Foundations for Large Diameter Tanks : Case Studies

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Large diameter cylindrical welded steel tanks are commonly used to store large volumes of crude oil, petroleum products, hazardous chemicals, molasses, water etc. This paper presents case studies illustrating installation of large diameter tanks in different soil conditions. These case histories have been selected to illustrate the selection of foundation type, the analysis done and performance evaluation.

INTRODUCTION

A cylindrical oil storage tank is one of the most important infrastructure facilities required for refineries. Large diameter welded steel tanks are used for storage of petroleum products, hazardous chemicals such as ammonia and molasses, and water.Normally, a cylindrical steel tank is an inexpensive structure in comparison to its size. The liquid storage tank is unique with respect to the nature of the load which primarily is a uniformly distributed load on a circular area. The foundations of these tanks are proportioned based on allowable bearing pressure on the substrata satisfying the shear failure and settlement criterion.

Where the tanks are required to be located on weak soils–loose sands, recent alluvium, soft clay, marine clays, etc–the foundations need to be designed carefully to ensure safety. If need be, the sub soil conditions should be improved so that the settlement is within permissible limits. Under such situation, there is a possibility that the cost of the foundation may exceed the cost of the tank itself.

Four case studies are presented in this paper. The purpose is to illustrate the importance of a thorough geotechnical investigation to ascertain soil parameters and to select suitable foundation type. In weak soils,the foundation treatment done[1] is explained in detail together with field testing and acceptance criteria developed in order to ensure that the foundation system performs as designed.

CASE STUDIES

Four case studies are presented here based on work done by the authors. The purpose of the information presented is to illustrate the selection of the foundation system and steps required to ensure performace of the tank.

Sand Pad Foundations for Crude Oil Storage Tank at Chaksu (Rajasthan)

Three oil storage tanks each 79 m in diameter and 13.4 m high (nominal capacity 60 000 kl) were proposed at Chaksu (Rajasthan). Detailed soil investigations revealed that in general the sub soil consisted of sand mixed with low to medium plasticity fines (SC). The refusal strata was observed at depths varying from 11.1m to 17.6 m. The stratigraphy at the site is shown in Fig. 1. Pad foundations were provided for the tank with a crushed rock toe[2]. Under a uniform loading of 14 t/m^2 at the base of the tank, the total settlement at the centre and edges is 79.8 mm and 49.3 mm, respectively giving a differential settlement of 30.5 mm.

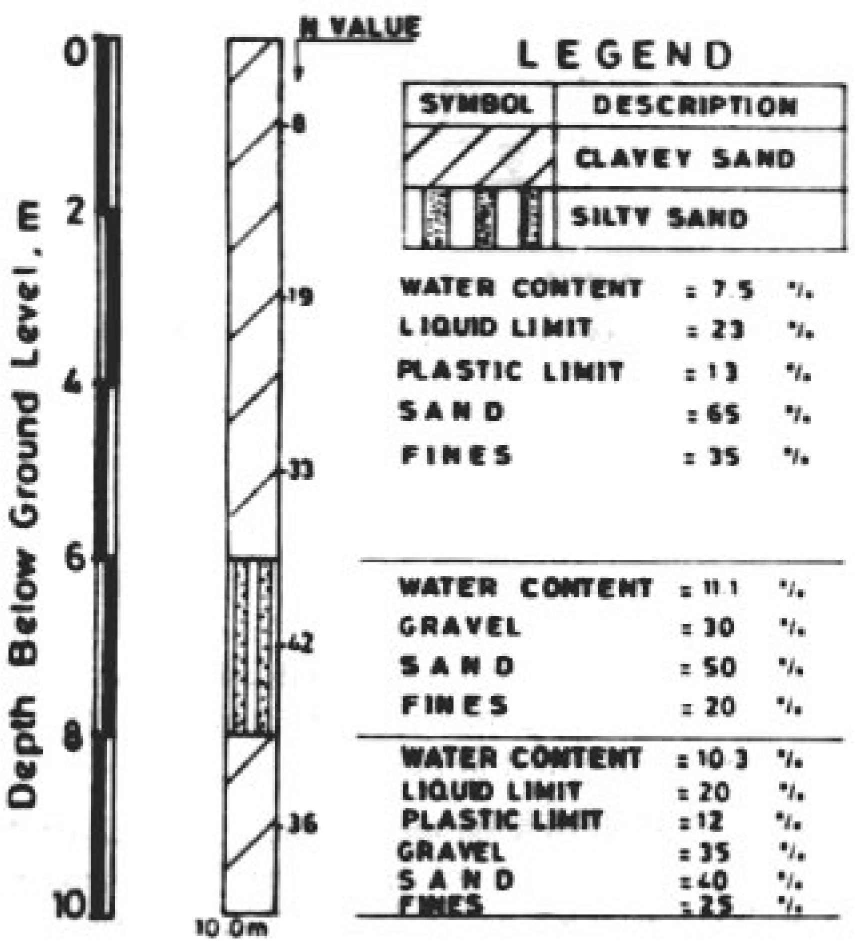

Figure 1 Site stratigraphy at Chaksu

Gravel Piles for Molasses Tank near Hapur, UP

The site for this study is near Hapur town, in Ghaziabad Dist (UP). A 30 m diameter steel digestor tank was proposed to be installed for a distillery unit. The tank was designed for a net bearing pressure of 11 t/m^2 and the tolerable total settlement was specified as 75 mm. The stratigraphy at the site is shown in Fig 2.

Trial stone columns (30 cm in diameter, 5.5 m long, with cut-off-level at ground surface) were installed using centre-to-centre spacings of 1.2 m, 1.3 m and 1.5 m. Test results are presented in Fig 3.

The load test results confirm that the loose soils to 5.5 m depth have been successfully strengthened. The load test data was used to optimize the spacing between the columns for the most economical design. The tank was designed with a centre-to-centre spacing of 1.3 m between the stone columns.

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This paper was received on March 19, 1999. Written discussion on the paper will be entertained till January 31, 2000.

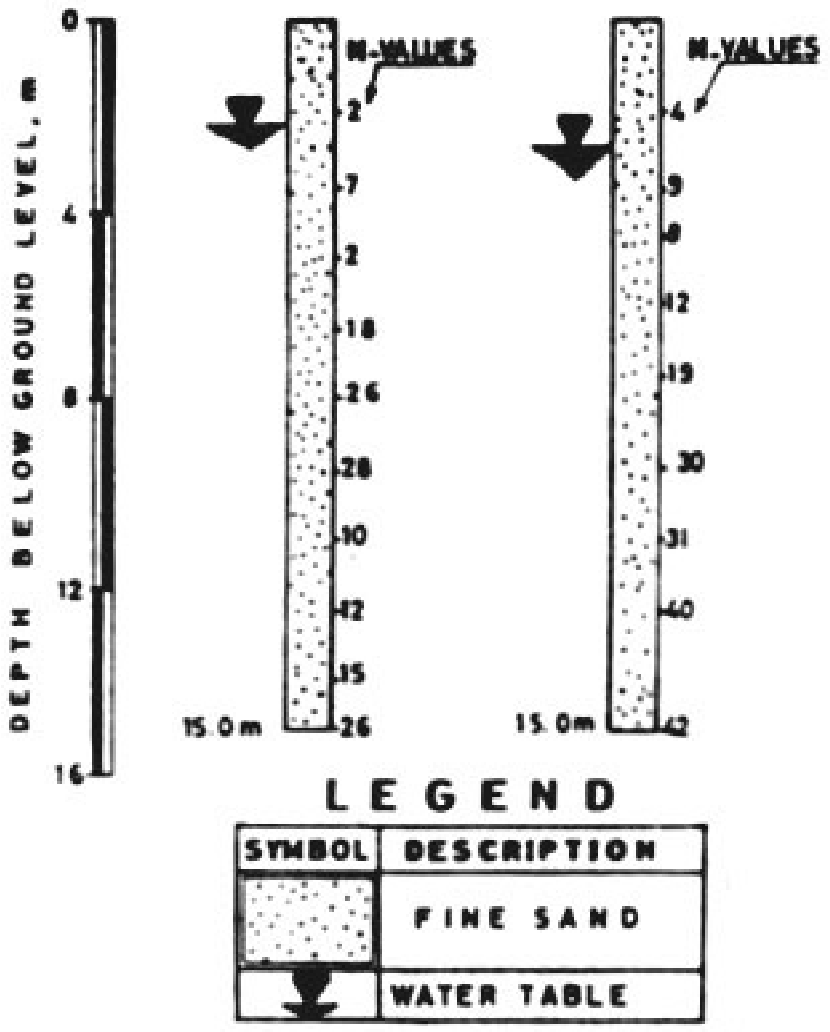

Figure 2 Borehole data

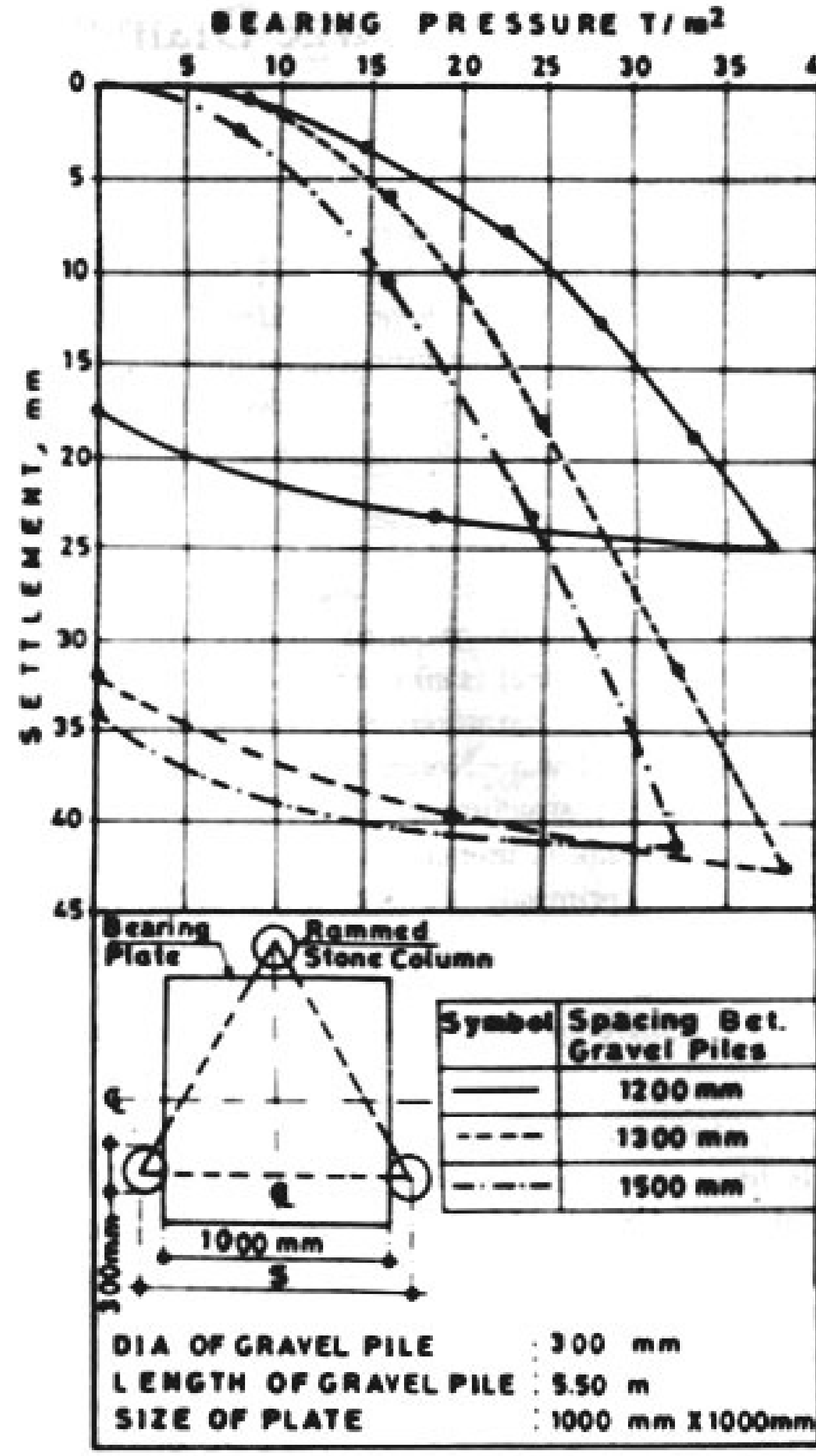

Figure 3 Load settlement behaviour of improved ground

Gravel Piles for Water Storage Tanks at Delhi

This case study discusses the load testing and performance evaluation of gravel piles installed at a project site near the bank of River Yamuna at Delhi. At this site,three 22 m diameter, 10 m high steel tanks were planned for storage of water for fire fighting purposes. The stratigraphy at the site consisted of fine sand, locally called 'Yamuna sand'. The sand is loose to about 8 m to 10 m depth and medium dense below. Groundwater was met at about 2.9 m depth. The site stratigraphy is illustrated in Fig 4.

The net applied pressure on the soil due to the load on the tank was about 10.5 t/m². On the periphery of the tank, due to stress concentration and hoop stresses, the pressure is about 12.5 t/m². 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/m². Trial stone columns were installed at spacings of 1.2 m, 1.5 m and 1.8 m. Boring was done by DMC method. A surface casing of about 2 m length was used. A thin (5%) 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 2 m to 2.5 m. Ramming was done on the gravel layer. The set criterion developed from field observations was :

(a) Apply minimum 25 blows on the gravel layer

(b) Record penetration of the gravel for every 5 blows

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

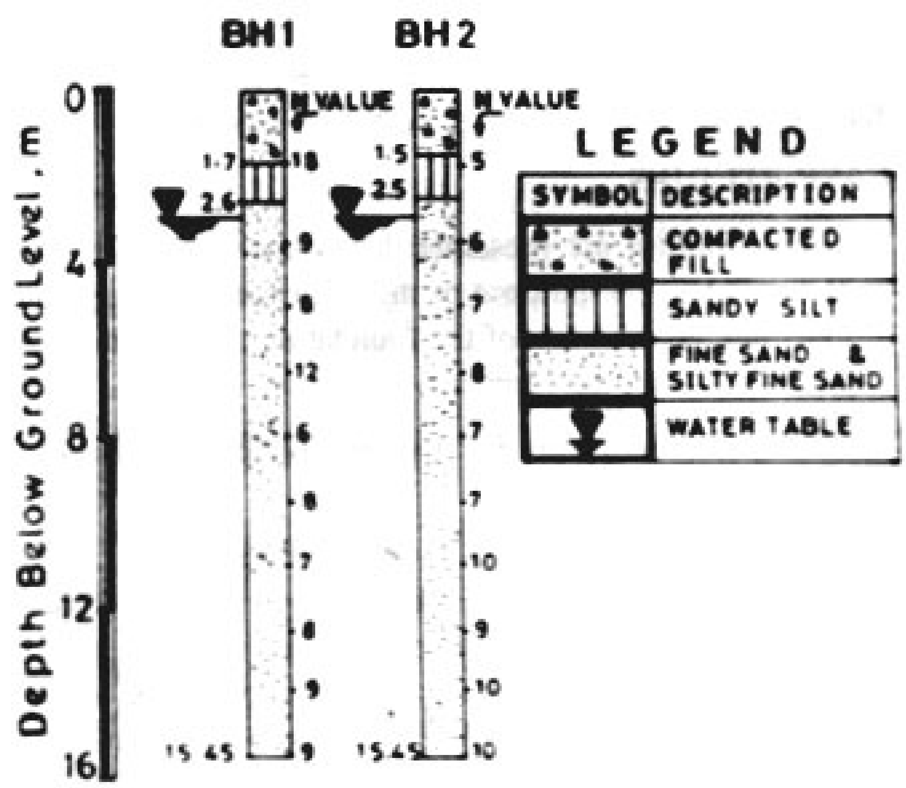

Figure 4 Site stratigraphy

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

Fig 5 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.

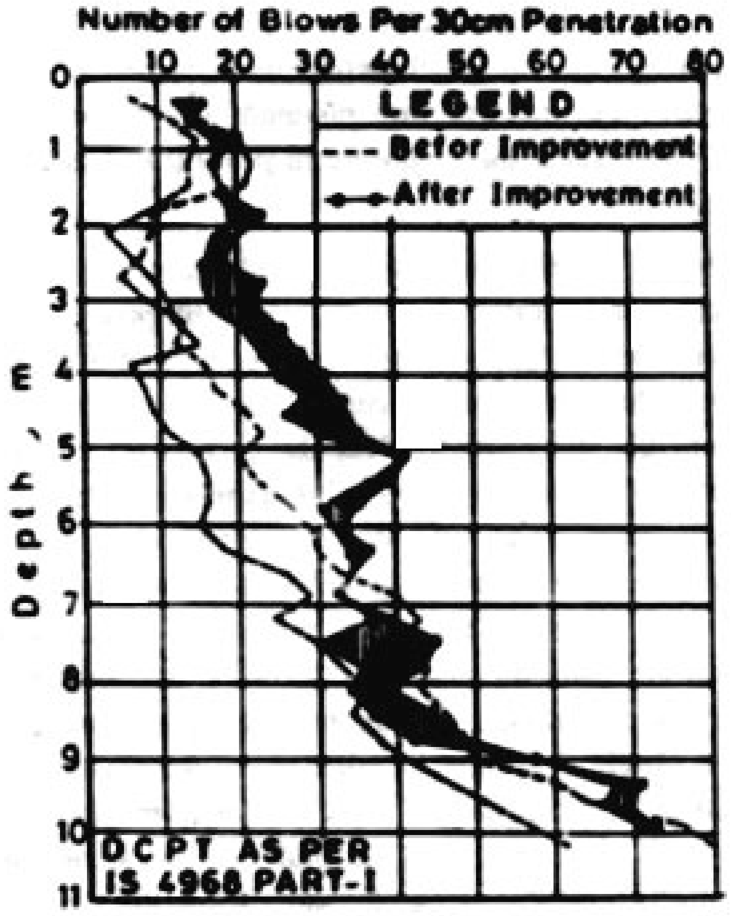

Figure 5 Dynamic cone penetration test before and after improvement

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

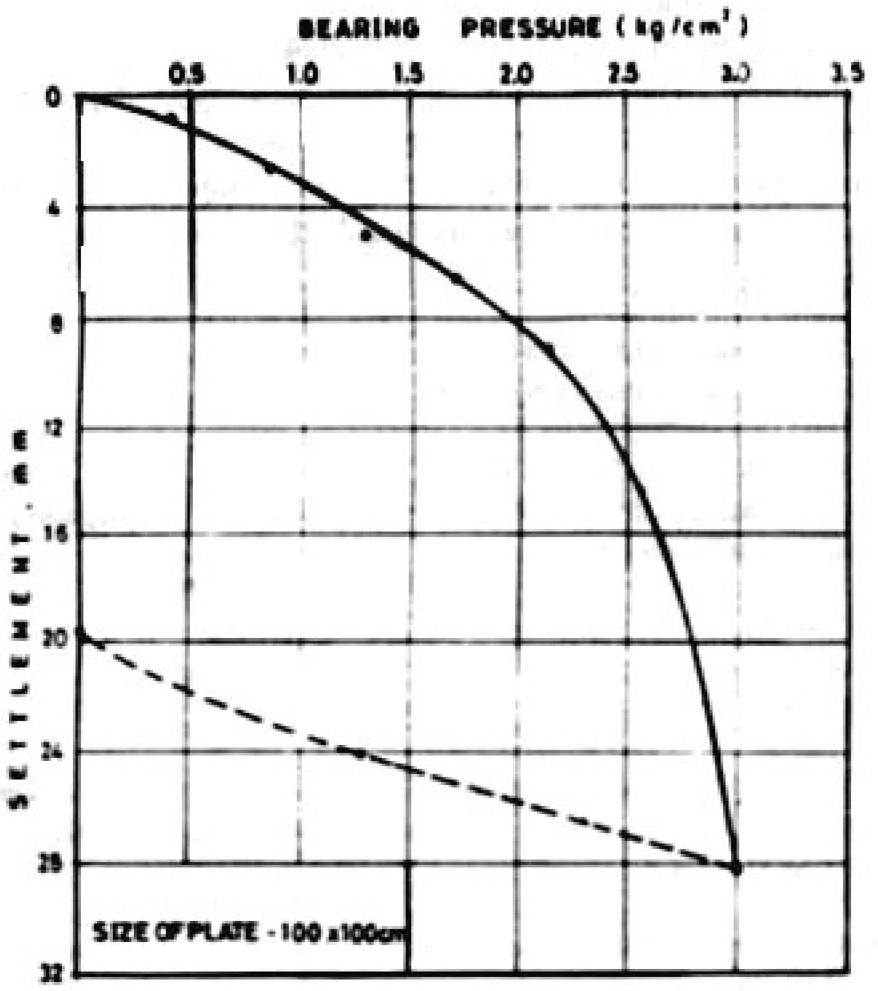

Figure 6 Plate load test on unimproved ground

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

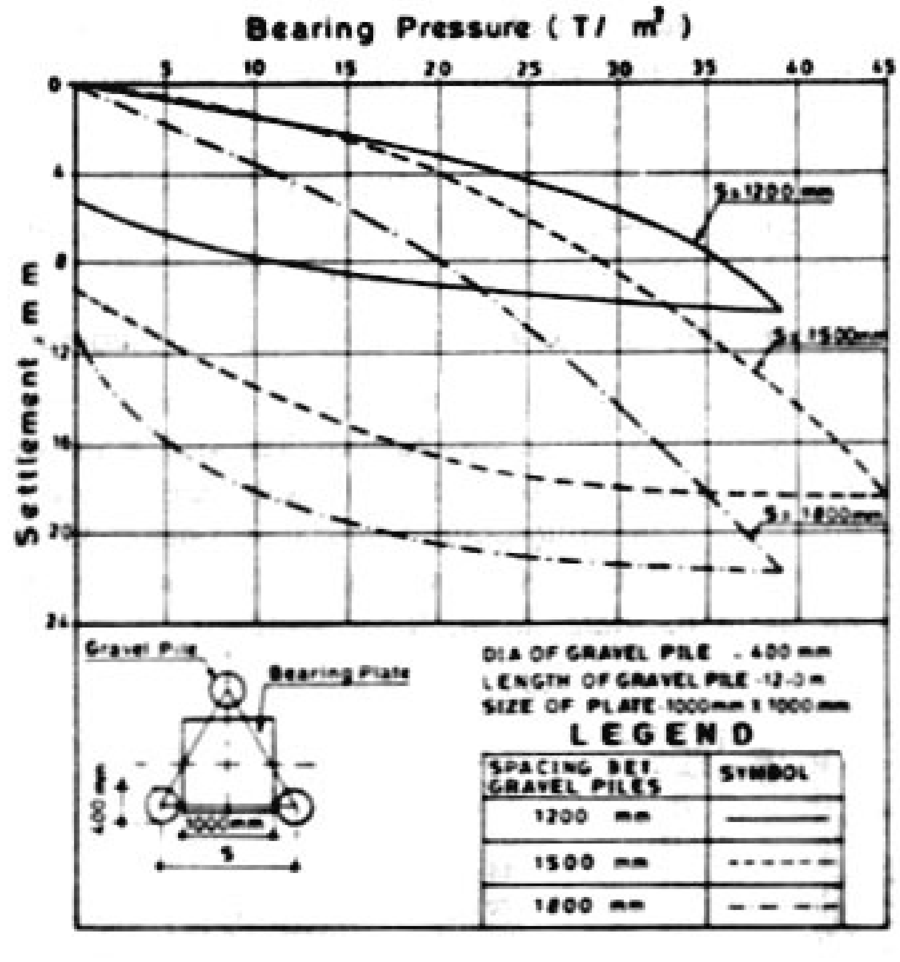

Figure 7 Load settlement behaviour of improved ground

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/m²	10 t/m²	12 t/m²	15 t/m²	20 t/m²
1.2	1.2	1.6	2.0	2.7	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

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

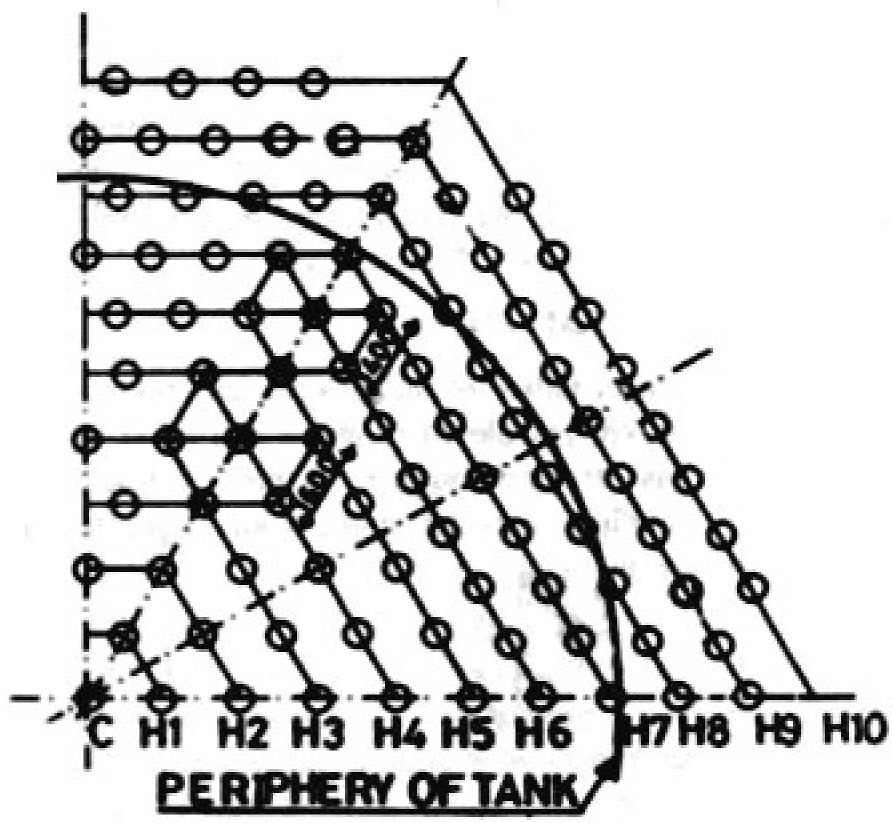

Figure 8 Layout of stone columns for 22 m dia tank

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 in Fig 8 was used.

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.

Pile Foundations for Ammonia Tank at Kandla (Gujarat)

To store about 15 000 t of ammonia, a 42.1 m diameter steel tank of 19 m height was planned. The soils at the site consisted of a 2 m fill underlain by soft marine clay to about 14.5 m depth. A deposit of hard clay was met at 18.5 m depth below which dense sand was met. The stratigraphy at the site is illustrated in Fig 9.

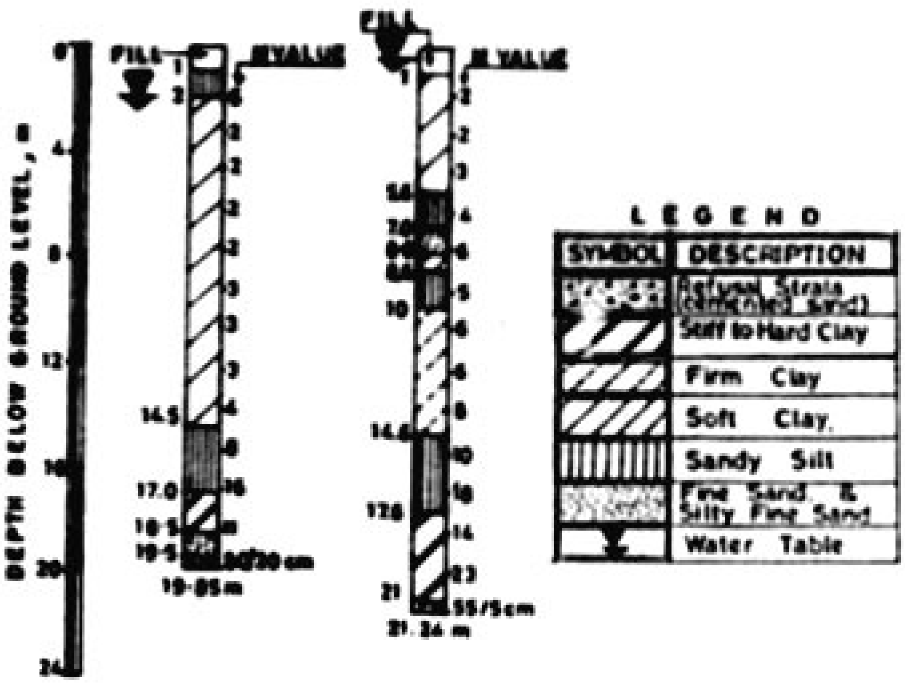

Figure 9 Site stratigraphy ammonia tank location

Ammonia being a highly explosive and hazardous liquid, the settlement criterion specified by the designer was restrictive. Further, the groundwater was highly corrosive with high concentration of sulphates and chlorides.

It was proposed to install 400 mm face-to-face octagonal driven precast RCC piles of M35 grade cast using sulphate resisting cement. The piles were driven to the refusal stratum at about 20 m depth. The negative downdrag on the piles in the soft clay was also considered in the analysis and the piles were designed for a safe axial compressive capacity of 72 t. About 230 piles were installed on a circular layout. An RCC pile cap was constructed over the piles and the tank was installed over the pile cap.

CONCLUDING REMARKS

Cylindrical storage tanks of mild steel are popular for storage of crude oil, petroleum products and other liquids. If the subsoil is strong enough to withstand foundation stress safely, smaller diameter tanks with larger heights would be preferred.

The first and the foremost requirement of tank foundation design is the information about the stratigraphy and physical properties of the soils at site including groundwater table and its fluctuations. In view of the complexity of natural deposits, no single method of soil exploration is suited for all situations. The choice depends on the nature of subsoils, their extent and the structure planned. A well planned and carefully executed soil exploration programme is therefore essential.

Once the soil exploration data is available, depending upon the magnitude and nature of loads imposed and the characteristics of the soil, type of foundation for the tank need to be decided. Keeping in view the safety requirements, the need to treat the ground to improve its engineering behaviour should be carefully evaluated. A detailed assessment of various methods of ground improvements[3] and their suitability for the particular site needs to be assessed. Based on this assessment,if granular piles / stone columns are to be installed assessment of the capacity of the stone columns/granular piles through field tests of single / group of piles[4,5] is necessary. A field acceptance criteria should be developed on site. Having verified the capacity of the granular pile / stone column, the ground treatment is carried out. After the treatment of the ground[3], the tank pad is constructed and fabrication of the steel tank carried out.

Hydrotests of tanks are essential from the point of view of safety of the tanks. However, there is need to laydown a proper procedure for hydrotesting specifying clearly the rate of loading, duration and pause.

The case studies presented in this paper illustrate the installation and performance of tanks in different soil conditions. The selection of foundation type depending upon the soil conditions and evaluation of the tank performance is explained. Field verification of the tank performance by hydrotests is also highlighted.

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