10 Mar 1998, 9:00 am - 12:00 pm

A Case Study on Settlement of Oil Storage Tank Foundations

G. Ramasamy
University of Roorkee, India

G. Kalaiselvan
Bharat Petroleum Corporation Ltd., Noida, India

Proceedings: Fourth International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, March 9–12, 1998.

A CASE STUDY ON SETTLEMENT OF OIL STORAGE TANK FOUNDATIONS

G.Ramasamy
University of Roorkee
Roorkee - 247 667
India

G. Kalaiselvan
Bharat petroleum Corporation Ltd.
Noida - 201 301
India

1.33

ABSTRACT

Foundations of 8 Steel Oil storage tanks and two fire water tanks were proportioned limiting total settlement to 100 mm. The soil at the site consists of alternating layers of cohesive and cohesionless soils. Settlement estimates were based on currently available methods with suitable modifications to the situation met with. The tanks were load tested (Hydrotest) and settlements observed at nine locations along the periphery on tank shell base. These observed settlements are compared with the estimated values.

KEYWORDS

OIL TANKS, LAYERED SOIL, SETTLEMENT, HYDROTEST, CASE STUDY

INTRODUCTION

Cylindrical storage tanks form a familiar part of petroleum refineries, chemical plants and many other manufacturing units. They hold large volumes of hazardous products. Failure of such tanks can lead to severe environmental damage, loss of human life and big financial losses. Literature suggests that differential settlement has been a major cause of distress in such tanks. Therefore, reliable estimation of settlements constitutes an important step in design of foundations of oil tanks.

Available methods on estimation of settlement are many. The estimates vary quite significantly depending on the method adopted. This necessitates evaluation of prediction methods through comparison of the estimated and observed values. The present article deals with one such exercise carried out with reference to foundations of a number of oil storage tanks constructed in a tank farm at a oil depot in the Gangetic plains of India.

DETAILS OF TANKS AND SITE CONDITIONS

A tank farm (Fig. 1) consisting of eight oil tanks form a part of the oil depot. The tanks are of different diameters varying from 9.0 m. To 17.0 m. and of height from 13.5 m. To 15.0 m. These tanks are intended to store High Speed diesal (HSD), superior kerosene oil (SKO) and motor sprit.

A detailed soil investigation was planned and executed to map the soil strata. The investigations consisted of three

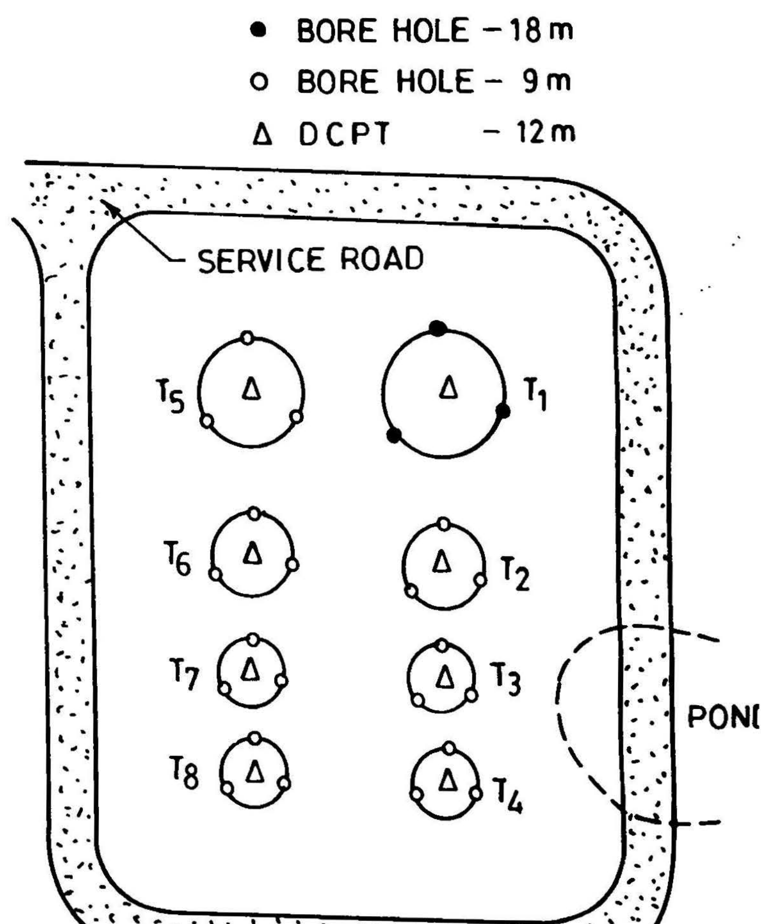


Fig. 1 Tank Farm

boreholes and one dynamic cone penetrate test at each of the tank locations. At the location of the largest tank (T-1), the boreholes were made upto a depth of 18.0m. and at other locations, they were made upto a depth of 9.0m. In each of the boreholes, standard penetration test (SPT) was conducted at 1.5m depth intervals. Representative sample collected through the SPT sampler were used for classification tests. Undisturbed samples collected in clay layers through thin-walled samplers were used for shear and consolidation tests.

Based on the field and laboratory test data, bore logs were prepared. It was observed that the subsoil conditions at the site are more or less identical at all bore hole locations. Accordingly, an average representative soil profile as shown in Fig.2 was obtained for the site. It can be seen that the subsoil consists alternating layers of clay and non plastic silt of varying thickness upto 18.0m, the maximum depth of exploration.

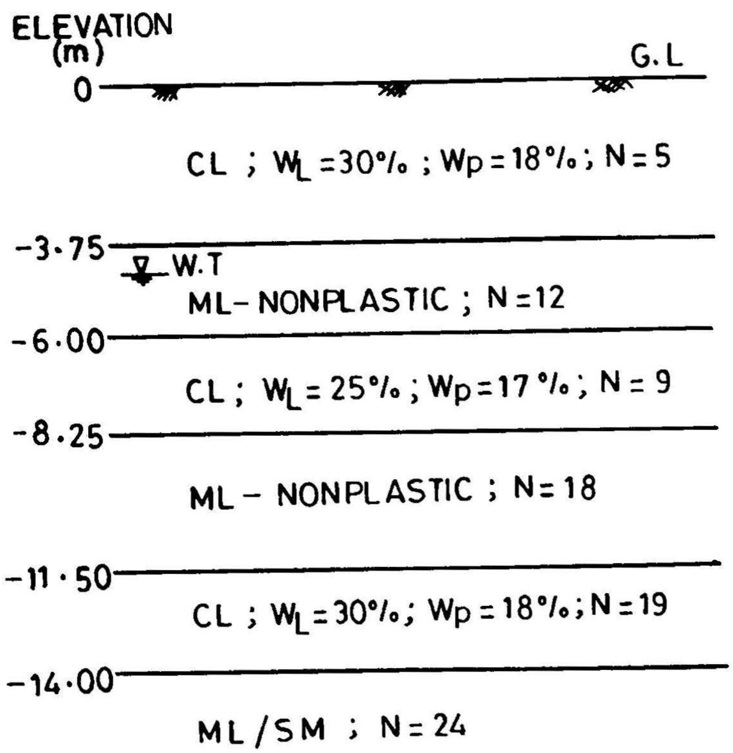


Fig. 2 Soil Profile

PROPORTIONING OF FOUNDATION

The oil tank foundations are generally proportioned based on limiting total and/or differential settlement. Marr et.al. (1982) describe detrimental settlement patterns that a tank foundation may develop and suggest that variable soil thickness and / or compressibility over the plan area of the tank foundation is the major of cause of foundation failures. D'Orazio and Duncan (1987) have studied data pertaining to 26 oil tanks and suggest that a differential settlement of 0.5% to 2.5% of tank diameter can be tolerated depending upon the settlement pattern of the bottom plate. Chen et.al (1987) compiled the work of a number of investigators and suggested a set of criteria on limiting shell and bottom plate settlements. Though these works suggest a much higher tolerable settlement, the foundations in the present case are proportioned for a tolerable total settlement of 100mm of the bottom plate.

ESTIMATION OF SETTLEMENT

The soil at the site is stratified consisting of layers of cohesive and cohesionless soils. In such cases, the settlement is calculated separately for each layer and then summed up to get the total settlement.

Settlement of Cohesionless Soil Layers

A number of methods are available for the estimation of settlement of cohesionless soil deposits of which, the methods proposed by Peck et.al. (1974), Burland and Burbidge (1985) which are based on SPT data and those proposed by De-Beer and Martens (1957) and Schmertmann et.al (1978) which are based on SCPT (Static Cone Penetration Test) are widely accepted. These have been developed for homogeneous deposits. In the present case, the method proposed by Peck et.al (1974) has been adopted with suitable modifications for the layered system as below

The settlement of each layer is obtained using the equaiton,

$$S = \frac{q}{0.044 \times N \times C_w} \times \frac{H}{D}$$

where,

- S = settlement of the layer considered in mm
- N = average corrected N value for the layer considered
- q = load intensity at the tank base, t/m^2
- C_w = water table correction factor, taken as 0.5 for submerged layers
- H = thickness of layers considered
- D = Diameter of the tank

The cohesinless soil layers coming within a depth equal to the diameter of the tank are considered in the computation.

Settlement of Cohesive Soil Layers

In the case of cohesive soil, a small part of total settlement occurs upon application of the load and the major part consists of the primary consolidation settlement. The settlement, when estimated using e-log p curve, includes both the immediate and consolidation settlement. In the present case, the settlement of the cohesive layers is estimated using the e-log p curves obtained from consolidation tests conducted on undisturbed soil samples.

The total settlement computed as above exceeds 100 mm for the anticipated load intensity of 15 t/m^2. The topmost cohesive layer contributes a major part of the total settlement. Therefore, replacement of the top cohesive soil by a well compacted granular material upto 2.0 m below ground level for tanks of diameter more than 14.0m and, 1.5m in the case of smaller tanks, as shown in Fig.3 was proposed to limit the bottom plate settlement at the centre of the tank to 100 mm. It is known from elastic theory that in the case of a flexible circular foundation resting on a elastic material, the settlement at the edge of the foundation is equal to 70 percent of that at the centre. Accordingly, it may be stated that the foundations are proportioned in the present case limiting the settlement of the shell base to 70 mm.

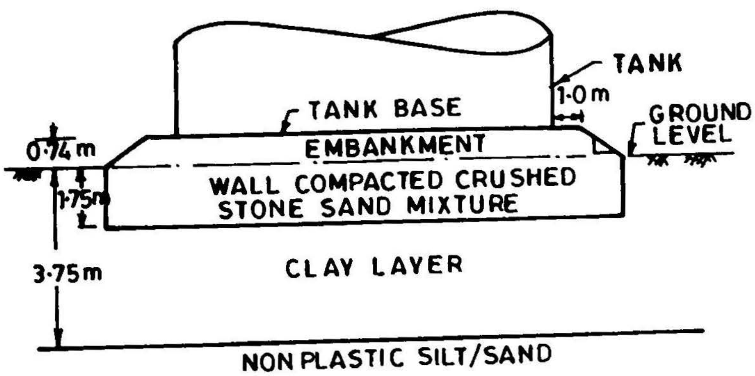


Fig. 3 Proportioned tank foundation

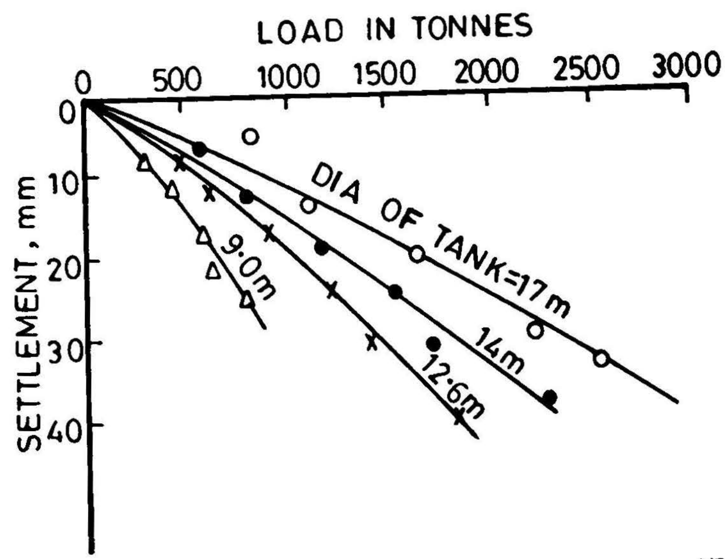
OBSERVED SETTLEMENT

After the construction of the tanks, the performance of the foundations were tested for full water load (Hydrotest). The tanks were filled in stages, 1/4, 1/3, 1/2, 2/3, 3/4 and full capacities and at each stage, the settlements were observed at nine locations along the periphery on the tank shell base. The settlements were observed 24 hours after loading at each loading stage. Thus, it may be stated that the observed settlements represent mainly the immediate (or elastic) settlement and only a very little part of the consolidation settlement. It is observed that settlements were more or less the same at all locations at each of the loading stages. These observed settlements are plotted in the form of load - settlement curve in Fig.4 for the tanks of different diameters.

COMPARISON OF PREDICTED AND OBSERVED SETTLEMENTS

As the settlements observed during hydrotest represent the immediate (or elastic) settlement of the soil strata, the same is compared with the corresponding estimated values. In the present case, the settlement of the cohesionless layer constitute most of the immediate settlement. At the design stage, this was estimated based on SPT data using the Peck et.al (1974) procedure. However, as an exercise of back - analysis, the settlement of the cohesionless layers is also computed using De-Beer and Martens (1955) method which is based on SCPT data. To enable settlement computation by De-Beer and Martens (1955) method, the SPT values are converted into equivalent SCPT values using the correlation proposed by Peck et.al (1974). These computed and the corresponding observed settlements for various tanks are shown in Table 1.

A comparison of the observed and estimated settlements show that whereas Peck et.al (1974) procedure, as adopted here for the layered system underestimates settlement, De-Beer and Martens (1955) method provides overestimation of settlement. The possible immediate settlement of clay layers, which is left out in the calculations, when estimated based on a procedure suggested by D'orazio and Duncan (1987) on a conservative basis, works out to less than 5 mm. Thus, there is a significant difference in the estimated and observed values. However, in view of the fact that the ground situations for which the adopted settlement computation procedures are valid and those actually met with, are not the same, the observed and the estimated values can be considered to agree satisfactorily.



Fi.g 4 Observed load - settlement of tank foundations

CONCLUDING REMARKS

Foundations for a number of oil tanks resting on a deposit consisting of alternating layers of cohesive and cohesionless soils were proportioned limiting the total settlement to 100 mm. The tanks were load tested (Hydrotest) and the observed settlements are compared with the estimated values. The exercise suggests that estimation of settlement of foundations in a real situation as the present one involves some logical modifications to currently available methods and judicial selection of soil parameters. The back analysis and comparison of observed and estimated values have provided valuable data base for judicious design decisions in foundation work of similar nature in the area.

REFERENCES

1. Burland, J.B. and M.C. Burbidge, [1985]. "*Settlement of foundations on sand and gravel*", Proc. of Institution of Engineers, London, Part 1, 78, pp. 1325-1381.

2. Chen, H.M. Pan, C.C. and S.T. Chung [1987]. "*Settlement criteria for large oil storage tanks*", 9th Southest Asian Geotechnical Conference, Bangkok, Thailand, 4-41 to 4-52.

3. De Beer, E. and A. Martens [1957]. "*Method of computation of an upper limit for the influence of heterogenity of sand layers in the settlement of bridges*", Proc. 4th Int. Conf. on SMFE, London, Vol. 1.

4. D'Orazio, T.B. and T.B. D'Orazio, [1984]. "*Stability of oil storage tanks*", J. Geotech. Engg. Div., ASCE, 1139, (9), 967-983.

5. Marr, W.A., Romas J.A. and J.W. Lambe [1982]. "*Criteria for settlement of tanks*", J. Geotech. Engg. Div. ASCE, 108 (8), 1017-1039.

6. Peck, R.B., Hansen, W.E., and T.H. Thornburn, [1974]. "*Foundation Engineering*", John Wiley and Sons, Inc., New York.

7. Schmertmann, J.H., Hartmann, J.P. and P.R. Brown, [1978]. "*Improved strain influence factor diagrams*", Journal of Geotech. Engg., ASCE, vol. 104, No. GE 8.

Table 1 - Comparison of Observed and Estimated Settlements

Tank Dia. M	Load intensity, t/m^2	Observed settlement, mm	Estimated Settlement	
			Peck et.al method	De-Beer and Martens method
17.0	15.0	40	19.7	81
14.0	15.0	39	18.3	66
12.6	15.0	40	20.0	58
9.0	13.5	26	12.8	40