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"Settlement Analysis of Elevated Water Tank using PLAXIS 2D"

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Abstract - *Foundation is a structural part of a building on which a building stands. Foundation transmits and distributes its own load and imposed loads to the soil in such a way that the load bearing capacity of the "foundation bed" is not exceeded. When the soil at shallow depth is not capable of supporting a structure, deep foundations are required to transfer the loads to deeper strata. If a firm stratum is so deep that it cannot be reached by open excavation, the deep foundation will be adopted.It is well known from many studies on water storage tank foundation systems that stability and settlement are two main factors which may lead to the rupture or even the complete failure of water tanks.The magnitude of maximum settlement, differential settlement, the shape of the settlement dish are of more importance in engineering. To avoid problems caused by differential settlement of the tank bottoms, three checks are required: (1) procedure for estimating the magnitude of settlement; (2) procedure for estimating the likely shape of the tank bottom upon settlement; and (3) a criterion for judging the acceptability of the magnitude of differential settlement.The thickness of the granular pad, the number and configuration of piles, the load distribution among piles in the system to achieve the most effective foundation system are still being studied. One method to enhance the water tank foundation system and minimize the differential settlement is the use of pile foundation. For the case where shallow raft foundation can provide enough bearing capacity but the average settlement and differential settlement is excessive, piles are introduced in order to limit settlement*s

***Key Words*: Elevated water tank, settlement, PLAXIS 2D**

1. INTRODUCTION

It is well known from many studies on water storage tank foundation systems that stability and settlement are two main factors which may lead to the rupture or even the complete failure of water tanks. In comparison with the absolute magnitude of maximum settlement, differential settlement, the shape of the settlement is of more importance in engineering.The selection and design of tank foundations must consider factors which are quite different than for other types of structure like dynamic loading conditions , percentage load transfer to foundation.Piles are columnar elements in a foundation which have the function of transferring load from the superstructure through weak compressible strata or less compressible soils onto rock.Service reservoirs are structures used for storage of water and other types of liquids for serving various purposes.A large number of elevated water tank were damaged during structural dynamic properties hence dynamic behaviour of this structure has to be characterized effectively. Water tanks are the structures used for storing drinking potable water. In present scenario, there is much emphasis for water storage projects all around the world. Water plays predominant role in day-to-day life, so water storage is not a need it is necessary to store the water as it transfers the load to the foundation and hence it is necessary to analyse settlement behaviour of foundation.

1.1 PROBLEM STATEMENT

-Elevated Service Reservoir (ESR) of 21 lakh litres capacity is undertaken by Surat Municipal Corporation which is uner construction.
-Load spread in the dense sand layer is considered as 1:1. The load of the self weight of overlying dense sand layer is taken as a mass 2m high and 12m diameter. The dense sand layer overlying the soft soil and the bed layer is drained material while the soft soil layer is taken as an undrainedmaterial. -The number of piles is 37square piles (300x300mm) in a cross-section piles in a rectangular grid of 2 m centre to centre spacing.
-At loading pressure of 220kPa
-the soil parameter is as follows:
c'=0; ϕ'=22; m=1; pref=100kPa; MPa E=1.3MPa

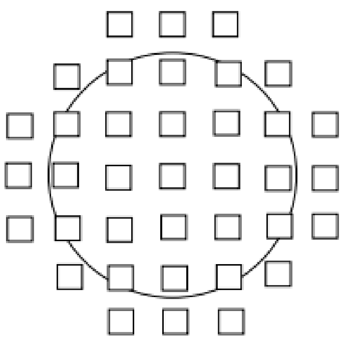


Fig.1. Plan showing pile configuration

1.2 OBJECTIVES OF THE ANALYSIS

The principal focus of this study is the quantitative characterization of the performance characteristics of the elevated water tank as determined by using finite element method PLAXIS 2D.

The objectives of present study are,

1) To demonstrate settlement characteristics of an elevated water tank through PLAXIS 2D software.
2)To identify whether Elevated water tanks should be competent of keeping the expected performance at given dynamic loading.
3)Identify the effect of elemental properties on foundation through geotechnical point of view with the help of analysis of model for intake capacity of 21 lakh litres carried out by using finite element software.
4)To analyse the test results to study the efficacy of pile foundation system with various elemental properties

2. SCOPE OF WORK

This project focuses on water tank foundation system. The finite element code PLAXIS 2D Foundation are used for the numerical simulation. The Surat Municipal Corporation undertaken the project of Elevated Service Tank of 21 Lakh litre capacity which is under construction. This report presents the study of dynamic performance of the elevated water tanks for given intake capacity. The effect of elemental properties on nodal displacement have been presented in this study with the help of analysis of model for same intake capacity is 21 lakh litre. Behavior of liquid storage tanks under dynamic loads has been studied as per Draft code Part II of IS 1893:2002. A FEM based computer software (PLAXIS 2D) used for analysis of tanks which gives the induced forces on tank systems. Draft code Part II of IS 1893:2002 which will contain provisions for all types of liquid storage tanks. Analysis of tank foundation by geotechnical point of view is carried out by using finite element software PLAXIS 2D. Then finally the values are represented in the form of tables and graphs.

3. LITERATURE REVIEW

Marr et al. (1982) stated that differential settlement is an important factor of tank rupture. Differential settlement is defined as the difference in vertical settlement between two points at the foundation-structure interface. Reasons leading to differential settlement could be non-homogeneous geometry or compressibility of the soil deposit, non-uniform distribution of the load applied to the foundation, and uniform stress acting over a limited area of the soil stratum. These causes exist with varying degrees of importance for a tank foundation.

Duncan and Doralie (1987) studied 31 case histories of tank settlement and damage to investigate which factors controlled the differential settlements of tank and the magnitudes of the differential settlement tolerance. They stated that the shape of the settlement dish, as well as the magnitude of differential settlements is important factors for the tank rupture caused by settlement. They classified the shape of settlement into 3 profiles. Profile A: The maximum settlement is located at the centre of the tank. This settlement profile could be seen from the case of flexible raft seated on deep soft soil. The depth of soft soil to produce this settlement profile depends on the factor of safety. Profile B: Settlement is relatively flat at interior and decreases rapidly toward the tank edge. This settlement profile could be seen from the case of flexible raft seated on shallower depths of soft soil. It also depends on the factor of safety Profile C: Maximum settlement is located about two third of the radius from the centre of the tank. This settlement profile could be seen from the case of flexible raft seated on a thin layer of soft soil. Different settlement profiles produce different amounts of distortion for the same magnitude of center settlement. The settlement profile A is the least severe with respect to distortion and profile C is the most severe.

Duncan et al. (1984). Significant findings of these case histories include:

Larger non-uniform settlement and tilting of the tank can lead to complete rupture of the tank. Either base shear or edge shear can be the critical failure mechanism, thus both should be evaluated. Thin weak layers near the surface have greater effects on the edge shear stability, whereas deep and thick weak layers have great effects on base shear stability. Either accelerating drainage or slow loading can be used to improve the strength of tank foundation on cohesive soils. A thin granular pad can improve edge stability but do not improve base stability. Tanks have been successfully stabilized after failure by: (1) reconstruction on pile foundations or repairing with very slow filling; (2) lifting the tank up, replacing soft foundation soils and constructing stability berms. All the case studies of this paper were with shallow foundations; theoretical method use to analyze the stability and estimate the settlement could not take in to account the influence of non-uniform soil layer.

Bayraktar et al. (2007) state "The finite element model of a structure is constructed on the basis of highly idealized engineering blueprints and designs that may or may not truly represent all the physical aspects of an actual structure." Utilizing a very limited blueprint of the elevated water tank, a 3D numerical model will be constructed and subsequently analyzed by a 3D modelling program capable of determining the modal properties of a structure. The 3D numerical model will be able to identify the frequencies and mode shapes for higher level bending modes. The initial results obtained from the 3D numerical model will assist in the design of the dynamic testing regimen. The number and location of the sensors used for the dynamic testing can be determined by evaluating the mode shapes identified by the 3D numerical model. This model will ultimately be validated using the results obtained from the field dynamic testing.

4. METHODOLOGY

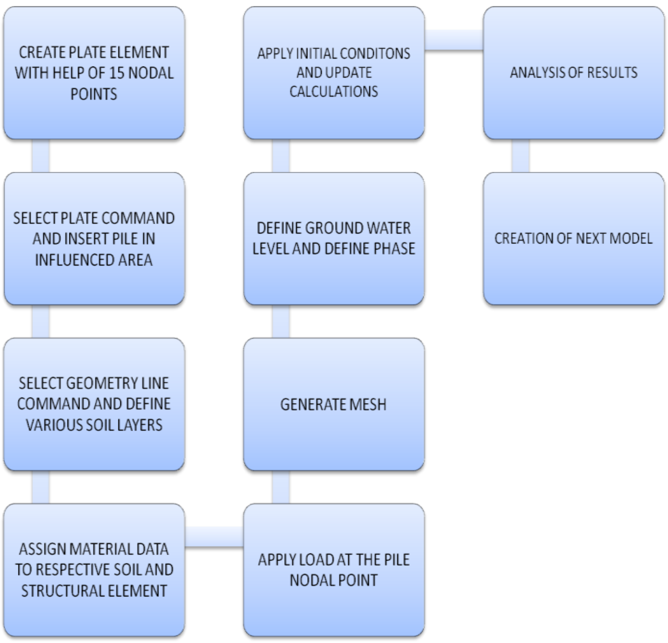


Fig -2. Flow chart showing procedure used for simulation and analysis of pile

4.1FINITE ELEMENT METHOD:

The finite element method (FEM) is a numerical method for finding fairly accurate solutions of partial differential equations as well as integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method.

For carrying out elasto-plastic analysis in this project, commercially available geotechnical software PLAXIS 2D is being used which uses Finite Element Analysis (FEA) for simulation of model.

4.2. PLAXIS 2D

PLAXIS 2D is a powerful user-friendly finite element package intended for two-dimensional analysis of deformation and stability in geotechnical engineering and rock mechanics. It is used worldwide by top engineering companies and institutions in the civil engineering and geotechnical engineering industries. Applications range from excavation, embankment and foundation to tunneling, mining and reservoir geo-mechanics. PLAXIS is equipped with broad range of advanced feature in model a diverse range of geotechnical problems, all from within a single integrated software package.

PLAXIS uses predefined structural elements and loading types in a CAD-like environment. This empowers the user with the fast and efficient model creation, allowing more time to interpret the results. The user-friendly interface guides the user the efficiency create model with the logical geotechnical workflow in cont. The versatile output programmed offers various ways to display forces, displacements, stresses and flow data in contour, vector and copied from tables or via python-based scripting for further processing purposes outside of PLAXIS. The curve manager enables graph creation, plotting various results type from available calculation data.

4.3. Soil Layers

The soil stratigraphy can be defined in the soil mode using the borehole feature of the programme. Boreholes are located in draw area at which the information on the positions of soil layer and the water table is given. If multiple boreholes are defined the programme will automatically interpolate between borehole and derived the position of the soil layer from the borehole information.

Groundwater and pore pressure play an important role in the soil behaviour, so this requires proper definition of water conditions. This definition of water condition can also be done with the creation of borehole.

A fixed end anchor is a point element that is attached to a structure at one side and fixed to the world at other side. Fixed end anchors can be used to simulate piles in a simplified way, that is without taking into account pile soil interaction. Alternatively, fixed end anchors can be used to simulate anchors or props to support retaining walls.

4.4. Embedded piles

An embedded pile is a pile composed of beam elements that can be placed in arbitary direction in the subsoil and that interacts with the subsoil by means of special interface elements. The interaction may involve a skin resistance as well as a foot resistance. The skin friction and the tip force are determined by the relative.

4.5. Interfaces

Interfaces are joined elements to be added to plates or geo-grids to allow for a proper modelling of soil structure in the action. Interfaces may be used to simulate, for example the thin zone of intensely sharing material at the contact between a plate and the surrounding soil. Interfaces can be created next to plate or geo-grid element of between to soil volumes.

4.6. Linear Elastic Model

Two elastic stiffness parameters, Young's modulus, E, and Poisson's ratio, ν, are used. This model is the simplest material model in Plaxis which employs Hooke's law of isotropic linear elasticity. The linear elastic model is seldom used to simulate soil behavior. It is primarily used for stiff structural systems installed in the soil, such as the piles, floor etc in this thesis.

4.7. Mohr-Coulomb Model

The elastic perfectly-plastic Mohr-Coulomb model is most widely used as the first approximation of soil behavior. Five parameters describing this model are Young's modulus, E', and Poisson's ratio ν' for soil elasticity; cohesion, c', internal friction angle, ø' for soil plasticity, and dilatancy angle, ψ'. Plasticity is associated with the development of irreversible strains. A yield function, f, is introduced as a function of stress and strain in order to evaluate whether or not plasticity occurs in a calculation. A yield function is often presented as a surface in principal stress space. Mohr-Coulomb yield condition consists of six yield functions representing six stress planes when formulated in terms of principal stresses.

4.8. Drained behavior

This setting is used for the case of dry soils and also for full drainage due to a high permeability (sands) and/or a very slow rate of loading in less permeable soils. This setting may also be used to simulate long-term soil behavior without the need to model the precise history of undrained loading and consolidation. Using this setting no excess pore pressures are generated.

4.9. Undrained behavior

This setting is used for a full development of excess pore pressures. Flow of pore water can sometimes be neglected due to a low permeability (clays) and/or a relatively fast rate of loading in higher permeability soils.

4.10. Mesh Properties

PLAXIS allows for a fully automatic generation of finite element mesh. The generation of the mesh is based on a robust triangulation procedure, which results in "unstructured" meshes. The mesh generator requires a general meshing parameter which represents the average element size, le, computed based on the outer geometry dimensions (xmin, xmax, ymin, ymax)

5. ANALYSIS OF PILE IN PLAXIS 2D

To facilitate data interpretation, the 37 piles are classified into 8 pile types: named as A, B, C, D, E, F, G and H based on symmetry. The center piles, henceforth, will be mentioned as pile types A, B and C, edge piles as piles D and E, outside piles as pile types F, G and H. the load spread in the dense sand layer is considered as 1:1. the load of the self weight of overlying dense sand layer is taken as a mass 2m high and 12m in diameter. Test model was set up with piles in a rectangular grid of 2 m center-to- center spacing. In all analysis. The number of piles is 37. The water tank diameter, which is 9.5m was 16 - sided-polygons with mean diameter of 9.9m in the FEM model due to the nature of mesh generation model tests aims to investigate the effect of thickness of dense sand layer to efficacy of the pile foundation system, load distribution in pile group, load transfer to soft soil, maximum settlement, differential settlement.

-The dense sand layer overlying the soft soil and the bed layer is drained material while the soft soil layer is as an undrained material.

-The model is analyzed perfectly undrained with no soil consolidation under the short-term load test.
-The pile is modeled as solid element with outside interface elements connected to the soil elements.
-the pile is installed along 8 pile types to obtain the axial load distribution along the piles.
-To avoid difficulties in mesh generation of the FEM model, the 9.5m diameter water tank was modeled as 9.9m diameter polygon with 16 short sides.
-Floor element was used for the bottom of water tank simulating 50mm thickness of steel.
-The boundary can be considered as on rollers. Because the standard boundary condition in Plaxis 2D is fixed, the size of the FEM model is taken as 40x40m. The number of nodes and elements are slightly different in different models.

-the soil parameter is taken into analysis as follows:
c’=0; ϕ’=22; m=1; pref=100kPa; E=1.3MPa
Loading increment in the model is 20kPa up to pressure of 220kPa except for the preliminary test tank load To check the appropriateness of soil parameter used in the FEM model compared to the real soil used in the model. For the purpose of study beyond the model data, most of the FEM models were loaded to a maximum pressure of 400 kPa with loading increment of 50kPa.

Loading stage

All models were loaded up to 400 kPa with increments of 50kPa and one stage loading of 220kPa was added in order to compare with the model test results.

Actual steps followed in FEM model is given below:

Open PLAXIS 2d and create new project in this step, we selected 15 nodal points and decided the dimension of influence area.

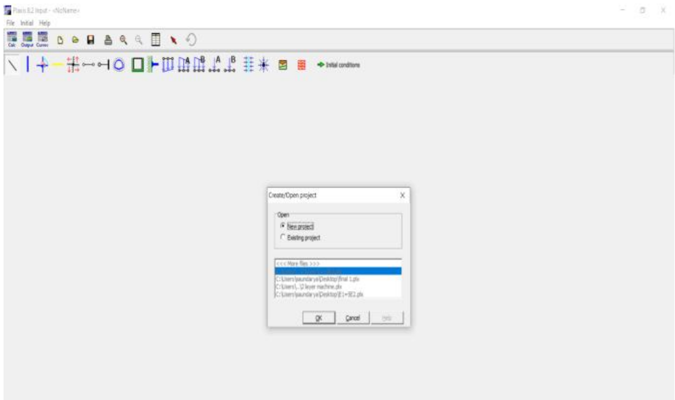


Fig-2.1: Window of new project

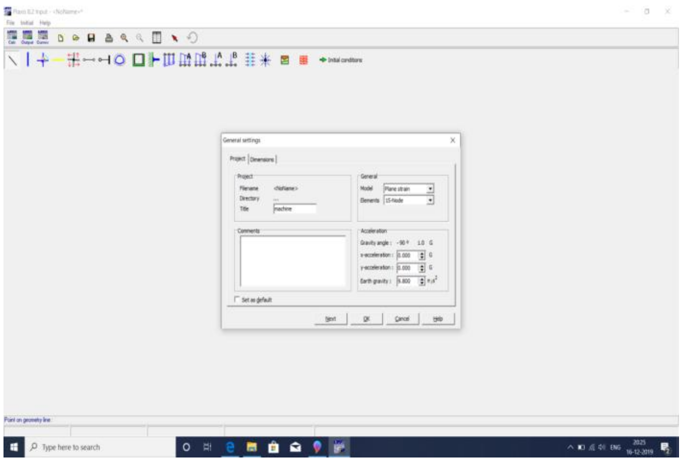


Fig-2.2. Selection of 15 node plain strained model

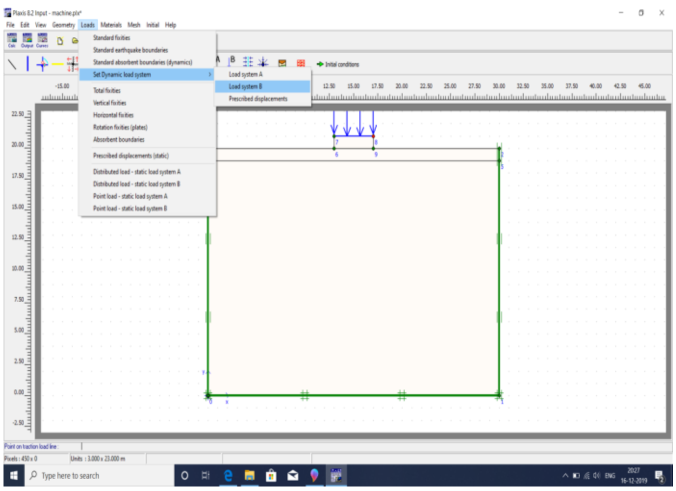


Fig-2.3. Application of load

Table .(1) Material properties.

Material	Material properties	Unit	Sand
Soil	Unit weight, γ	(kN/m^3)	18.5 **
	Young's modulus, E	(kN/m^2)	35000 **
	Poisson's ratio, ν	-	0.32 **
	Friction angle, φ	(°)	35 **
	Cohesion, c	(kN/m^2)	1
	Dilatancy angle, ψ	(°)	5
	Horizontal permeability, k_x	(m /sec)	10^{-4} **
	Vertical permeability, k_y	(m /sec)	10^{-4} **
Foundation	Young's modulus of concrete, $E_{concrete}$	(kN/m^2)	2×10^7 *
	Unit weight of concrete, $\gamma_{concrete}$	(kN/m^3)	24 *
	Poisson's ratio of concrete, $\nu_{concrete}$	-	0.15 **
Machine	Weight of machine, $W_{mach.}$	(kN/m^2)	10 *

Table -1: Material properties

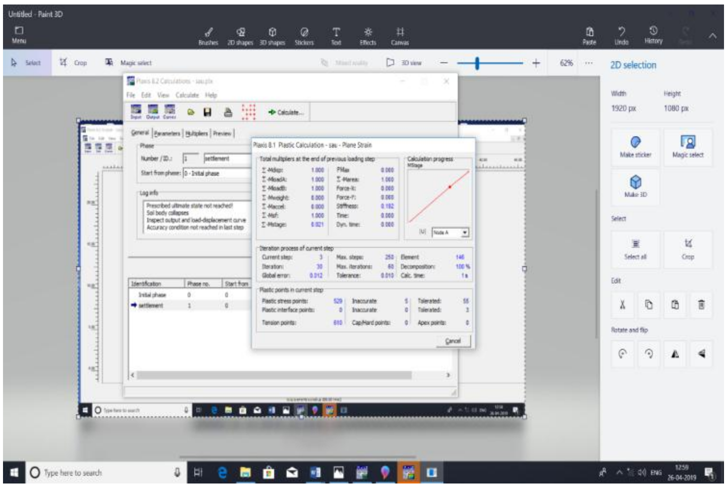


Fig-2.4. Output calculations

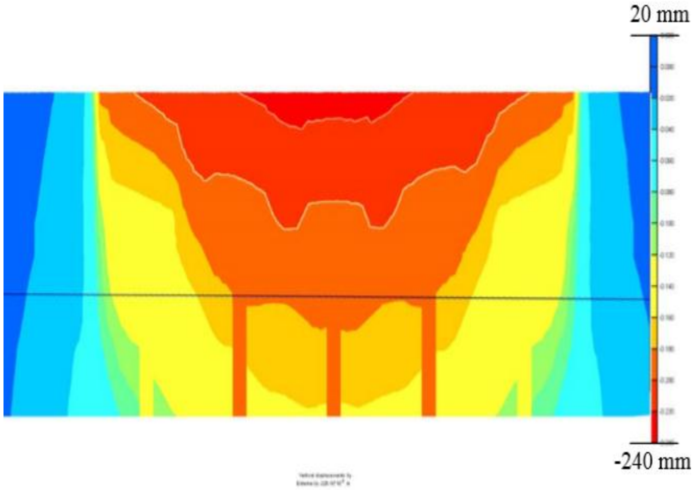


Fig-2.5. Vertical displacements at pressure of 400kPa– cross section

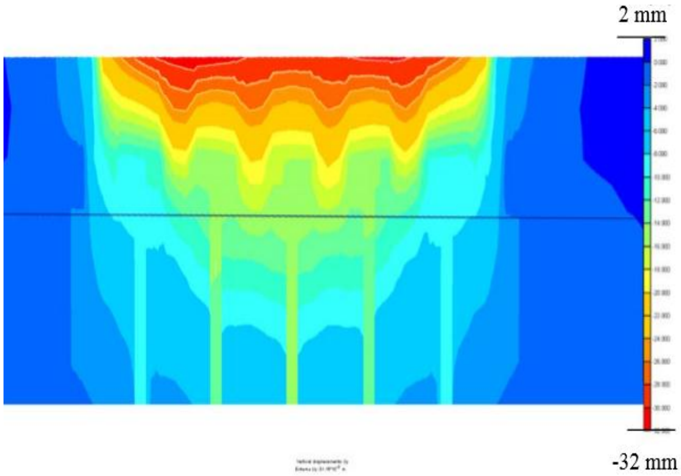


Fig-2.6. Vertical displacements at pressure of 220kPa

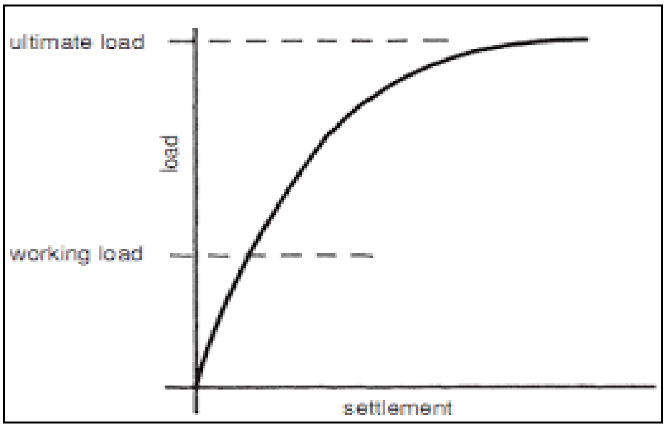
6. RESULTS AND DISCUSSION

The findings can be summarized as follows:

1)Loading increment in the model is 20kPa up to pressure of 220kPa. For the purpose of study beyond the model data, most of the FEM models is loaded to a maximum pressure of 400 kPa with loading increment of 50kPa.

Some cases showed failure before reaching 400kPa and others needed refinement of the loading increment because the maximum number of iterations is not enough for convergence. To compare with the test results, all the load distribution and load transfer curves were evaluated at the loading of 220 kPa.

At 220kPa loading pressure, the model with dense sand bed layer gives a settlement of 30 to 31.57mm.



Graph 1. Load Vs Settlement

-At 220kPa applied pressure, about 81% of the tank loads have been transmitted to the piles based on dense sand. After the tank load exceeds 200kPa, the percentage of load carried by the piles decreases.

2) From the given configuration of piles, we analyzed that as the load increases, the rate of load distribution to the centre piles increases faster than the load transfer to the edge and outside piles. From the comparison of results, it has been found out that, installing high capacity piles at region with maximum load concentration and reinforcing the rest of the raft with medium capacity piles have the most important effect on significantly reducing maximum settlement and the differential settlement. From all the possible diameters, it is best to provide larger diameter piles in the interior region to reduce the maximum settlement and the differential settlement.

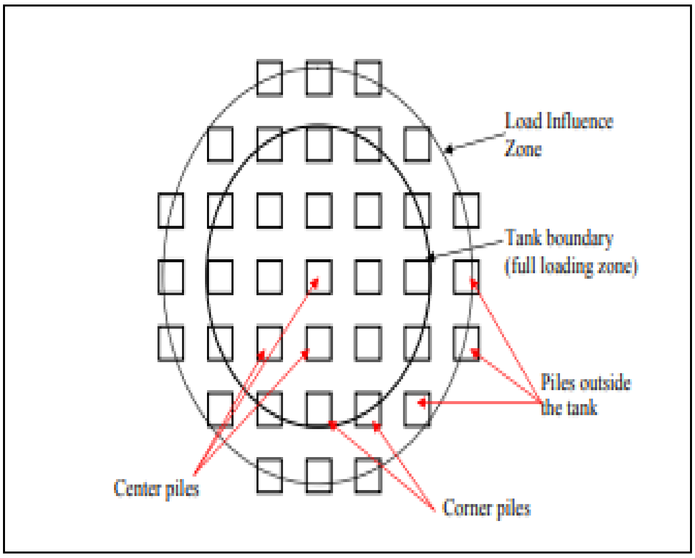
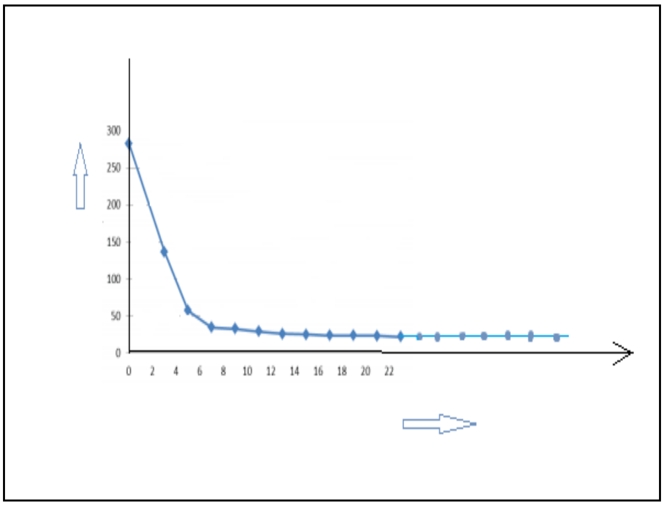


Fig-2.7. Configuration of pile group

3)The addition of even a small number of piles decreases the settlement of pile foundation but after reach a certain number of piles, increasing the number of piles showed the settlement tends to be constant. The addition of piles is to reduce the settlements to an acceptable amount.

-For a given no of piles, settlement showing the constant result.



Graph 1.1. No. of piles Vs rate of settlement curve

7. CONCLUSION

- Thus, from our study on settlement characteristics of pile foundation using Plaxis-3D following points can be concluded,
- The demonstration of settlement of the elevated service tank and comparison of various foundation parameters by geotechnical point of the view is done effectively by PLAXIS 2D software.
- We can conclude that the maximum settlement is at the centre of tank as axial forces carried by the centre piles are much higher when compared to the corner piles
- The results obtained; it is advisable to provide piles with different diameter than with equal diameter irrespective of soil type.
- It can be seen that FEM described not only load settlement but also the shape of the settlement; not only the load distribution between the piles but also the load transfer from pile to each soil layer is important for stability of foundation of elevated service tank.

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