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Research Article

Foundation design of an Overhead Water tank: A Case study

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Abstract

Background: Foundation is known as the base structure of a structural element that allows transferring a load of the superstructure to the soil. A shallow foundation is provided for low-rise buildings. Water tank is a high-rise structure that is used for storage and supply purposes of water, for more efficiency elevated areas were considered for gravity flow of water. The Foundation of water tank can is designed as per site condition and load capacity of the tank. A weak foundation led to extreme damage to the tank causing loss of money, inconvenience caused to people.

Scope and approach: This case study shows that the foundation of a water tank can is designed either with spread or raft foundation that depends upon the load-bearing capacity of the soil, lesser will be bearing capacity more accuracy, and effective design needed. The study of two different sites and soil conditions is shown.

Key finding and conclusion: The design of the foundation is done manually using IS code. If the bearing capacity of the soil is adequate spread footing can hold, if not raft or mat footing is provided. Foundation design mainly depends on the soil capacity and types of soil.

Keywords: Foundation design, spread footing, Raft or mat footing, Bearing Capacity, Overhead water tank (OHT).

1. Introduction

All engineered structures constructed on the earth's surface need an anchorage element called the foundation. It is a part of the structural member that supports and anchors the overall load and directly transfers to the ground. Vertical loads or concentrated loads of super structure are transmitted to the ground beneath the foundation [1]. Foundation is generally considered as shallow and deep. A shallow foundation has a depth by width ratio less than or equal to 1 ($D/B \leq 1$), while a deep foundation may have a ratio greater than 1. A shallow foundation consists of spread footing, raft or mat footing, combined footing, and strap footing. Spread footing support directly column or wall and distribute the loads directly into the ground. It can be constructed in any condition if the soil bearing capacity is adequate for the applied load [2]. When two or more column lines were supported over a large concrete slab is called a raft or mat foundation. They can be rectangular, trapezoidal, or circular. Raft foundations are constructed in case of very low "soil bearing capacity" or when spread or combined footing is unable to retain the structure load [3]. The bearing capacity is the potential of soil to resist or support the load that is applied through the structure. Shear failure and excessive settlement are the problems that occur due to low bearing capacity. Structure such as liquid storage tank (overhead water tank) and mat over soft clay are more susceptible to base shear [2]. Due to the high rise in population and due to unavailability of safe water Government of India (GOI) has launched a scheme named “JAL JEEVAN MISSION” to provide clean and adequate drinking water through individual household tap connections across India, for this numerous overhead water tank were constructed throughout the cities and villages of India according to locality population [4]. The water tank can be classified on basis of material and basis of location. This case study includes an RCC overhead water tank. The overhead water tank has many advantages as it can store a huge amount of water from the channel or any source (submersible pumps) [5]. Design of overhead water tank shall be based on worst possible load combination and type of staging should be decided before design. Staging of the tank can be chosen as per site and availability conditions. The economical design of OHT depends upon the following points- maximum height of the water, the height of staging, soil bearing capacity of foundation, the capacity of the tank, and other site conditions [6]

1.1. Literature Review

A literature review is completed after the study of various researches and article related to the foundation design of OHT that helps in the case study of two different tanks of the same capacity but having different site conditions. From a survey of the site to design the tank manually and perform soil tests for the appropriate foundation. This helps to reduce the risk of foundation failure and make the project more economical.

Chawlaet al,[5], economic criteria are also the main factor in any project, while strength criteria can never be compromised. In the same way, this journal on the economical design of intze water tank for wind speed in India help in knowing the factors affecting the foundation of the tank with high wind intensity. In elevated tank base shear obtained by manual dynamic analysis at tank full condition increase by 6.5% and by software, it increases by 0.1%. And at the end, he concluded that weight inside and outside the tank is different and fluctuating in nature, also contextual investigation can decrease or resolve the cost of the project. [5]

Chowdhury and Tarafdar,[13], all the water tanks designed on the ground base are on the assumption of fixed base consideration. According to this paper by calculation using Housner’s formulations and Lagrange’s theory, using this equation on mathematical model is designed for dynamic soil-structure interaction response that acts on the water tank. This method is more accurate, closer, and more efficient. He concludes that assumption taken into account in previous years was the main cause of damage of OHT during an earthquake because fixed base consideration is valid for bed-rock, for the rest of the soil base the response of earthquake gets to rai. Later it is seen that structures on bedrock undergo a very small amount of settlement and displacement. [13]

Latha,[14], this research is based on the comparison between the shapes of water tanks -rectangular and circular. The tank was manually designed using IS code references and also tank was modelled and analysed using ETABS software, modelled was analysed under dynamic behaviour to resist lateral loads while the design was based on the working stress method. Load combination was applied using IS code. Parameter like story drift, displacement, deflection, stiffness, story shear, base shear, steel requirement, etc. comparison to this above parameter results show that a circular water tank is suitable for large capacity and more economical than a rectangular tank. Only base shear generated in the circular tank is greater than the rectangular tank, while all other parameter gives less value for stiffness, story displacement, steel required, etc. [14]

Dutta et al,[15], soil-structure interaction with seismic activity is more vulnerable. Dynamic behaviour of R/C elevated tank have been studied mainly shows that column and wall of shaft staging of the tank are susceptible to tension, mainly in empty condition. The analytical formulation developed in terms of lateral stiffness of system during an earthquake, while handily formula can be used in design office to resist soil-structure interaction. An approximate formula for lateral stiffness may be conventionally used in a standard procedure for the calculation of seismic base shear design. Dimension of the shaft can affect and resit the seismic activity as seen in Bhuj (2000) and Kashmir (2005).[15]

Chaduvula et al,[16], fluid-structure -soil -structure affects the water tank, the fluid-structure interaction causes hydrodynamic behavior, and soil-structure interaction causes rocking motion. She took a 1:4 scale model for her study and by enforcing the earthquake excitation of 0.1g and 0.2g of acceleration with increasing the angle of rocking motion. She concluded that based shear and base moment increases with an increase in acceleration of earthquake but decreases with an increase in angular motion. Sloshing of water causes nearly no rocking motion. The nonlinearity was observed when impulsive pressure decreases with an increase in acceleration. Pressure variation also increases with the increase in height of the tank.[16]

Jabar and Patel,[17], elevated tanks are damaged and may collapse during earthquakes because of improper knowledge regarding proper behavior of supporting system. The tank was evaluated with various fluid levels using SAP2000 software. The lateral and cross-bracing system was evaluated in this paper, for lateral response water mass have been taken as impulsive and convective using Westergaard's added mass approach. The response includes the base shear, overturning, and roof displacement was observed and the results were compared. The result from the software shows that structure response affects the structure. Tabular data from TABLE II shows the adverse effect of the earthquake on the tank is in tank full condition, hence the bracing provided shall be well enough to resist the dynamic activity.[17]

Soni et al,[18], water tanks were constructed by proving a certain foundation depth that somehow denotes the cost analysis of the project. He took an intze type water tank with different depths of soil above footing as 800mm, 1000mm, 2000mm till 7500mm and 7775mm. STAAD Pro software (V8i) version is being used for analysis purposes. He concluded that foundation cost decrease by 8.11% by increasing soil depth by 1.0m but cost gradually increases up to 3.0m by the rate of 37.07% and drastically changes up to 98.7% when reaching 7.7m.[18]

Mhamunkar et al,[19], most of the Indian population live in rural areas where domestic water availability is very less for that OHT was constructed for proper supply of water. He designed the tank of 1000cum. manually using IS code IS 3370(2009) and IS 456:2000, he also analyzed it by using STAAD Pro software. He concluded that high capacity and flat bottom tanks need large reinforcement in-ring beams to resist the stresses, to minimize intze tank are adopted.[19]

McKeen and Johnson,[20], a raft or mat foundation requires analysis when constructed over soil that swells and shrinks easily (black cotton soil). Same as Case II water tank has been constructed on black cotton soil. The rational method was adopted for the calculation of active zone depth (z) and edge moisture penetration distance (Lm). Their data had been collected by their 18-months observation of airport pavement over expansive soil and all climatic parameter for raft foundation were kept in mind. Results show that soil moisture variation can be calculated by simple diffusion equation using field determined coefficient while suction-based parameter can be used to calculate diffusion coefficient. They also conclude at the end that the climate cycle is a key role in the calculation of moisture content of active zone depth. Weather and drainage condition may change the values during observation.[20].

Table-1 Dynamic load and soil-structure interaction effect on OHT as per literature review

S. no	Parameters	Methodology	Earthquake on OHT	Key Findings	Reference
1	• Economical design • With Wind speed	A broad review of all past reviews related to the water tank and by finding the literature gap.	When it comes to strength criteria every critical combination was studied and hence no effect of the economy directly on tank designs.	• The finite element method is the best way to know the specific pressure. • Tank weight inside and outside fluctuates.	[5]
2	• Dynamic Soil-structure interaction.	Mathematical approach by assuming a rectangular tank resting on the ground.	Tank having a fixed base (bedrock) will undergo less settlement than base assumed to be fixed (strata base).	• Moment and shear get increases in soft soil deposit. • The assumption of taking a fixed base had caused damage to the tank in past years.	[13]
3	• Storey drift and stiffness • Base shear • Hoop tension • Deflection • Storey displacement • Area of reinforcement	ETABS software was used for analysis and comparison among rectangular and circular water tanks.	The dynamic effect causes story drift, development of base shear, hoop tension, stiffness, etc. parameters result gives better result for circular tank	• The circular water tank is more suitable for large capacity and is more economical than the rectangular overhead tank. • Steel area and hoop tension are greater in the circular tank.	[14]
4	• Dynamic behavior • Soil-structure interaction	By using analytical formula and validating it by rigorous finite element method analysis on small scale.	The lateral period and torsional to lateral period ratio will increase if soil-structure interaction is less during an earthquake.	Soil structure raises the value of the lateral period Shaft staging reduces the torsional lateral period for small radii foundations.	[15]
5	• Fluid-structure • Soil-interaction	Steel overhead tank model of scale1:4 been investigated by performing an experiment on a	Impulsive base shear and base moment were increased due to the increase in the earthquake. While convective shear and	Tank with different pressure along with height because of excitation increase which leads to increase in the	[16]

		shake table in Chennai by giving acceleration of 0.1g and 0.2g	moment decrease with angular motion.	acceleration with time.	
6	• Radial bracing • Cross bracing • Dynamic loads	SAP2000 software was used for the analysis purpose of the tank under seismic conditions.	Base shear, roof displacement, and overturning parameters have the highest value in Imperial valley during any condition of the tank either empty or full.	Results show that not only tank full or empty tanks are critical, half-full tanks are also critical as an overturning moment for normal staging.	[17]

Bhattacharya et al,[21], soil is the key factor for the designing of foundation loose or flexible soil become more dangerous when dynamic behaviour is taken into account. The overall stiffness decreases if the soil is compressible. While the natural period of the system may get change due to seismic torsional response. This type of system resting on a raft needs detailed investigation, he studied the variation by changing soil condition and building type. The natural period to fundamental torsional to lateral period ratio and conclude the variation. Due to flexible soil, the response spectrum increases, and a building may be seismically vulnerable if this effect is not accounted for during design. Also, he stated about raft foundation building that all the building frames having stories of more than 3 need to be increased by a factor of 1.1 [21]

Loukidis and Tamiolakis, [22], mat foundation of the building is done by performing static analysis of slab resting on vertical uncoupled Winkler spring. The assumption of uniform modulus of soil throughout the mat leads to an inaccurate result. This Winkler spring method is the same as the finite element method that treats soil continuity. After performing his analysis, he concluded that at the center 60% of the stiffness of the mat is constant which is nearly equal to 0.55 times the spring constant. Closer to edge spring constant increase nearly 1.5-3 times. Also, the assumption of linearity of soil for mat foundation is considerable because of more shearing near to edges.[22]

Shen et al,[23], analysis of rectangular raft done on elastic half-space under vertical loading by the principle of potential energy. By both analytical and numerical methods for the analysis of raft foundation viewing its stress variation under it. He led his method by thin-plate acting as raft slab. His result after calculation shows the satisfactory result by comparing both analytical and plate bending finite element methods which show a simplified result that can be simply performed before the design of raft foundation. Although the finite element method is tedious and more economical than the elastic half-space method.[23]

Livaoglu and Dogangun,[24], foundation has given in every building bears some seismic load. This paper investigates the effect of the foundation of elevated fluid storage tanks having six different soil types using computer software ANSYS. Method of finite element method was adopted, he considered that tank is in full condition with any liquid (water) and at the end, he concluded that tank roof displacement was affected significantly by soft soil; while the effect was lesser in stiff soil. The sloshing effect on the embedded foundation is negligible. [24]

Table- 2 SBC variations and effect on the foundation of OHT as per literature review

S. No	SBC	Location	Methodology	Effect on OHT/other structure	Key finding	Reference
1	150K N/m^2	Computer-based model.	Analysis of OHT using STAAD Pro software by the varying height of footing soil.	The cost of OHT increases adversely after 3.0m height.	For the greater value of SBC 2-3 m of footing, depth is most economical.	[18]
2	196K N/ m^2	Pehul Nagar, Ambernath, Maharashtra.	Analysis and design of an overhead water tank using STAAD Pro	The tank in both manually and by software gives safe results, but an overhead circular tank with higher storage capacity needs large reinforcement for the ring beam.	Excess reinforcement requirements can be reduced by giving conical bottom or spherical bottom.	[19]
3	100K N/ m^2	Airport pavement of Dallas, Houston, San-Antonio, Jackson Gallup, Denver	Mitchell (1979) had developed a method that uses the method of suction of soil on expansive soil that gives the variation at different sites.	The 18-month investigation for the same no of frequency (n) max suction went up to 9.84KPa that comes under extreme conditions.	Foundation shall be designed for all climatic conditions throughout the year. Also, drainage conditions and soil structure can be a key role.	[20]

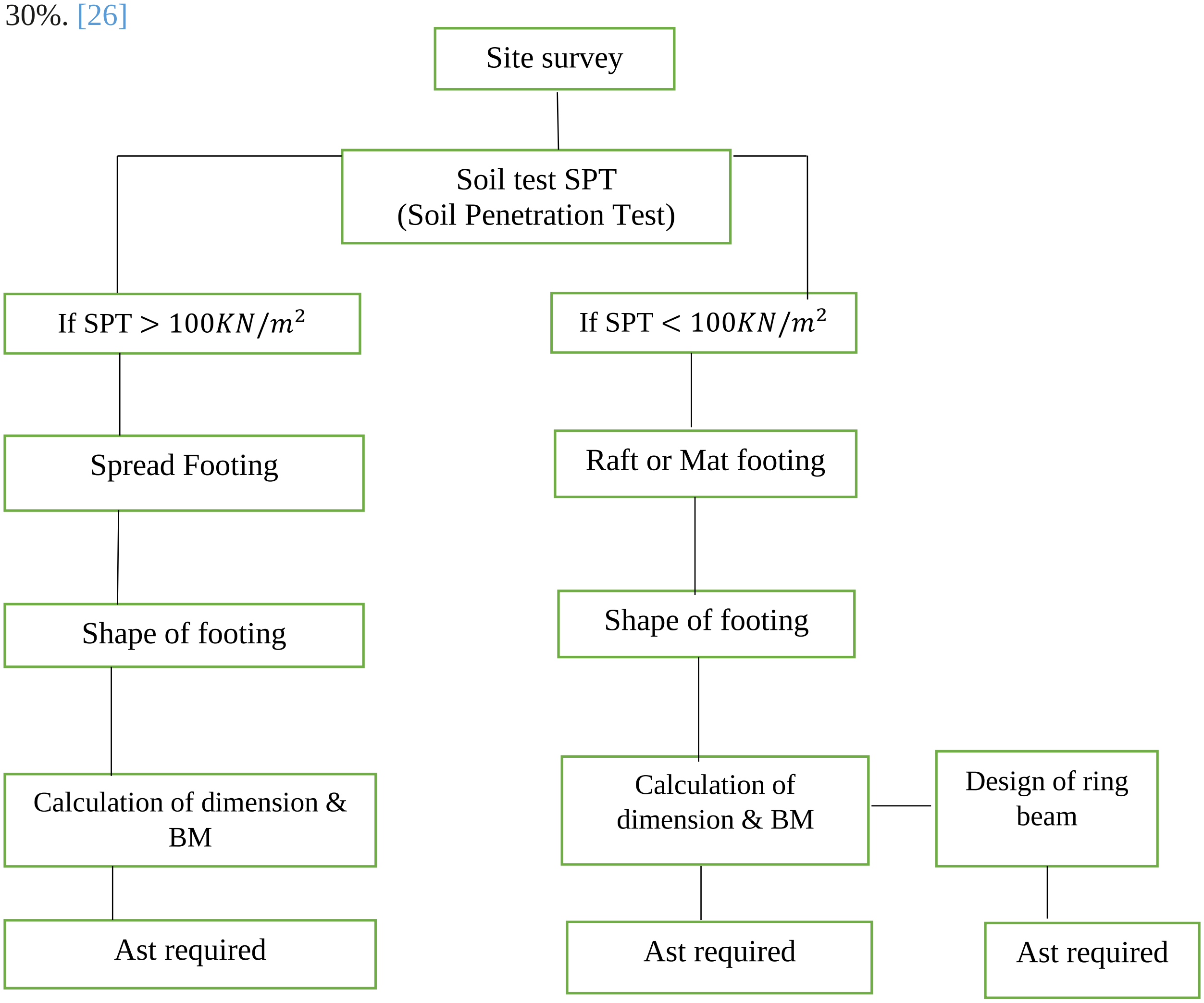
Zhang et al,[25], a circular raft foundation and clay being investigated to support the load and resist from failure like a shear failure, punching failure, etc. These all load has been transferred to soil and hence soil condition need to be checked for long term cases (Design life 50 years). The calculation is done by using the fractional Maxwell model, considering it as an analogous elastic problem so complex load cases can be considered in the calculation. Mintage-Laffler function and Bessel function had been used for calculation of deflection, bending, and reactions of a foundation constructed over clay deposit. Later these values were compared by Nassar's solution, with a special case taking α=1. This result concludes that primary and secondary consolidation concerning settlement curves indicates that ground settlement can be evaluated more accurately by taking α=1rather than by taking a single coefficient of viscosity. [25]

Jahangir et al,[26], shrinkage and swelling of soil denote an expansive soil. During drought, conditions soil shrinks completely cause settlement of the structure. To find out the solution a soil-structure interaction model has been taken and settlement has been calculated according to structure stiffness and hydromechanical property. The Monte Carlo approach has been taken for uncertainties of soil. Their result shows higher the structure stiffness lesser will be a final settlement, also final settlement can be minimized by soil-structure interaction. While the second parameter of hydromechanical property influences the parameters like foundation depth, stiffness, and expansive soil(c). Particularly an increase in depth of foundation from 0 to 45cm can decrease the amplitude of final settlement up to 60% during drought. Monte Carlo approach of group building considering average settlement by uncertainties of ±10%, 20%, and 30%. Average values of the settlement were evaluated as10mm with an increment in the standard deviation of 1.2 to 2.3 mm when uncertainties increase from 10% to 30%. [26]

Key Finding from review

i. Moment and shear get increased by the presence of soft soil.
ii. Circular water tank is more suitable for high capacity.
iii. Greater the value of SBC economical depth of footing will be in between 2-3m.
iv. Design of foundation shall also be done on basis of climatic condition and soil.
v. Raft foundation is more stable from the center than the edges.
vi. More will be embedment ratios more stable will be the structure.

Greater will be stiffness smaller will be the differential settlement.



1.2 Research significance

The overhead water tank is mainly used for providing safe and adequate water for household and other industrial purposes (drinking, fire suppression, irrigation, etc.). Water towers create a pressure of 1 kPa per 10.2 cm. The capacity of the building may vary from 40KL to 2000KL as per requirement and population. These high rises structure with higher dead load is more vulnerable to seismic activity, their base needs to be strong enough to hold the structure without settlement and prevent the lateral moment of the structure. So, the design adopted and type is more important to resist the dynamic loading as much as possible.

Table- 3 Type of foundation and selection criteria for structure as per literature review

S. No	Types of foundation	Parameter	Methodology	Effect of foundation on structure	Key finding	Author
1	Raft foundation	• Types of soil • No of stories • No of bays • Ground frequency • Stiffness ratio of the column to beam	The base had been prepared by filling brick considering fixed support and others with a flexible base.	Flexible soil base is vulnerable to seismic activity and lateral period and the ratio of lateral to torsional changes with intensity.	For raft foundation having low rise building factor of 1.1 can be considered.	[21]
2	Rectangular mat foundation	• Soil elastic property • Slab geometrical characteristic • Column load configuration	A rectangular slab act as a mat foundation will be analyzed by the Winkler spring stiffness (Ks) method. And Finite method has been used for back-calculation.	Ks value calculated reversely by FEA with rigid base show structure is stable 60% at the center. SF diagrams were adversely affected by deduced spring stiffness.	The shear at the center of the mat is constant (60%) which allows it to hold the heavy load of the structure.	[22]
3	Rectangular raft foundation	• Vertical loading	Rectangular raft analysis on elastic half-space by using the	Plate bending finite elements were modeled that represent the structure	By raft using as plate bending finite element, it does not require	[23]

			principle of minimum potential energy.	foundation which will be easy to calculate the deflection of the raft, soil pressure, and bending.	discretization of the raft itself.	
4	Foundation of the tank embedded on seismic behavior	• Base shear • Roof displacement • Sloshing displacement • Lateral displacement	ANSYS software has been used along with a finite element model with viscous boundary.	The Foundation of the tank becomes more effective as the soil gets softer. The sloshing effect can be ignored for design	Greater will be embedment ratio, the water tank will be more stable.	[24]
5	Circular mat foundation	• Deflection • Bending • subgrade reaction	Using Mittag-Leffer function long-term effect of the circular foundation over clay.	The circular mat foundation will be affected by the climatic change because of the presence of clay under it.	Comparison with Nassar's solution implies that taking α=1, will be more efficient for the calculation of primary and secondary settlement.	[25]
6	Isolated foundation	• Expansive soil • Drought condition	A coupling of the hydromechanical method was used for the state surface approach.	Drought conditions of expansive soil led to shrinkage of soil that will allow settlement of structure, which can be reduced by implementing soil-structure interaction.	Greater will be stiffness of building smaller will be the settlement of that building.	[26]

2. Methodology

For writing my case study paper, all journal and research papers related to my keywords helped me. These papers were available at Elsevier, Springer, and Google Scholar, etc. As the foundation is the base structure of any building and is more essential to pay attention to construction. In the same way, two different site visits of the proposed OHT of 40KL having two different foundation designs give me an idea to perform the case study on the foundation design of OHT. The research is done related to foundation design to resist lateral motion caused by seismic activity or by wind load.

Foundation design requires a preliminary survey of the site to get an overview in the mind before designing manually or by using the software. Some basic data are required for the selection of footing type that can be obtained by performing soil tests (soil penetration test) on the ground or by taking samples to the laboratory. This test result provides the value of moisture content in the soil, which was later calculated in terms of the soil bearing capacity. The soil bearing capacity allows us to choose the type and shape of footing.

Table 4 Foundation design criteria of two different site

S. No	Criteria for foundation	Case I	Case II
1	Site Location	Anjani (Kanker)	Pandripani (Kanker)
2	Type of tank	Circular OHT	Circular OHT
3	The capacity of tank	40KL	40KL
4	No of footing	4	4
5	SBC of soil	120KN/m^2	50KN/m^2
6	Type of soil	White moorum	Black cotton soil
7	Cement	Ultratech, grade 33	Ultratech, grade 33
8	Coarse agg	20mm Nominal dia	20mm Nominal dia
9	Fine agg.	Natural Mahanadi River sand (Block Kanker)	Natural Mahanadi River sand (Block Kanker)
10	Reinforcement	10mm, grade Fe415	8mm,10mm,12mm and 16mm dia., grade Fe415
11	Mix design for foundation	M_{25}	M_{25}

2.1. Design steps as per IS 456:2000 [7]

No of columns : $4, \theta = 90°$
Divided into no of panels : 3
Height of each panel : 4.0m

Table 5 Types of loads acting on footing of the Overhead Water Tank

S. No	Types of loads	Weight (N)
1	Self wt of the top dome	42588N
2	Self wt of top ring beam	14765N
3	Self wt of the vertical cylindrical wall	206717N
4	Self wt of bottom dome	63882N
5	Self wt of bottom ring beam	73827N
6	Self wt of the balcony	34495N
7	Self wt of an empty tank	436275N
8	Wt of water in the tank	420148N
9	LL on the top dome	12776N
10	LL on balcony	34495N
11	Total wt from tank portion under tank full condition	903694N
12	Self wt of all column	182212N
13	Self wt of all bracing	79762N
Total wt.		**2505636N**

Case I:

Step 1: Determine the size of the footing

Load on one footing= $626.409\ KN$

Area of footing = $\frac{Total\ wt}{SBC}$= $5.22m^2$ **5.1**

For square footing, side=$\sqrt{5.22}$ = 2.28 m **5.1.1**

Provide square footing of size 2.3m*2.3m

Step 2: Net upward pressure

$P_0 = \frac{total\ wt}{size\ of\ footing} = 118.41\ KN/m2$ **5.2**

Step 3: Depth of footing on basis of Max BM

Max BM act at face of column

$= P_0 \frac{B}{8}(B-b)^2 = 110.3$ KN.m **5.3**

Ultimate moment Mu $=1.5 \times M = 170.96$ KNm

$D_{req,}$Mu$=0.138 f_{ck}.B.d^2 = 14.6mm \approx 150mm$ **5.3.1**

Provide 50mm cover; $D = 200mm$

Due to shear consideration adopt higher effective depth, hence take 400mm as effective depth (d) and provide cover 50mm, $D = 450\ mm$

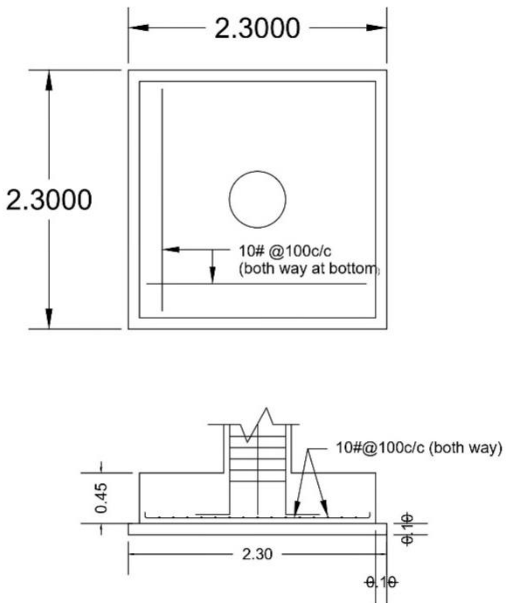


Fig 1: Reinforcement detail of spread footing

Step 4: Area of reinforcement

$A_{st}=\frac{0.5f_{ck}}{f_y}\left[1-\sqrt{1-\frac{4.6Mu}{f_{ck}.B.d^2}}\right]B.d$=1210.8mm^2 **5.4**

% Of steel Pt $=\frac{Ast}{Bd}\times 100$ = 0.131% **5.4.1**

Min. criteria of Pt of steel is 0.12%,

Using 10mm bars in both directions

Ast$=\frac{\pi}{4}\times 10^2 = 78.54mm^2$ **5.4.2**

No of bars = $\frac{1210.8}{78.54}$ =15.92≈16 no **5.4.3**

Spacing = $\frac{B}{no\ of\ bars} = \frac{2300}{16} = 143.75mm$ **5.4.4**

Provide 16 no of 10mm bar @100mm c/c.

Case II:

Step 1: Area of raft foundation

Central radius of raft r_c 2.35m, ($r_c > 1.93m$)

Outer radius $r_0 > 2.97m$

For optimum proportion compute

$\frac{A_f}{\pi rc^2}$=1.545 **5.5**

$\frac{rc}{r0} = 0.74$ ∴r_0=3.18m **5.5.1**

$\frac{ri}{r0} = 0.39$ ∴r_i=1.24m **5.5.2**

Consider r_0=3.3m and r_i=1.1m

Area of foundation

$A_f = \pi(r_0^2 - r_i^2)$ = 30.41m^2 **5.5.3**

Table 6 Load and moments acting on circular raft foundation of OHT

S. No	Types of loads and moments on OHT	Values
1	Load at the base, tank full case W	1341KN
2	Upward load per meter run w due to tank full condition	78.95 KN.m
3	Sagging BM at column support	93.82 KN.m
4	Hogging BM at mid-span	47.94 KN.m
5	Maximum torsion	14.38 KN.m at 19.25° fromsupport
6	Maximum shear force at the support	145.71 KN

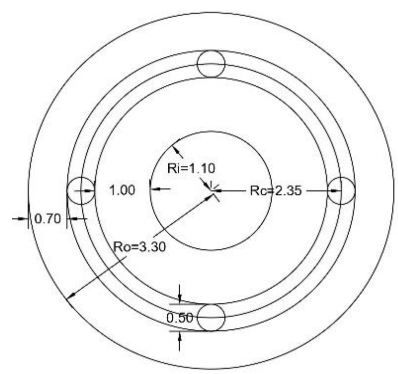


Fig 2: Footing and ring beam dimension

Step 2: Net upward pressure

$P_0 = \frac{total\ wt}{size\ of\ footing}$ = 44.09 $KN/m2$ **5.6**

Step 3: Depth of footing on basis of Max BM

Max BM act at face of column

= $P_0\frac{B}{8}(B-b)^2$ =35.04 KN.m **5.7**

Mu = 1.5 × 35.04 =52.5 KN.m

D_{req}Mu = 0.138 f_{ck}.B. d^2= $83mm \approx 90mm$ **5.7.1**

Provide 50mm cover; $D = 140mm$

Take D= 200mm

Step 4: Area of reinforcement

$A_{st}=\frac{0.5f_{ck}}{f_y}\left[1-\sqrt{1-\frac{4.6Mu}{f_{ck}.B.d^2}}\right]B.d$=748.54mm^2

5.8

% Of steel Pt $=\frac{Ast}{Bd}\times 100 = 0.17\%$ **5.8.1**

Min criteria of Pt of steel is 0.12%, hence Ok

Using 10mmØ bars in both directions

Ast$=\frac{\pi}{4}\times 10^2 = 78.54mm^2$ **5.8.2**

No of bars $=\frac{748.54}{78.54}$ =9.53≈10 no. **5.8.3**

Spacing $=\frac{B}{no\ of\ bars} = 220mm$ **5.8.4**

Provide circumferential reinforcement, 10 no. of 10mm bars @220mm c/c spacing.
Provide radial, 10 no. of 10mm bars @196mm c/c spacing.

Step 5: Design of ring beam

F_{ck}=25 MPa F_y=415 MPa
$\sigma_{st} = 230\ MPa$ $\tau_c max = 1.9\ MPa$
m=10.98039MPa k= 0.28866 j=0.90378
R=1.108761MPa $\sigma_{cbc} = 8.5MPa$

Size of ring beam 500mm$\times 500mm$
Assuming severe condition d" =45mm

Assuming 16mm dia. of bar, d'=53mm
d_{eff}=447mm

Step 6: Area of reinforcement

Longitudinal

Mu=0.87 F_y.Ast.d (1-$\frac{Ast.fy}{bd.fck}$) **5.9**

Ast=608.86mm^2

$\frac{A_{st}}{bd} = \frac{0.85}{f_y}$ **5.9.1**

Min A_{st}=457.77mm^2
Max A_{st}=0.04bD= 1000mm^2 **5.9.2**
No of bars $=\frac{608.86}{\frac{\pi}{4}\times16\times16}$=3.02≈ 4 no. **5.9.3**
Provide 4 no of 16mm bar longitudinally.

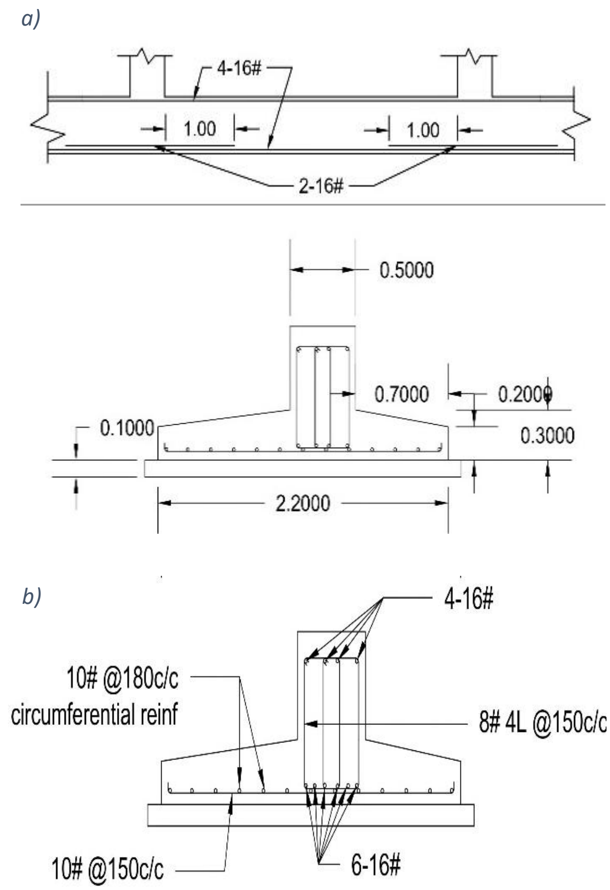


Fig. 3 Reinforcement detail of a) circular ring beam b) raft footing

Transverse

- **At the point of Max. torsion**

Ve=Vu+1.6$\frac{T_u}{b} = 129.96\ KN$ **5.10**

Nominal shear $\tau_v=\frac{V_u}{bd}$=0.63 **5.10.1**
τ_c=0.19
by interpolation Table 19

There fore $\tau_v > \tau_c$
Hence shear reinforcement is req.
Vs=$\tau_c$bd=42.465KN **5.10.2**
Vs=V-Vs=86.54KN **5.10.3**
Spacing=$\frac{\sigma_{st}\times Asv\times d}{Vs}$== $238.8mm$ **5.10.4**
Spacing of 4 legged stirrups 8mm bars @ 238.8mm c/c

- **At the point of Max Shear (at support)**

Shear force at support = 146KN
$\tau_v = 0.71\ N/mm^2$
% Of reinf. At support =0.38
$\tau_c = 0.37N/mm^2$

Spacing of 4 legged stirrups 8mm bars @ 266mm c/c

- **At mid-span**

At mid-span shear forces is zero, hence providing nominal reinf.

Spacing of 2 legged stirrups 8mm bars @ 238.8mm c/c

3. Result and Discussion

3.1. Foundation selection

The selection of the foundation for Case I is square spread footing because soil bearing capacity is120 KN/m^2 ($> 100\ KN/m^2$) which is sufficient for a design load of 2505636N.The load transference is primarily through sheer resistance of the bearing strata (the fractional resistance of soil above bearing strata is not taken into consideration). [33]. Due to sufficient capacity to hold the structure load isolated spread footing had been adopted. Also, due to the presence of stiff strata at the depth of 2m, that had been attained by 'White moorum' type of soil easily. After calculation square footing dimension and reinforcement is

- Square footing dimension 2.3×2.3 m^2
- 16 no of 10mm bar @100mm c/c. in both the direction. Spacing can be reduced as per convenience but can't be exceeded from the calculated value.

In Case II the bearing capacity of soil is 40KN/m^2 ($< 100\ KN/m^2$) which means the soil cannot resist the design load of 2505636N, also due to the presence of black cotton soil at the site of "Pandripani" which means extra moment shall be added from Table-6. That will make the structure more critical to dynamic loads. Black cotton soil can swell and shrink easily that can lead to uneven differential settlement. So as per IS 2950-1 (1981) code design steps, spread footing is replaced by a circular raft foundation. Now as per code raft foundation constructed for industrial building, storage tank, store house, were constructed on assumption of flexible foundation.[11]. Also, a deep foundation is not adopted here because it may lead to an increase in estimation cost of the project, even though circular raft footing requires the extra design of ring beam but is the more economical than deep foundation. Design of ring beam will be on basis of IS 456-(2000). [7]. Circular raft foundation consists of a circular base surmounted by a ring beam.

- Circular raft base has inner diameter of 1.1m and outer diameter 3.3m.
  - ➢ Provide circumferential reinforcement, 10 nos of 10mm bars @220mm c/c spacing.
  - ➢ Provide radial, 10 nos of 10mm bars @196mm c/c spacing.

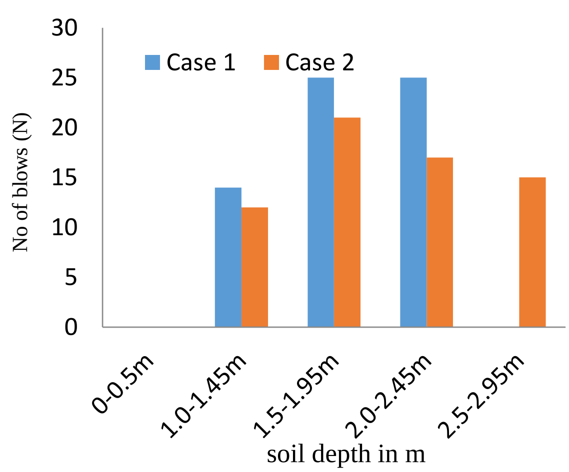


Fig. 5 SPT value (N) vs depth

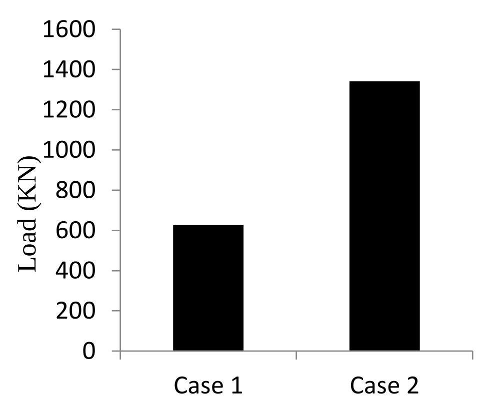


Fig. 6 Load acting on Footing in KN

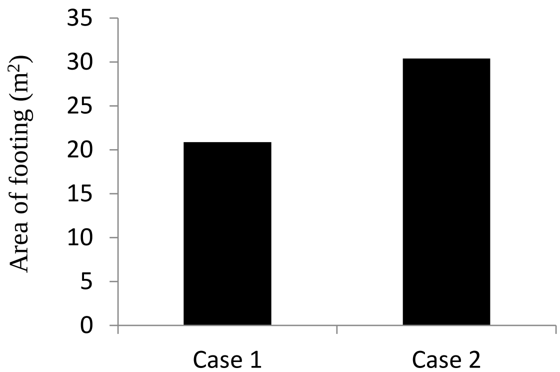


Fig. 7 Footing Area calculated in m^2

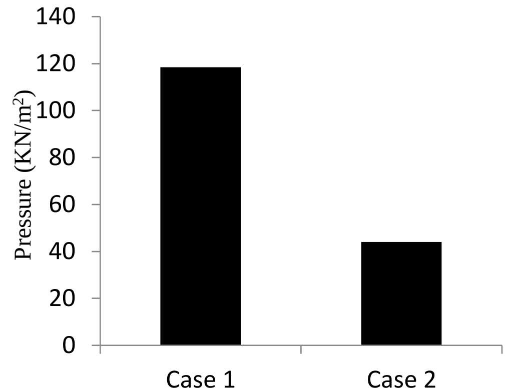


Fig. 8 Net Upward Pressure in KN/m^2

- Ring beam dimension of 500×500 mm.
  - 4 no. of 16mm bar longitudinally
  - 4 legged stirrups 8mm bars @ 238.8mm c/c- At max. torsion
  - 4 legged stirrups 8mm bars @ 266mm c/c- At max shear (at support)
  - 2 legged stirrups 8mm bars @ 238.8mm c/c-At mid span

3.2 Discussion on the basis of bar chart

Fig 5, for depth up to 1m clay soil is present in case 1 while for case 2 clay present only upto 0.5m. Than for case 1 sandy soil present at depth 1-1.5m, then up to 2m white moorum is present which is good for footing design. So, the STP test terminated. For case 2 after 0.5m to 2.5m black soil is present. Calculated N value gives the value of safe bearing capacity, for case 1 SBC comes out as 18.40T/m^2 (180.44KN/ m^2) and for case 2, SBC comes out as 9.4 T/m^2 (92.18 KN/ m^2). Ultimately SBC for case 2 is below 100KN/ m^2, hence above design is valid for this SBC. This above result has been collected by the test occurred at site by Government Polytechnic Kanker Chhattisgarh. SBC for case 1 is greater than case 2 which influence the foundation design criteria as per IS 1904 (1986), lesser will be SBC, Isolated footing will be replaced by raft or deep piled foundation. Due to economic criteria piled foundation is not accepted in case 2.

Fig 6, Load in case 2 is greater than case 1 because of extra design parameter (ring beam) and due to bracing design. This is due to low SBC value of case 2 that require different footing design type.

Fig 7, shows that total area required for case 1 is 20.88m^2 (5.22×4) which is less than case 2 raft footing which require area of 30.41m^2.

Fig 8, shows the net upward pressure is much greater in case 1 (118.41KN/m^2) than case 2 of raft footing. Lesser will be net upward pressure more critical design required.

Fig 9, shows that moment generated in case 1 is greater than case 2, in spite of taking moment as a critical loading for design, spread footing is adopted because other parameter compensates the design parameter.

Fig 10, Area of reinforcement is clearly seen from that in case 1 for footing 1256.4mm^2 is required while 2877.69mm^2 of reinforcement is needed for construction that ultimately increases the cost.

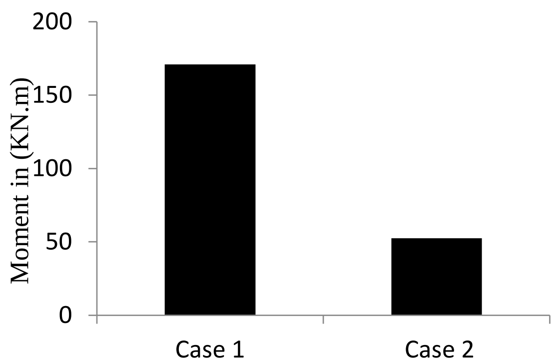


Fig. 9 Ultimate BM in KN.m

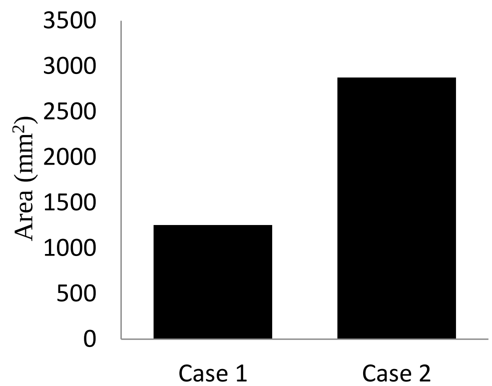


Fig. 10 Reinforcement calculated for foundation in mm²

Conclusion

The above calculation and discussion clearly state that the foundation design of any structure mainly depends on the Soil Bearing Capacity, while bearing capacity depends on-

- Type of soil. example- black cotton soil, sandy soil, etc. because they can swell and shrink easily due to change in climate condition
- Size of particles as well graded particles is stronger than an ungraded particle.
- Shape of particles
- Cohesive property of particles-more will be cohesive soil less differential settlement occur.
- Internal frictional resistance of particles
- Depth of embedment of load
- Bed-rock base gives a very small amount of settlement and hence stiff soil base shall be adopted for the foundation.
- In the case of loose base (black cotton soil) foundation type and shape need to change as the circular raft is better for water tank than rectangular raft foundation. To overcome settlement in soft clayey soil raft or mat foundation are account in use, as it consists of thick concrete slab with reinforcement embedded in it that hold entire structure.

Conflict of interest

The author declares no conflict of interest.

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