The Effects of Subsoil on the Dynamic Response of Rectangular Tanks

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ABSTRACT: The seismic responses of rectangular tanks founded on the three subsoil classes defined in Eurocode-8 (EC-8) are investigated. The distribution of hydrodynamic pressures obtained by considering requirements defined in EC-8. Rigid and flexible wall assumptions are considered in the seismic analysis of the tank. Maximum wave heights are obtained Housner Method considering these three subsoil classes.

1 INTRODUCTION

It is known that, some of the fluid containers are damaged in many earthquakes. Damage or collapse of these containers causes some unwanted events such as shortage of drinking and utilizing water, uncontrolled fires and spillage of dangerous fluids. Even uncontrolled fires and spillage of dangerous fluids subsequent to a major earthquake may cause substantially more damage than the earthquake itself (Priestley et al. 1986). Due to these reasons this type of structures must be constructed well to be resistant against earthquakes. But very few studies on the dynamic response of rectangular containers exist, when compared to that of the cylindrical tanks (Rammerstorfer et al. 1990). Soil-tank-fluid interaction for cylindrical tanks is investigated many investigators. But according to authors' literature investigations there are two studies considered the subsoil for rectangular tanks (Doğangün 1995, Kim et al. 1998). These two studies may be assumed preliminary studies. Result obtained these two studies show that more detailed investigations are needed for subsoil effects for rectangular tanks.

European Committee for Standardization prepared a new code named EC-8 (1998). Part 4 of this code is related to tanks, silos and pipelines. But, requirements for rectangular tanks are very limited according to cylindrical tanks in this code due to lack of studies related to rectangular tanks.

As mentioned above, there is lack of knowledge about the effect of subsoil on the dynamic behaviour of rectangular tanks. Thus, this study had two main purposes is made. One of the purposes is to present recent practical knowledge and an example about seismic analysis of rectangular tanks to designers. The other is to investigate the effects of subsoil on the dynamic response of rectangular tanks and to constitute a step for future studies. For these purposes the seismic responses of rectangular tanks founded on the three subsoil classes defined in EC-8 are investigated.

2 DESIGNS OF RECTANGULAR TANKS ACCORDING TO EC-8

The total pressure (p) is given by the sum of an impulsive (pi) and a convective (pc) contribution: for the tanks whose walls can be assumed as rigid:

$$p(z,t) = p_i(z,t) + p_c(z,t) \tag{1}$$

The impulsive and the convective pressures are given by following equations:

$$p_i(z) = q_0(z) \cdot \rho \cdot L \cdot A_g \tag{2}$$

$$p_{cn}(z) = q_{cn}(z)\rho \cdot L \cdot A_n \tag{3}$$

Where L is the half-with of the tank in the direction of the seismic action, q0 (z) is the function plotted in Fig. 1 and Ag(t) is the ground acceleration, qcn (z) is shown Fig.2 for first and second sloshing modes and An is the acceleration response function of a simple oscillator having frequency of the n. mode

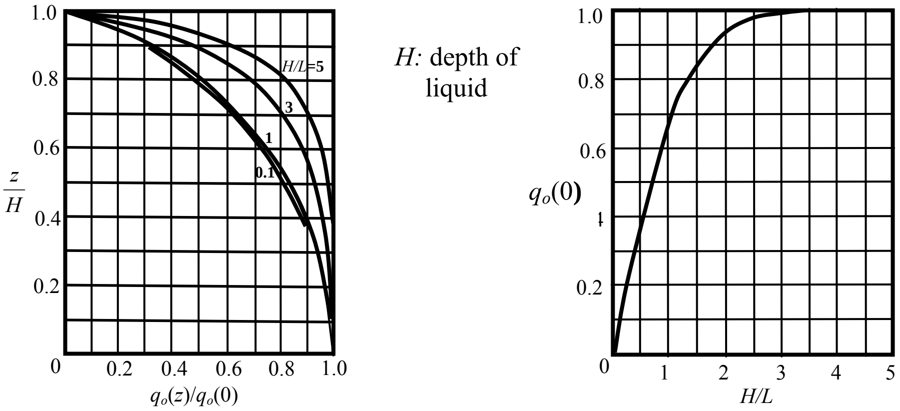
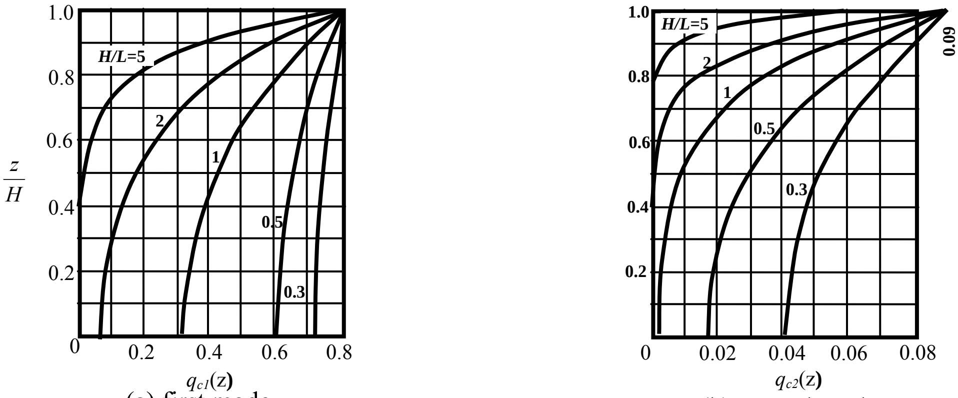


Figure 1. Dimensionless impulsive pressure on rectangular tank wall (Eurocode-8, 1998)



(a) first mode

(b) second mode

Figure 2. Dimensionless convective pressure on rectangular tank wall (Eurocode-8, 1998)

The period of oscillation of the first sloshing mode is:

$$T_1 = \sqrt{(L/g)/[\frac{\pi}{2}\tanh(\frac{\pi}{2}\frac{H}{L})]} \tag{4}$$

For flexible rectangular storage tanks, an approximation which is suggested in Priestley et al.(1986) is to use the same pressure distribution valid for rigid walls. But ground accelerations Ag(t) in equation (2) replaced with the response acceleration of a simple oscillator having the frequency and the damping factor of the first impulsive tank-fluid mode. The period of vibration of the first impulsive storage tank-fluid horizontal made is given approximately by:

$$T_f = 2\pi\sqrt{d_f / g} \tag{5}$$

Where df is the deflection of the wall on the vertical centre-line and at the height of the impulsive mass, when wall is loaded by a load uniform in the direction of the ground motion and of magnitude mig /(4BH). Where B is the half with perpendicular to the direction of loading (earthquake direction) and m_i is the impulsive mass which include the wall mass. For thanks without roofs the deflection d_f may be calculated assuming the wall to be free at the top and fixed on the other three sides.

3 ELASTIC RESPONSE AND DESIGN SPECTRUMS

Dynamic parameters of structure and subsoil are considered together for seismic analysis using elastic response and design spectrums. Three subsoil classes described in the EC-8 (1998) as given in Table 1.

Table 1. Classification of subsoil conditions according to EC-8

Subsoil class	Detail
A	Rock or other geological formation characterized by a shear wave velocity v_s of at least 800 m/s, including at most 5 m of weaker material at the surface. Stiff deposits of sand, gravel or overconsolidated clay, at least several tens of m thick, characterized by a gradual increase of the mechanical properties with depth and by v_s values of at least 400 m/s at a depth of 10 m.
B	Deep deposits of medium dense sand, gravel or medium stiff clays with thickness from several tens to many hundreds of m, characterized by v_s values of at least 200 m/s at a depth of 10 m, increasing to at least 350 m/s at a depth of 50 m.
C	Loose cohesionless soil deposits with or without some soft cohesive layers, characterized by v_s values below 200 m/s in the uppermost 20 m. Deposits with predominant soft-to-medium stiff cohesive soils characterized by v_s values below 200 m/s in the uppermost 20 m.

The elastic response spectrum $S_e(T)$ described in Eurocede-8 may be drawn as Figure 3. In this figure, S is soil parameter, β_0 is spectral acceleration amplification factor, T_B , T_C are limits of the constant spectral acceleration branch, T_D value defining the beginning of the constant displacement range of the spectrum, k_1 , k_2 are exponents which influence the shape of the spectrum for a vibration period greater than T_C, T_D respectively, k_{d1} , k_{d2} are exponents which influence the shape of the design spectrum for a vibration period greater than T_C, T_D, respectively, a_g is design ground acceleration for the reference return period, T is vibration period of a linear single degree of freedom system, η is damping correction factor with reference value η=1 for 5% viscous damping and q is behaviour factor. For design spectrum $S_{pe}(T)$ some parameters (a_g, k_1 , k_2 , β_0) in the elastic response spectrum changed as seen from Figure 3. For the reference return period the design spectrums $S_d(T)$ for damping values of ξ=4% and ξ=0.5%, normalized by the acceleration of gravity are given in Figure 4. Values of the parameters describing elastic response and design spectrums in EC-8 are given in Table 2.

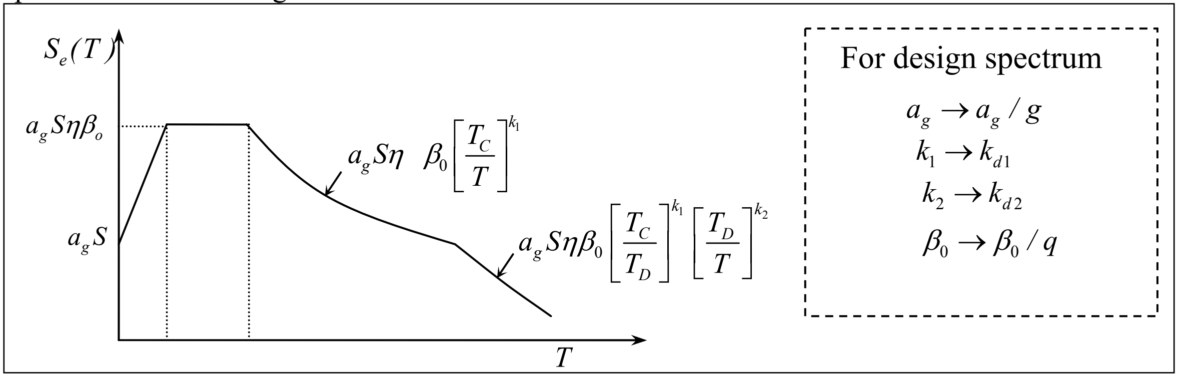
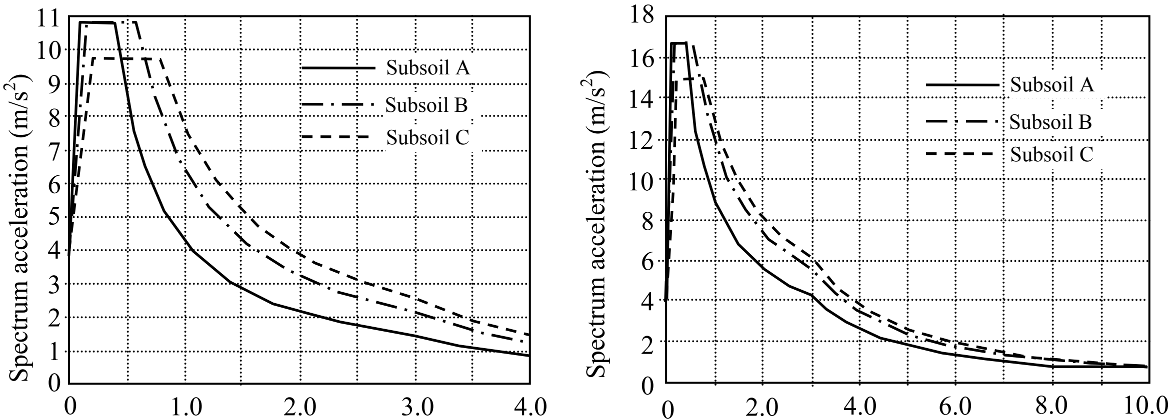


Figure 3. Elastic response spectrum according to EC-8 (1998)

Table 2. Values of the parameters describing the spectrums

Subsoil class	S	β_0	K_1	k_2	T_B (s)	T_C	T_D	k_{d1}	k_{d2}	For considered tanks		
										η	q	a_g
A	1,0	2,5	1,0	2,0	0,10 s	0,40 s	3,0s	2/3	5/3	1,08	1,0	4m/s^2
B	1,0	2,5	1,0	2,0	0,15 s	0,60 s	3,0 s	2/3	5/3	1,08	1,0	4m/s^2
C	0,9	2,5	1,0	2,0	0,20 s	0,80 s	3,0 s	2/3	5/3	1,08	1,0	4m/s^2



a) for ξ=4%

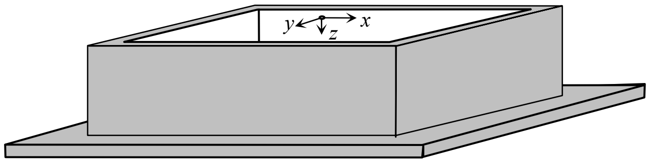
b) for ξ=0.5%

Figure 4. Design spectrums for different soil classes defined in EC-8

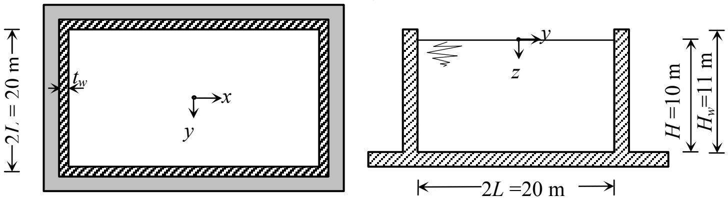
Drawing of Fig. 4, design ground acceleration A_g is taken to be 4 m/s^2 suitable for seismic zone one described in Turkey. Behaviour factor (q) is taken to be 1,0 as recommended in EC-8.

4 NUMERICAL EXAMPLES

In this study a reinforced concrete rectangular water tank with two different wall thicknesses of 0.5m and 1.0 m is considered as seen from Figure 5. Mass density, Poisson ratio and Young Modulus of the walls are taken to be 2500 kg/m^3, 0.2 and 28x10^6 kN/m^2, respectively. Mass density of water is 1000 kg/m^3.



a) Tank



b) Plan

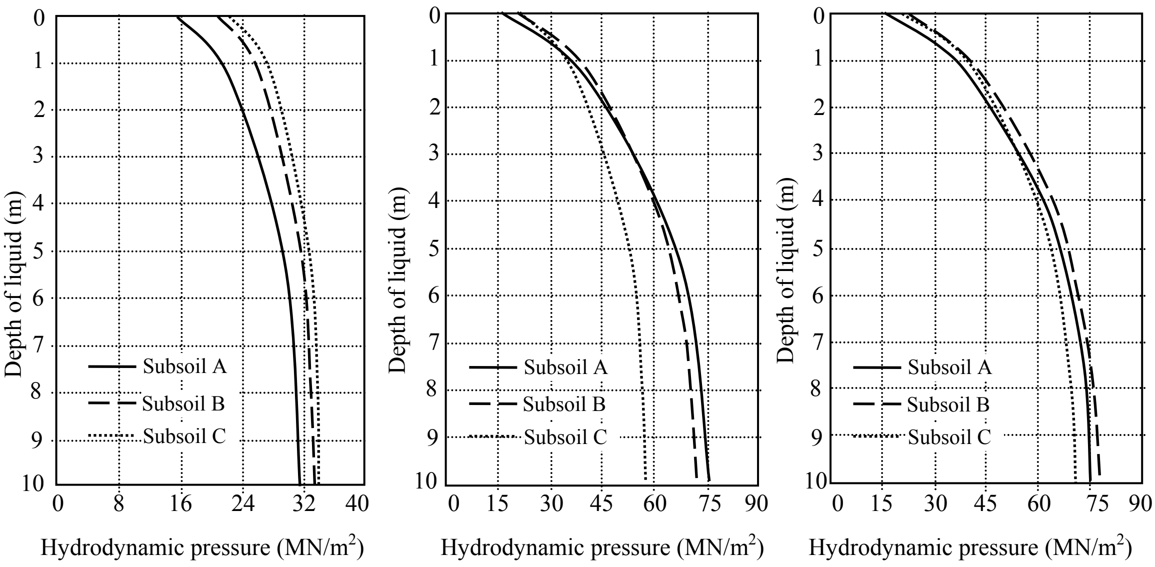
c) Elevation

Figure 5. Plan and elevation of the sample rectangular tank

It is assumed that the sample storage tank is subjected to earthquake in the direction parallel to the short side walls. The tank is assumed to be founded on thee different subsoil classes defined in EC-8. Damping value (ξ) fixed to the ground. It is recommended for reinforced concrete structures to be ξ =4% and ξ =7% for serviceability and ultimate limit states, respectively. The value of ξ =4% is selected for structural system of the tank. The value ξ=0.5% is used for water as recommended in EC-8.

Hydrodynamic pressure, wave height and displacement of walls are very important parameters for design of storage tanks. Determination of these parameters is given below:

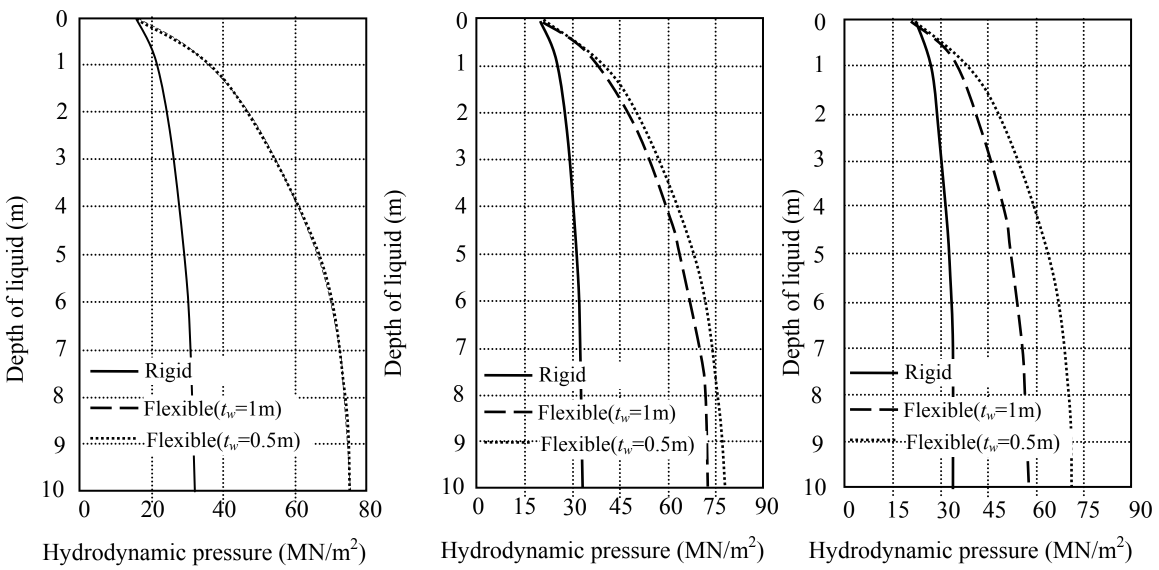
Firstly, rigid solution is carried out for seismic analysis of the tank. Then flexible solutions for wall thickness of 1.0 m and 0.5 m are carried out. Three subsoil classes defined in EC-8 are considered in all solutions. The distributions of hydrodynamic pressures acting on the tank walls in the horizontal direction are given in Figure 6. As seen from this figure the maximum and minimum hydrodynamic pressures for rigid solution are determined for subsoil class C and A, respectively. But, the maximum and minimum hydrodynamic pressures for flexible solution of t_w=1.0 m are determined for subsoil class A and C, respectively. These results are opposite of above results. The maximum and minimum pressures are determined for flexible solution of t_w=0.5 m for subsoil class B and C, respectively. The maximum difference is obtained for flexible solution of t_w=1 m. The value for subsoil class A is 1.32 times greater than the value for subsoil class C.



a) Rigid solution b) Flexible solution (t_w=1.0m) c) Flexible solution (t_w=0.5m)

Figure 6. Plan and elevation of the sample rectangular tank

The hydrodynamic pressures obtained by the solutions (rigid, flexible for t_w=1.0m and flexible for t_w=1.0m are given in Figure 7 for the three subsoil classes. As seen from this figure, rigid solutions for three subsoil classes gave the minimum value.



a) Subsoil class A b) Subsoil class B c) Subsoil class C

Figure 7. Plan and elevation of the sample rectangular tank

Housner Method is used for determination of wave height by the following equation (Epstein 1976).

$$d_{\max} = \frac{0.833\dfrac{A_n L}{g}}{1 - 1.58\dfrac{A_n}{g}\tanh(1.58\dfrac{H}{L})} \tag{6}$$

In order to obtain d_{max} by Housner method, the acceleration spectrum considering the firs mode 5.26 s and 0.5% damping ratio is taken to be 1.106 m/s^2 , 1.44 m/s^2 and 1.58 m/s^2 for subsoil class A,B and C, respectively from the Figure 4b. The maximum wave heights (d_{max}) for the rigid tank are determined to be 2.06 m, 3.02 m and 3.44 m for subsoil class A, B and C, respectively. This equation (6) is valid only for small amplitudes of motion partly due to nonlinear effects which enter d_{max} is greater than 0.2L(=0.2*10=2m)(Epstein 1976). So these wave heights for considered rectangular tank exceed the limit of 0.2L.

CONCLUSIONS

The seismic responses of rectangular tanks founded on the three subsoil classes defined in EC-8 are investigated. Conclusion drawn from this study may be summarized as:

The values of hydrodynamic pressures for the solution which the walls are rigid are the smallest values for all subsoil classes considered. It is supposed the reinforced concrete tank walls are rigid due to big thickness. But, as obtained from this study, the hydrodynamic pressures at the base of the walls for flexible solution of t_w=1.0 m are approximately two times larger than that of the rigid solution.

The difference of the base ordinates of the diagrams of hydrodynamic pressure obtained considering three subsoil classes reached about 30% for the sample tank. This situation can not be ignored for design of rectangular tanks.

The maximum wave height (d_{max}) is affected very strongly by the subsoil classes. This height for subsoil C is 1.77 times larger than that for subsoil class A. Furthermore the values of these heights are greater than 0.2L limit given in literature.

It is demonstrated for the designers interested in the tanks that how subsoil conditions consider for the design and how they affect the dynamic parameters of the rectangular tanks.

It is recommended that the subject on soil-structure interaction for the rectangular tanks should be researches due to lack of the studies about this subject.

REFERENCES

Doğangün, A. (1995). Earthquake Analysis of Rectangular Water Tanks Considering Liquid-Structure-Soil Interaction Using Finite Element Method by Comparing With Analytical Methods. (in Turkish), Dissertation, Karedeniz Technical University, Trabzon, Turkey.

Epstein, H.I (1976). Seismic design of liquid storage tanks. J.Struct. Div. ASCE, 102, 1659-1673.

Eurpcode-8 (1998). Design of Structures for Earthquake Resistance-Part 4: Silos, Tanks and Pipelines. European Committee for Standardization, 65 pp.

Kim, J.K., Park, J.Y., and Jin, B.M. (1998). The effects of soil-tructure ınteraction on the dynamics of 3-D flexible rectangular tanks, Proceedings of the 6th East Asia-Pacific Conf.on Struc. Engng. & Construction, January 14-16, Taipei, Taiwan.

Priestley, M.J.N., Davidson, B.J., Honey, G.D., Hopkins, D.C., Martin, R.J., Ramsey, G., Vessey, J.V., and Wood, J.H. (1986). Seismic Design of Storage Tanks. Recommendation of a Study Group the New Zealand Society for Earthquake Engineering, New Zealand, 180 pages.

Rammerstorfer, F.G., Scharf, K., and Fischer, F.D. (1990). Storage tanks under earthquake loading. Appl. Mech. Reviews, 43, 261-281.