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INTERACTION ANALYSIS FOR OIL STORAGE TANK ON MARINE CLAY

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ABSTRACT: The engineering behavior of marine clay is very different than that of the moist and dry clay because of its structural and mineral composition [1]. Marine structure is subjected to the waves which create a cyclic stresses inside the soil mass [2]. The huge storage tanks experiences a heavy wind and current load which produces a adverse effect in the soil settlements. In this paper a cylindrical reinforced cement concrete tank with diameter 100 m and 40 m height founded on soft marine clay of undrained shear strength of 10 kPa is considered for the analysis. The huge pile group is modeled by equivalent pier method and interaction factor method for the full and empty loading conditions. Settlement including the soil pile interaction has been estimated for both the cases mentioned above for different pile configuration including pile length, diameter and spacing of piles in a group. It has been observed that the spacing of the piles plays a vital role in estimating the settlements and stresses. With the comparison of the equivalent pier method (EPM) [8] and interaction factor method (IFM) for settlement estimation, the later is found to be more suitable for interaction analysis to achieve the safety of the tank.

Keywords: Soil pile interaction, Oil storage tank, Settlement analysis, Pile foundation, Marine clay

1. INTRODUCTION

Due to an increase in the use of marine resources like petroleum products, biological products etc. a coastal activities are increased tremendously. Due to this, there is a huge necessity to build marine structures like offshore platforms, storage structures like fuel storage tanks, temporary halt structures and so on. Such offshore structures considered under heavy structures and give much impact on the soft clay settlement which affects the structural stability. Hence settlement analysis is needed to be performed for such type of heavy structures. In general a very soft clay in sea bed or onshore clay called as marine clay, has very poor shear strength and shows shrinkage and swelling properties due to its structural arrangement and the minerals compositions like montmorillonite, chlorite, kaolinite and illite and non-mineral traces like quartz and feldspar. Along with these minerals and non-mineral compositions, marine clay consists of organic matter with very high proportion.

2. LETERATURE REVIEW

In offshore structures the foundation is deeply embedded to hard strata, thus pile experiences the fluid foundation interaction as well as soil foundation interaction for the given loading conditions throughout the life span of the structure.

It is now well recognized that the settlement of a pile group can differ significantly from that of a single pile at the same average load level. In settlement analysis the soil mass is estimated for the exact prediction of the response of the structure along with the soil behavior.

2.1 Loading considerations for marine structures

The analysis, design and construction of offshore structures are one of the most demanding sets of tasks faced by the engineering profession. Over and above the usual conditions and situations met by land-based structures, offshore structures have the added complication of being placed in an ocean environment where hydrodynamic interaction effects and dynamic response become major considerations in their design. All most all marine structure is heavy structure and subjected to the wave impacts, current load, wind load and huge gravity loads [13]. Addition to this the soft soil experiences a non-linearities under hydrodynamic loading which makes the task more challenging to get the response of the marine structure supported by the deep foundation system [11]. A per the API guidelines offshore structure is subjected to the various loads including Wind Loads, Wave Loads, Transverse (Lift) wave loads, Diffraction wave forces, Effect of compliancy (relative motion), Inertia Force and Drag forces[13].

2.2 Charecteristics of the marine clay

Marine clay is very soft and plastic clay found in coastal regions around the world. Generally, the marine clay is available at fully saturated condition in the costal corridor and the natural water content of the marine clays is always greater than its liquid limit. Many attempt has been made to determine the characteristics and strength parameters of the marine clay [1,14,15,16,17]. Study reveals that the compressibility and the strength of the marine clay causes more differential settlement in the supporting structure [16] .From the previous studies it has been found that the soft marine clay is very sensitive to change the stress system, moisture content and system chemistry of the pore fluid [15]. The mineral structure of the clay also pays a vital role in exhibiting its behaviour under load for e.g. clay minerals with expanding lattice structure shows high compressibility and moderate swelling when comes in contact with moisture. The marine clay is very hard when it is dry but loses its strength on wetting [1].

2.3 Significance of settlement in soft soil strata

Prediction of settlement is an important part of foundation design to ensure the future stability and serviceability of the structure supported by the foundation [12]. As per the codal guideline the prediction of settlement needs the proper site investigation and appropriate laboratory or field tests identifying the conditions of the groundwater and the ground that contribute to the settlement of the foundation. The range of settlement varies with the local sit condition and the characteristics of the superstructure. In case of differential settlement the settlements are governed by the strength and serviceability of the superstructure. In practice, the settlement caused even by self-weight is predicted based on the effective stress. The concept of effective stress has been widely accepted in settlement prediction. In soft marine clay where the pore water pressure is one of the governing parameter which defines the strength of clay, thus in such cases strength or stiffness can be simply correlated with effective stress [1].

2.4 Effect of soil structure intercation on settlement

It has been observed that the stiffness of a structure will affect the distribution of settlement along the along the the foundation element like strip, raft and pile , which in turn distribution of structural loads and moments will affected by the foundation flexibility. Methods of incorporating the foundation-soil interaction into a settlement analysis have been described by several reserchers [10,11]. The study has been found that the stiffness of the structure generally leads to a reduction in the differential settlement, compared to the usual methods which take the structural loads as being constatnt and statically determinant. It has been studied that the effect of increasing the foundation flexiblity i.e. incorporating the effect of the soil-structure intercation leads to the a more uniform distribution of structural loads than in case of rigid foundation. It also been revealed that the use of the Winkler soil moel predicted the reverse trend, and attributed this incorrect trend to the different settlement profiles which emerges from the subgrade reaction theory [10] . There are a number of approaches commonly adopted for the estimation of the settlement of pile groups which employ the concept of interaction factors and the principle of superposition [3]. Few methods estimate the group settlement by modifying the single pile load-settlement curve, to take account of group interaction effects. Some of the methods are briefly explained in this section.

1. *The settlement ratio method:* In this method the settlement of a single pile at the average load level is multiplied by a group settlement ratio *Rs*, which reflects the effects of group interaction.
2. *The equivalent raft method:* In this method the pile group is represented by equivalent raft acting at some characteristic depth along the piles.
3. *The equivalent pier method:* In this method the pile group is represented by a pier containing the piles and the soil between them. The pier is treated as a single pile of equivalent stiffness in order to compute the average settlement of the group.
4. *The Interaction Factor Method:* In this method the settlement for one pile (reference pile) in the group is estimated and considering the interaction factor the settlement of the other piles in the group is calculated. The algebraic sum of the settlement value of all piles gives the settlement of the group.
5. *Numerical methods:* Different numerical techniques such as finite element method and the finite difference method have been used to find out the group settlement. While earlier work employed two-dimensional analyses, it is now less uncommon for full three-dimensional analyses to be employed [7].

3. METHODS ADOPTED FOR ANALYSIS

In this research paper the settlement for both empty and full loading condition has been carried out using Equivalent Pier Method (EPM) and Interaction Factor Method (IFM). These methods are detail explained in detailed in following section.

3.1 Equivalent pier method (EPM)

Paulos and Davis (1980) proposed an Equivalent Pier method for heavy and large superstructures where a large pile group needs to analyze. Fig. 1 shows the details of the equivalent pier method. Few researchers adopted a methodology of EPM to find out the settlement analysis for the huge pile group [25].

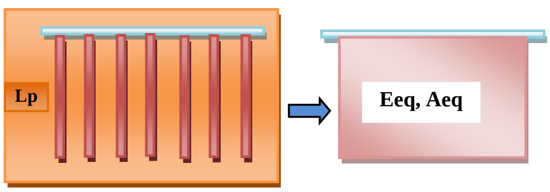


Fig. 1 Concept of equivalent pier method.

In this method the pile groups act as a whole pier to simplify the procedure for estimating the settlement of pile groups which equals that of single pile by means of load-transfer functions. The diameter of the equivalent pier is given by the following equation

$$Deq = 2\sqrt{\frac{Ag}{\pi}} \tag{1}$$

Where, A_g is the plan area of pile group.

3.2 The Interaction Factor Method

For pile groups one of the common means of analyzing pile group behavior through the interaction factor method [20]. In this method, referring to Eq. 2, the settlement *wi* of a pile *i* within a group of *n* piles is given as follows:

$$Wi = \sum_{j=1}^{n} Pav * S1 * \alpha ij. \tag{2}$$

where,
Pav = average load on a pile within the group;
S1= settlement of a single pile under unit load (i.e., the pile flexibility);
αij = interaction factor for pile *i* due to any other pile *j* within the group, corresponding to the spacing *sij* between piles *i* and *j*, can be written for each pile in the group, thus giving a total of *n* equations, which together with the equilibrium equation solved for the a rigid (non-rotating) pile cap, in which case all piles settle equally. In this case, there will be a uniform settlement but a non-uniform distribution of load in the piles. Generally the interaction factors (αij) is computed from boundary element analysis and plotted in graphical form. In numerical analysis closed-form expressions are used for the estimation of interaction factors which provided the ease in prediction of group settlement behavior using numerical techniques [3]. The expression for the interaction factor is given as follows.

$$\alpha = A(s/d)^B \tag{3}$$

where, A = 0.57 to 0.98
B = –0.60 to –1.20.

3.3 Load Transfer function for individual pile in pile group

The analysis method [13], proposed originally by Coyle Reese and O'Neil [12], is an efficient method to predict the load settlement relationship for single piles subjected to vertical load for its simplicity and capability of incorporating the nonlinear behavior of soils. However, due to the emission of influence of pile-to-pile interaction on the deformation of the soil surrounding the pile, it is rather difficult to be extended to pile-group analysis. In this work, a load-transfer function is developed based on the analysis of the aforementioned interaction between individual piles in pile group. Pile *i* , supported by a series of nonlinear springs along pile shaft or pile bottom to resist the vertical load P*i* at the pile top, is taken out to be analyzed separately, as shown in Fig. 2. The stiffness of spring at the pile bottom can be conveniently expressed using the following equation suggested [12].

$$k = 4 * \frac{G}{\pi r(1-\mu^2)} \tag{4}$$

Where, G is the shear modulus and μ is the poison's ratio of soil.

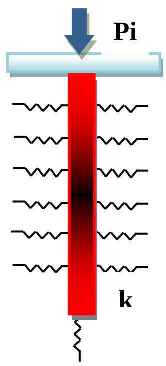


Fig. 2 Equivalent/single pile with soil represented as a spring for soil pile interaction analysis [25].

3.4 Pile interaction

In this study the main focus in given on the vertically-loaded pile groups consisting of *n* identical piles with the same length L, diameter d, pile space S, and elastic modulus E_P embedded in the homogenous soft soil. Generally, the resistance of the surrounding soils at the pile/soil interface, i.e. shaft frictional force named as τz, is mobilized once the displacement of the piles occurs. The displacement of pile groups at a given depth is different from that of single pile under the same load due to the fact that the reinforcing effect caused by the interaction between some neighboring piles confines the displacement of soils along piles. Therefore, it is necessary to consider the interaction between individual piles in calculating the settlement of pile groups. The soils are assumed to be a series of nonlinear springs attached along the pile shaft to simulate the behaviors of soils subjected to shaft frictional force. Obviously, the stiffness of springs, denoted as the ratio of the shaft frictional force to the displacement of soils, is relative to the interaction between individual piles in pile group.

According to the formulation [25] to estimate the shear- deformation mechanism of surrounding soils around piles subjected to the shaft frictional force τiz, the displacement of a point of soils is expressed as

$$\frac{dy}{dz} = PZ(y)/(E_p A_p) \tag{5}$$

Considering the interaction between soil and pile and pile to pile in the group the interaction factor is proposed as

$$If = \frac{E_s}{E_p} \tag{6}$$

Hence the Modulus of the equivalent pier is modified as *If *Eq* considering the fact that the soil has been entrapped between the piles in the group.

4. SCOPE OF THE PRESENT STUDY

4.1 Detils of the Finite Elemne model

Large ground storage is considered to be located in western part of India. A settlement analysis considering the soil pile interaction of marine deposits under static loading is carried out including the wind and gravity loading combination for the full and empty oil in the tank. The concrete oil storage tank of diameter 100m and height including free board is 40 m is supported by a initial set of pile foundation of diameter 0.4 m. Initially at a first iteration a pile is considered to be spaced on 3D to 6D and typical length of the pile is 10 m. General layout of the pile is explained in the Fig. 3.

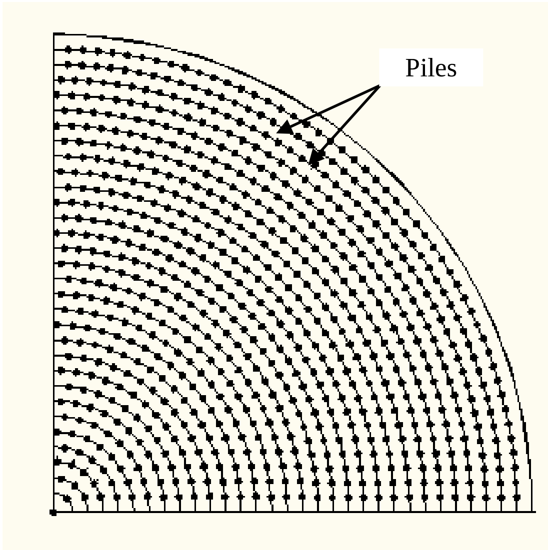


Fig. 3 General layout of the initial arrangement of the piles in a group.

Pile is provided with a uniformly thick pile cap of thickness 0.5 m. Fig. 4 explains the basic model geometry of the circular tank.

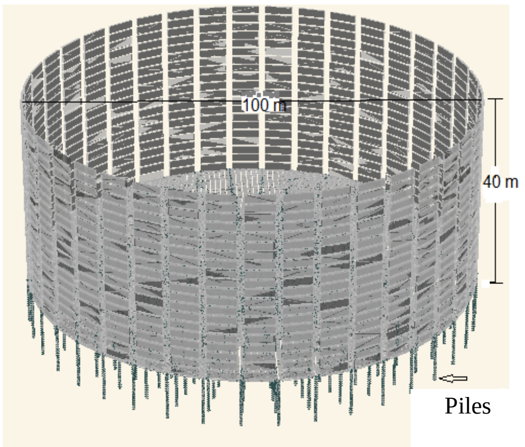


Fig. 4 Geometry of storage tank.

The tank is constructed to store oil of specific gravity 7.6 kN/m^3. Large ground storage is supported by a local marine clay deposits. Table 1 explains the engineering properties local deposit.

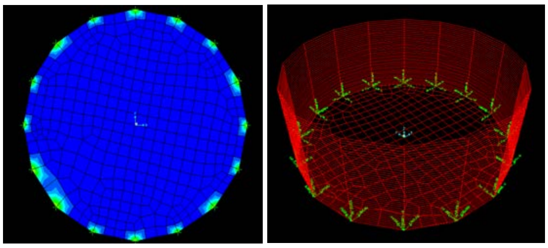
Table 1 Soil properties considered for analysis [1]

Parameter	Unit	Value
Unit Wt.	kN/m^3	16
Moisture Content	%	38

Shear Strength	kPa	10
Poisson's Ratio		0.35

The concrete grade is taken as M-30 for both tank and foundation system with the rebar reinforcement of Fe-415 steel grade.

The tank is modeled using Finite element software SAP 2000 using circular wall as a shell element and slab as a plate element and piles as a 1-D element along with the soil modeled as a linear spring to capture the realistic soil pile interaction scenario (Fig. 5).



(a) (b)

Fig. 5 Details of the finite element model for slab (a) and circular wall (b).

The analysis is carried out for considering single pile which takes load considering the group action and equivalent pier representing the pile group. The loading considered in analysis for is done for both empty and full condition of the tank. In this method it is needed to consider a correction factor for the equivalent pier as soil trapped between the piles reduces the overall stiffness of the pile group. The correction in the equivalent stiffness of the soil group is calculated. The interaction analysis is carried out for linear static condition and the results are compared with the analysis case which excludes the interaction for all pile configuration. The parametric study is carried out for the different pile to pile spacing, pile diameters, pile length and the different D/L (diameter to side length ratio) ratio for the above mentioned conditions of the tank.

5. RESULTS AND DISCUSSIONS

The settlement analysis is carried out for the huge water tank of diameter 100m and height 40m founded on the marine clay of very less shear strength using Equivalent Pier Method (EPM) and Interaction Factor Method (IFM) for different pile configuration of diameter, length and spacing considering the soil pile interaction including the linear spring with spring constant of equal to the soil coefficient. Fig 6a and Fig 6b shows the general settlement profile for the working load condition at the bottom node of the Equivalent pile for full and empty conditions respectively.

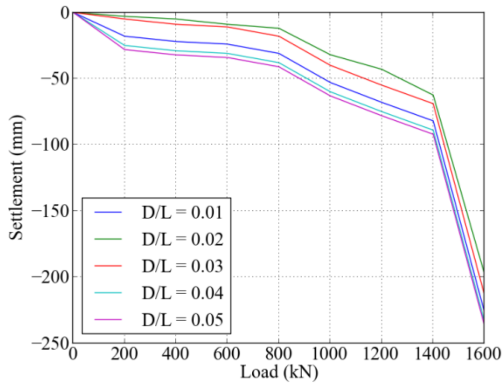


Fig. 6a.Settlement for tank by EPM (full condition).

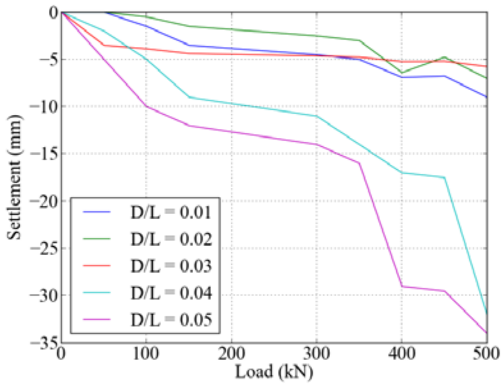


Fig.6b. Settlement for tank by EPM (empty condition).

The maximum settlement is calculated with interaction method considering the interaction between pile to pile using Eq. 2. The settlement for each pile is calculated manually considering the central pile as a reference pile and the maximum settlement for a pile group is estimated by performing a numerical summation of all settlement values obtained analytically.

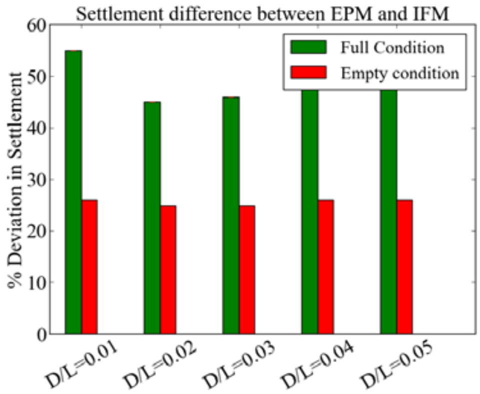


Fig.7 Percentage deviation in maximum settlement for critical load condition for EPM and IFM.

The settlement obtained by EPM and IFM is compared and the difference is shown in Fig. 7 for both empty and full loading conditions. The comparison for the maximum settlement has been carried out for both empty and full loading conditions.

6. CONCLUSSIONS

The present study has drawn the following conclusions.

1) The Maximum settlement of the huge fuel tank for empty and full both conditions are found to be permissible range.
2) The settlement is found to be less for the pile configuration with D/L ratio 0.02 and for other ratios settlement is found to 20% more for the empty loading conditions where as D/L = 0.04 is proves to be an good choice as it gives minimum settlement for the full loading condition with EPM and IFM methods. Thus the pile configuration diameter 0.4 m, total length 10 m and spacing 1.6 m is found to be a good combination for the least settlement criteria.
3) Equivalent pier method proves to be simple to get the settlement of the huge fuel tank but interaction is need to explicitly provided with the springs which is a the lengthy method with respect to the calculation.
4) Interaction factor method accounts for interaction between soil and pile with springs and the pile to pile interaction with the formulation of the interaction factors thus this method is found to be more precise as in pile group pile to pile interaction is one of the important criteria.
5) The settlement values was found to be more by the interaction factor method (IFM) as compared to the equivalent pile (EPM) method which leads to fact that pile to pile interaction also plays a vital role in settlement analysis.
6) The % deviation in settlement with EPM and IFM method is found to be more in the full load condition that the empty load condition of the tank which proves that the interaction between soil pile and pile to pile is more as the loading on the structure increases from the gravity load condition.

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