Parametric Study of Slit Reinforced Concrete Shaft in Elevated Water Tanks for Seismic Behaviour

[1]Mayank Patel, [2]Prof. Nikunj Patel

[1]Student M.tech., [2]Asst. Professor,
[1]Post-Graduation (Structural Engineering) Department,
[1]Sardar Patel College of Engineering, Anand, India

Abstract: Elevated water tanks are used within water distribution facilities in order to provide storage and necessary pressure in water network systems. During the occurrence of a severe seismic event, the failure or severe damages in the reinforced concrete shaft could result in the total collapse of the structure. In a reinforced concrete shaft, plastic hinge formation only occurs at the base of the shaft. This research presents an innovative technique for the assembly of shafts for elevated water tanks, using the slits in the reinforced concrete shaft design, which reduces the stress concentration at the base of the shaft and distributes stresses uniformly along the height of the shaft. The main aim of this study is to investigate the seismic performance of the Slit reinforced concrete shaft in elevated water tanks for different slit width and different Earthquake zones by means of a finite element approach. Analysis will be done according to IS-1893 using Bentley STAAD Pro Software.

***Keywords* – Intze type water tank, Seismic analysis, Slit reinforced shaft, STAAD Pro.**

1. INTRODUCTION

The reinforced cement concrete overhead water tank is the most effective storing facility used for domestic and even for industrial purposes. These structures play an imperative role in municipal water supply and firefighting systems. Elevated water tanks are water storage facilities, which are installed on a supporting staging to provide necessary pressure for the water distribution system obtained by gravity instead of the implementation of a heavy pumping facility.

Overall, the supporting structure of the elevated water tanks can be classified as reinforced concrete frame, steel frame, masonry shaft or a reinforced concrete shaft. In this thesis, the term "Elevated Water Tank" only refers to the last group, which is the tank, mounted on the reinforced concrete shaft and will be the subject of this research.

In case of high intensity earthquakes, flexible support systems are preferred as they can receive large deformations. On the other hand, for low intensity earthquakes that occur frequently, or for wind action; solid shafts should be considered, for the reason that they prevent large displacements.

However, elevated water tanks in the past have not performed up to expectations during earthquakes. The extent of the damages ranges from minor cracks in the shaft up to complete collapse of the entire structure.

1.1 TYPE OF WATER TANK

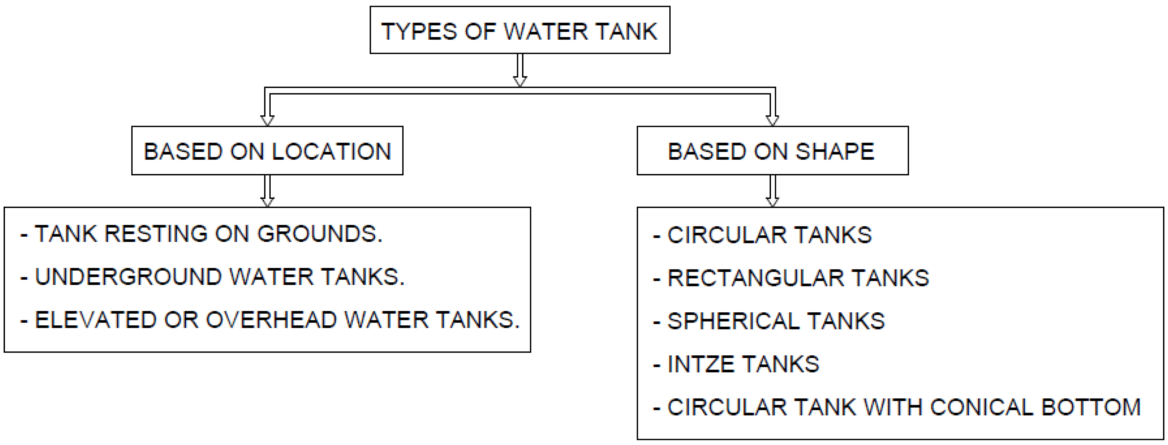


Fig 1.1 Types of water tank

For recent work, intze type water tank which supported on RC shaft will use for parametric study.

1.2 STRUCTURAL ELEMENTS OF INTZE TANK

The various structural elements of an INTZE type tank comprises of the following:

1. Top spherical dome
2. Top ring beam
3. Circular side walls
4. Bottom ring beam
5. Conical dome
6. Bottom spherical dome
7. Bottom ring beam
8. Cylindrical RC shaft
9. Foundation

1. Top Spherical Dome

Top dome is designed for self-weight and a service live load as per provision of the relative Indian standard codes. The top dome is supported on cylindrical wall. Two type of forces that is the meridional (T) acting along the direction of meridian and the hoop stress (H) along the latitude develop on the dome due to the applied loads.

Top dome is designed for these two forces. As the stresses developed are very small in magnitude, minimum reinforcement as specified in code is normally provided in the form of mesh.

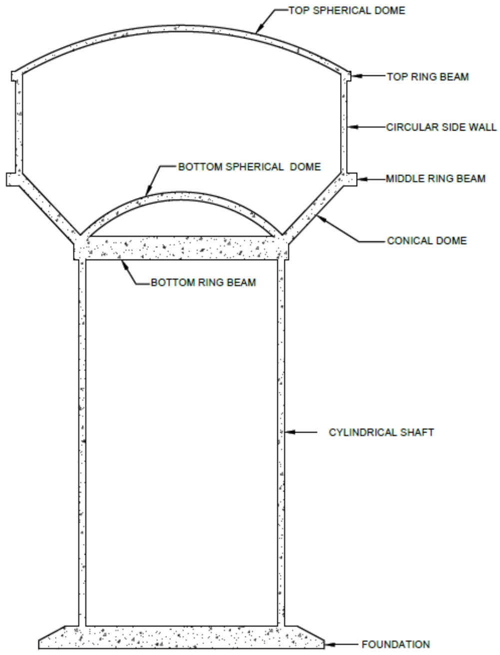


Fig 1.2 Elements of Intze tank

2. Top Ring Beam

Normally the dome is segmental and the meridional thrust developing at the base of the dome is at some inclination with the horizontal. The horizontal component of the meridional thrust produces hoop tension which is resisted by providing a ring beam at the base along the periphery of the dome. The ring beam is supported on the cylindrical wall of the tank and is designed for direct tension.

3. Cylindrical Side Walls

The cylindrical side wall is supported on the bottom ring beam the wall of tank are assumed to be free at top as well as bottom. Due to this, the tank wall will be designed for hoop tension caused by the horizontal water pressure, without any bending moment. The maximum hoop tension will be occurred at base. The tank wall is adequately reinforced with horizontal rings provided at both faces. In addition to this, vertical reinforcement is provided on the both faces in the form of distribution steel. The spacing of the vertical steel is halved and the bottom portion of the wall to cater for any bending moment.

4. Middle Ring Beam

This ring beam is provided to resist the horizontal component of the reaction of the conical wall on the cylindrical wall. The ring beam will be designed for the induced hoop tension.

5. Conical Dome

This will be designed for hoop tension due to water pressure. The slab will also be designed as a slab spanning between the ring beams at top and the ring girder at bottom.

6. Bottom Spherical Dome

The bottom dome is subjected to vertical loads consisting of self-weight and weight of water.

7. Bottom ring beam

Bottom circular beam is supported usually on column and is designed to support the tank and its content. The girder should be designed for the bending moments, shear forces and torsion. In addition to these forces, it is also subjected to hoop tension due to meridional thrust of bottom spherical dome.

8. Cylindrical RC Shaft

These are to be designed for the total load transferred to them.

9. Foundations

A combined footing is usually provided for all supporting columns. When this is done it is usual to make the foundation consisting of a ring girder and a circular slab.

1.3 REINFORCED CONCRETE WALL

Reinforced concrete walls are strength and portent elements frequently used in constructions in seismic areas, because they have a high lateral stiffness and resistance to external horizontal loads.

The dissipation of the accumulated energy in the structural wall systems occurs generally through concentrated degradation at the base of the wall (Fig. 1.3), which are difficult to repair.

For the wall showed in Fig. 1.3 two negative characteristics are pointed:

- low ductility
- low redundancy

Slit walls are a special variant of structural walls with improved ductility. The specialist's intention was to reduce the degradation from the base of the wall and distribute it on the wall height.

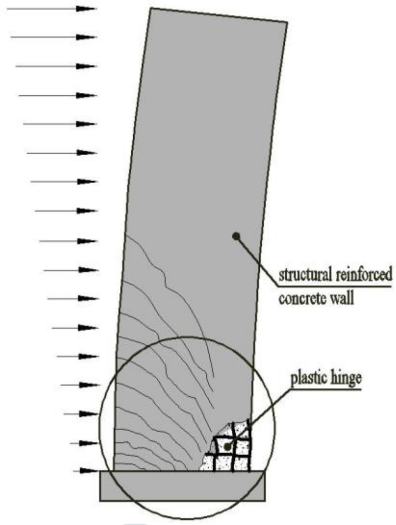


Fig 1.3 Destruction of reinforced concrete walls at horizontal seismic action.

1.4 SLIT REINFORCED CONCRETE WALL WITH SHEAR CONNECTION

This type of slit wall is analyzed by researchers from Chinese University of Hong Kong (Fig. 1.4).
Reinforced concrete connections were placed on the slit height which attach the structural walls forming a dissipative zone.
Researches have been conducted in comparison with a solid reinforced concrete wall without slits.
Results showed the efficiency of the slit wall,

- The displacements decrease with 14-25% in case of a cycle loading.
- Reduced drift by 19-26%.
- The seismic force induced in the wall is reduced by 20-25%.
- The structure period is also reduced.
- The overall ductility is improved.

Seismic performance depends on the yielding resistance of the connections. An efficient design of these systems must take into account a rational design of the connectors.
The premature yielding of the connectors must be avoided and also the destruction of walls without yielding of the connectors.

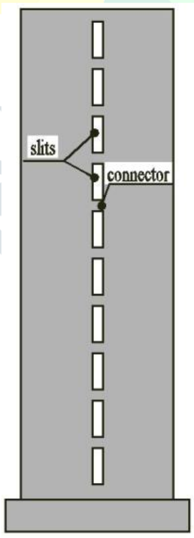


Fig. 1.4 Slit wall with RC connections

The concept of slit shear wall will be used in concrete shaft of elevated water tank in which four slits are situated at 90° intervals along the full height of the shaft and connected by RC connecting beam.
Typical drawing of proposed slit reinforced elevated tank as figure 1.5.

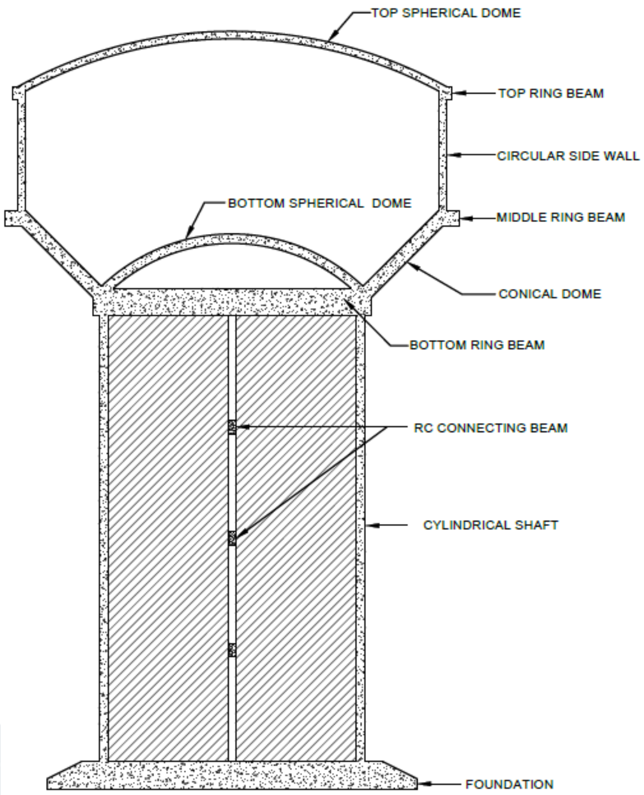


Fig 1.5 Slit reinforced RC shaft intze tank

2. MODELLING AND ANALYSIS

2.1 MODEL CONFIGURATION

Capacity of Intze tank = 5,00,000 litre.

Table 2.1 Parameters of model

No.	Item	Size
1	Thk. Of Top Dome	120 mm
2	Thk. Of Bottom Dome	200 mm
3	Thk. Of Cylindrical Wall	200 mm
4	Thk. Of Conical Wall	350mm
5	Thk. Of Shaft	300 mm
6	Size of Top Ring Beam	350 x 350 mm
7	Size of Middle Ring Beam	600 x 450 mm
8	Size of Bottom Ring Beam	600 x 800 mm
9	Connecting beam	300 x 450 mm
10	Connecting beam location	5 m and 10 m from the ground

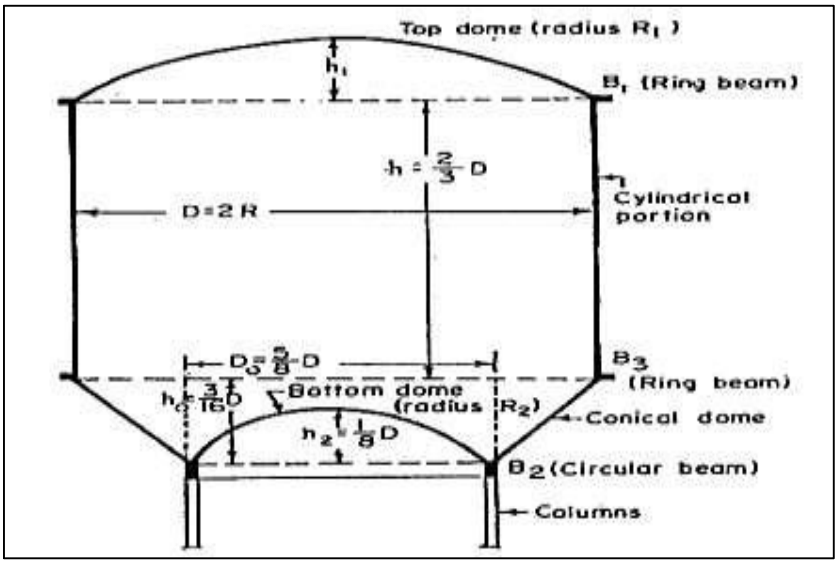


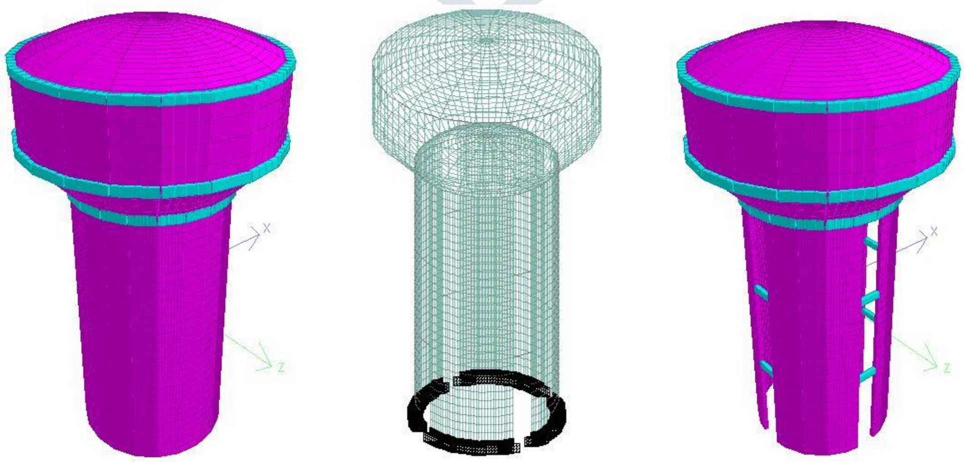
Fig 2.1 Reference geometry of tank container

2.2 FE MODEL ID OF SELECTED WATER TANKS

Table 2.2 Model ID

Nos.	Slit width	Full Tank		Empty Tank	
		Z-0.10	**Z-0.16**	**Z-0.10**	**Z-0.16**
1	Solid shaft	F-S0-Z0.10	F-S0-Z0.16	E-S0-Z0.10	E-S0-Z0.16
2	Slit width 50 mm	F-S50-Z0.10	F-S50-Z0.16	E-S50-Z0.10	E-S50-Z0.16
3	Slit width 100 mm	F-S100-Z0.10	F-S100-Z0.16	E-S100-Z0.10	E-S100-Z0.16
4	Slit width 150 mm	F-S150-Z0.10	F-S150-Z0.16	E-S150-Z0.10	E-S150-Z0.16
5	Slit width 300 mm	F-S300-Z0.10	F-S300-Z0.16	E-S300-Z0.10	E-S300-Z0.16
6	Slit width 450 mm	F-S450-Z0.10	F-S450-Z0.16	E-S450-Z0.10	E-S450-Z0.16
7	Slit width 600 mm	F-S600-Z0.10	F-S600-Z0.16	E-S600-Z0.10	E-S600-Z0.16
8	Slit width 750 mm	F-S750-Z0.10	F-S750-Z0.16	E-S750-Z0.10	E-S750-Z0.16
9	Slit width 900 mm	F-S900-Z0.10	F-S900-Z0.16	E-S900-Z0.10	E-S900-Z0.16
10	Slit width 1050 mm	F-S1050-Z0.10	F-S1050-Z0.16	E-S1050-Z0.10	E-S1050-Z0.16
11	Slit width 1200 mm	F-S1200-Z0.10	F-S1200-Z0.16	E-S1200-Z0.10	E-S1200-Z0.16

Zone: II and III.
Condition: Tank full and tank empty condition.



S0 S1200

3. RESULTS:

3.1 COMPRESSIVE STRESS

Model: Z-0.10

Table 3.1 Compressive stresses (Full Tank)

Compressive stresses (N/mm2) (Z-0.10 - Full Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	3.676	4.244	4.268	4.297	4.475	4.637	4.698	4.827	4.887	5.018	5.087
3-6M	3.314	4.529	4.393	3.889	3.601	3.69	3.754	3.854	3.927	4.042	4.123
6-9M	3.026	3.15	3.18	3.199	3.236	3.298	3.353	3.425	3.49	3.573	3.646
9-12M	2.738	4.489	4.398	3.833	3.343	3.212	3.178	3.299	3.403	3.52	3.627
12-15M	2.539	5.061	5.109	5.013	5.278	5.543	5.623	5.844	5.888	6.107	6.225

Table 3.2 Compressive stresses (Empty Tank)

Compressive stresses (N/mm2) (Z-0.10 - Empty Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	1.455	1.653	1.658	1.666	1.756	1.834	1.866	1.925	1.957	2.018	2.053
3-6M	1.259	1.607	1.559	1.392	1.371	1.415	1.442	1.485	1.517	1.565	1.6
6-9M	1.092	1.135	1.144	1.15	1.175	1.205	1.225	1.253	1.278	1.309	1.337
9-12M	0.926	1.492	1.464	1.28	1.142	1.108	1.097	1.11	1.126	1.153	1.193
12-15M	0.764	1.527	1.535	1.505	1.64	1.759	1.804	1.893	1.927	2.015	2.075

Model: Z-0.36

Table 3.3 Compressive stresses (Full Tank)

Compressive stresses (N/mm2) (Z-0.16 - Full Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	4.308	5.124	5.155	5.2	5.456	5.672	5.738	5.9	5.954	6.116	6.176
3-6M	3.819	5.782	5.557	4.74	4.212	4.319	4.384	4.505	4.579	4.718	4.8
6-9M	3.422	3.593	3.63	3.651	3.678	3.742	3.794	3.872	3.935	4.025	4.096
9-12M	3.026	5.752	5.589	4.687	3.873	3.628	3.653	3.796	3.914	4.048	4.167
12-15M	2.642	6.374	6.458	6.309	6.711	7.033	7.12	7.361	7.389	7.621	7.733

Table 3.4 Compressive stresses (Empty Tank)

Compressive stresses (N/mm2) (Z-0.16 - Empty Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	1.667	1.946	1.954	1.967	2.104	2.215	2.259	2.341	2.381	2.464	2.507
3-6M	1.429	2.02	1.941	1.672	1.588	1.647	1.681	1.738	1.777	1.841	1.884
6-9M	1.225	1.284	1.295	1.302	1.334	1.37	1.394	1.428	1.458	1.496	1.528
9-12M	1.023	1.905	1.853	1.562	1.331	1.264	1.236	1.265	1.314	1.371	1.421
12-15M	0.826	1.938	1.956	1.912	2.124	2.283	2.345	2.456	2.498	2.607	2.679

3.2 TENSILE STRESS

Model: Z-0.10

Table 3.5 Tensile stresses (Full Tank)

Tensile stresses (N/mm^2) (Z-0.10 - Full Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	0.703	0.977	0.986	1.004	1.089	1.15	1.155	1.192	1.185	1.22	1.21
3-6M	0.562	1.393	1.293	0.946	0.679	0.698	0.7	0.723	0.725	0.751	0.753
6-9M	0.44	0.493	0.5	0.503	0.491	0.493	0.49	0.496	0.495	0.502	0.501
9-12M	0.319	1.403	1.323	0.949	0.589	0.496	0.527	0.553	0.569	0.587	0.6
12-15M	0.199	1.459	1.499	1.44	1.593	1.656	1.664	1.685	1.667	1.683	1.675

Table 3.6 Tensile stresses (Empty Tank)

Tensile stresses (N/mm²) (Z-0.10 - Empty Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	0.236	0.326	0.328	0.335	0.387	0.424	0.437	0.462	0.471	0.496	0.505
3-6M	0.189	0.459	0.425	0.311	0.242	0.258	0.266	0.281	0.289	0.307	0.316
6-9M	0.148	0.166	0.168	0.169	0.176	0.184	0.188	0.195	0.2	0.208	0.212
9-12M	0.108	0.459	0.432	0.313	0.21	0.184	0.201	0.217	0.228	0.242	0.253
12-15M	0.069	0.456	0.468	0.452	0.537	0.581	0.601	0.625	0.635	0.657	0.671

Model: Z-0.16

Table 3.7 Tensile stresses (Full Tank)

Tensile stresses (N/mm²) (Z-0.16 - Full Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	1.124	1.564	1.578	1.606	1.743	1.841	1.848	1.907	1.897	1.951	1.936
3-6M	0.898	2.228	2.069	1.513	1.087	1.117	1.121	1.157	1.16	1.202	1.205
6-9M	0.705	0.788	0.8	0.804	0.785	0.789	0.785	0.794	0.792	0.804	0.802
9-12M	0.511	2.244	2.118	1.518	0.942	0.793	0.844	0.885	0.91	0.939	0.96
12-15M	0.319	2.335	2.398	2.304	2.549	2.649	2.662	2.696	2.667	2.692	2.68

Table 3.8 Tensile stresses (Empty Tank)

Tensile stresses (N/mm²) (Z-0.16 - Empty Tank)											
	S-0	S-50	S-100	S-150	S-300	S-450	S-600	S-750	S-900	S-1050	S-1200
0-3M	0.378	0.522	0.525	0.536	0.619	0.678	0.699	0.74	0.754	0.794	0.807
3-6M	0.302	0.734	0.68	0.497	0.386	0.412	0.425	0.45	0.463	0.491	0.505
6-9M	0.237	0.265	0.268	0.27	0.282	0.294	0.301	0.312	0.319	0.332	0.34
9-12M	0.173	0.734	0.692	0.5	0.336	0.295	0.322	0.346	0.365	0.386	0.405
12-15M	0.111	0.73	0.749	0.724	0.859	0.93	0.961	1	1.015	1.051	1.074

3.3 BASE SHEAR

Model: Full Tank

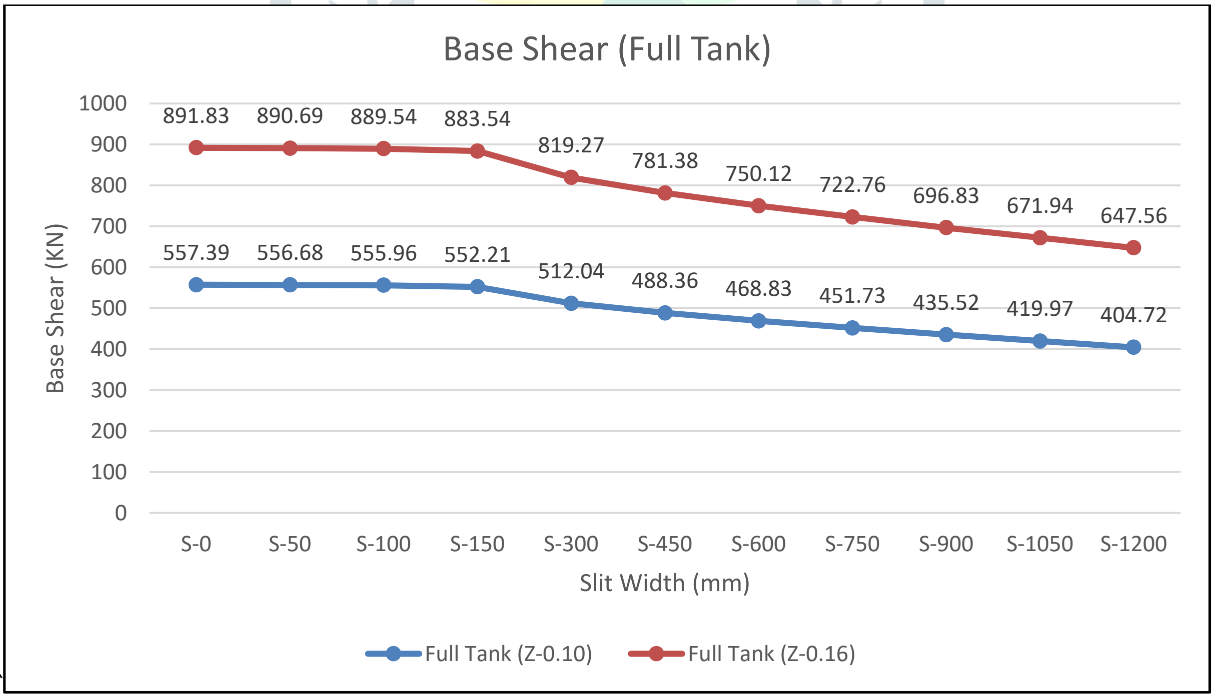


Fig 3.1 Base Shear Full Tank

Model: Empty Tank

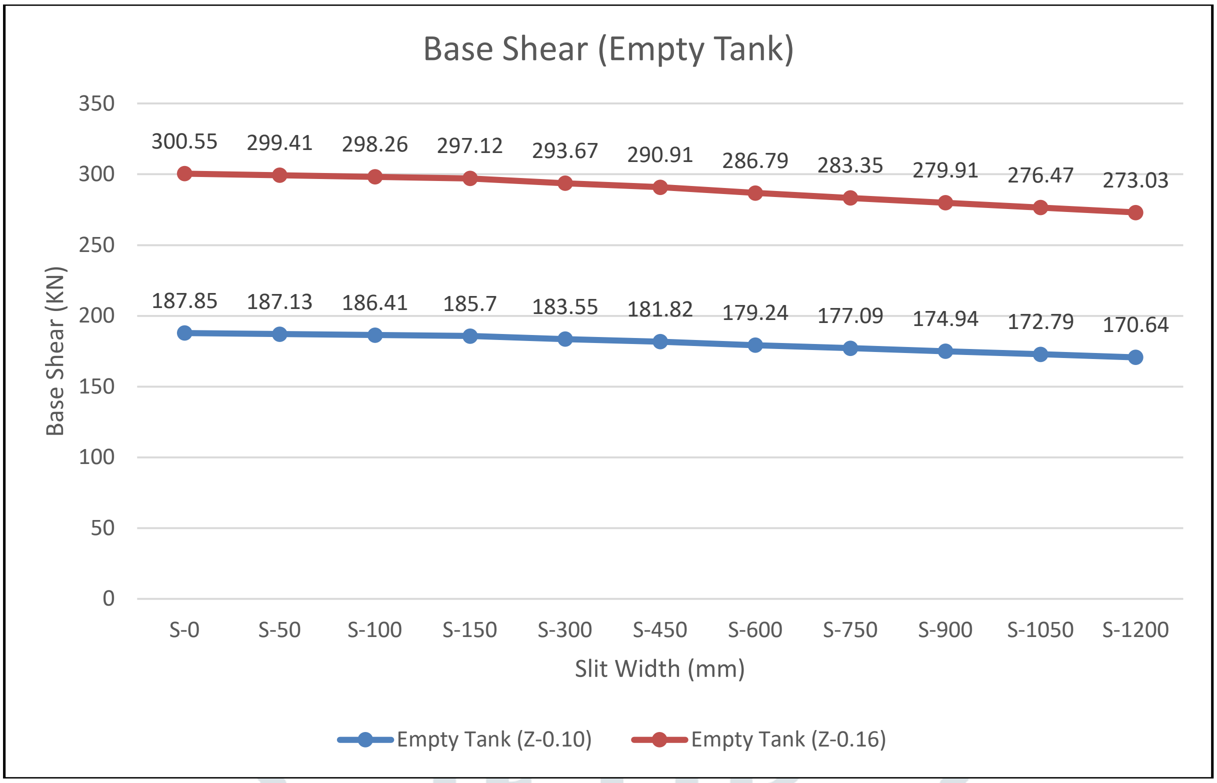


Fig 3.2 Base Shear Empty Tank

3.4 LATERAL DISPLACEMENT

Model: Full Tank

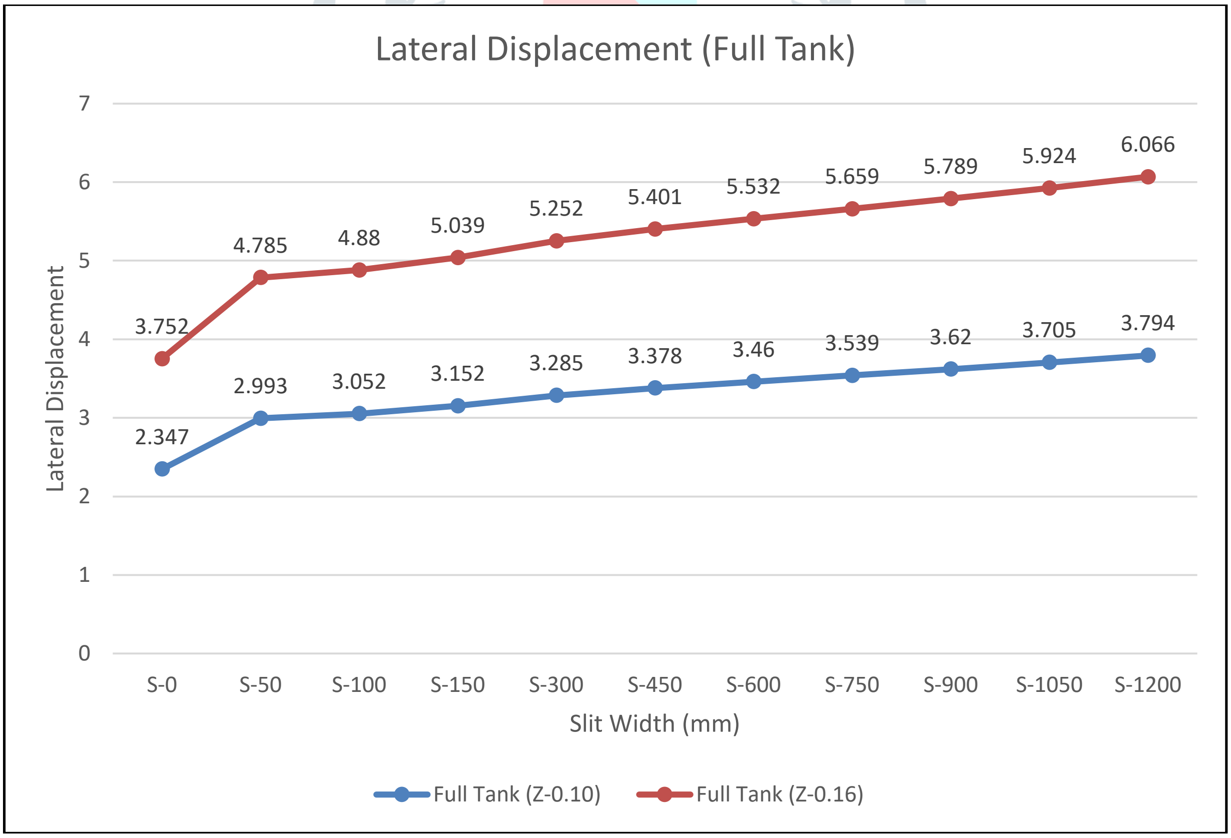


Fig 3.3 Lateral Displacement Full Tank

Model: Empty Tank

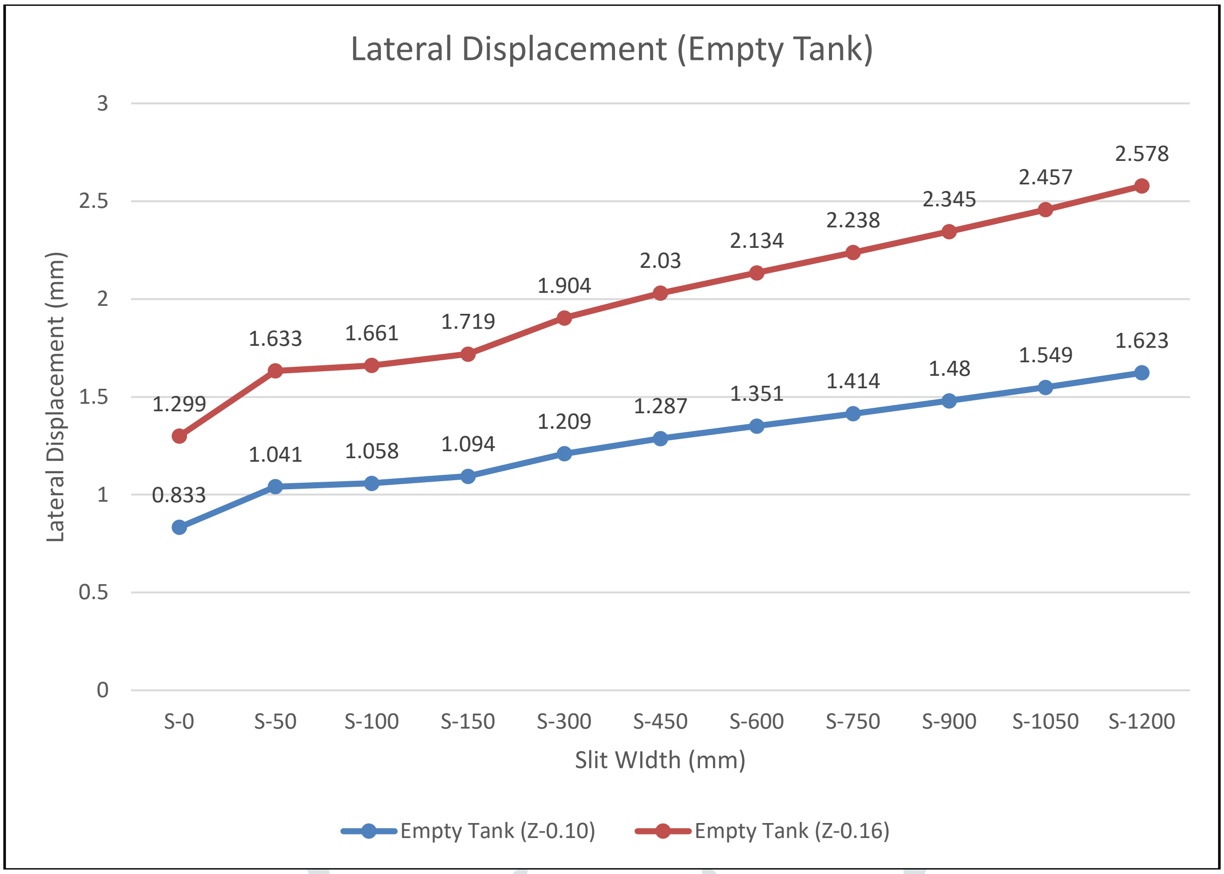


Fig 3.4 Lateral Displacement Empty Tank

3.5 TIME PERIOD

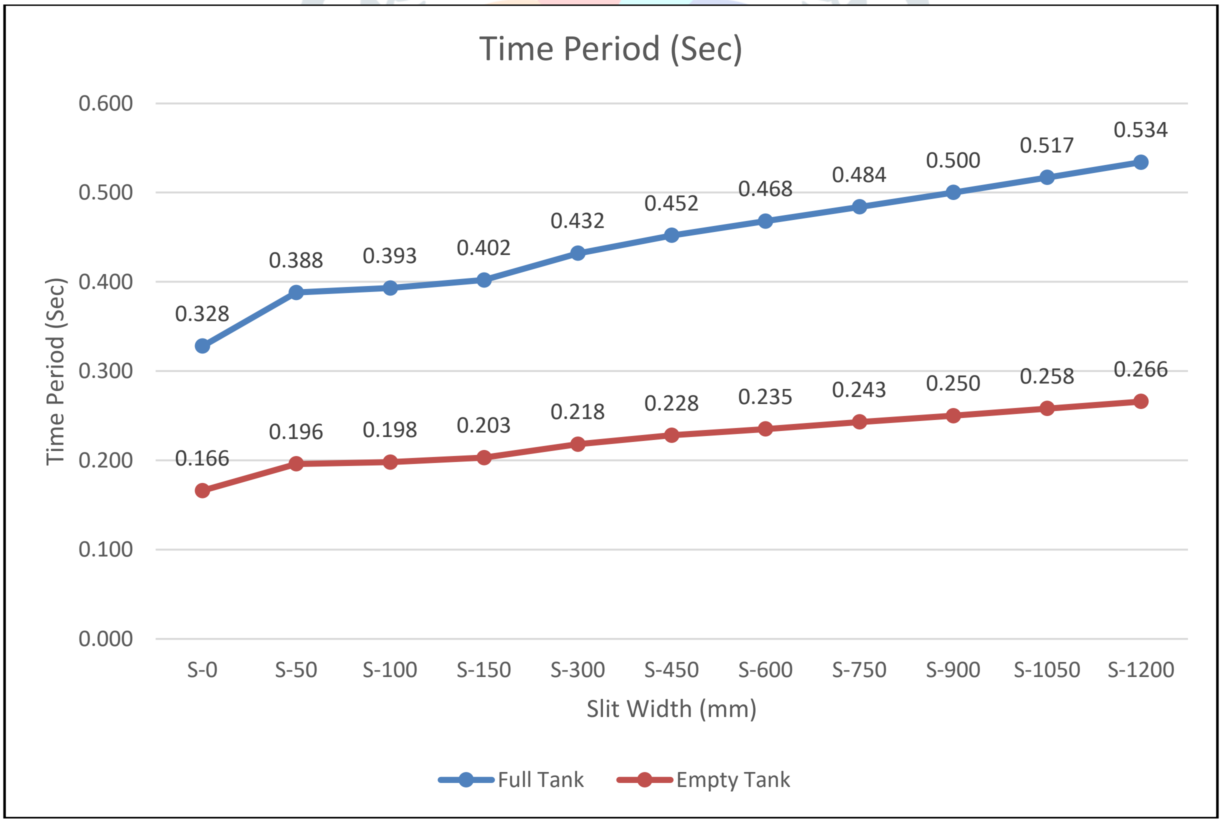


Fig 3.5 Time Period

Conclusion:

- Using the slit in reinforced concrete shaft design, reduces the stress concentration at the shaft base and distributes the stresses uniformly along the shaft height.
- The increase of the slit width in RC shaft decrease the ability to withstand an earthquake of the water tank. That happened because of slit width increase resulted to ductility increase and stiffness reduction of the RC shaft.
- The increase of the slit width resulted to an increase in compression stress concentration at the base and at the top of the shaft and reduction of compression stress concentration at the coupling.
- Time period and lateral displacement of the water tank is increase with the increase in slit width of RC shaft.
- Base shear of the water tank is decrease with increase in slit width of RC shaft.
- It is observed from analysis that 150mm slit width is most convenient as it has uniform stress distribution. After 150mm slit width stresses are sudden increasing.
- For zone-II stresses are in permissible limit up to 150mm slit width. For more than 150mm slit width more shaft thickness is required as stresses increasing than the permissible value.
- For zone-III shaft thickness is required as stresses are increasing than the permissible value. However, 150mm gives the uniform stress distribution.

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