FOUNDATION DESIGN ANALYSIS WITH FINITE ELEMENT METHOD IN THE REINFORCEMENT OF LIQUID STORAGE TANKS

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ABSTRACT

The calculation tables created for the liquid storage tank examined in this study cover the design of the tank foundation. The soil bearing capacity was checked according to the allowable stress design d and the settlement-swelling potential was evaluated. The geometry of the ring foundation wall proposed for reinforcement is an inverted T-section rotating around the tank diameter. In this context, the model ring wall was analyzed for each load case using the finite element method with the SAP2000 software. In this study, a different solution method was proposed to transfer the seismic load to the foundation, and only the induction of the seismic shear force at the center of gravity of the tank was sufficient to design the ring circumferential foundation. This force was transferred to the ring wall by hypothetical rigid members, and then computer software multiplied the shear force by the loading distance to generate the seismic moment. Therefore, there is no need to use both seismic moment and shear in the basic model of the liquid storage tank. In the study, the results related to stability control and anchor design are given in detail.

Keywords: *Foundation Reinforcement, Settlement Calculations, Finite Element Method, Stability.*

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1. INTRODUCTION

The calculation tables created for the storage tank examined in the study cover the design of the tank foundation. The reinforced concrete structure was designed in accordance with the latest design method using the Turkish standard and the cement type was selected according to the geotechnical report. Soil bearing capacity was checked according to the allowable stress design method (Elastic Design Requirement) and soil parameters were taken from a geotechnical survey. The allowable bearing capacity is given as 270 kN/m^2. Thus, the soil strain constant Ks is estimated to be equal to 37500 kN/m^3. The basic geometry of the ring wall is an inverted T-section rotating in the Z-axis around a tank diameter of 19.00 m. The inverted T-section has a flange 500 mm thick and 3000 mm wide. The connecting plate is 1500 mm high and 700 mm thick. The tank design provides the input loads applied to the ring wall foundation. This download is used for the design of the ring wall and related controls requested from the relevant codes.

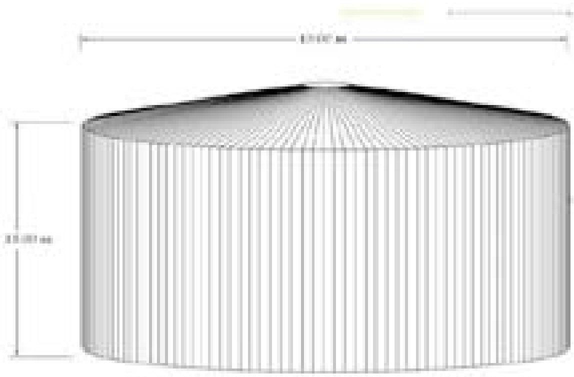


Figure 1: Dimensions of liquid storage tank

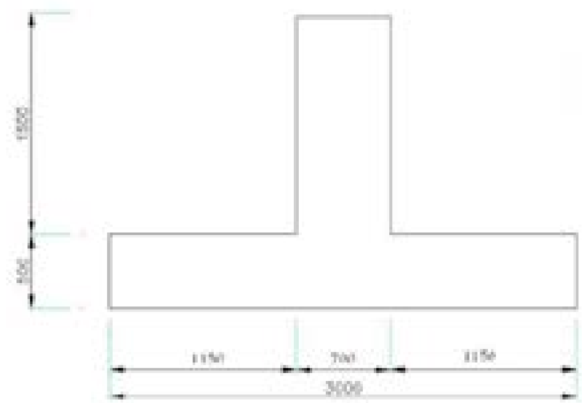


Figure 2: Dimension of foundation

The springs are applied to the foundation mat, and the software calculates the relevant spring constant automatically. The average size of the finite element mesh is 0.50 m. Concrete grade C30 and reinforcement steel grade St 420.

Table 1: Equipment data and general assumptions

Physical quantities	Value	Unit	Statement
C.L.D.	*19*	*m*	*Mechanical data*
f_c	*300*	*kg/cm²*	*Assumption*
f_y	*4200*	*kg/cm²*	*Assumption*
Seismic shear	*1182,00*	*ton/m²*	*Mechanical data*
G_S	*2*	*ton/m²*	*Basic geotechnical investigation*
Maximum liquid level	*18*	*m*	*Mechanical data*
Allowable soil bearing pressure	*27*	*ton/m²*	*Basic geotechnical investigation*
Area	*283,52*	*m*	*Calculated*
G_L	*1*	*ton/m²*	*Mechanical data*

Loads considered to act upon the tank are dead, lifeve, operating, test load\ and operating condition earthquake.

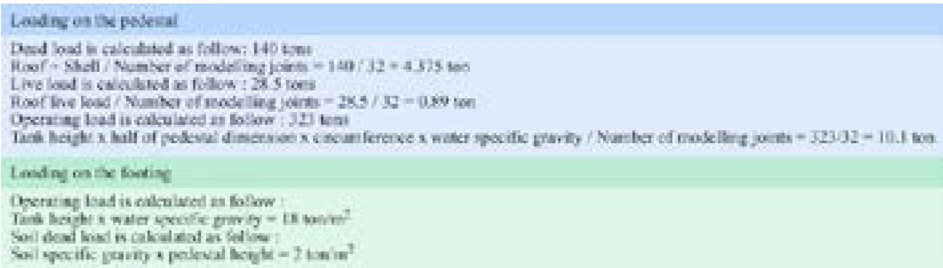
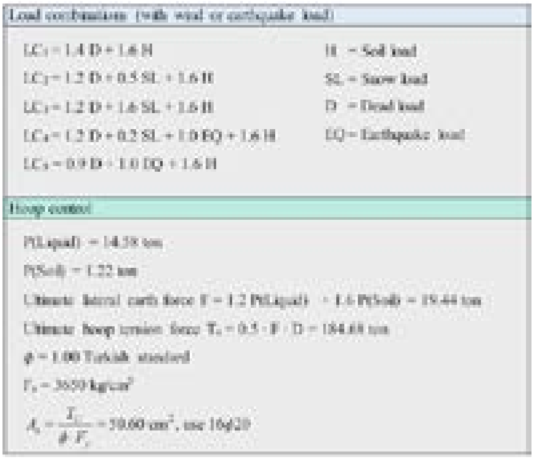


Figure 3: Loading

Figure 4: Calculation of soil lateral pressure



Load combinations (with wind or earthquake load)

$LC_1 = 1.4\,D + 1.6\,H$ H = Soil load

$LC_2 = 1.2\,D + 0.5\,SL + 1.6\,H$ SL = Snow load

$LC_3 = 1.2\,D + 1.6\,SL + 1.6\,H$ D = Dead load

$LC_4 = 1.2\,D + 0.2\,SL + 1.0\,EQ + 1.6\,H$ EQ = Earthquake load

$LC_5 = 0.9\,D + 1.0\,EQ + 1.6\,H$

Hoop control

P(Liquid) = 14.58 ton

P(Soil) = 1.22 ton

Ultimate lateral earth force F = 1.2 P(Liquid) + 1.6 P(Soil) = 19.44 ton

Ultimate hoop tension force $T_u = 0.5 \cdot F \cdot D$ = 184.68 ton

ϕ = 1.00 Turkish standard

F_s = 3650 kg/cm^2

$A_s = \dfrac{T_u}{\phi \cdot F_s}$ = 50.60 cm^2, use 16φ20

Figure 5: Design of foundation

2. FINITE ELEMENT ANALYSIS OF LIQUID STORAGE TANK

The empty space is the rigid zone under the ring wall foundation. The values of bending moments should be considered outside of this zone which means just on both sides of the ring wall. Pink section lines were taken into account for reinforcement and the rigid zone was excluded.

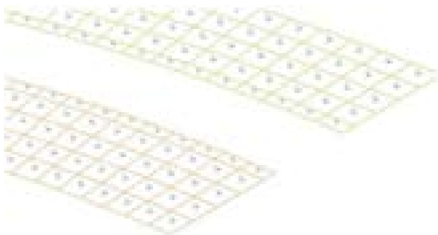


Figure 6: Area under ring wall foundation

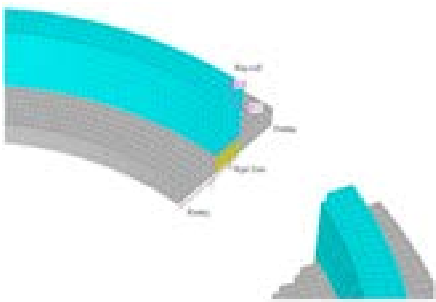


Figure 7: Foundation cross-section sample

All loading visualizations are illustrated with SAP2000. The internal forces of the shell elements are F11, F22, M11, M22, and V23, and these are indicated as limit values. These values have been selected for the reinforcements to be designed. Bending moment contours on footings, axial forces contours on footings, shear force contours on footings, ring wall bending moment contours, ring wall axial force contours (Circumference), ring wall axial force contours (Vertical direction), and ring wall shear force contours are analyzed with SAP2000.

Figure 8: Ring wall foundation design

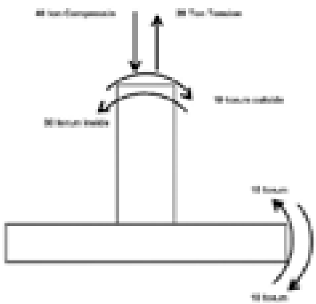


Figure 9: Minimum calculation of section for foundation

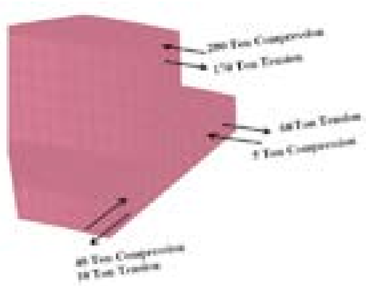


Figure 10: Axial force in circumferential direction

$$T_i = \frac{1}{\sqrt{2000}} \cdot \frac{C_i H}{\sqrt{\frac{t_u}{D}}} \cdot \frac{\sqrt{\rho}}{\sqrt{E}} \tag{1}$$

$$T_c = \frac{1.0404 \cdot \sqrt{D}}{\sqrt{\tanh\left(\frac{3.68H}{D}\right)}} \tag{2}$$

Equation 1 calculates the natural period of vibration for an impulsive mode of behavior and equation 2 calculates the natural period of convective (sloshing) mode of behavior [1].

Figure 11: M11 bending moment in footing (Top)

This reinforcement can carry about 248 kN.m of the moment. Therefore it can be used for all section having such a moment below this value.

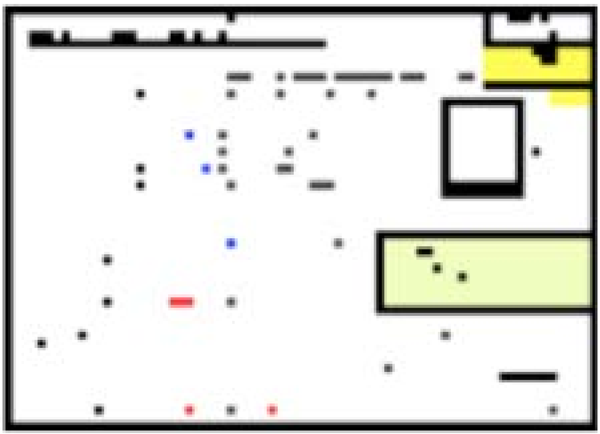


Figure 12: M22 bending moment in vertical direction

Equation 3 calculates the impulsive spectral acceleration parameter and equation 4 calculates the convective spectral acceleration parameter [2].

$$A_i = 2.5 \cdot Q \cdot F_a \cdot S_0 \left(\frac{I}{R_{wi}} \right) \tag{3}$$

$$A_c = 2.5 \cdot K \cdot Q \cdot F_a \cdot S_0 \left(\frac{T_S \cdot T_L}{T_c^2} \right) \left(\frac{I}{R_{wc}} \right) \tag{4}$$

Equation 5 calculates the effective impulsive weight of the product and equation 6 calculates the effective convective weight of product. Where Wp total weight of tank contents based on the design-specific gravity of the product [3].

$$W_i = \left(1 - \frac{0.218 \cdot D}{H} \right) \cdot W_p \tag{5}$$

$$W_c = 0.230 \cdot \frac{D \cdot W_p}{H} \cdot \tanh\left(\frac{3.67 \cdot H}{D} \right) \tag{6}$$

Equation 7 calculates the total design base shear. Where, Wf weight of the tank bottom, Ws total weight of tank shell and appurtenances, Wr total weight of fixed tank roof including framing, knuckles, any permanent attachments, and 10 % of the roof design snow load [4].

$$V = \sqrt{A_i^2 \cdot \left(W_s + W_r + W_f + W_i \right)^2 + A_c^2 \cdot W_c^2} \tag{7}$$

Equation 8 calculates the total combined hoop stress in the shell. Where, Nh product hydrostatic membrane force, Ni impulsive hoop membrane force in tank shell, Nc convective hoop membrane force in tank shell.

$$\sigma_T = \frac{N_h \pm \sqrt{N_i^2 + N_c^2 + \left(A_v \cdot N_h \right)^2}}{t} \tag{8}$$

Equation 9 calculates ring wall moment and equation 10 calculates slab moment [5].

$$M_{rw} = \sqrt{A_i^2 \cdot \left(W_i X_i + W_s X_s + W_r X_r \right)^2 + A_c^2 W_c^2 X_c^2} \tag{9}$$

$$M_s = \sqrt{\left[A_i^2 \cdot \left(W_i X_{is} + W_s X_s + W_r X_r \right)^2 + A_c^2 W_c^2 X_{cs}^2 \right]} \tag{10}$$

Course No.	Course width(m)	Y(m)	Course thk.(mm)	Course C.A.(mm)	σ_h (Mpa)	N_t (N/mm)	N_c (N/mm)	σ_s (Mpa)	σ_T (Mpa)	S_d (Mpa)	σ_{all} (Mpa)	Stress ratio	
1	2	15.5	10	3	138	121	1	12	150	137	182	0.83	OK
2	2	13.5	9	3	140	121	1	13	154	137	182	0.84	OK
3	2	11.5	8	3	143	121	2	15	158	137	182	0.87	OK
4	2	9.5	8	3	117	121	3	15	132	137	182	0.73	OK
5	2	7.5	7	3	115	116	6	16	131	137	182	0.72	OK
6	2	5.5	6	3	110	98	10	16	127	137	182	0.70	OK
7	2	3.5	6	3	68	71	17	12	80	137	182	0.44	OK
8	2	1.5	6	3	25	34	31	8	33	137	182	0.18	OK

Figure 13: Hoop stress

For 200 tons of tension in the circumferential direction along the ring wall, 200/3,650 = 55 cm^2 reinforcement should be 17.4 Ø 20. This means 18 Ø 20. Therefore, the reinforcements at the top of one meter of the ring wall should be 18 bars 1 meter high from the top. For simplicity, all 1.5 m ring wall reinforcements are used at the same value. The maximum tension in the vertical direction along the ring wall is about 30 tons, which requires 8.24 cm^2 of rebar. We have a value of 30 tons.m for the bending moment and the required rebar is 13.00 cm^2. So a total of 8.24 + 13.00 = 21.25 cm^2 and we can use Ø 20/20 for both sides [6].

3. CONCLUSIONS

In the method we use to model the structure, taking into account the ground and structure interaction, we first obtain the primary frequency of the structure. To do this, we enter the type of soil layers, the layer radius, soil shear modulus, poisson ratio, damping, and soil depth. This method gives us the movement and damping of the ground, which effectsthe structure.

It is clear that dynamic processes will occur in the soil environment during an earthquake in the study area. The shear wave propagating during the earthquake causes the groundwater pressure in the ground to rise and the amplitude of the shear strength to decrease. This reduction may cause some failures in the ground, depending on the amplitude of repetitive deformations. In addition, liquefaction develops depending on earthquake parameters such as the distance and magnitude of the earthquake source and the maximum horizontal ground acceleration in the study area.

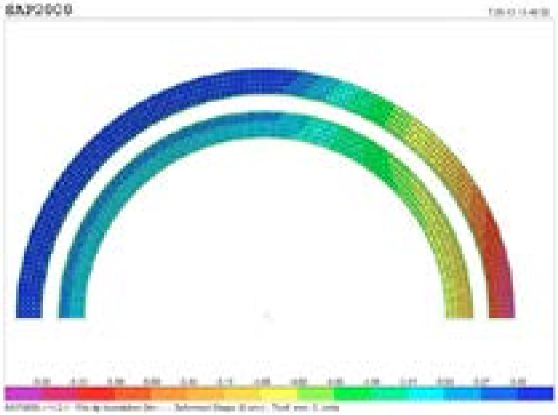


Figure 14: Soil deformation values

Considering these principles, evaluation methods that take into account all these factors have been proposed topredict whether there is a liquefaction problem or not. Accordingly, calculations were made based on the SD-13 drilling. The value of ah= 0.087 g was taken into consideration in the layers examined in relation to the ground movements that may occur in the study area due to the effect of dynamic loads that may cause liquefaction and an earthquake with a magnitude of M=7,5. The ground settlement calculation was made using the corrected SPT-N55 numbers obtained in the field.

$$\Delta H = \frac{31.2 \cdot q_{net}}{N} \tag{11}$$

The total settlement for foundations is calculated by the above equation. Where ΔH (cm) is the settlement that will occur in the soil layer, qnet (kg/cm2) is the structural load, N is the average SPT impact number and qnet will be taken as the amount of the total load of the structure corresponding to the unit area. The amount of the structure load corresponding to the unit area is accepted as 1.25 kg/cm2 and since the corrected average obtained in the field is SPT-N55 = 9, these values are substituted in the above equation and the total settlement ΔH = 4.33 cm is obtained. Since these obtained values are within the limit values, no settlement problem is expected on the ground. The results regarding stability control and anchor design are as follows. Since the maximum deformation is 6.5 mm and 37500 x 0.0065 = 243 kN/m2 < 405 = 270 x 1.5, there is no negative response, so the foundation can be considered safe. Tank anchor calculation is 5000 m3, seismic moment (N-m) Mrw = 76.821.330.27, tank and roof weight affecting the shell base Wt = 23400 N/m, Av = 0, D = 19 m. Per unit circumferential length the uplift load on the anchors is WAB and the anchor seismic design load is $P_{AB.}$

$$W_{AB} = \left(\frac{1{,}273 M_{rw}}{D^2} - W_t \left(1 - 0{,}4 A_v\right) \right) \quad (12)$$

$$P_{AB} = W_{AB} \left(\frac{\pi D}{n_A} \right) \quad (13)$$

Firstly, it is calculated as WAB = 248000 N/m from the related relations. Where, nA is to denote the number of equally spaced anchors around the tank circumference and PAB = 739784 N for nA = 20. An allowable tensile stress for anchor bolts and straps equal to 80% of the published minimum yield stress. With the analysis, it was found that the minimum yield stress of the bolts is 355 Mpa and the required area of a bolt is 739784 / (0.8 x 355) = 2605 mm^2. This gives a 57.8 mm diameter bolt.

In this study, a different solution method was proposed to transfer the seismic load to the foundation and to design the annular circumferential foundation, it was sufficient to induce the seismic shear force only in the center of gravity of the tank. This force was transferred to the ring wall by hypothetical rigid members. The computer software then multiplied the shear force by the loading distance to create the seismic moment. Therefore, there is no need to use both seismic moment and shear in the tank foundation model.

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