A Study on the Seismic Response of Elevated Circular Water Tank

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***Abstract* - Water tanks are important public utility and industrial structure. Liquid containing elevated circular tanks are critical and strategic structures. They are considered one of those sensitive structures affected by dynamic loads. The design of circular water tank should be based on the worst possible combination of loads, moments and shears arising from vertical loads and horizontal loads acting in any direction when the tank is full as well as empty. In order to study the seismic behavior of elevated circular water tanks caused by dynamic loading the soil structure interaction (SSI) and numerical analysis plays a major role. This work is focused on the study of seismic response of elevated circular water tank considering the sloshing effect and this work evaluates the behavior of the circular water tank considering SSI effect in seismic Zone II and III and different soil conditions as per IS1893(Part 2):2014.**

***keywords* - Water Tank, Seismic Response, Circular water tank, SSI, Sloshing effect.**

I. INTRODUCTION

Water tanks are one of the most essential requirements for human life mainly for storage and supply of water. Accordingly water tanks assumes an indispensable part for public utility just as modern design having fundamental reason to protect steady water supply from longer distance with adequate static head to the ideal area under the impact of gravitational power. With the rapid increment of human population, the demand for drinking water has expanded by many folds. India is profoundly helpless against cataclysmic events like quake, drafts, floods, twisters and so on Larger part of Indian states and association domains are inclined to one or various fiascos. These regular disasters are causing numerous causalities and gigantic property misfortune consistently. As indicated by IS 1893(Part-1):2000, over 60% of India is inclined to earthquakes which indicates that the water tanks to be built after performing the seismic analysis which reduces the damage caused to them during the unforeseen earthquakes.

The chance of event of seismic tremors and its harming impacts is distinctive at various areas. Thus, to analyses the earthquakes we should concentrate on the Zones identified. In India there are five seismic zones characterized by different factors which affects the earthquake magnitude they are Seismic Zone Factor, Z Importance Factor, I Response Reduction Factor, R Structural Response Factor, (Sa/g). The present work is focused on the study of seismic response of elevated water tank considering the sloshing effect and to evaluate the behavior considering Soil-structure interaction (SSI) in seismic Zone (II and III) and in different soil conditions as per IS1893(Part 2):2014 using FEM based software SAP2000.

II. SCOPE AND OBJECTIVES

The proposed work involves the design and seismic analysis of elevated circular water tank for empty and full condition along with the soil structure interaction considering the sloshing effects and seismic behavior on different soil types.

The objective of the proposed work involves,

1. To evaluate the dynamic displacement of circular water tank subjected to ground motion using response spectrum.
2. To evaluate the associated base shear due to dynamic loading.
3. Analyze the tank considering the soil structure interaction.
4. To restrict staging displacement under the allowed limit of (H/500).

III. METHODOLOGY

The methodology includes designing the dimensions of components for the circular elevated water tank and performing nonlinear dynamic analysis by 1893- 2016 (Part 2) code. This work proposes to study circular tanks of zone II with all soft soil condition. The analysis is carried out for tank with full tank and empty condition. The analysis of the elevated circular water tank is performed using FEM SAP-2000 software.

The Analysis of the circular elevated water tank includes various concentrates on various parameters. Some of these parameters include pressure distribution on tank wall due to lateral and vertical base excitation, time period of tank in lateral and vertical mode.

Impulsive Mass: When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass (mi), which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented.

Convective Mass: Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass (mc) and it exerts convective hydrodynamic pressure on tank wall and base.

Time period in Impulsive mode (Ti)

When a tank subjected to horizontal earthquake ground motion, tank wall and liquid in lower region of tank will accelerates with same horizontal acceleration and it will possess fundamental natural time period i.e. Time period in Impulsive mode (Ti) in seconds.

Time period in convective mode (Tc)

When a tank subjected to horizontal earthquake ground motion , liquid mass in upper region of tank undergoes sloshing motion some horizontal acceleration that differ from above case and in this case fundamental natural period of time i.e. Time period in Convective mode (Tc) in seconds.

Design Horizontal seismic coefficient

Design Horizontal seismic coefficient, A_h obtained by the following expression,

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)$$

Where,

Z= Zone factor (Table 2 IS 1893(Part-I) :2016)

I= Importance factor (=1.75, for hazardous liquid, =1.5, for water storage tank)

R= Response reduction factor

IV. Problem Statement

The present study consists of the design and analysis of the elevated circular water tank of height 3.3 m and diameter of 3 m and capacity 21.2 m3 which is resting 6 m above the ground level on the staging containing 4 columns. The depth of the foundation is 1.5 m below ground level. The location of tank is around Bengaluru region which comes in seismic zone II.

Table 1 Details of Tank Geometry

Component	Dimensions (mm)
Wall	180
Floor Slab	180
Floor Beam	300X500
Columns	300X300
Braces	300X300

Table 2 Dynamic characteristics of Circular water tank

Structure	SMRF
Soil Type	I, II, III
Seismic Zone	II &III
Zone factor	0.10 and 0.16
Importance factor	1.5
Response reduction factor	4

V. Analysis and Results of Modelled Circular Water Tank

The circular water tank was modelled and analyzed using SAP2000. The fixed base analysis and soil structure interaction (SSI) are considered for the circular water tank study.

Fixed Base Analysis

The fixed base analysis is done with the columns' support fixed. Hard, medium, and soft soil conditions are considered in the response spectrum approach of study.

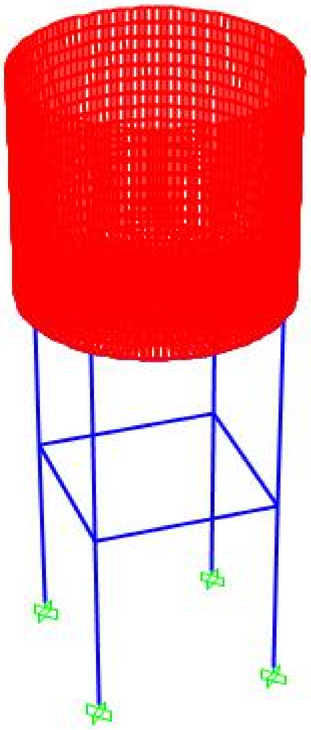
For empty Tank condition,

- The structure's dead load is considered for performing the analysis.
- The Response spectrum approach is used to accomplish the dynamic analysis.
- The response spectrum function is defined using a damping factor of 5%.
- Base shear, Base moment, and Modal characteristics are considered for performing the analysis.

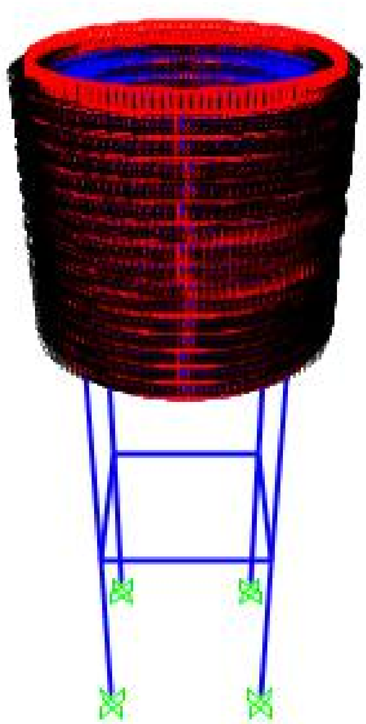
For full Tank condition,

- The full tank study takes structure's dead load as well as the hydrostatic load into account.
- Impulsive and convective hydrodynamic pressures are considered for the analysis.
- The Response spectrum approach is used to conduct the dynamic analysis.
- The response spectrum function is defined using a damping factor of 5%.
- Base shear, Base moment, and Modal parameters are calculated and considered for analysis.

- Figure 1 shows the empty tank and full tank fixed support conditions. Table 3 shows the base shear and base moment for fixed base analysis. The Model time period and frequencies for empty and full tank are shown in Table 4. The time period for the empty tank is 0.3224s and for full tank is 0.3945s. For different types of soils, the base shear, base moment, and displacement are the same because of the same average acceleration coefficient (Sa/g).



Empty Tank Condition



Full Tank Condition

Figure 1 Circular water tank model with fixed base

Table 3 Base Shear and Base Moment for Empty and Full Condition

Output case	Condition	Base shear (X- dir) kN	Base shear (Y- dir) kN	Base Moment (X- dir) kN-M	Base Moment (Y- dir) kN-M
EQ(Equivalent static method)	Empty	13.683	13.683	108.823	108.823
RS(Response Spectrum method)		13.682	13.682	102.073	102.073
EQ(Equivalent static method)	Full	19.796	19.796	151.059	151.059
RS(Response Spectrum method)		19.797	19.797	143.176	143.176

Table 4 Modal period and frequencies for empty and full tank during RS analysis

Mode	Empty Tank		Full Tank	
	Time period (Secs)	*Frequency (Cyc/Sec)*	*Time period (Secs)*	*Frequency (Cyc/Sec)*
Mode 1	0.3224	3.1009	0.3945	2.5348

Mode 2	0.3224	3.1009	0.3945	2.5348
Mode 3	0.2539	3.9373	0.2875	3.4777

Table 5 Displacement of water tank for different seismic zones

Height (m)	**Empty Tank-Displacement (mm)**		**Full Tank-Displacement (mm)**	
	Zone II	***Zone III***	***Zone II***	***Zone III***
Top	1.4	2.2	2	3.2
6	1.3	2.1	1.9	3.1
3	0.6	1	0.9	1.4
Base	0	0	0	0

Soil Structure Interaction (SSI)

The Soil Structure Interaction helps in determining and analyzing the performance of the water tank in real time. In this work the SSI is considered for soft, medium and hard soil conditions in Zone II and Zone III for the circular water tank analysis. Figure 3 shows the SSI model for the circular water tank.

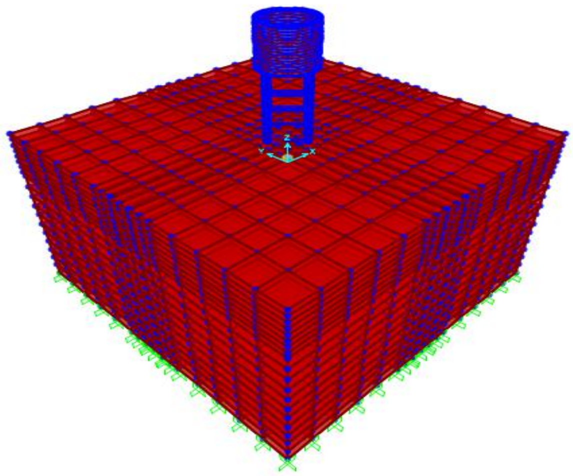


Figure 2 Soil structure interaction for circular water tank

The properties of the soil considered for the analysis is shown in Table 6.

Table 6 Soil Properties

Soil Type	**Unit weight (kN/m^3)**	**Modulus of elasticity (kN/m^2)**	**Poisson's ratio (μ)**
Hard	18	85000	0.3
Medium	16	35000	0.4
Soft	16	15000	0.4

I. Soil Structure Interaction (SSI) for Empty Tank Condition

i. Hard Soil

Table 7 Displacement for Empty tank condition- Hard Soil

Height (m)	**SSI Displacement (mm)**		**Fixed Base Displacement (mm)**	
	Zone II	***Zone III***	***Zone II***	***Zone III***
Top	4.5	7.2	1.4	2.2
6	4.1	6.5	1.3	2.1
3	3	4.7	0.6	1
Base	1.9	3.1	0	0

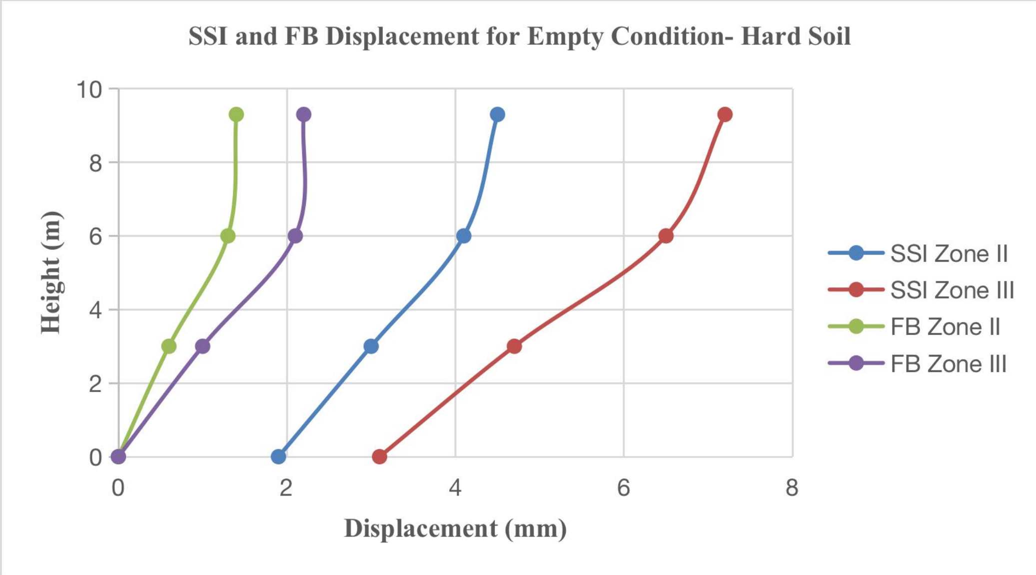


Figure 3 SSI and FB Displacement for Empty Condition- Hard Soil

ii. Medium Soil

Table 8 Displacement for Empty tank condition- Medium Soil

Height (m)	SSI Displacement (mm)		Fixed Base Displacement (mm)	
	Zone II	*Zone III*	*Zone II*	*Zone III*
Top	6.3	10.1	1.4	2.2
6	5.8	9.2	1.3	2.1
3	4.5	7.2	0.6	1
Base	3.3	5.1	0	0

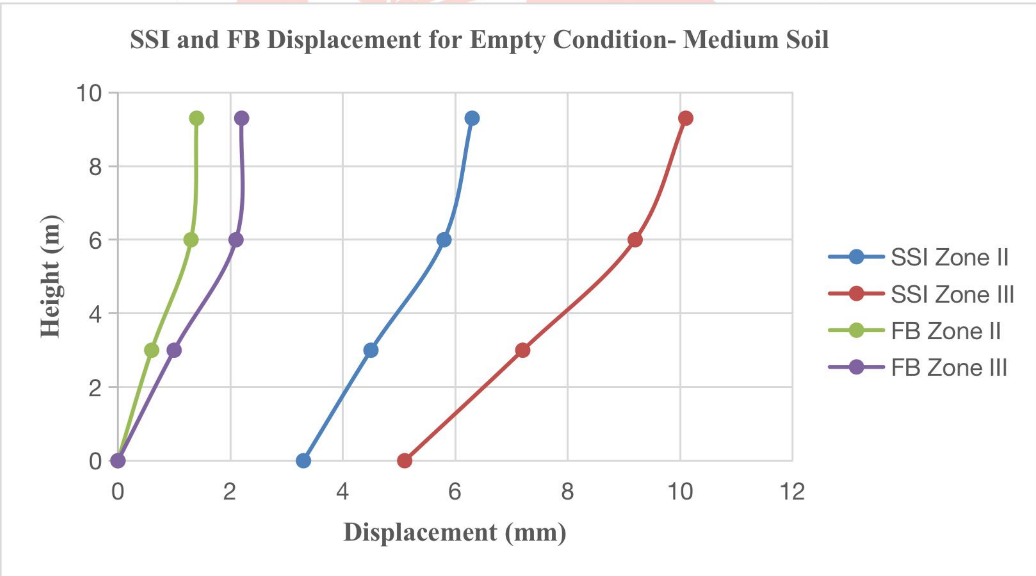


Figure 4 SSI and FB Displacement for Empty Condition- Medium Soil

iii. Soft Soil

Table 9 Displacement for Empty tank condition- Soft Soil

Height (m)	SSI Displacement (mm)		Fixed Base Displacement (mm)	
	Zone II	*Zone III*	*Zone II*	*Zone III*
Top	8.2	11.6	1.4	2.2
6	7.4	10.4	1.3	2.1
3	5.8	8.5	0.6	1
Base	4.5	7.2	0	0

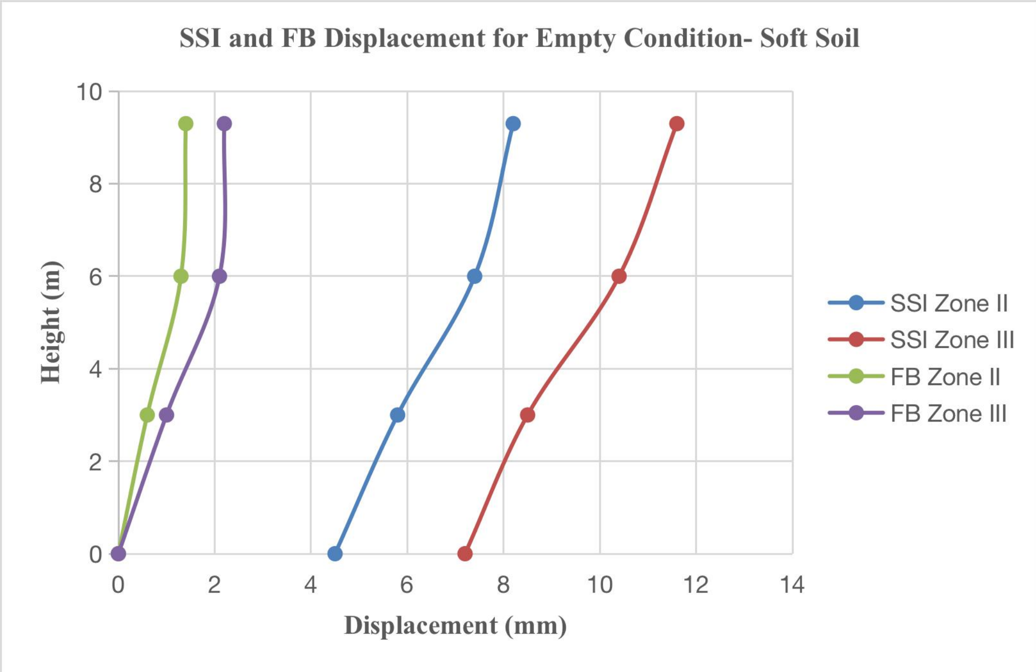


Figure 5 SSI and FB Displacement for Empty Condition- Soft Soil

II. Soil Structure Interaction (SSI) for Full Tank Condition

i. Hard Soil

Table 10 Displacement for Empty tank condition- Hard Soil

Height (m)	SSI Displacement (mm)		Fixed Base Displacement (mm)	
	Zone II	*Zone III*	*Zone II*	*Zone III*
Top	6.2	9.8	2	3.2
6	5.6	8.9	1.9	3.1
3	3.8	6	0.9	1.4
Base	2.1	3.4	0	0

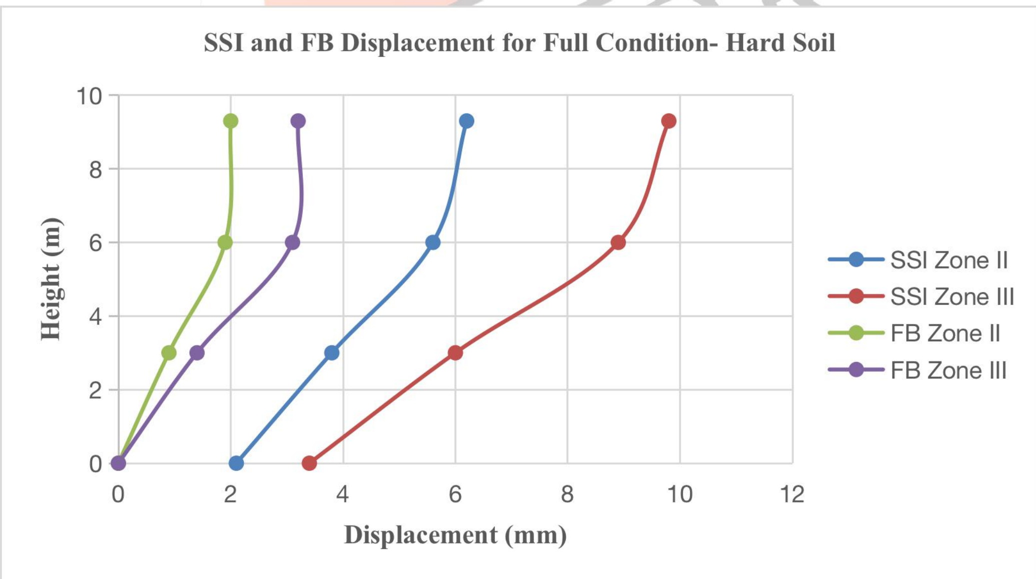


Figure 6 SSI and FB Displacement for Full Condition- Hard Soil

ii. Medium Soil

Table 11 Displacement for Full tank condition- Medium Soil

Height (m)	SSI Displacement (mm)		Fixed Base Displacement (mm)	
	Zone II	*Zone III*	*Zone II*	*Zone III*
Top	7.9	11.6	2	3.2

6	7.2	10.4	1.9	3.1
3	5.2	7.3	0.9	1.4
Base	3.4	4.4	0	0

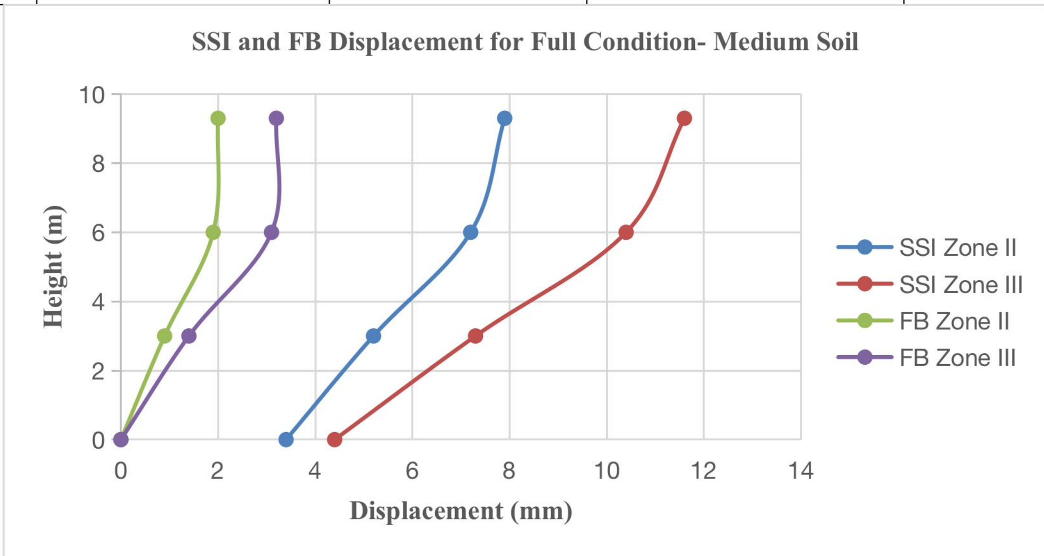


Figure 7 SSI and FB Displacement for Full Condition- Medium Soil

iii. Soft Soil

Table 12 Displacement for Full tank condition- Soft Soil

Height (m)	SSI Displacement (mm)		Fixed Base Displacement (mm)	
	Zone II	*Zone III*	*Zone II*	*Zone III*
Top	9.4	12.1	2	3.2
6	8.4	10.7	1.9	3.1
3	6.2	8.1	0.9	1.4
Base	4.5	6.3	0	0

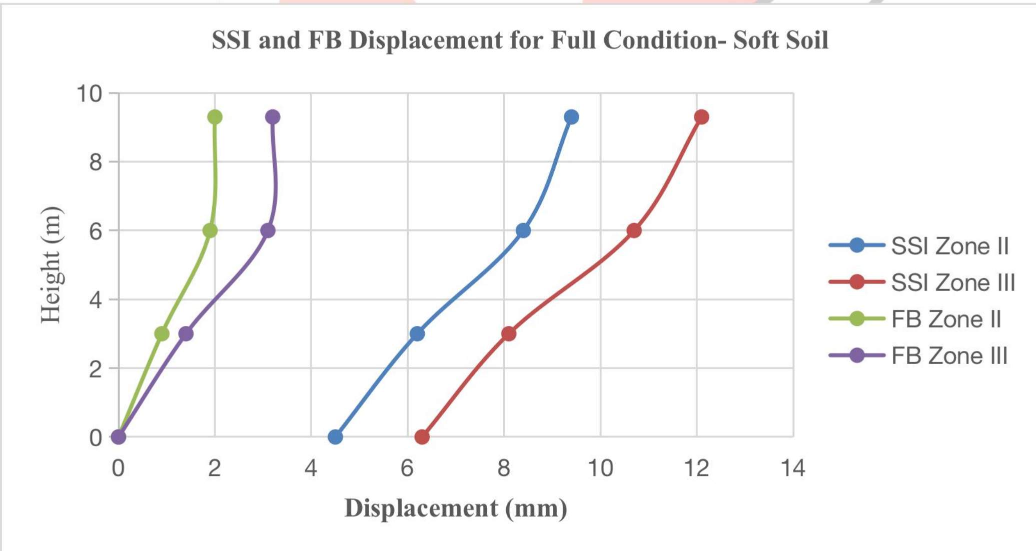


Figure 8 SSI and FB Displacement for Full Condition- Soft Soil

III. Time Period for fixed base and Soil Structure Interaction (SSI)

The Time period is higher in tank full condition due to the presence of water and in soft soil condition, the SSI impact enhanced the structure's time period when compared to a fixed base time period.

Table 13 Comparison of time period between fixed base and soil structure interaction

Soil Type	Time period (Secs) - Empty Tank		Time period (Secs) - Full Tank	
	Fixed Base	*SSI*	*Fixed Base*	*SSI*
Hard	0.32	1.275	0.39	1.275
Medium	0.32	0.734	0.39	0.737

Soft	0.32	0.582	0.39	0.645

IV. Sloshing wave height in different seismic zones

Soil Type	Zone II		Zone III	
	Sloshing wave height (m)	*Freeboard (m)*	*Sloshing wave height (m)*	*Freeboard (m)*
Hard	0.168	0.3	0.27	0.3
Medium	0.138	0.3	0.216	0.3
Soft	0.096	0.3	0.162	0.3

VI. Conclusion

The following conclusions were drawn from the seismic analysis of the elevated circular water tank.

- Due to the lack of water, base shear in a full tank is greater than in an empty tank.
- In Zones II and III, a freeboard height of 0.3m is adequate for sloshing wave height, but the tank must be revised for Zones IV and V.
- The total base shear and base moment in a full tank are greater than the total base shear and base moment in an empty tank, hence full tank conditions will govern the design.
- Due to the presence of water, the time period and displacement are increased when the tank is full.
- Due to soil flexibility, the soil structure interaction (SSI) shows an increase in values of displacement and time period when compared to fixed base analysis.
- Maximum displacement is observed in soft soils and increases with seismic zones.
- The maximum displacement must not exceed (H/500) However, in soft soils, displacements have surpassed permitted limits, necessitating the use of various bracing systems to control displacement values.
- Soft soils have larger displacement values than medium and hard soils, hence bracings are only advised in soft soils.
- In soft soil conditions, the SSI impact enhanced the structure's time period when compared to a fixed base time period.

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