide 500 mm dia gravel piles to improve the ground. The ultimate bearing capacity of the single gravel pile was calculated as 84.5 tonnes. This value was computed recognising the contribution of the load shared by the ambient clay (Ranjan and Rao, 1986, Ranjan, 1988). For safety factor of 3, the safe bearing capacity of the single pile is 28 tonnes. Settlement of the treated ground (500 mm dia gravel piles at 3 dia spacing, i.e. 1.5 m) was worked out as 219 mm at the centre and 101 mm at the edge. The stone columns were installed to the top of the underlying sand layer. The effective length of the stone columns was 10 m.

To assess the field behaviour of the stone columns designed as discussed above, trial stone columns were installed and load tested. Boring was done using bailer and a 3 m long surface casing. Bentonite slurry of thin consistency was used to stabilise the borehole. The aggregate used was a mix of 75 mm, 40 mm and 20 mm down graded. Each layer placed was about 1m high. At the site, these were installed using a 1200 kg down-the-hole rammer falling through a height of about 3 to 4m. The set criterion developed at site after installation of a few trial stone columns at site was as follows :

(1) Apply minimum 30 blows on each layer
(2) Record the set for each 5 blows
(3) If the set for 5 blows is less than 2 cm in two consecutive observations, the next charge may be placed.

Load tests were performed after about 15 to 20 days of installation of the trial stone columns to evaluate the behaviour under load. Close up view of the load test arrangement is shown on Fig.10

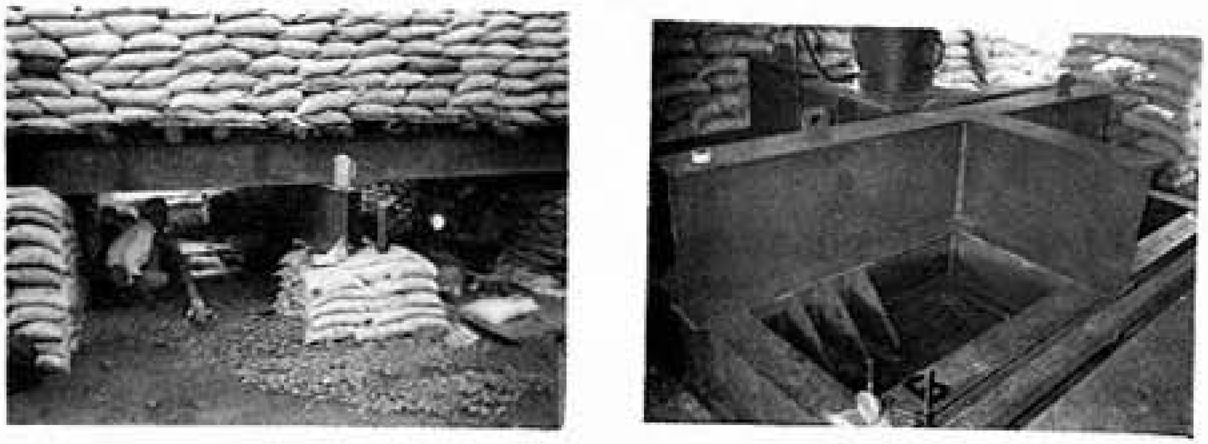

Fig.10 Close up view of Test Arrangement on Group of Stone Columns

Results of load test on single stone column are presented on Fig.11. The test was done after installing six stone columns all around. It may be seen that the ultimate capacity from the test matches well with the theoretical prediction.

Load test on group of three stone columns was done on a 2.5 m by 2.5 m square area. The test plate was stiffened adequately using I sections and stiffener plates in order to prepare a rigid base so that there is no uplift at the edges. The test was carried out to about 126 tonnes or 20.2T/sq.m. (See Fig. 12)

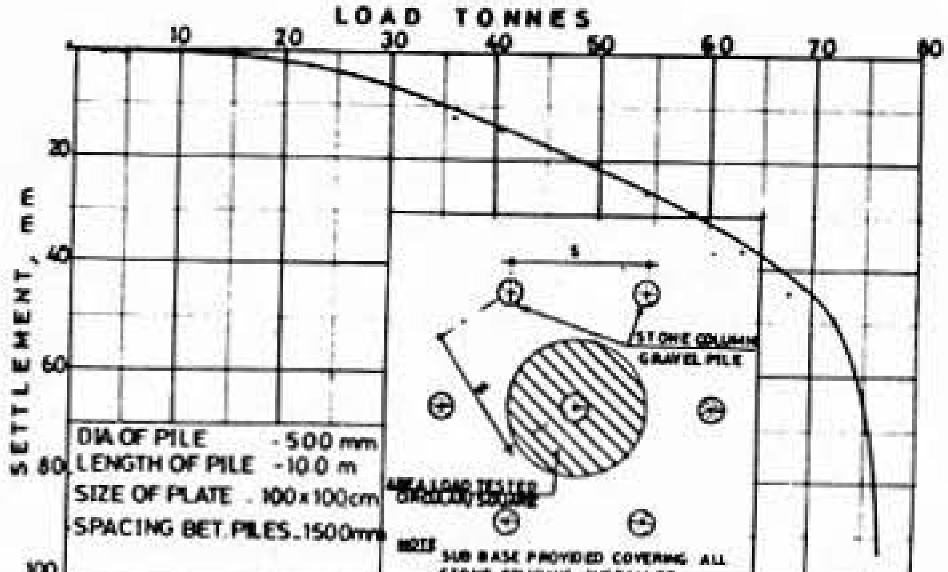

Fig-11: Single Column Load Test
CASE STUDY - II

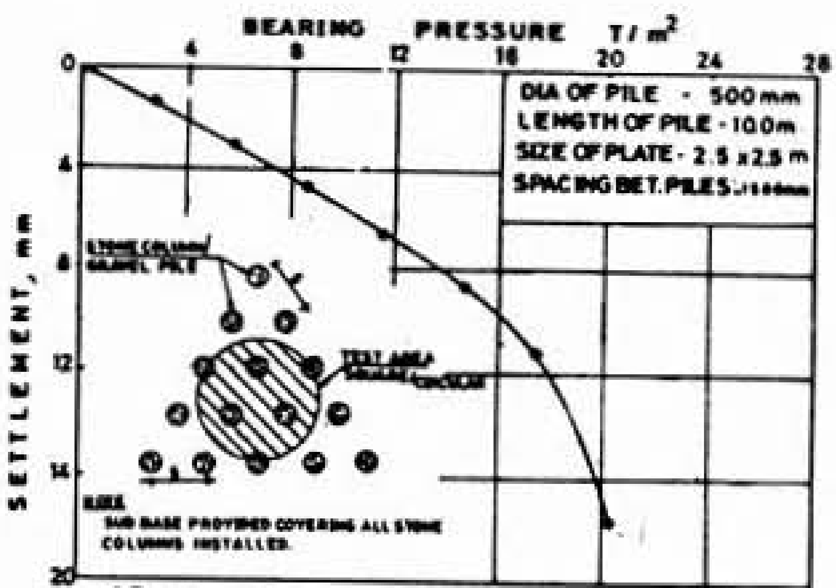

Fig.12 : Load Test on Group of Three Gravel Piles
CASE STUDY - II

After completion of the load tests, the area was excavated to expose the gravel piles installed. Fig.13 is a photograph showing the exposed gravel piles.

Fig. 13 View of Exposed Gravel Piles

Based on the results of the load test, the final system for the stone column installation was developed. A triangular grid pattern built up on a hexagonal layout was developed. For the gravel piles on the central area inside the tank, a spacing of 1.7 m was selected. For stone columns along the periphery, a spacing of 1.35 m was selected. Three rows of stone columns were provided outside the tank area for restrainment.

CLOSURE

Rammed stone columns can successfully be used to cost-effectively improve weak ground. However, soil conditions and loading conditions that are suitable for installation of rammed stone columns should be selected with caution. Key points are listed below :

1. Gravel piles are more effective for large loaded areas. For individual foundations, they yield less advantage.

2. For very heavily loaded foundations and where settlement criteria is stringent/restrictive, stone columns are not recommended.

3. If loose soils occur below the termination level of the gravel piles, excessive/uneven/differential settlement or tilt of foundations may occur.

4. The diameter and spacing between the stone columns should be very carefully selected. In general, it may range between 3 to 5 times the diameter. For large spacings, the improvement achieved may not be significant. If the spacing is too close, construction problems such as collapse of boreholes and flow of stones into adjacent boreholes during boring can occur.

5. Field control and experienced supervision personnel is essential for successful installation of stone columns.

REFERENCES

Bhandari, R.K.M. and Nayak, N.V. (1984), "Guidelines for Design and Execution of Stone Column Foundation System", Proc. Indian Geotechnical Conference 1984 (IGC-84), Calcutta, Vol. I, pp V/21-26.

Bhandari, R.K.M. (1986), "What Foundation Systems are appropriate for Large Diameter Oil Storage Tanks Resting on Weak Soils", Synthesis Paper, Indian Geotechnical Conference 1986, Vol. III, pp 121-128.

Bhandari, R.K.M. (1991), "Foundation Problems for Oil Tanks on Weak Soils", Proc. National Workshop on Ground Improvement, NAWOGI-91, Vol. II, pp 10-25.

Broms, B.B. (1987), "Stabilization of Soft Clay in South East Asia", Proc. Fifth International Geotechnical Seminar on Case Histories in Soft Clay, Singapore, 163-198.

Datye, K.R. (1982), "Simpler Techniques for Ground Improvement", Indian Geotechnical Journal, Vol.12 (1).

Gopal Ranjan and B.G. Rao (1986), "Granular Piles for Ground Improvement", Proc. International Conference on Deep Foundations, Beijing, China.

Gopal Ranjan (1988), "Ground Treated with Granular Piles and its Response under Load", Eleventh IGS Annual Lecture, Indian Geotechnical Journal 19 (1) 1989.

IS : 1888 - 1982 (Reaffirmed 1988) : Method of Load Test on Soils (Second Revision), Bureau of Indian Standards.

Mitchell, J.K. and Katti, R.K. (1981), "Soil Improvement - State of the Art Report" Proc. X ICSMFE, Stockholm.

Rao, B.G. (1992), "Behavioural Prediction and Performance of Structures on Improved Ground and Search for New Technologies", 15th IGS Annual Lecture, Indian Geotechnical Journal, January, 1993, pp 1-194.

Rao, P.J., Kumar, S., and Bindumadhava (1991), "Experimental Studies on Stone Columns", Proceedings, National Workshop on Ground Improvement - NAWOGI - 91, Indian Geotechnical Society Delhi Chapter.

Ravi Sundaram and Sanjay Gupta (1994), "Small Diameter Rammed Stone Columns in Fine Sands" , Proc. Indian Geotechnical Conference 1994 (IGC-94),Warangal, pp 345-348.