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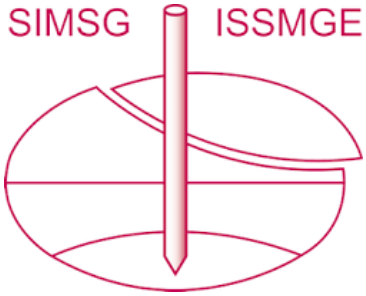

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Field monitoring of an oil tank founded on soft clay deposit treated with stone columns

Monitor de champ d'un réservoir d'huile fondé sur un dépôt d'argile tendre traité avec colonnes de pierre

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ABSTRACT

Present trend in modern world is for large diameter tall tanks. In India same trend is seen. A number of large diameter tanks have been built in recent past; almost all of them located on deep deposits of soft clay. Ground improvement by stone columns have been done to improve bearing capacity of soft virgin clay. Because of the complex load sharing mechanism of stone columns and their group behaviour, large gap exists between "prediction" and "performance" of the behaviour of these tanks. Authors firmly feel that Geotechnical Instrumentation is the best vehicle to bridge the gap between prediction & performance. The paper brings out the need for instrumentation for better understanding of the soil structure interaction effect on large oil storage tanks.

INTRODUCTION

According to the present trends, oil tanks are expanding both in diameter and capacity. With floating roofs, they approach 100 m mark and their capacities are getting closure to 1 60 000 m^3. If the tanks of less than 50 m diameter are regarded as small to medium size, and between 50 m and 100 m as large size, the following trends seem to emerge:

$(h/\phi) = -\phi/100 + 0.8$ for 20 m $\leq \phi \leq$ 50 m

$(h/\phi) = -\phi/500 + 0.4$ for 50 m $\leq \phi \leq$ 100 m

The international trend noted above, finds expression in the tank sizes commonly adopted in India, Table 1.

Table 1:Common Sizes of Large Oil Tanks In India

Site of oil tanks	Dia(ϕ) m	Capacity m^3	Height(h) m	(h/ϕ)	Max. stress(q) t/m^2
Mathura	79	65 000	14.4	0.18	15
Madras	79	65 000	14.4	0.18	15
Haldia	79	60 000	13.4	0.16	15
Baroda	79	65 000	14.4	0.18	15

The choice between the smaller diameter and taller versus larger diameter and smaller height tanks to attain same capacity is a matter normally considered at the planning stage with respect to the master plan, availability of space in the refinery, ground conditions, quantities to be handled, future expansion programme and of course the cost aspect. The focus of this paper is the instrument oriented observational method suited to Indian soft clay deposits on which a number of large tanks are frequently being placed.

The foremost problem is the one of choice between placing the tank on improved ground or staying with the orthodox piling approach. Where ground improvement is favoured, the question arises which methodology is most appropriate. Likewise, where piling is favoured, the question arises regarding the selection of appropriate piling system.

Where stone columns are used for ground improvement it is often the designers' concern to produce a reliable design despite grave uncertainties lumped with soil characteristics, load estimates, methodologies for prediction of settlements, potentiality for shear failure.

Where tanks are supported on piles in deep deposits of soft clay, in one case spectacular failure have come to light, Mohan et. al (1981). Their failures led to discouraging of cast-in-place piles suggesting an essential switchover to precast piling system, yet to be introduced in India, Although decisions on piling and mobilization of crew to undertake the assignment can be quickly done at site, in keeping with usually tight time schedule, the fact remains that the designer must face the problems of negative drag, of piles of questionable integrity and of course, of the long term settlements. On the other hand, approaches based on ground treatment may involve relatively longer project duration but often free the builders from the post construction anxities.

In India, almost all of the oil tanks are being founded on artificially strengthened ground. Of the large number of tanks being built today, those in Haldia rest on rather deep deposits of highly compressible soft clay. Large diameter tanks involving comparable dimensions are also being built in Madras, Baroda, Vizag and elsewhere on compressible cohesive soil deposits, Fig. 1.

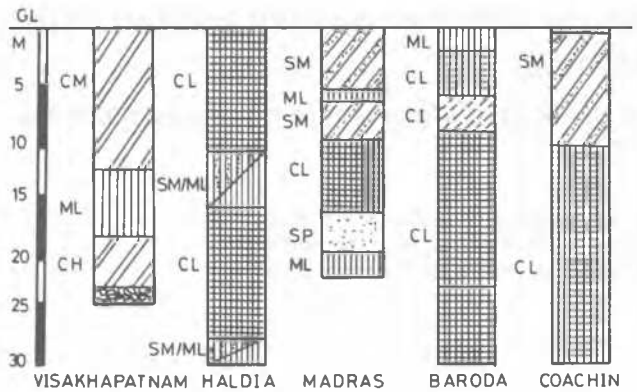

Fig.1:Soil profiles at different tank sites

In all the above cases stone columns are being used to improve the ground characteristics. Some of the typical foundation designs are presented in Fig.2.

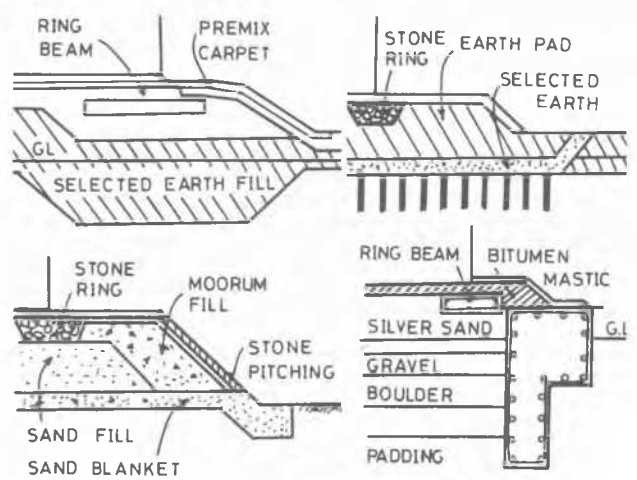

Fig.2:Typical tank foundation on soft clay

GROUND TREATMENT USING STONE COLUMNS IN INDIA

The history of application of stone column technology in India may be recent but ever increasing constructions on them bear testimony to their general acceptance. Considerable developmental effort has been given in evolving appropriate technologies including design procedures, installation techniques and field compaction and control procedures suited to Indian soils, Datye et. al (1975, 1981). Comparative evaluation of the efficacy of different installation procedures using vibrofloat, super vibrofloat and augering methods have all been made. What is however not done is to account for the installation procedures and the degree of quality control, in making or evaluating a design.

Where soft clay deposits are very deep such as at Haldia and Cochin, stone columns have to be perforce 'floating' rather than 'end bearing'. On the other hand, where competent stratum is encountered at shallow depths such as in Baroda, the stone columns are essentially end bearing. The designer has therefore to recognise the basic mechanisms of load sharing in the two cases and modulate the design accordingly.

With the present day Indian technology, it does not seem possible to construct stone columns deeper than 15 m, if they are not of questionable integrity.

PRIME CONSIDERATIONS OF DESIGN

Datye (1982) has attempted to unfold the mechanism of load sharing between the relatively rigid stone column and the ambient clay deposit. Ideally speaking, when stone columns penetrate down to hard stratum, their yielding is, conceptually accompanied with five zones, Fig. 3.These are the zones of arching, slip, compatibility and dispersion.

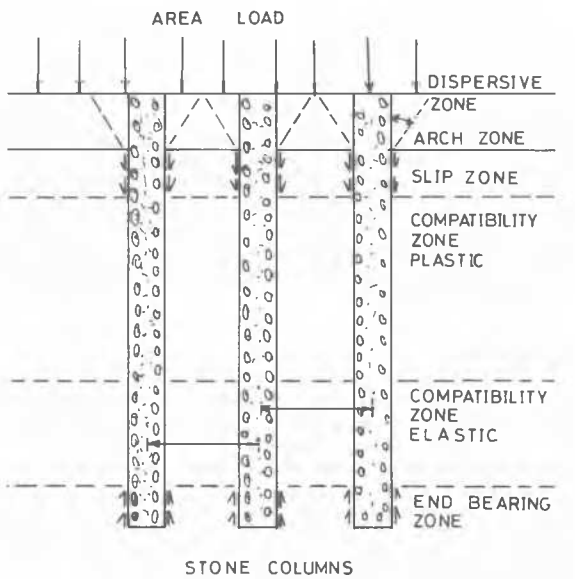

Fig.3: Zone categorization

The tank foundation soil system is to be designed to ensure its satisfactory performance both in the short and the long term. The major considerations in design are to limit the total settlement, angular distortion, edge distortion, tilt etc. to acceptable proportions.

SETTLEMENT CONSIDERATIONS

Whereas from the geotechnical engineering considerations it is comparatively easy to evaluate the safety against possibility of shear failure, it is not equally easy to have estimates of differential settlement, even if total settlements could be calculated to some degree of satisfaction.

According to Greenwood (1967), Penman (1977)and Datye (1982), stone column reduces the settlement to about 1/2 - 1/3 of that estimated without treatment. Contradicting the above, Bishop (1976) has pointed out that in some cases effect of remoulding caused by stone column installation may increase settlement. Burland (1976), while generally supporting the above view suggested that in insensitive soil the stone columns may be effective although he doubted if the settlement could be significantly reduced in the soft clay.

For one of the large oil tanks founded on a deep deposit of soft clay, nearly 4 000 stone columns, each of 60 cm diameter and 12 m deep were provi-

ded. Volume replacement was of the order of 23%. In this way stone columns besides providing columns for load transfer also reduced volume of compressible ground. Naturally, the settlement could be expected to reduce on both counts.

Considering fully penetrating stone columns and the approach followed by Datye (1982), reductions of settlement, if large tanks were to be supported on Haldia or Cochin clay would most probably tend to be in the range of 40-50%, Table 2.

Table 2: Reduction of Settlement

Area of stone column=0.3316 m^2; Yield capacity= 40 t ; E_{eq} = 1500 t/m^2 from back analysis

Area load (t/m^2)	Spacing of stone column (m)	Ratio of settlement with stone column to settlement without stone column (%)
15	2.0	23
15	3.0	58

The State-of-the-art does not provide any reliable and satisfactory criterion for limiting differential settlement and the task is compounded further by the reported observations that some tanks have stood large differential settlements without failure whereas some others have failed at rather low differential settlements. Green and Height (1975) suggest that differential settlement exceeding 2% of tank diameter lead to permanent damage and differential settlement of about 3% to failure.

A check is necessary to exclude the possibility of rupture of base plate for which a minimum base gradient 1:80 is considered desirable, Bhandari (1983). Many tanks have infact failed due to the rupture of base plate. The two tanks on Thames-site, Penman and Watson (1967) provided striking examples.

PORE PRESSURE

For one of the oil tanks, the rise of excess hydrostatic pressure corresponding to the loading during the tank construction is given in Table 3.

Table 3: Load versus excess pore pressure

Load (t/m^2)	Excess pore pressure (m of water)	Depth (m)
6.4	2.48	6
11.3	2.54	6
12.5	2.59	6

Clearly the excess pore pressures recorded were much lower than the applied stress intensity because of the rapid dissipation through the stone columns.

OBSERVATIONAL APPROACH FOR DESIGN AND CONSTRUCTION

The hiatus between prediction and performance is large even while speaking of well established technologies and therefore the gaps could be feared to be much wider when dealing with newer techniques like stone columns. Surest way to narrow down the gap is to promote more and more of feedback studies through instrumentation. The question of instrumentation is intimately linked with the choice of most appropriate locations. And these must be decided with respect to the questions to be answered and the anticipated behaviour under load.

CRITERIA FOR LOCATING INSTRUMENTS

Where tanks are founded on rather thick, homogeneous, uniform semi infinite soil mass which could be regarded as elastic, one would theoretically predict maximum settlement at the tank centre to be of the order of $\pi/2$ times that at the tank edge. Naturally in such a situation one must insist on measurement of pore pressure and settlements at the tank centre, edge and one or two intermediate locations.

It has been theoretically predicted that if the ratio of tank diameter to the thickness of compressible stratum exceeds 3. the settlement is maximum at a distance of 2R/3 from the tank centre, R being the radius. According to Butler (1975), if tank diameter is about four times the thickness of compressible stratum the maximum settlement will take place at 0.83 R. Naturally it will be a mistake not to plant instruments at these locations.

The pattern of settlement monitored across a diameter of a large tank on soft clay deposit is reported in Table 4. The maximum settlement appears to be at 2R/3 from the tank centre.

Table 4: Settlement at tank base

Location from centre	Load = 8 t/m^2 Settlement (cm)
1.13 R	10.0
0.96 R	12.0
0.63 R	15.0
0.25 R	12.0

R = Radius of tank

It is not the locations prone to maximum pore pressures or settlements that bother a designer, he is equally concerned about locations where the pore pressures and the settlements would be of the lowest order. Only then calculation of differential settlement and the evaluation of tank performance become possible.

The installation layout in respect of two oil tanks, one at Madras and other at Haldia are shown in Fig. 4.

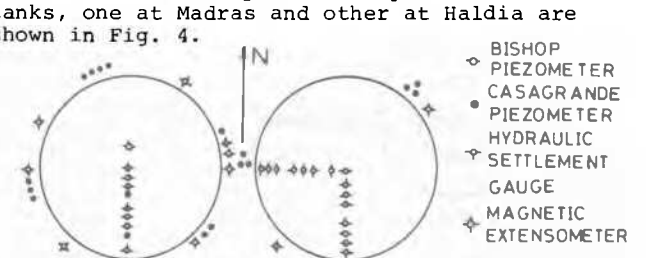

Fig.4:Layout of tank instrumentation

The spatial distribution of pore pressures and settlements is important and for this, the depth wise locations are to be guided by the thickness of compressible stratum, stress intensity and distribution pattern and the geological details of the site. Care is of course required to ensure that the piezometers are not fouled by stone columns. It is always a good decision to let the instruments define depth wise piezometric and settlement profiles at critical locations rather than spreading them thinly all over the zone of influence of loading and then extrapolating values to arrive at design decisions.

The best of the instrumentation scheme can be marred by lack of care during installation. In hydraulic systems involving long length of tubings awkward curves and sharp bends may prove disastrous making the entire scheme worthless no matter how sophisticated and reliable are the instruments.

Where instrumentation is planned along two diameters, one possibility would involve layout marked in Fig. 5(a). If however one selects the alternative shown in Fig. 5(b), the hazards associated with the kinks and bends in tubings could be totally avoided. This scheme, although technically sound may prove expensive inasmuch as two gauge houses are required adding to the cost of instrumentation scheme. The engineering solution would therefore be to go in for scheme shown in Fig. 5(c).

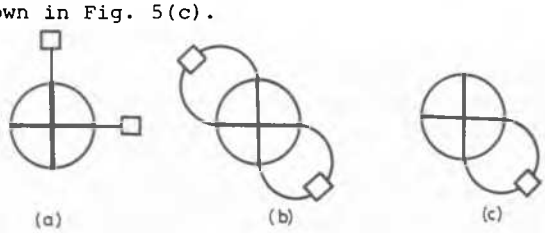

Fig.5: Two Diameter Instrumentation Scheme

The instrumentation along two diameters covered by this scheme is generally adopted where the thickness of compressible stratum is non-uniform If the funds available for instrumentation are restricted, instrumentation across two diameters may not always be possible, and a '120° pattern' may come up for consideration. In such a situation it will be incorrect to force all tubings into a single gauge house as shown in Fig.6(a). The better solution would be to provide the major gauge house connecting instrumentation along two radii and a smaller chamber may be provided for the instrumentation along the third radius, Fig. 6(b). Such a pattern would although enable recording directly the response along three radii only but, where soil strata is more or less uniform meaningful extrapolations are possible along three diameters by assumption of symmetry.

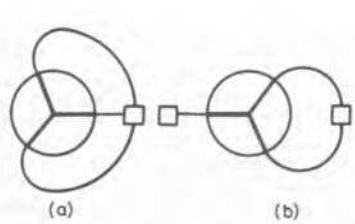

Fig. 6: 120° Instrumentation Scheme

Likewise, for the instrumentation along two radii only scheme shown in Fig. 7(a) would prove to be a better choice when compared with the one shown in Fig. 7(b). Such an arrangement is most ideal when the soil strata is of uniform thickness throughout.

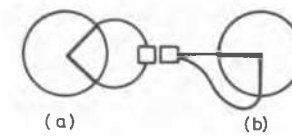

Fig. 7: Two radii instrumentation scheme

CONCLUDING REMARKS

The gap between 'prediction'and 'performance' of the behaviour of oil tank foundations on soft clays treated with stone columns is glaring. The predictions are chiefly complicated by nonclarity about load sharing mechanism between the column and the ambient soft clay. The time and load dependent spatial distribution of applied stresses, the smear and the consolidation and plastic flow effects are not amenable to reliable estimates at the present. The paper advocates use of instrumentation as a vehicle to narrow the gap. It discusses the criteria for locating the instruments and links their layout with geotechnical situation at a site.

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REFERENCES

Bhandari, R.K. (1983). Problem of floating roof storage tanks. Proc. Intl. Workshop on Soil Structure Interaction, Roorkee, India.

Bishop, A.W. (1976). Discussions-Proc. B.G.S. Symp.Ground Treatment by Deep Compaction. Instn. Civ. Engrs.,London.

Burland, J.B. (1976). Discussion:Proc. BGS Symp. Ground Treatment by Deep Compaction, Instn. Civ.Engrs, London.

Datye, K.R. (1982). Settlement and bearing capacity of Fdn. system with stone columns. Symp. on Soil & Rock improvement Tech. including Geotextiles, Reinforced earth and modern piling methods, Bangkok.

Datye, K.R. & Nagaraju, S.S. (1981). Design approach & field control for stone columns volume 3, X ICSMFE Stockholm.

Datye, K.R. & Nagaraju, S.S. (1975). Installation and testing of rammed stone columns, 5 ARC, IGS speciality session, Bangalore.

Green, P.A. & Height, D.W. (1975). The failure of two oil-storage tanks caused by differential settlement. Proc. BGS Conf. Settlement of Structures, Pentech Press,London

Greenwood, D.A. (1975). Differential settlement tolerances of cylindrical steel tanks for bulk liquid storage. Proc. BGS Conf. Settlement of Structures, Pentech Press,London

Mohan et. al (1981). Negative drag on an instrumented pile a field study. Proc. X ICSMFE Stockholm.

Penman, ADM & Watson, GH (1967). Found. for storage tanks on reclaimed land at Teesmouth. Proc. Instn. Civ. Engrs. London.