IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⪤ Peer-reviewed & Refereed journal ⪤ Vol. 12, Issue 9, September 2025

DOI: 10.17148/IARJSET.2025.12909

PERFORMANCE BASED EVALUATION OF RESPONSE REDUCTION FACTOR FOR ELEVATED INTZE WATER TANK

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Abstract: The aim of this study is to assess the response reduction factor (R) for raised Intze water tanks that have been seismically loaded based on their performance. When earthquakes strike, the collapse of essential lifeline buildings like elevated water tanks may have a devastating impact on communities and economies. This research utilises CSI SAP2000 software to model Intze tanks with capacity of 300 m3 and 600 m3, respectively, with staging heights of 14 m and 18 m. Various seismic zones (II–V) and medium soil types are taken into account in the nonlinear static pushover analysis, which takes into account both empty and full tank situations. Base shear, lateral displacement, and fundamental time period are some of the important performance metrics that are examined in the research. In addition, in order to evaluate the response reduction factor (R), structural performance parameters including overstrength, ductility, and redundancy are assessed. Insights for safer and more affordable seismic design of raised Intze water tanks are provided by the results, which emphasise the impact of staging height, tank capacity, and seismic zone on the structural reaction.

Keywords: Water tank, Pushover analysis, Earthquake, Staging.

I. INTRODUCTION

1.1 GENERAL

A tank for holding water is a common kind of container. Throughout the globe, water tanks serve a multitude of applications in a broad range of environments. The purpose of certain tanks is to collect water. Water from a well, a stream, a river, or a lake may be piped into them, or they can collect precipitation. The water may be moved to another tank or kept in the tank after it has been collected. Depending on its intended function, collection tanks may be constructed from various materials such as steel, plastic, or concrete. For sanitary reasons, they can be connected to filtering systems.

One of the most important parts of any water distribution system is the water tank, which is especially crucial in areas that are vulnerable to earthquakes. Many buildings either fell or were severely damaged in the last earthquake, which resulted in casualties and destroyed property. As a result, testing the structure's response to seismic loads is essential prior to construction. Retrofitting work must be conducted if the building is already in existence. Uneven vertical surfaces, uneven strength and stiffness, uneven mass, uneven torsional stiffness, and so on all contribute to structural damage in an earthquake.

The abrupt release of energy in the Earth's lithosphere causes ground shaking, which in turn causes earthquakes, one of the most harmful natural dangers that may damage or destroy people's livelihoods. Heavy economic and human casualties occur as a result of earthquake ground vibrations. Buildings, bridges, water retention facilities, and the like collapse most often, causing losses.

1.2 TYPES OF WATERTANK

In general water tanks are classified as

(1) Underground Water Storage Tank
(2) Ground Water Tank
(3) Elevated Water Tank

(1) Underground Water Storage Tank

A tank that is buried under the surface of the earth to hold water is called an underground water storage tank. To make it long-lasting and leak-proof, most people choose materials like plastic, fibreglass, or concrete. These storage tanks may hold a variety of water types, including potable, non-potable, rainfall, and water used for irrigation or industrial

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processes. Primarily, it helps with space-saving, temperature regulating, and keeping the tank out of sight, which is great for aesthetics. Water conservation and backup storage are prominent uses for them in residential, industrial, and municipal applications.

Figure 1: Underground Water Tank

(2) Ground Water Tank

One common way to store water for later use, whether for irrigation, firefighting, or household needs, is in a groundwater tank, which is buried below the surface. These are different from raised tanks in that they are either placed on the surface or partly underground but remain on the ground. They link to a water supply system or a rainwater harvesting system and may be constructed from materials such as concrete, plastic, or steel. Both business and residential properties often use groundwater tanks to provide a steady supply of water.

Figure 2: Ground Water Tank

(3) Elevated Water Tank

A device that stores water and takes use of gravity to exert pressure is called an elevated water tank. Tanks, support towers, and pipe systems are the usual components. No pumps are required to maintain the water pressure in the tank since gravity disperses the water to the surrounding region. These tanks are ubiquitous in both urban and rural water distribution systems; they store water at a constant pressure and are useful during times of high demand or temporary water outages.

Figure 3: RC frame type Staging

Figure 4: RC shaft type Staging

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II. LITERATURE REVIEW

2.1 Parth N. Patel

"Performance Based Evaluation of Response Reduction Factor of Steel Staging Water Tank" (2017)

By including a seismic response factor (R), the majority of nations' seismic design laws and standards permit a structure's nonlinear reaction. Because of this component, designers may take non-linear behaviour and deformation limitations into consideration while using designs based on linear elastic forces. The article details the design and construction of a steel staging raised water tank that complies with applicable IS requirements and uses a systematic technique to calculate the seismic response reduction factor. In order to determine the capacity/pushover curve, the research water tanks are subjected to nonlinear static pushover analysis. At the member level and the structural level, respectively, the response reduction factors of the tanks under consideration are assessed.

2.2 Sowndarya. A S

"Performance Based Evaluation of Response Reduction Factor for Elevated Circular Water Tank" (2022)

Using nonlinear analysis in CSISAP2000, this study aims to determine the response reduction factor of elevated water tanks with varying capacities, compare this factor to that of tanks in different seismic zones, and assess the response modification factor, ductility factor, and redundancy factor for each seismic zone. Investigations on the impact of base shear, maximum lateral displacement, and fundamental time period across different zones are to be conducted. The study's final results show that water tank staging height has a significant impact on the response reduction factor, that the time period and redundancy of an elevated tank are constant across zones with the same tank height, and that an increase in the zone factor reduces the overstrength factor of an elevated tank. Thus, it is evident that when the zone factor increases, the conserved strength of the water tank decreases.

III. OBJECTIVE

- Using CSI SAP2000's nonlinear static analysis (push over analysis), we will assess the response reduction factor of an elevated water tank with a capacity of 300 m3 and 600 m3, and a staging height of 14m and 18m, respectively.
- An elevated water tank situated on medium soil conditions will have its response reduction factor (R) assessed, taking into account several seismic zones (Zones II, III, IV, and V) and operating circumstances (empty and full).
- This study aims to assess the impact of structural performance elements like strength, ductility, and redundancy factor on seismic response parameters including base shear, maximum lateral displacement, and fundamental time period.

IV. METHODOLOGY

4.1 PROCEDURE

- The CSI SAP2000 software is used to simulate the elevated Intze water tank.
- The research is conducted using the raised water tank's nonlinear static analysis, also known as push over analysis.
- A water tank with a fixed support is being contemplated.
- Factors including gravity, living load, water load, wind load, and seismic load are applied to the structure.
- The structural type is Ordinary Moment. Fighting Structure
- At the container's centre of gravity, apply the static lateral force caused by an earthquake.
- IS 1893:2016 specifies the earthquake loading.
- Applying static pushover analysis to force the structure to displacements greater than the goal displacement by utilising the load patterns of static lateral loads.
- The beam and column were given their respective hinges.

V. PROJECT DESCRIPTIONS AND MODELING

We use SAP 2000 software to model and analyse the high overhead water tank. The data and analyses performed in this research adhere to the seismic codal regulations, including zone factor, gravity, and lateral load analysis. A nonlinear static pushover study is conducted using SAP2000.

5.1 TANK DESCRIPTION

300 m^3 – Capacity Tank

Consider

Diameter of Tank = 9 m (D)

Diameter of Lower Ring Beam = 0.6 * 9 = 5.4 m

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Take Approximately 6 m (D_0)
Rise of Top Dome = 0.2 * 9 = 1.8 m (h_1)
Rise of Bottom Dome = 1.5 m (h_2)
Height of Conical Dome = 1.5 m (h_0)
Capacity of Tank = $(\pi/4 * D^2 * h) + (\pi/12 * h_0 * (D^2 + D_0^2 + D.D_0)) – (\pi/3 * h_2^2 * (3R_2 – h_2))$
$R_2 = ((D_0/2)^2 + h_2^2) / (2 * h_2)$
$R_2= ((6/2)^2 + (1.5)^2) / (2 * 1.5)$
$R_2 = 3.75$ m
h = ?
$300 = (\pi/4 * 9^2 * h) + (\pi/12 * 1.5 * (9^2 + 6^2 + (9 * 6))) – (\pi/3 * (1.5)^2 * (3 * 3.75 – 1.5))$
300 = 63.62 h + 67.16 – 22.98
h = 4.02 m
Consider h = 4.5 m

Table 1: Description for water tank for 300 m^3

	TANK PROPERTY			STAGING PROPERTY	
1	Tank Capacity	$300m^3$	1	No. of Columns	8
2	Cylinder Diameter	9m	2	Columns Diameter	0.65m
3	Wall Height	4.5m	3	Columns Height	14 & 18m
4	Top Dome Rise	1.8m	4	Diameter of Lower Ring Beam	6m
5	Conical Dome Rise	1.5m	5	Bracing Interval	4.5m
6	Bottom Dome Rise	1.5m	6	No of Bracing per level	8
7	Top Ring Beam	0.23×0.3m			
8	Middle Ring Beam	0.5×0.3m		SEISMIC DATA	
9	Bottom Ring Beam	0.5×0.6m	1	Response Reduction Factor	2.5
10	Top Dome Thickness	0.1m	2	Zone	II, III, IV, V
11	Cylinder Thickness & Bottom Dome Thickness	0.2m	3	Soil Type	Medium
12	Conical Dome Thickness	0.25m	4	Type of Structure	OMRF

a) MATERIAL PROPERTIES

The following are the material properties of an existing water tank are

- Grade of concrete = 25 N/mm^2
- Grade of steel = $500N/mm^2$
- Modulus of elasticity of steel = 210000 N/mm^2
- Modulus of elasticity of concrete = $5000\times\sqrt{fck}$ = 25000 N/mm^2

b) DEFINING FRAME AND SLAB PROPERTIES

- The RC beams and columns are modeled as 3D frame elements with grid dimension.
- Wall and domes are modeled as shell elements.
- Columns are fixed to the ground. Hinges are considered for analysis
- Flexure moment (M3), axial biaxial moment (P-M2-M3) and axial compressive shear force (V) hinges are assigned at the face of beam, column, and bracing respectively.

c) LOAD CONSIDERATION

- Dead load of structure is considered
- For Static behaviour live load considered as 1.25 KN/m^2.
- Lateral seismic load was considered confirming IS 1893(Part 1)-2016.
- Wind Load is considered as per IS 875 (Part 3)
- Water pressure is considered as per IS1893 (Part 2) - 2014 code.

d) SEISMIC PARAMETERS CONSIDERED

- Seismic Zone: zone II, zone III, zone IV, zone V.
- Zone Factor: (0.10), (0.16), (0.24), (0.36).

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- Soil type: II
- Importance Factor: 1.5 [as per IS 1893-2014 (Part 2)]
- Response Reduction Factor: 2.5 [as per IS 1893-2014 (Part 2)]
- Damping ratio: 5%
- Time period calculated [as per IS 1893-2014 (Part 2)]

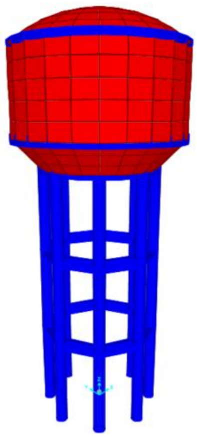
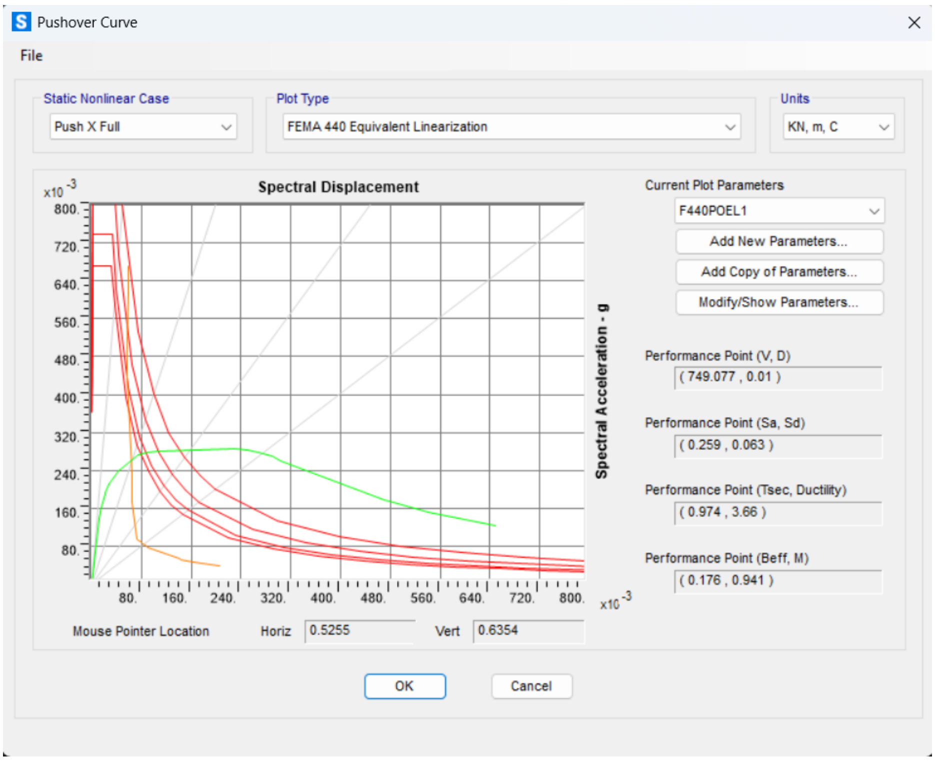


Figure 5:3D Model of water tank for 300 m^3 with 14m height

VI. CALCULATIONS

6.1 CALCULATION OF RESPONSE REDUCTION FACTOR

Full Tank 300 m^3 – 14m Staging Height



For Zone 2

(a) Estimation of strength factor

Maximum Base Shear (from pushover curve) $V_O = 749.077$ KN

Design Base shear (as per EQ calculation) $V_B = 286.12$ KN

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Using equation for strength factor [ATC-19]

$R_s = V_O / V_B$= 749.077 / 286.12

$\mathbf{R_s = 2.62}$

(b) Estimation of ductility factor

Maximum drift capacity Δm =87.2 mm (0.004 H)

Yield drift Δy = 32 mm (From Table)

Using equation for ductility factor, derived by Miranda and Bertero

$R_\mu = \{(\mu - 1 / \phi) + 1\}$

ϕ for medium soil = $1+ \{1 / (12T - \mu T)\} - \{(2 / 5T) * e^{-2(\ln(T) - 0.2)\,\hat{}\,2}\}$

$\phi = 0.37$

T =0.65 seconds (From SAP model)

$\mathbf{R_\mu = 3.2}$

(c) Estimation of redundancy factor

R_R = 0.86 (Redundancy factor (RR) from ATC-19)

(d) Estimation of response reduction factor R:

$R = R_S \times R_\mu \times R_R$ = 2.62 *3.2 *0.86

R= 7.2

Table 3: Comparing value of R-Factor for different zones of 300 m³ Capacity of tank 14m Height, Empty Condition

ZONE	II	III	IV	V
Time period	0.57	0.57	0.57	0.57
Base Shear (KN)	139	223	335	503
Over Strength Factor	4.43	2.66	1.74	1.16
Ductility Factor	2.65	2.5	1.81	1.41
Redundancy Factor	0.86	0.86	0.86	0.86
Response Reduction Factor	10.11	5.9	2.72	1.41

Figure 6: Base Shear v/s Seismic Zones for different tank condition

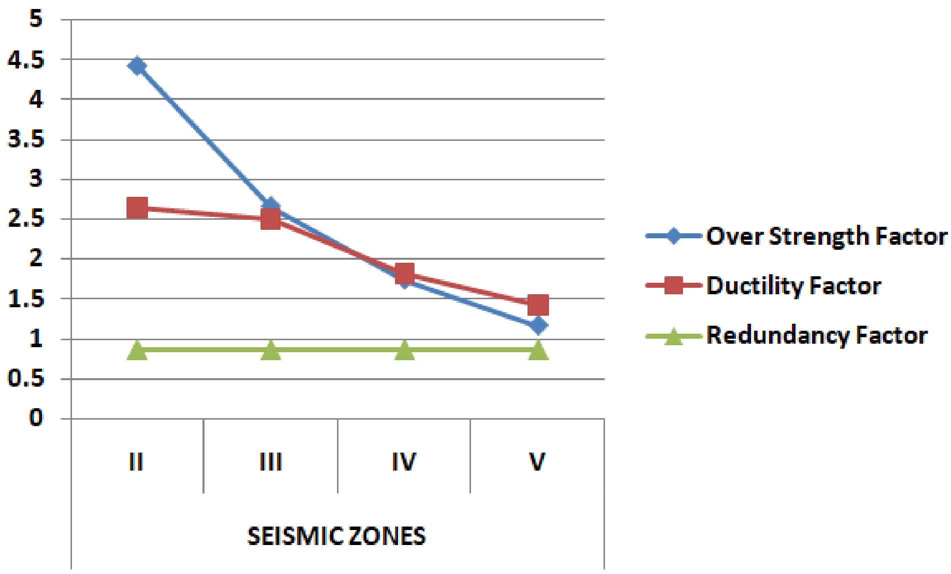

Figure 7: Factors v/s Seismic Zones for Full Water Tank

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VII. RESULT AND DISCUSSIONS

7.1 TIME PERIOD
7.1.1 Variation of Time Period for 300 m^3

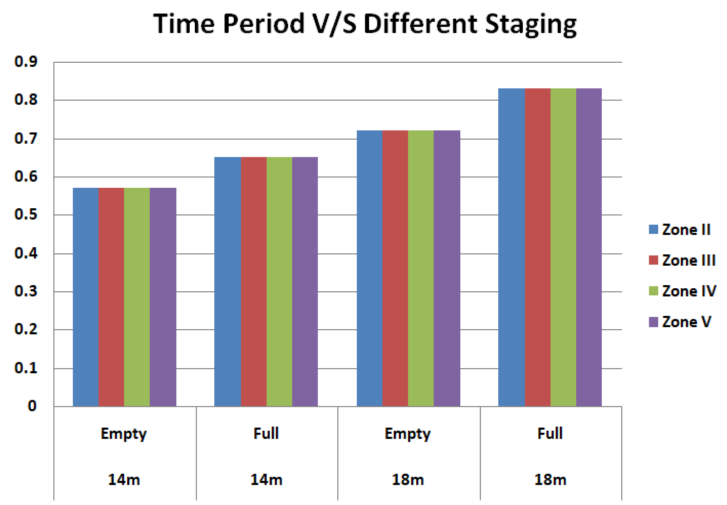

Figure 8: Time period v/s Different Staging for different zones and tank condition of water tank

7.2 RESPONSE REDUCTION FACTOR
7.2.1 Variation of Response reduction factor for 300 m^3

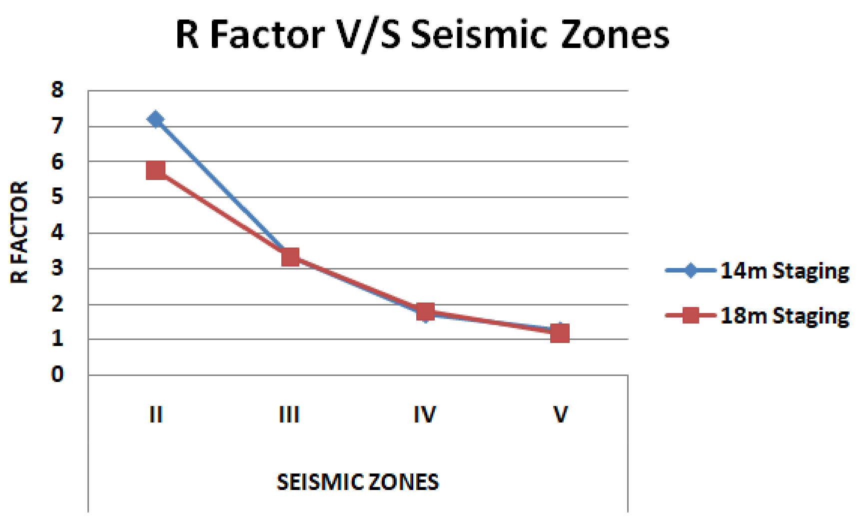

Figure 9: R factor v/s seismic zones for different staging of Full water tank

VIII. CONCLUSION

- According to this research, the staging height, seismic zone, and operational conditions are the three key factors that determine the seismic performance of an elevated Intze water tank.
- The crucial argument for design is strengthened because base shear rises with increasing seismic zones.
- The need for meticulous design under extreme seismic circumstances is shown by the fact that the overstrength factor declines as seismic zones increase, suggesting a loss in reserve strength.
- The fact that the time period grows as the staging height does indicates that tanks have a higher level of flexibility.
- To construct raised Intze water tanks in a safer and more cost-effective manner, performance-based pushover analysis is useful for assessing nonlinear behaviour.

DOI: 10.17148/IARJSET.2025.12909

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