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Seismic Analysis of Underground Water Tank Considering Soil Structure Interaction

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ABSTRACT
To minimize leakage and corrosion of reinforcing steel, the design rules prescribe high serviceability criteria as well as strict criteria for water tightness and crack prevention. Considering these demanding constraints, additional emphasis is placed on precisely calculating the governing design forces to satisfy both economic and serviceability requirements. Limited number of studies have been found for seismic analysis of underground water tank considering dynamic soil pressure and soil structure interaction. The purpose of the present study is to understand the behaviour of underground water tank subjected to seismic loading and soil structure interaction and comparison of their output result to understand its behaviour. For the study existing underground water tank have been used and finite element modelling of same tank has been done in ETABS17 for two different soil condition as per IS 1893 part-2-2014.

***Keywords* –** Design Forces, Earth Pressure, Seismic Analysis, Soil Structure Interaction, Underground Water Tank, Water Pressure

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I. INTRODUCTION

Liquids are stored in underground water tanks (oil, water, gas, etc.). These tanks are subjected to both internal water pressure and external ground pressure. The bottom of tanks is vulnerable to water pressure from within and soil reaction from below. It is always covered at the top. These tanks should be designed for the worst-case scenario of loading. The design and operating principles of underground tanks are the same as those of tanks resting on ground. The underground tanks walls are susceptible to both internal water pressure and external earth pressure. The part of the wall is designed to withstand both water pressure and earth pressure working separately and simultaneously. During earthquakes, concrete liquid-containing structures as part of environmental engineering structures are regarded as critical utilities. While the leakage of tanks containing hazardous materials must be managed in storage tanks, the contents are critical for firefighting operations and addressing public needs. The loading conditions of water storage tanks subjected to seismic ground motion earthquakes are quite challenging. In addition to the inertial force caused by the weight of the tank walls, hydrodynamic pressures are applied to the tank walls. The most of conventional structures are constructed on one or more layers of soil. When a structure with certain dynamic properties interacts with a soil layer with similar dynamic properties, the total behavior is governed by the interaction of both systems. As a result, the impact of soil conditions on the dynamic response of liquid-storage tanks should be addressed.

Due to the interaction effects between the flexible structure and the contained liquid, the hydrodynamic pressure in a flexible tank can be much higher than in a rigid container during seismic excitation. The hydrodynamic pressure caused by an earthquake is often divided into impulsive and convective elements. The impulsive component is driven by the interaction between the tank wall and the liquid and is strongly dependent on the wall's flexibility, whereas the convective component is induced by the slosh wave. Sloshing is the dynamic load acting on a tank structure because of fluid motion with constrained free surface within a tank. Its properties can differ considerably depending on the tank configuration and seismic characteristics of the applied load, resulting in highly localized pressure on the tank walls in some cases. IS 1893 - Part 2-2014 suggested to conduct seismic analysis of underground water tank as procedure given for on ground water tank considering dynamic soil coefficient for earth pressure but the procedure to calculate to calculate dynamic soil coefficient is not given in the IS code.

The specific objectives of this work are as follows: -

- To investigate effect of soil condition on seismic loading for underground water tank.
- To analyze effect of soil structure interaction on underground water tank using Wrinkler's spring method

II. MODELLING PARAMETERS

Existing water tank situated at Solsinda, Sanwer, Indore (M.P.) is taken for the study. The dimensions of water tank and elements are shown in Table 1 and 2 respectively. Existing water tank modelling in ETABS is shown in figure 2.

TABLE 1: UGT Dimension

S.No.	Parameter	Dimension
1	Length	9 m
2	Width	4 m
3	Height	3 m

TABLE 2: UGT Elements Dimension

S.No.	Element	Thickness
1	Outer Wall	250 mm
2	Bottom Slab	300 mm
3	Centre Partition Wall	300 mm

Clay of high Compressibility (CL) and Silt of high Compressibility (MH) is taken for this experiment as per IS 1893-Part- 1-2016. CL is categorized under medium or stiff soil and MH is under soft soil. In UGT, water pressure from inside and soil pressure from outside are two most important loads for which UGT are designed and checked. Both water pressure and soil pressure are assigned as non-uniform shell loads on walls of UGT in ETABS. Walls are designed for a non-uniform load of 30 kN/m^2 for water pressure and 27 kN/m^2 of earth pressure.

III. SIESMIC LOAD CALCULATION

Hydrodynamic forces exerted by earthquake on tanks walls should also be considered in addition with hydrostatic forces. As per IS 1893-Part – 2-2014, hydrodynamic forces on UGT can be calculated by adopting same procedure of on ground tank. In UGT, dynamic soil pressure must be calculated. In this study as per the location of UGT, seismic zone-3 has been considered for earthquake analysis with two different soil conditions i.e. medium stiff (CL) and soft soil (MH). Classification of soil has been taken from IS1893-Part 1-2016. Excel sheet has been used to calculate seismic forces in terms of total base shear, total moment at base of wall and hydrodynamic pressure on wall in both X and Y direction considering impulsive and convective modes for medium and soft soil categories.

Soil dynamic pressure for CL soil is 94.18 kN/m^2 and 75.34 kN/m^2.

IV. SPRING CONSTANT FOR SOIL STRUCTURE INTERACTION

Spring constants has been calculated as per the FEMA 356 recommendation. In the expression given, length(L), width(B) and shear modulus(G) for CL and MH soil has been used to calculate spring constant.

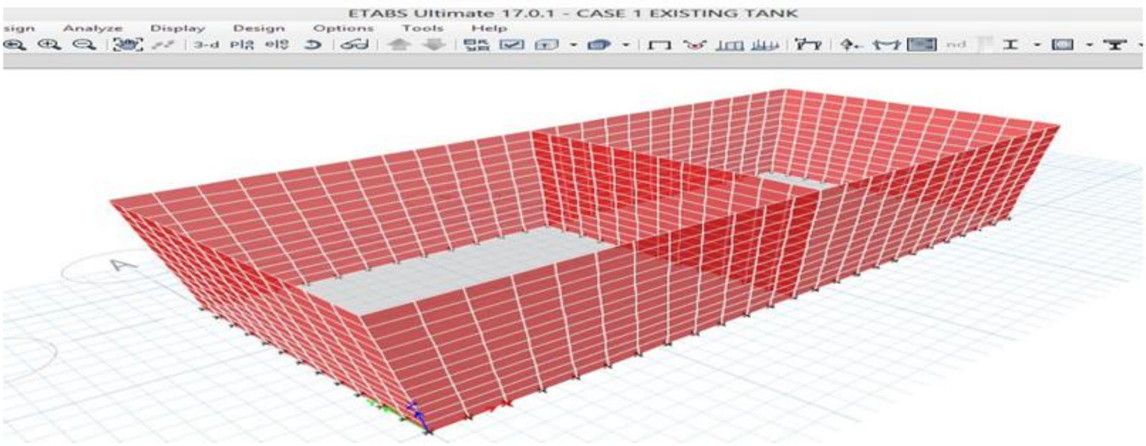

Figure 1: Existing UGT modelling in ETABS

Modulus of subgrade reaction or coefficient of subgrade reaction is the reaction pressure sustained by the soil sample under a rigid plate of standard diameter per unit settlement measured at a specified pressure or settlement. For the existing tank permissible settlement is 10 mm. Therefore, subgrade modulus has been calculated for all cases considering 10 mm settlement. Modulus of subgrade for existing tank condition, CL and MH soil are 100000,150000 and 80000 kN/m respectively.

TABLE 3: Hydrodynamic Pressure Distribution

Soil Type	Top	Bottom
CL(X)	0.93 kN/m^2	2.63 kN/m^2
MH(X)	1.01 kN/m^2	2.62 kN/m^2
CL(Y)	2.47 kN/m^2	10.15 kN/m^2
MH(Y)	2.50 kN/m^2	10.15 kN/m^2

TABLE 4: Spring Constant for CL and MH soil

DOF	CL	MH
K_x	352614	35251
K_y	356234	35613
K_z	438353	43822
K_{xx}	1547241	154679
K_{yy}	1849767	184923
K_{zz}	2397113	239641

V. RESULT AND DISCUSSION

Different models have been modelled and analyzed considering seismic and soil structure interaction effect on existing underground water tank for medium stiff and soft stiff soil. For the calculation of seismic forces procedure given in IS1893-Part-2-2014, excel sheet have been used. For the tank walls, design forces are studied for the influence of the soil-structure interaction under CL and MH soil conditions. The effects of soil-structure interaction on the analysis of cylindrical tanks have been demonstrated.

A three-dimensional finite element analysis has been performed using ETABS. The soil reactions had represented using elastic springs under the base slab.

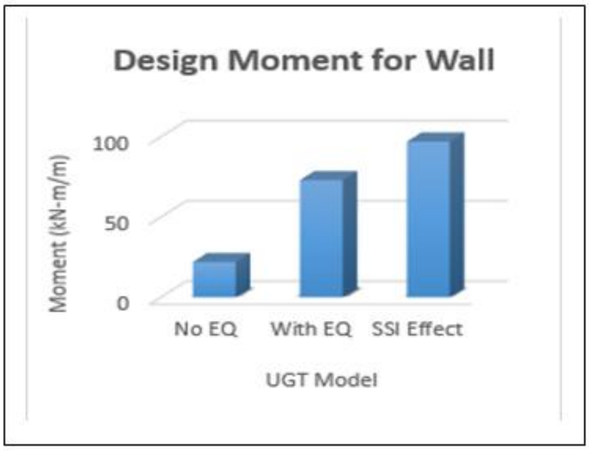

Figure 2: Design Moments on UGT Walls for CL Soil

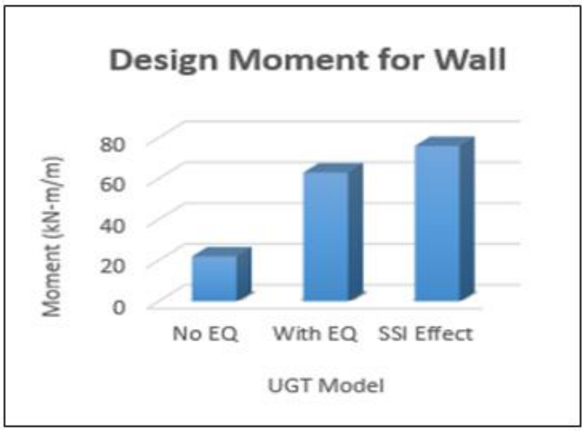

Figure 3: Design Moments on UGT Walls for MH Soil

On considering SSI effect design moments increased by considerable amount. On considering seismic forces the magnitudes of moments, at the base of the wall, exceed the corresponding moments resulting from without considering seismic forces. Although for seismic condition, the soil type has no major influence on the resulting bending moments. In case of shear forces, on considering seismic forces shear forces increased significantly which leads to failure of wall thickness. On considering SSI effect design moments increased by considerable amount. The deformation of the base slab shows the settlement of the soil beneath. As expected, the settlement due to seismic is quite large w.r.t non seismic condition. In case of soft soil, the settlement is very high. The bending moments in the base slab resulting from seismic forces are larger than those resulting by considering non seismic forces

VI CONCLUSION

Following conclusion are drawn from present study
1.From the study it is concluded that considering seismic forces is beneficial for underground water tank.

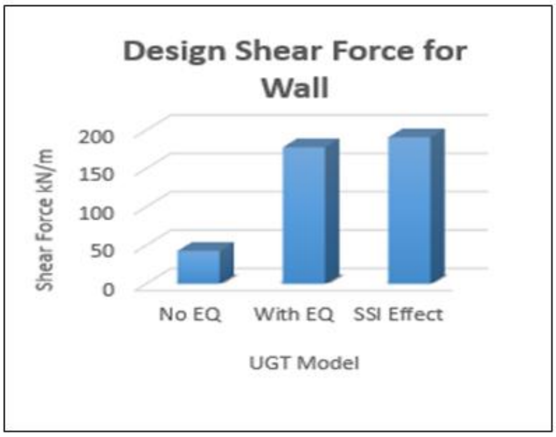

Figure 4: Design Shear Force on UGT Walls for CL Soil

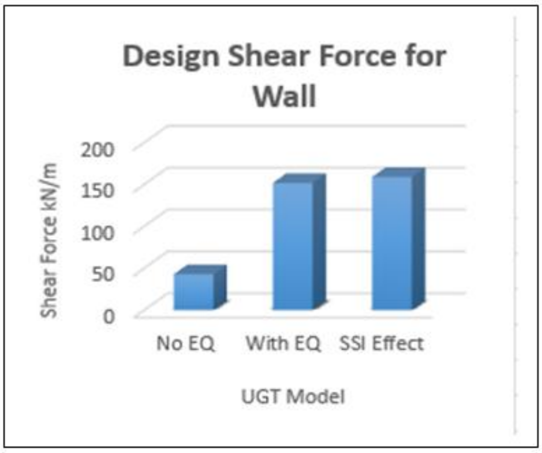

Figure 5: Design Shear Force on UGT Walls for CL Soil

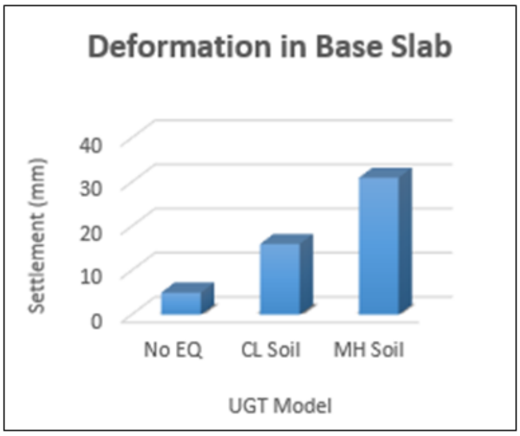

Figure 6: Deformation in Base slab

2. On considering seismic forces the moments in walls along both X and Y at the base, exceeds moments in walls of existing tank. Although soil condition does not influence design force significantly.
3. Shear force dominates the thickness of wall, on considering seismic forces shear forces increased which tends to redesign thickness of slab.
4. On considering SSI effect with elastic spring at base, design forces increased as compared to seismic design with rigid base. Although SSI effect is not very much significant.

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