Performance of steel tanks

Le comportement des réservoirs en acier

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SYNOPSIS: A methodology is proposed for the delineation of the zone of shear deformation under large steel tanks. Based on this delineation, techniques are suggested for loading the tanks rapidly without endangering their performance, even though only a small percentage of apparent settlement is completed. The time-dependent interrelationship between bearing capacity improvement and settlement is also illustrated.

INTRODUCTION

Steel storage tanks are frequently hydrotested in stages to improve the bearing capacity of subsoils and reduce long term settlement during product storage. Due to their flexible nature, steel tanks can tolerate significant settlements (Ahmed, 1984). With increased soil compression, the bearing capacity of soil also improves significantly; thus it requires time-dependent evaluation. Unlike rigid structures, i.e. buildings, where bearing capacity and settlement constraints are independently satisfied, the flexible steel tanks also require an additional consideration of the time-dependent interrelationship between bearing capacity and settlement. As previously illustrated by the author (Ahmed, 1984) the settlement criterion presented by Marr et al. (1982) appears adequate. However, evaluation of the performance of tanks on the basis of settlements alone, (D'Orazio and Duncan, 1987) may not be sufficient.

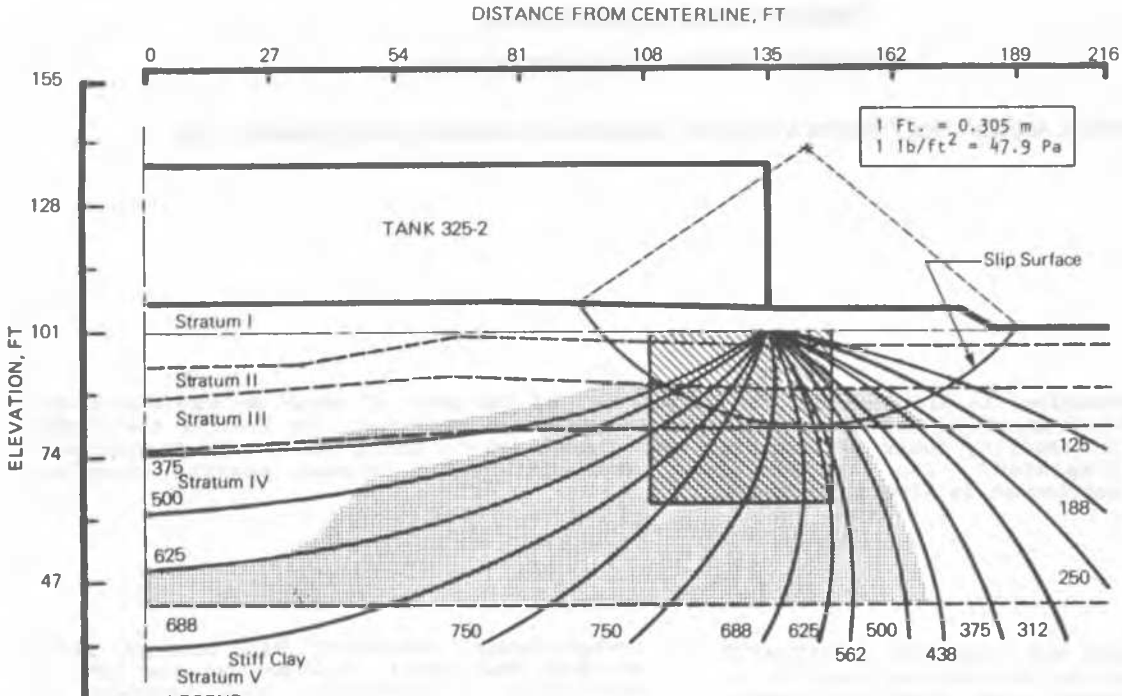
This paper focuses on the shear distortion and bearing capacity aspect which is frequently the difference between success and failure of tanks during controlled loading. Only after the shear distortion related tank performance is properly evaluated does the application of settlement criteria have any relevance. The methodology presented here is based on the evaluation of instrumentation and measurement data from more than 50 tanks located in coastal geologies of Louisiana and Texas, U.S.A., Canton, China, and Cano Limon, Colombia.

BEARING CAPACITY

Most steel storage tanks cover a large plan area. Accordingly, the geometric relationship between the tank diameter and the thickness of the underlying soft soil stratum becomes a governing criterion in estimating bearing capacity. Of most concern to previous investigators, (Meyerhof, 1951; Darragh, 1964) has been the plastic flow or "squeeze out" of soft soils. Accordingly, they recommend to limit the bearing capacity to an empirical product pressure which will promote plastic flow. These closed form solutions are dependent on the use of one value of cohesion for the soft soil stratum. If a low average is used, then the bearing capacity is underestimated, whereas, a high average may result in failure. These methods do not provide a means of delineating the zone of plastic flow.

The bearing capacity analysis should begin by delineating the zone of plastic flow. This zone is localized within a band near the tank edge, when tank diameter is significantly larger than the thickness of the soft soil stratum. By recognizing this, means can be found to achieve a higher bearing capacity (Ahmed, 1984). In one case, the writer used counterbalancing berms, in conjunction with artificial drains, within a peripheral band, to achieve higher bearing pressures more rapidly than would otherwise be possible by assuming the above mentioned empirical hypotheses.

A rational method of estimating the bearing capacity is to determine the critical slip surface. The critical slip surface analysis is first performed using undrained parameters to determine the first safe hydrotesting stage or the earth preload, Fig. 1. Making use of the pore pressure transducer data, contours similar to those shown in Fig. 2 are drawn for intermediate hydrotesting stages. It is now possible to perform effective stress analysis. For the case shown in the above figures, the safe pressure for a factor of safety of one, as determined for the undrained condition, was 2170 psf (104 kPa). An earth preload equivalent to this pressure was built and held for a total period of 110 days and the factor of safety improved to 2.2, based on the



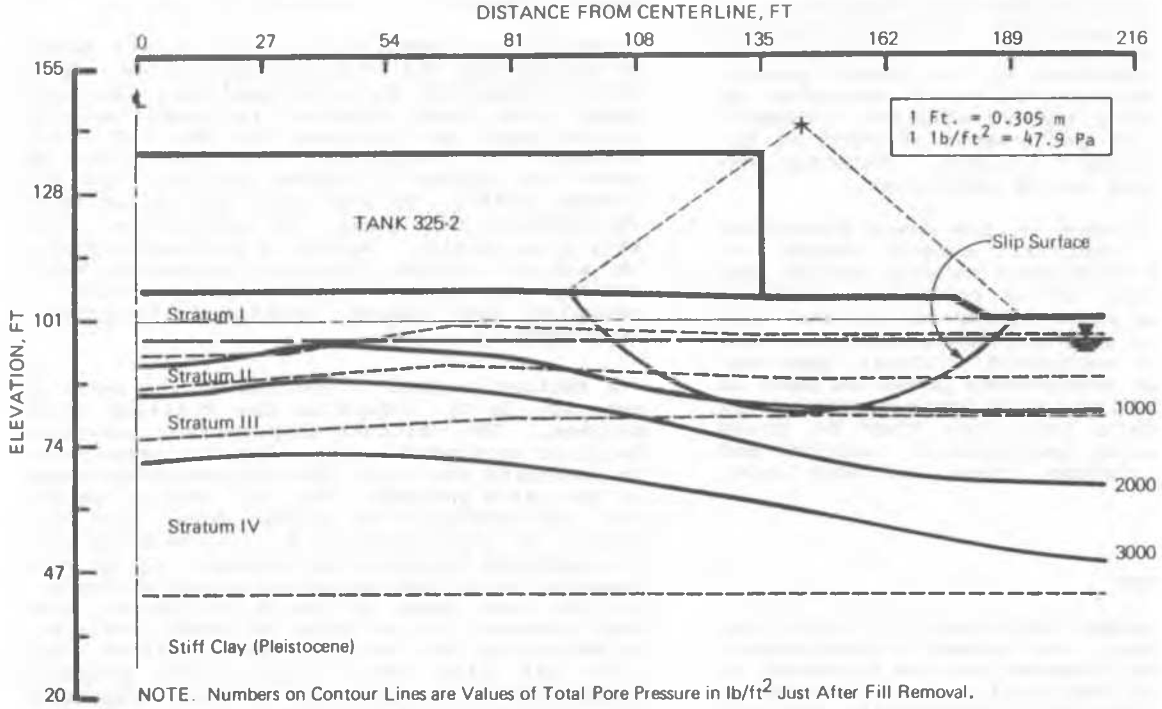
LEGEND:

▒ Zone where maximum shear stress increment exceeds undrained shear strength

▨ Zone where Alidrains were installed

Note: Numbers on contour lines are values of maximum shear stress increments in lb/ft^2 due to 2500 lb/ft^2 applied pressure.

Fig.1 Total Stress Critical Surface Analysis



NOTE. Numbers on Contour Lines are Values of Total Pore Pressure in lb/ft^2 Just After Fill Removal.

Fig.2 Effective Stress Critical Surface Analysis

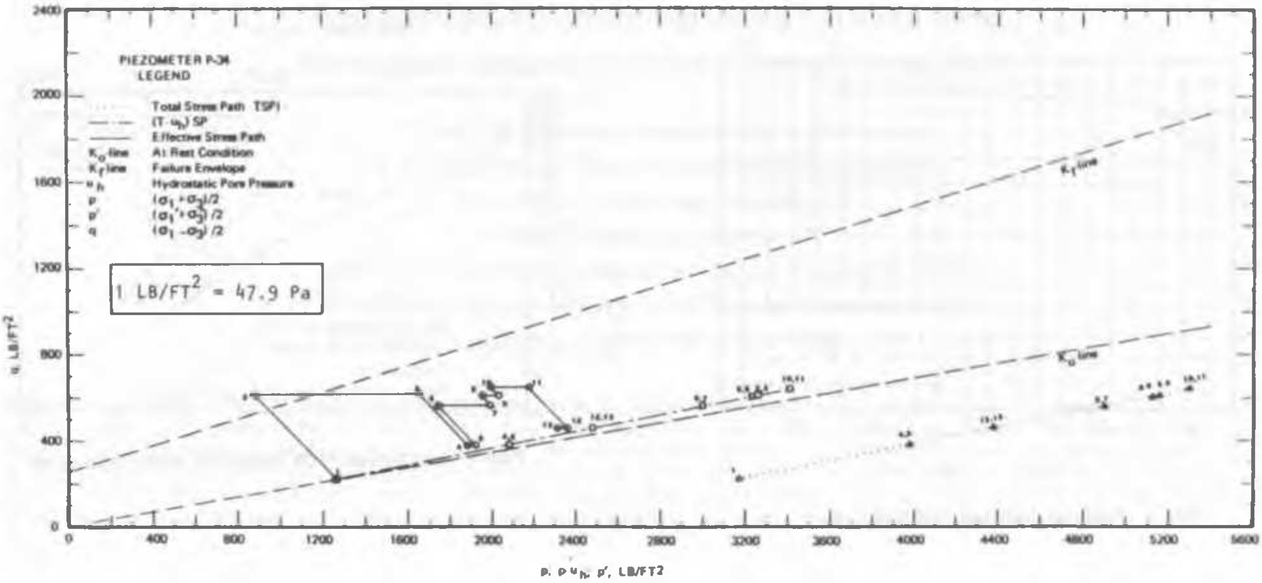


Fig.3 Stress Path Tracking

effective stress analysis, as shown in Fig. 2. Certain simplifying assumptions are necessary to treat the circular tank load as a strip load in making the stability analysis. However, these assumptions do not make the analysis overly conservative.

For those cases where the ratio of tank diameter to the thickness of shallow soft layer is large, i.e. a ratio of diameter to depth of bottom of soft layer of one or more, another means of monitoring tank instability is to monitor the stress paths as shown in Fig. 3. The numbers on stress paths represent the various stages of loading. However, this method becomes cumbersome when tank diameter is significantly larger than the thickness of the soft soil stratum due to rotation of principal stresses near the edge of the tank.

The progression of plastic flow can be monitored by measuring and observing the trend of movement of vertical inclinometers as shown in Figs. 4 and 5.

It is not the total deformation but the rate of lateral deformation which is of interest. As long as the curve of maximum deflection flattens out with time, plastic flow will not contribute to tank instability. A sudden increase of lateral deformation shows signs of instability. For a 40 ft. (12.3m) diameter tank, the rate of lateral deformation was 0.1 inch (2.54 mm) per day during tank loading stages which were expected to produce shear deformation. However, during the last stage, the inclinometer deflected 0.5 inch (12.7 mm) within an hour, giving early warning of potential incipient failure. There was no other visible sign of instability. The tank was emptied, relevelled, reloaded and placed in service without problem.

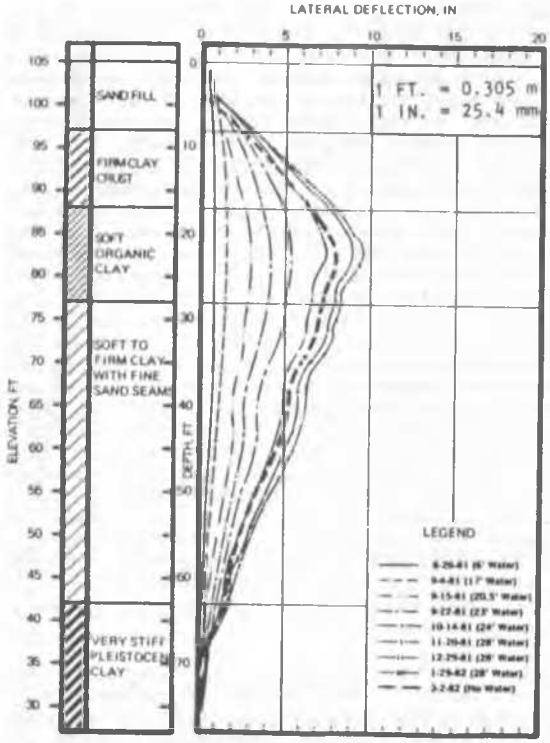


Fig.4 Lateral Deformation Profiles

SETTLEMENT

The prediction of magnitude and rates of various types of settlement is essential to the prediction of the performance of the tanks.

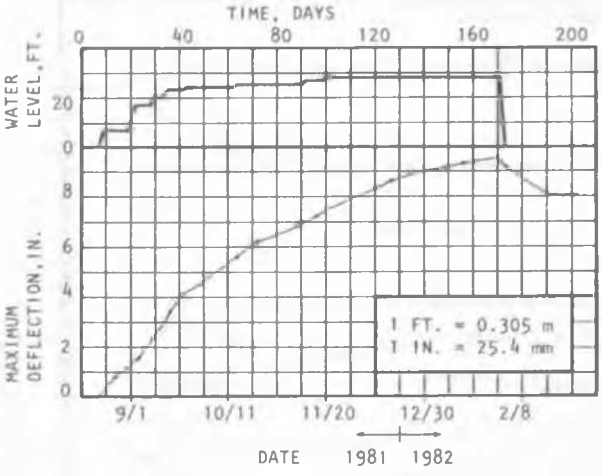


Fig.5 Rate of Lateral Deformation

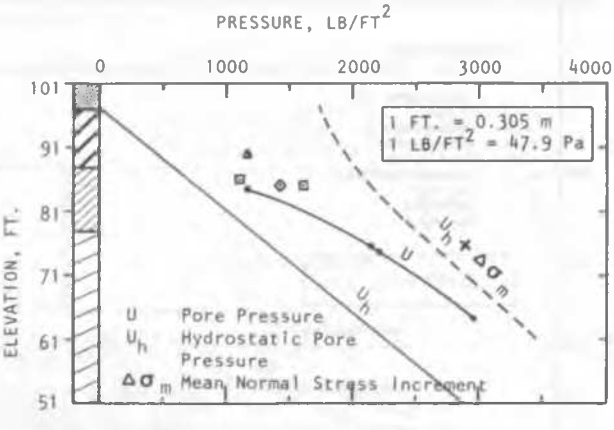


Fig.6 Isochrone From Measured Pore Pressures

Of primary concern is the type of settlement associated with the dissipation of pore pressures. The consolidation of soil under a circular tank is a three dimensional problem. For a uniform soil stratigraphy, it becomes a two dimensional problem of the axisymmetric type. There is much debate in the literature about the most suitable method of settlement calculation, and the superiority of 2-D and 3-D analyses over the estimates made by one dimensional consolidation theory. This debate is rather unnecessary. The writer has placed many tanks in service when the actual settlement following hydrotesting was in the range of 20 to 60% of the one dimensional consolidation estimate. Seven years later they show no sign of lack of performance. In other tanks which showed distress, the cause was shear deformation and not excessive consolidation settlement. A more fundamental and reliable method of monitoring the progress of consolidation settlement is to install pore pressure transducers and draw isochrones. Fig. 6 shows measured pore pressures near the edge of four tanks where artificial drains were installed in a band. Even with artificial drainage, only 50 to 60 percent of settlement was completed. By extrapolation, completed settlement under the center of the tank would be an even smaller percentage of the total, yet these tanks have performed well over the past seven years.

At the present time (1988) there is no reliable method available to accurately predict the time rate of settlement in the field. The time rate of settlement, based on one dimensional consolidation theory is usually inaccurate. Consolidation settlement usually occurs much more rapidly in the field. Ahmed (1984) reported field rates up to 10 times higher. Therefore, settlement rate prediction should be based on data available in the geographic vicinity of similar types of soil, or by extrapolation as data is collected. This area of tank settlement rates requires further research.

CONCLUSIONS

The prediction of performance of steel tanks should be based on shear deformations related to bearing capacity and tolerable settlements. There is a time dependent inter-relationship between bearing capacity and settlement. Tank performance should not be based on settlement criteria alone. Geotechnical instrumentation and evaluation of data plays a very crucial part in the performance evaluation methodology. Emphasis must be placed on instrumentation and monitoring of actual pore pressure and shear deformation data, in conjunction with actual tank performance measurements, i.e. ovality, tilting and bottom distortions, rather than on clever refinement of analytical procedures to predict the apparent performance of tanks.

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