Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 4, April -2017

NON-LINEAR STATIC (PUSHOVER) ANALYSIS ON ELEVATED STORAGE RESERVOIR (ESR)

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Abstract — *Earthquake is the major natural calamities which have potential to cause damage to lives and lifeline facilities. Elevated storage reservoir need to be functional even after the severer earthquake event. During past Earthquakes Elevated Storage Reservoirs experience damage or collapse all over the world. General practice is to design elevated reservoir as crake free structure to eliminate any leakage and as far as staging is concern SMR frame is to be provide. Existing codes give elastic analysis which is not capable to give any measure of deformation capacity of structure during Earthquake event.*
Thus, this paper presents nonlinear static analysis for evaluate seismic demand for 250m^3 and 500m^3 capacity of tank with zone II, zone III, zone IV, zone V in empty case and full water load condition. This gives the plastic hinge formation and plots the total base shear versus top displacement curve, which is known as 'capacity curve' of the structure. The Purpose of this paper is to carry out non-linear behavior of different type of staging height with empty and full water condition of Elevated Storage Reservoir, using CSI SAP2000 software package, and to evaluate the performance and failure mechanism of the ESR. And compare the reduction factor with assumed R factor.

Keywords- *Elevated storage reservoir, Capacity of tank, Different staging height Different Zone factor, Base shear, Ductility factor, Redundancy factor, Over strength factor, Non-linear static analysis-CSI SAP2000.*

I. INTRODUCTION

Earthquake is known to produce one of the most destructive forces on earth. It cause damage to man-made structures, like Buildings, Chimneys, Towers and Public Infrastructures like, Bridge, Roads, Dams and Irrigation structures, Water supply and Sewerage systems, Telecommunications systems, Power Plants Industries, Life line systems etc. The earthquakes are also known to cause landslides, liquefaction, slope-instability and damage to earth and rack structures. The earthquake causes loss of life and property and shakes the moral of people.
Elevated storage reservoir is the very important component of water distribution system for any country therefor it is necessary to remain function even after the major earthquake event. The present work aims to carry out a seismic evaluation case study for an existing reinforced concrete elevated storage reservoir using pushover (nonlinear static) analysis as per ATC-40 & FEMA-356, which provide the target displacement and the yielding mechanism.
ESR is structurally different from a multi-storied building which will be taking into account during analysis. Nonlinear static analysis has been research and developed over past twenty years of time period and has become the recommended analysis procedure now a days for design and to check seismic performance of the structure.
In structure, In India, most municipalities have water supply which depends on elevated tanks for storage. Elevated water tanks are the large elevated water storage container constructed for the purpose of holding a water supply at a sufficient height to pressurize a water distribution system. For that purpose the elevated water tanks are one of the most popular and important components of water distribution system in India. To support the vessel of the tank, a concrete shaft has been used. The classification chart of ESR is shown in figure.

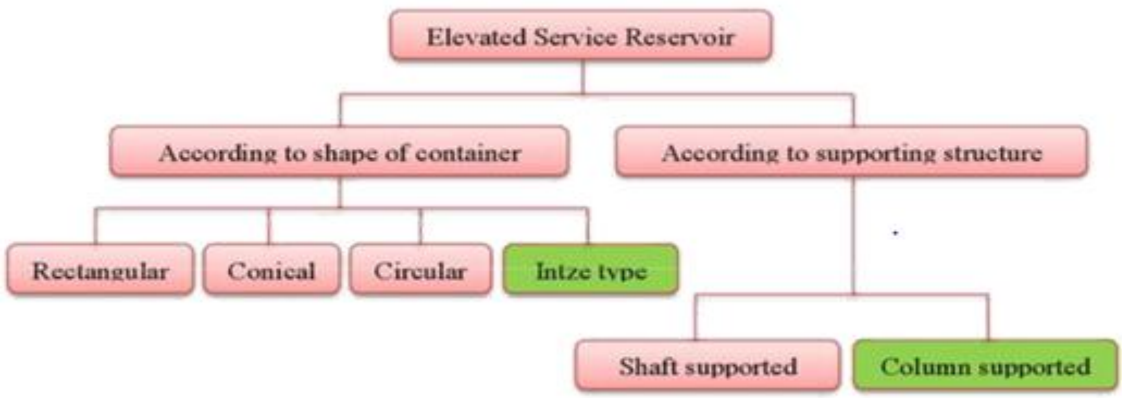
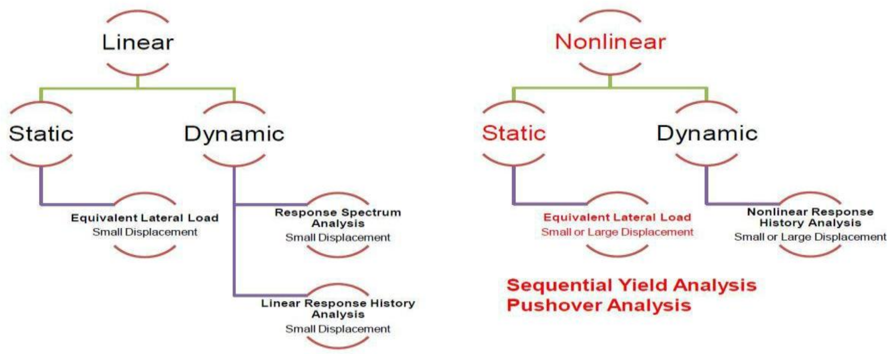


Figure1: Classification of ESR

II. DESIGN METHODOLOGY

2.1. Methodology of seismic analysis

The Figure shows the different methods of seismic analysis which are basically linear and nonlinear. Indian standards dose provide the linear method of analysis and design of structural analysis and design but it does not contains nonlinear analysis approach of analysis which gives the realistic behavior of the structure and it is useful for the performance based design structure as well as the seismic damage assessment to the new or existing structure. The linear method of analysis dose allows the structure under go higher deformations and serviceability of cracking and collapse which means that the linear design code allows the nonlinear behavior of the structure but it does not provides the degrees of nonlinearity generates during the lateral loading. This analysis can be of static or dynamic, user may use the method as per the contingency or the data available for to carry out seismic analysis. Here the Nonlinear static analysis thoroughly described and used over an existing ESR.



2.2 Pushover analysis

Pushover Analysis or Nonlinear static analysis allows structural engineers to perform nonlinear static analysis as per FEMA -356 and ATC-40. Nonlinear static analysis contains a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. To a three dimensional model gravity loads are applied initially and bi-linear or tri-linear load-deflection diagrams of all lateral force resisting elements is created. The load pattern which is distributed then applied along the building height. The lateral forces are increased until some members start to yield. The structural model is modified for to account the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. Then the roof displacement is plotted with base shear to get the global capacity curve. Nonlinear static analysis can be performed as force-controlled or displacement-controlled.

Nonlinear static analysis is becoming the preferred method for seismic performance evaluation of building by the guidelines of major rehabilitation and codes because it is conceptually and computationally simple. It allows tracing the sequence of yielding of members, Plastic Hinge formation and failure on member and structural level as well as the progress of overall capacity curve of the structure.

In present work nonlinear static analysis is carry out for two different capacity of water tank with different staging height and different zone factor which is full half and empty as the water level in elevated tank during earthquake events have greater impact over its seismic behavior.

2.3 Purpose of pushover analysis

- Allows engineers to understand structure's nonlinear behavior and progression of damage with increasing ground motion intensity.
- The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic dynamic or static analysis.
- Does not require selection and scaling of ground motions
- Estimates of the inter story drifts that account for strength or stiffness discontinuities and that may be used to control the damages and to evaluate P-Delta effect.
- Consequences of the strength deterioration of individual elements on behavior of the structural system.
- Enable to perform with or without nonlinear analysis software.

2.4 Objective of work

- Seismic behavior study using by non-linear static analysis of an Existing Circular.
- Elevated Storage Reservoir (ESR) having beam column staging is selected.
- To Study & apply the nonlinear static analysis methodology over ESR using by the CSI SAP2000 (V17.1.1) Software Package.

- Evaluate Response parameters are Performance point, natural time period, displacement, Targeted displacement, Base shear, and axial forces, Response Reduction Factor (R), with Different Dynamic Loading Condition of water level of Tank.
- Also evaluate the parameters with different zone of water tank, and capacity of container.

2.5 Plastic hinge properties

Basically a hinge represents localized force-displacement relation of a structural element through its elastic and inelastic simulation under seismic loading.

Hinges are of various types namely

- Hinges for Flexural
- Hinges for Shear
- Hinges for Axial

Nonlinear behaviour of structural member is the nonlinearity of the material which does not allow only the plastic behaviour of member thus it is necessary to generate the moment-rotation curve which characterizes the yield criteria of nonlinear frame. For each and every degree of freedom define a moment-rotation relation curve that gives the plastic deformation, yield value and the following yield. This is done in terms of an idealized curve with values at five points A-B-C-D-E as following figure.

The following points should be noted:

- Point A is always will be the origin.
- Point B represents start of yielding. Deformation does not occur in the hinge up to point B. Only the plastic deformation beyond point B will be shown by the hinge.
- Point C represents the ultimate capacity of structure by pushover analysis.
- Point D represents a residual strength or after damage of structure.
- Point E shows total failure of structure. Beyond E point the hinge will drop shear down to point F, which is not visible in figure, directly below point E on the horizontal axis. If user does not want fail hinge this way, user need to be sure to give a large value for the deformation at point E.

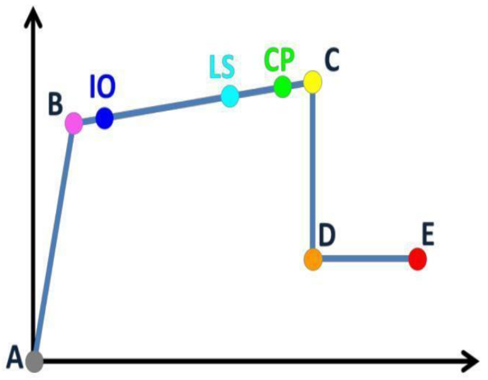


Figure 2: Moment Curvature curve

2.6 Building performance level

A limiting damage state or functional condition described by the physical damage within the building and the post-earthquake serviceability of the building or structure. A building performance level is the combination of a structural performance level and a non-structural performance level to form complete information of an overall damage level of building.

The three Structural Performance Levels and two Structural Performance Ranges are:

S-1: Immediate Occupancy Performance Level
S-2: Damage Control Performance Range
S-3: Life Safety Performance Level
S-4: Limited Safety Performance Range
S-5: Collapse Prevention Performance Level

The four Non-structural Performance Levels are:

N-A: Operational Performance Level
N-B: Immediate Occupancy Performance Level
N-C: Life Safety Performance Level
N-D: Hazards Reduced Performance Level

III. PROBLEM FORMULATION & ANALYSIS

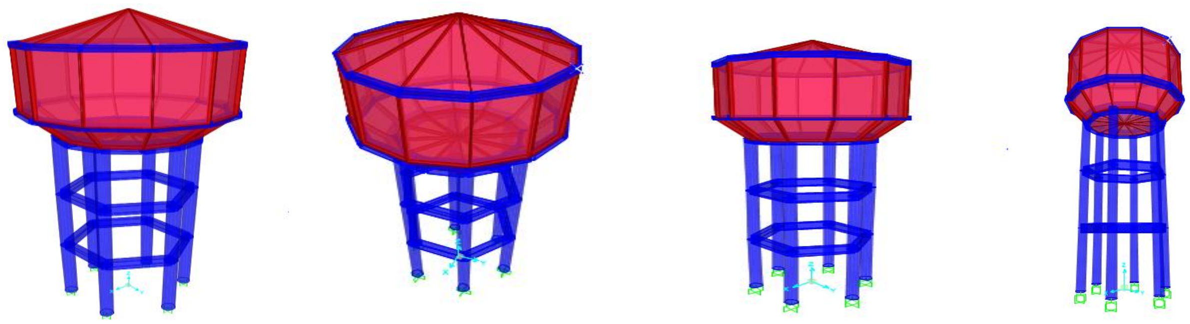
3.1. General

The non-linear static procedure is a simple option for estimating the strength capacity in the post-elastic range. The procedure consists of applying a predefined lateral load pattern to structure model which is distributed along the structure height. The lateral forces are then monotonically increase in constant proportion with a displacement control node of the building until a certain level of deformation is reached. The applied base shear & the associated lateral displacement at each load increment plotted. Based on the capacity curve, a target displacement which is an estimate of displacement which is produced by design earthquake on the building is determined. At this target displacement extent of damage experienced by the building is considered representative of the damage experienced by the building when subjected to design level ground shaking.

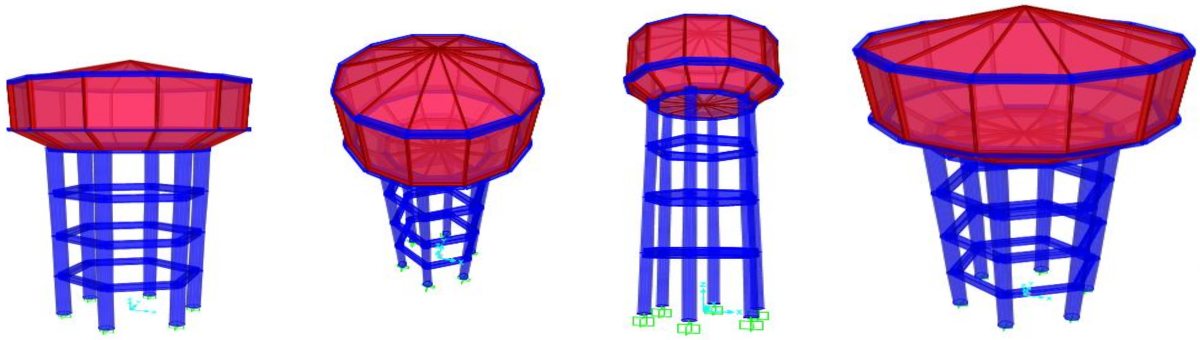
3.2 Modeling

Table 1: Description for water tank for 250 m3

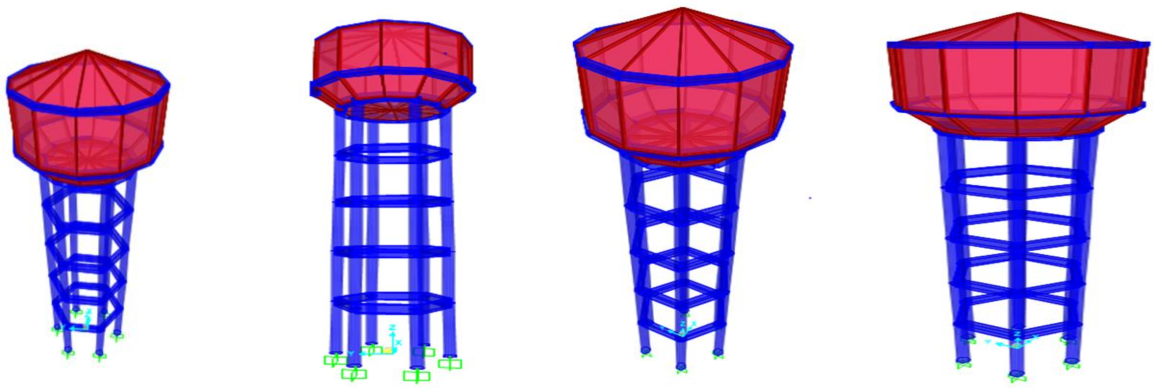
Tank vessel property (m)		Tanks staging property (m)	
Vessel Capacity	250 m^3	**No. of column**	6 Nos
Cylinder diameter	8.6 m	**Columns Diameter**	0.65 m
Wall Height	3.7m	**Columns height**	12 m, 16m, 20m
Top Dome rise	1.75m	**Staging diameter**	5.78m
Conical dome rise	1.5m	**Bracing Interval**	4.00 m
Bottom dome rise	1.5m	**Beams bracing Size**	0.3m × 0.6m
Top Ring Beam	0.25m × 0.3m	**No of bracing per level**	6 Nos
Middle Ring Beam	0.5m × 0.3m		
Bottom Ring Beam	0.5m × 0.6m	**Seismic Data**	
Top Dome thickness	0.12 m	**Zone**	II, III, IV, V
Vessel thickness	0.20 m	**Response Reduction Factor**	2.5
Conical dome thickness	0.25m	**Soil Type**	Medium
Bottom Dome thickness	0.20 m		



3D Modeling of water tank for 250 m 3 with 12 m height in zone-II, III, IV, V



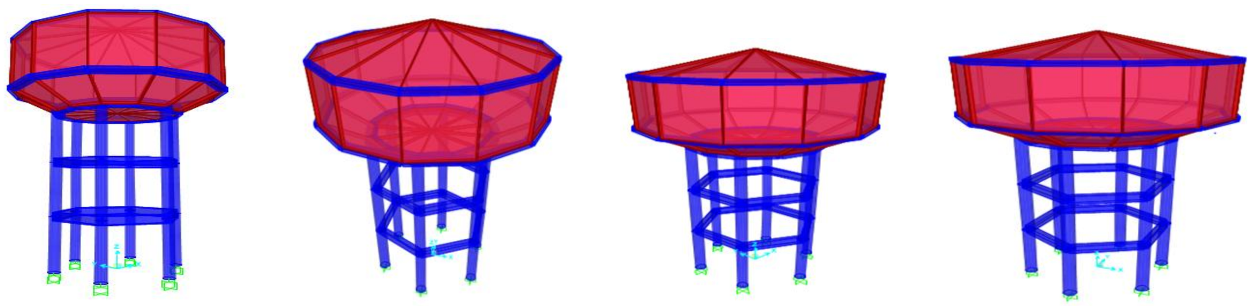
3D Modeling of water tank for 250 m 3 with 16 m height in zone-II, III, IV, V



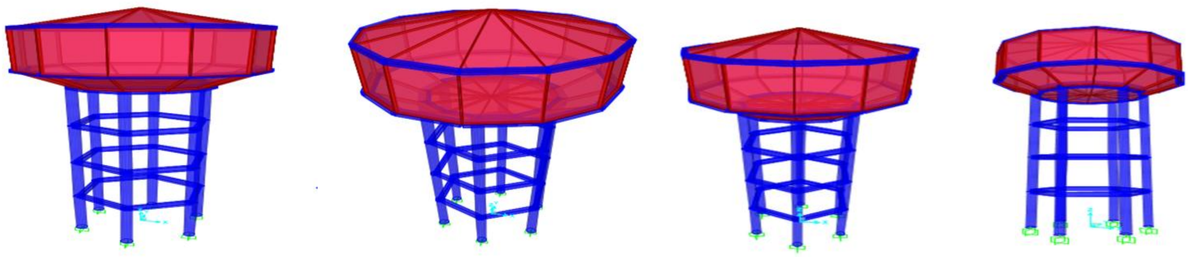
3D Modeling of water tank for 250 m 3 with 20 m height in zone-II, III, IV, V

Table 2 : Description for water tank for 500 m3

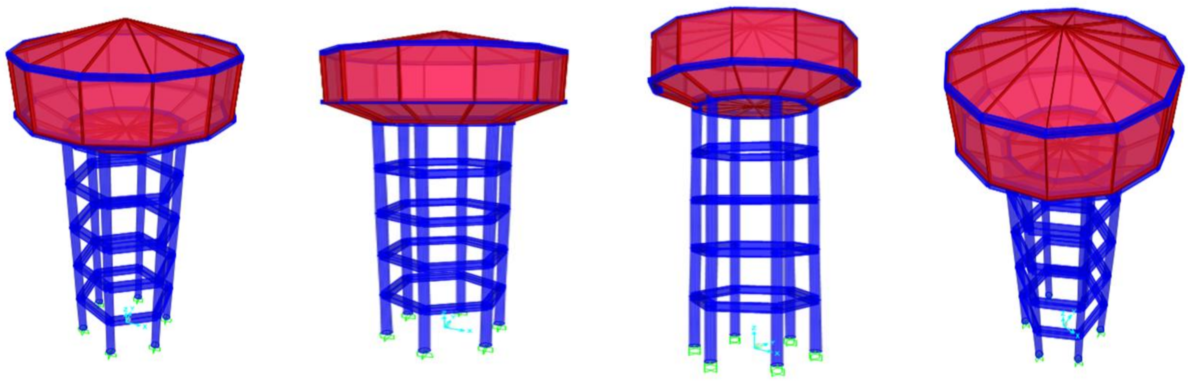
Tank vessel property (m)		Tanks staging property (m)	
Vessel Capacity	500 m^3	**No. of column**	6 Nos
Cylinder diameter	12 m	**Columns Diameter**	0.65 m
Wall Height	3.7m	**Columns height**	12 m, 16m, 20m
Top Dome rise	1.75m	**Staging diameter**	7 m
Conical dome rise	1.5m	**Bracing Interval**	4.00 m
Bottom dome rise	1.5m	**Beams bracing Size**	0.3m × 0.6m
Top Ring Beam	0.25m × 0.3m	**No of bracing per level**	6 Nos
Middle Ring Beam	0.5m × 0.3m		
Bottom Ring Beam	0.5m × 0.6m	**Seismic Data**	
Top Dome thickness	0.12 m	**Zone**	II, III, IV, V
Vessel thickness	0.20 m	**Response Reduction Factor**	2.5
Conical dome thickness	0.25m	**Soil Type**	Medium
Bottom Dome thickness	0.20 m		



3D Modeling of water tank for 500 m 3 with 12 m height in zone-II, III, IV, V



3D Modeling of water tank for 500 m 3 with 16 m height in zone-II, III, IV, V



3D Modeling of water tank for 500 m 3 with 20 m height in zone-II, III, IV, V

IV. RESULT AND DISCUSSION

4.1 Result for250 m^3 capacity of water tank with 12m staging height in Full condition

Tank Type : Intz Tank	250 m^3			
Staging Type	Staging Height 12m			
6 Column circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.48791	0.48791	0.48791	0.48791
Base Shear (KN)	110.505	176.809	265.213	397.82
Ductility Factor	0.93	0.93	0.93	0.93
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	6.72	4.20	2.80	1.87
R Factor	5.37	3.35	2.24	1.49

4.2 Result for250 m^3 capacity of water tank with 16m staging height in Full condition

Tank Type : Intz Tank	250 m^3			
Staging Type	Staging Height 16m			
6 Column circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.6020	0.6020	0.6020	0.6020
Base Shear (KN)	109.064	174.504	261.75	392.632
Ductility Factor	0.89	0.89	0.89	0.89
Redundancy Factor	0.6	0.86	0.86	0.86
Over strength Factor	5.38	3.36	2.24	1.49
R Factor	2.89	1.79	1.21	0.80

4.3 Result for250 m^3 capacity of water tank with 20m staging height in Full Condition

Tank Type : Intz Tank	250 m^3			
Staging Type	Staging Height 20m			
Staging Height 20m	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.94465	0.94465	0.94465	0.94465
Base Shear (KN)	72.174	76.404	183.369	275.053
Ductility Factor	0.73	0.73	0.73	0.73
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	5.92	5.59	2.33	1.55
R Factor	3.72	3.50	1.46	1.00

4.4 Result for250 m^3 capacity of water tank with 12m staging height in Empty Condition

Tank Type : Intze Tank	250m^3			
Staging Type	Staging Height 12 m			
6 Col Circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.47784	0.47784	0.47784	0.47784
Base Shear (KN)	106.63	169.63	254.45	381.67
Ductility Factor	13.83	8.70	5.80	3.86
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	0.86	0.86	0.86	0.86
R	10.22	6.43	4.30	2.85

4.5 Result for250 m^3 capacity of water tank with 16m staging height in Empty Condition

Tank Type : Intze Tank	250m^3			
Staging Type	Staging Height 16 m			
6 Col Circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.60711	0.60711	0.60711	0.60711
Base Shear (KN)	107.410	171.856	257.784	386.676
Ductility Factor	1.13	1.13	1.13	1.13
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	7.36	4.60	3.06	2.044
R	7.15	4.40	2.97	1.99

4.6 Result for250 m^3 capacity of water tank with 20m staging height in Empty Condition

Tank Type : Intze Tank	250m^3			
Staging Type	Staging Height 20 m			
6 Col Circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.73437	0.73437	0.73437	0.73437
Base Shear (KN)	99.058	158.493	237.740	356.611
Ductility Factor	0.97	0.97	0.97	0.97
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	4.99	3.12	2.08	1.39
R	4.16	2.60	1.75	1.16

4.7 Result for 500 m^3 capacity of water tank with 12m staging height in Full Condition

Tank Type : Intze Tank	500 m^3			
Staging Type	Staging Height 12 m			
6 Col Circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.64618	0.64618	0.64618	0.64618
Base Shear (KN)	133.057	212.891	319.336	479.05
Ductility Factor	0.72	0.72	0.72	0.72
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	6.69	4.18	2.79	1.86
R	4.14	2.56	1.72	1.15

4.8 Result for 500 m^3 capacity of water tank with 16m staging height in Full Condition

Tank Type : Intze Tank	500 m^3			
Staging Type	Staging Height 16 m			
6 Col Circular	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Time Period (Sec)	0.95023	0.95023	0.95023	0.95023
Base Shear (KN)	89.226	142.762	214.143	321.215
Ductility Factor	0.61	0.61	0.61	0.61
Redundancy Factor	0.86	0.86	0.86	0.86

Over strength Factor	6.97	4.36	2.90	1.94
R	3.66	2.29	1.52	1.017

4.9 Result for 500 m^3 capacity of water tank with 20m staging height in Full Condition

Tank Type : Intz Tank	**500 m^3**			
Staging Type	**Staging Height 20m**			
Staging Height 20m	**ZONE-II**	**ZONE-III**	**ZONE-IV**	**ZONE-V**
Time Period (Sec)	0.80716	0.80716	0.80716	0.80716
Base Shear (KN)	126.971	203.154	304.731	457.096
Ductility Factor	0.96	0.29	0.29	0.29
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	3.32	2.08	1.39	0.93
R Factor	2.74	1.72	1.15	0.76

4.10 Result for 500 m^3 capacity of water tank with 12m staging height in Empty Condition

Tank Type : Intze Tank	**500 m^3**			
Staging Type	**Staging Height 12 m**			
6 Col Circular	**ZONE-II**	**ZONE-III**	**ZONE-IV**	**ZONE-V**
Time Period (Sec)	0.65157	0.65157	0.65157	0.65157
Base Shear (KN)	135.881	217.411	326.116	489.174
Ductility Factor	0.81	0.81	0.81	0.81
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	6.19	3.87	2.58	1.72
R	4.31	2.69	1.79	1.2

4.11 Result for 500 m^3 capacity of water tank with 16m staging height in Empty Condition

Tank Type : Intze Tank	**500 m^3**			
Staging Type	**Staging Height 16m**			
6 Col Circular	**ZONE-II**	**ZONE-III**	**ZONE-IV**	**ZONE-V**
Time Period (Sec)	0.95888	0.95888	0.95888	0.95888
Base Shear (KN)	90.786	145.316	217.887	326.830

Ductility Factor	0.57	0.57	0.57	0.57
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	6.77	4.23	2.82	1.88
R	3.32	2.07	1.38	0.92

4.12 Result for 500 m^3 capacity of water tank with 20m staging height in Empty Condition

Tank Type : Intze Tank	**500 m^3**			
Staging Type	**Staging Height 16m**			
6 Col Circular	**ZONE-II**	**ZONE-III**	**ZONE-IV**	**ZONE-V**
Time Period (Sec)	0.90238	0.90238	0.90238	0.90238
Base Shear (KN)	107.952	172.723	259.085	388.628
Ductility Factor	0.847	0.847	0.847	0.847
Redundancy Factor	0.86	0.86	0.86	0.86
Over strength Factor	5.48	3.42	2.28	1.52
R	3.99	2.49	1.66	1.10

FUTURE SCOPE OF WORK

- To study the Spring-Mass modeling technique for the modeling of the Empty, Full & Half Conditions of water tank as per the Guidelines of IS 1893: Part 2 (Draft).
- Modeling of BRB carry out as per guidelines of NEHRP and FEMA-450.
- CSI PERFORM3D v 5.0) is use to model & assign BRB to the imported models from SAP2000 to carry out nonlinear static analysis and establish parametric study of the model for with and without bracing system.

CONCLUSION

- The Base shear is decreases as the staging height increases that is due to increase in Time period and the dispersion of base shear is increased when the percentage of the filling in the storage tanks are increasing.
- The response reduction factor is considerably affected by the staging height of water tanks. It reduces as the height of water tank is increasing.
- R factor is highly dependent on seismic zones. For various seismic zones R factor also changes.
- Time period and Redundancy of elevated tank will remaining same for all zones of same height of tank.
- Base shear will increasing by changing the zone from II to V for the same height of elevated tank.
- Over strength factor of elevated tank is decreased by increasing zone factor. So, it shows that reserved strength of water tank is decreasing by increasing the zone factor.
- R factor is decreasing by changing the condition of water tank from full to empty.
- Time period and base shear of elevated tank is also increased in full condition of tank.
- The critical response is occurs in case of full tank conditions. This result may be due to the fact that the hydrodynamic pressures higher in tank full case as compared to empty water tank.

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