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Nonlinear Static Analysis-an Advanced Analytical Approach to Mitigate Seismic Risks of Overhead Circular Water Tank

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Abstract:

Overhead water tanks are vital components of water distribution systems, subject to varying loads and environmental conditions that can impact their structural integrity. Traditional linear static analysis methods often provide limited insights into the true behavior of these tanks under extreme loading scenarios. Nonlinear static pushover analysis offers a comprehensive approach to the assessment of the structural response of overhead water tanks under large deformations and nonlinear material behavior. This paper delves into a detailed investigation of the application of nonlinear static pushover analysis techniques for evaluating the seismic performance of overhead circular water tanks. Key aspects of the methodology include the development of pushover curves to assess the tank's capacity and ductility, as well as the identification of potential failure mechanisms and critical regions prone to damage. The structural response is evaluated for the 200Cu.m. capacity tank through the force-displacement curve, hinge formation pattern, and period of the tank for variable staging heights of tanks 18m, 14m and 10m. The value of the base shear for the 14m staging height tank is around three times the 10m staging height tank and for the 18m staging tank, it is around eight times. From the pushover curve for 18m, 14m and 10m it can be observed that sufficient ductility is achieved. For all heights of the tank, it can be seen that there is no significant failure of the structural members of the tank. The variation of base shear values in pushover analysis for tanks with staging heights of 18m, 14m, and 10m shows that taller tanks generally experience higher base shears due to increased mass and dynamic effects associated with their height. The period of the tank reduces with a reduction in the height of the tank. From the formation of the hinges pattern, it can be seen that hinges are within immediate occupancy: IO to life safety: LS performance level and life safety to collapse prevention: CP level. The findings emphasize the importance of adopting a nonlinear static analysis advanced analytical approach to mitigate risks associated with seismic events and ensure the structural reliability of overhead water tanks in earthquake-prone regions.

Keywords: Nonlinear analysis, pushover curve, base shear, hinge formations

1. Introduction:

Overhead water tanks are the main water supply system elements which are used to provide water for human consumption in both urban and rural areas, thereby ensuring a continuous and reliable water supply. Structural integrity and operation performance are two crucial conditions for these tanks, necessary for the quality of water and the realization of the demand fluctuations. The traditional linear method mostly fails to provide an accurate portrayal of the complex behaviors of the overhead water tanks which are the most prominent under the conditions of the different loading and environmental situations. The damages to elevated water tanks in the event of past earthquakes are the focal point of the poor performance of the system.

Impulsive mode of elevated tank is considered in the older version of Indian seismic code [9]. In the revised Indian seismic code [7-9], both impulsive and convective mode are taken into account for elevated tank. In 2-DOF system approach, George W. Housner [14] proposed a 2-DOF system approach which is adopted in many international codes. The FEMA-273/274 [12] & ATC-40 [5] documents contain this simplified non-linear analysis procedure. Chetan C. et.al, [10] state that different countries adopts the different approach towards seismic analysis and design. Indian code restricts on construction of elevated tanks supported on masonry shaft having reinforcement with horizontal band in zone IV and V.

Nonlinear static analysis, commonly known as pushover analysis, has emerged as a powerful tool for evaluating the seismic performance of structures characterized by nonlinear material behavior and large deformations [3]. P. Deepak [18] performed the comparartive study of rectangular tanks using codal provisions. In the context of overhead water tanks, pushover analysis offers a systematic approach to assess their capacity, ductility, and vulnerability to seismic force [18]. By simulating gradual lateral displacement and corresponding internal forces, engineers can obtain valuable insights into the tank's behavior at different stages of loading, identifying potential failure mechanisms and critical regions susceptible to damage [2, 16]. Effect of geometric imperfections is important aspect in nonlinear analysis of structures [17]. Structural performance of water tanks governs in tank fully filled condition [11].

This paper presents an in-depth examination of the application of the non-linear analysis method using a static pushover analysis technique for the evaluation of the seismic performance of a circular water tank. The main elements of the approach are the development of the pushover curve for assessment of tank capacity and ductility, identification of failure modes, and also localizing the critical locations. The force-displacement curve, hinge formation pattern, and the time period of the tank which is the variable staging heights of 10 m, 14 m, and 18 m are used which is the structural response for the 200Cu.m. capacity tank.

2. Description of Nonlinear Static/Pushover Analysis:

Pushover analysis, also known as non-linear static analysis, is a structural engineering method used to evaluate the performance of structures under lateral loads, such as those caused by earthquakes. This technique allows engineers to understand how a structure behaves as it undergoes progressive deformation and ultimately reaches its failure capacity.

This method provides insights into potential weak points in a structure and helps predict the sequence of damage that may occur under seismic loading. Nonlinear static pushover analysis is a nonlinear analysis method used to evaluate the seismic performance of structure for which the lateral loads of constant relative magnitude are applied and gradually increased until a target displacement is reached, while gravity loads are kept constant. Figure 1 shows the typical capacity/pushover curve.

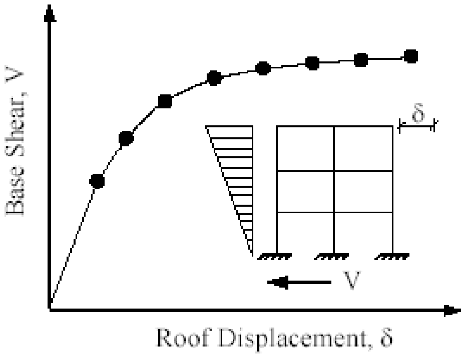


Figure 1: Capacity (or Pushover) Curve

Due to its conceptually and computationally simple approach pushover analysis is preferred method for evaluation of seismic performance [6, 23] of structures by the major rehabilitation guidelines and codes. This method [4] provides insights into potential weak points in a structure and helps predict the sequence of damage that may occur under seismic loading [20, 21]. The primary purpose of pushover analysis is to simulate the post-elastic behavior of structures during seismic events. Traditional linear static analysis methods are limited because they assume that structures remain elastic under load, which is not always the case during significant seismic events [15]. As such, pushover analysis addresses these limitations by considering the inelastic behavior of materials and components. Linear static analysis often uses a Response Reduction factor (R) to account for ductility, but it does not explicitly analyze the ductile capacity or redistribution of forces due to yielding [19]. Pushover analysis overcomes these challenges by providing a more accurate representation of how structures will perform when subjected to large deformations and progressive failures. Tejas et al [24] evaluated the response reduction factors for using non-linear static analysis.

2.1 Seismic Design Philosophy and Seismic Performance Levels:

The seismic design philosophy is a framework that guides engineers in creating structures that can withstand the forces generated by earthquakes. This philosophy is based on understanding the different levels of earthquake shaking and how structure should respond to these varying intensities. The seismic design philosophy for water tanks is fundamentally about ensuring the structural integrity and functionality of these tanks during and after an earthquake. Given that water tanks are critical infrastructure for municipal water supply, fire protection, and industrial processes, their ability to withstand seismic forces is paramount.

Under minor but frequent shaking, the main structural elements (those carrying vertical and lateral loads) should remain undamaged, while non-structural components may sustain repairable damage. During moderate but infrequent shaking, primary structural members may incur repairable damage, while other parts of the building could be damaged to the extent that they need replacement after an earthquake. In the case of severe shaking, which is rare but possible, buildings are designed to prevent collapse even if they sustain significant damage. The goal here is to ensure life safety for occupants and minimize catastrophic failures.

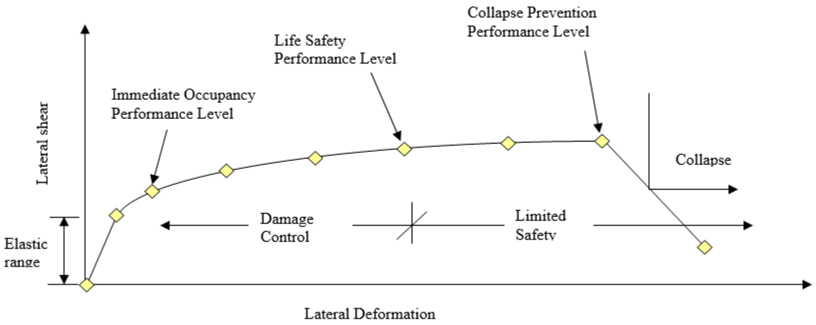


Figure 2: Performance and Structural Deformation Demand

Figure 2 illustrates performance and structural deformation demand. Seismic Performance Levels (SPLs) [1, 13] describe the expected behavior of a structure during and after an earthquake. These levels help engineers, designers, and regulators understand how buildings will perform and guide design codes to minimize damage and loss of life. [21]. SPLs typically fall into four categories: These levels are used by various guidelines, including the FEMA 274 [12] standard, which describe the expected post-earthquake condition and serviceability of structures.

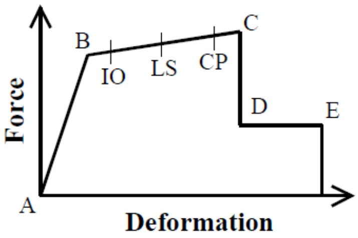


Figure 3: Generalized Force Deformation Relationship

Figure 3 shows the generalized force deformation relationship. Points A, B, C corresponds to unloaded condition, yielding of element and nominal strength respectively. The initial failure of element starts from the drop from point C to D. Beyond point C resistance to lateral load is unreliable. Frame elements can sustain gravity loads with residual resistance from point D to E. Ultimate deformation and gravity loads cannot be sustained beyond point E. Points from B to C represent hinges formation acceptance for immediate occupancy: IO, life safety: LS and collapse prevention: CP.

3. Methodology & Problem Statement:

3.1 Material Nonlinearity:

This section outlines the material properties used to define the nonlinear behavior of each structural element, which play a crucial role in determining structural performance. The mechanical properties of components and connection materials significantly influence their response under loading. Key properties of interest include expected yield strength (Fy), modulus of elasticity, ductility, toughness, and elongation characteristics. In this study, the following material properties have been considered.

3.1.1 Concrete:

The evaluation of concrete properties should include the determination of compressive strength, modulus of elasticity, and variability. Transverse reinforcement can be utilized to enhance both the strain capacity and compressive strength of concrete. In this study, the stress-strain model proposed by Mandar J.B. has been adopted. This model is applicable to both unconfined and confined concrete, with appropriate limiting strain values for each case. The relationship between strain and corresponding stress is expressed through the following equation.

$$f_c = \frac{f'_{cc} \cdot x \cdot r}{(r-1) + x^r} \tag{1}$$

where $$x = \frac{\varepsilon_c}{\varepsilon_{cc}} \tag{2}$$

and $$\varepsilon_{cc} = \varepsilon'_{co} \cdot \left[1 + 5 \cdot \left[\frac{f'_{cc}}{f'_{co}} - 1\right]\ \right] \tag{3}$$

$$r = \frac{E_c}{(E_c - E_{sec})} \tag{4}$$

$E_c = 5000 \cdot \sqrt{f'_{co}}$ = Tangent modulus of elasticity (5)

E_{sec} = Secant modulus of elasticity.

f_{cc} = Maximum compressive strength of concrete.

ϵ_{cc} = Strain corresponding to maximum strength.

For confined concrete, the enhancement in strength and strain is determined using the relations provided by Mandar. In this study, the strength enhancement is considered to be 15% of the maximum strength. The Stress-Strain Model for Confined Concrete is illustrated in Figure 4. The ultimate strain is computed for each grade of concrete, maintaining a constant ratio of the volume of transverse reinforcement to the volume of the concrete core. The ultimate strain for confined concrete is calculated using the following equation.

$$110 \cdot \rho_s = \int_0^{\varepsilon_{cu}} f_c \cdot d\varepsilon_c + \int_0^{\varepsilon_{cu}} f_{sl} \cdot d\varepsilon_c - 0.017 \cdot \sqrt{f'_{co}} \tag{6}$$

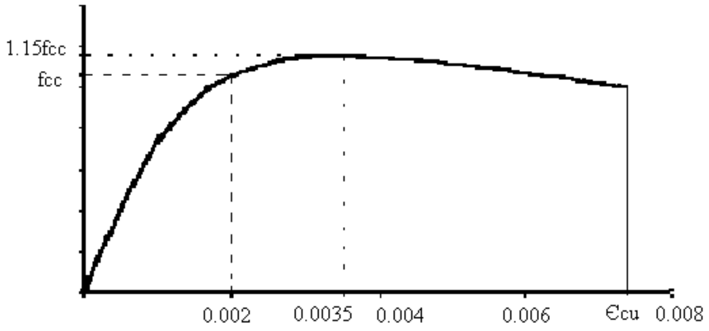


Figure 4: Stress-Strain Model for Confined Concrete

A typical stress-strain relationship for confined concrete used in this study is illustrated in Figure 4. The stresses and strains considered in this study are specified accordingly. To determine the ultimate strain for confined concrete, Equation (6) is solved using numerical integration. In this study, concrete of grade M25 is used.

Table 1: Stress –Strain Parameters for Confined Concrete

Concrete	f_{ck}	f_{co}	f_{cc}	ϵ_{co}	ϵ_{cc}	ϵ_{cu}
M_{25}	14.23	25	16.36	0.002	0.0035	0.0074

3.1.2 Reinforcement:

The stress-strain model for reinforcing steel is considered as elastic-perfectly plastic, similar to the approach used by R. Park and M.J.N. Priestley for computing the moment-rotation relationship of reinforced concrete sections. After reaching the yield stress (Fy), the steel is assumed to exhibit plastic behavior, as illustrated in Figure 5. In this study, Fe-415 grade steel is used.

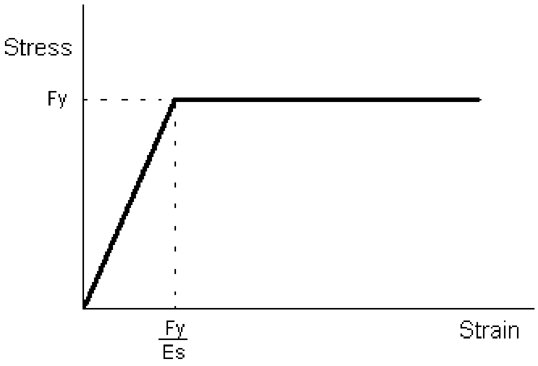


Figure 5: Stress – Strain Curve of Steel

3.2 Nonlinear Hinge Properties:

These essential properties are crucial for performing nonlinear analysis as they define the component behavior in terms of initial stiffness, ultimate strength, and deformability. The behavior of each component is represented using nonlinear load-deformation relationships, defined by a series of straight-line segments. These relationships are derived based on fundamental principles of mechanics of materials and validated through experimental results. The following section provides a brief overview of the component models used for different structural elements.

3.2.1 Moment Hinge:

These hinges are used to define the load-deformation relationship of beams where flexural actions are predominant. In beams, flexural effects are most significant at mid-span and support sections. The load-deformation characteristics are derived based on the equilibrium conditions of internal forces induced by flexural actions.

Total compressive force = Total tensile force.

C = T

To determine the total compressive force in a beam section, the area above the neutral axis is divided into multiple narrow strips, as illustrated in Figure 6. Strains along the edges of each strip are used to calculate stresses based on the stress-strain relationship, allowing the determination of forces on each strip. The total compressive force is obtained by summing the forces across all strips. For the total tensile force, the tensile strength of concrete is neglected. Instead, the stresses at the steel reinforcement level are calculated using the stress-strain relationship of steel, which provides the total tensile force.

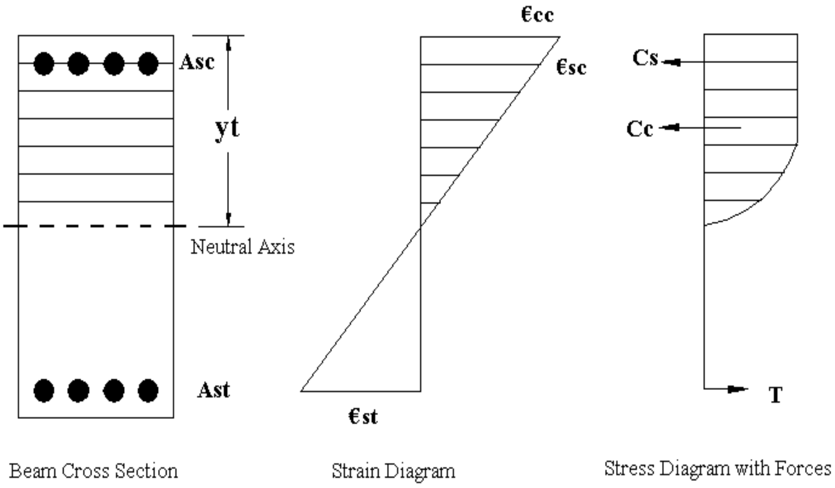


Figure 6: Strip Model for Beam

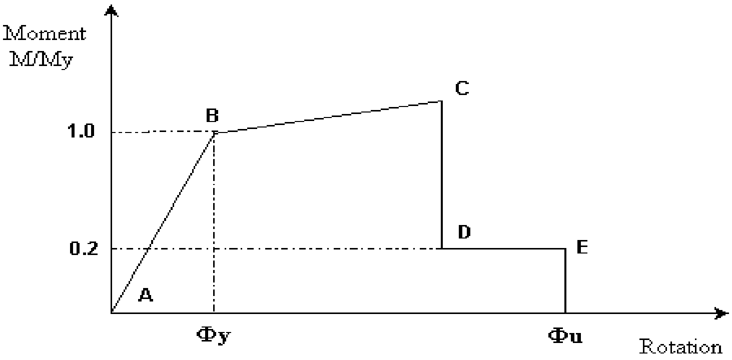


Figure 7: Typical Moment – Rotation Curve

The typical simplified moment hinge property is illustrated in Figure 7.

3.2.2 Axial force and Moment Hinge:

This type of hinge property is used to define load deformation relation for columns in which both the axial force and moment are significant. In column the combined effect of both actions is dominant near support sections. For deriving moment rotation relation including effect of axial force, equilibrium of total internal and external forces induced due to both actions is taken.

(Total compressive force) – (Total tensile force) = (Axial force)

(C – T) = P

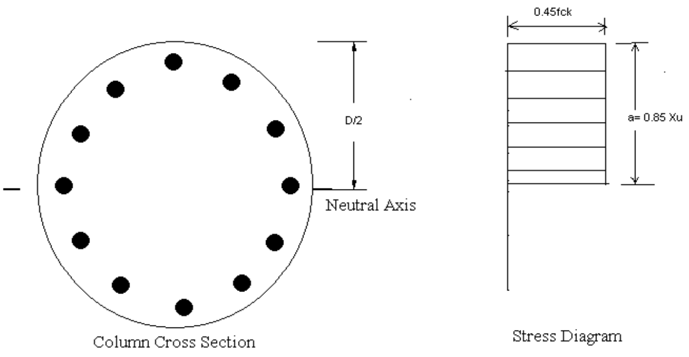


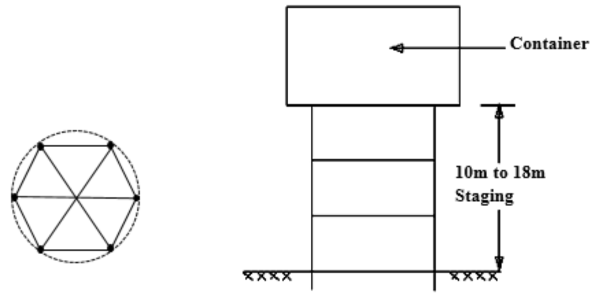
Figure 8: Strip Model of Column

The axial force in a structure is primarily induced by gravity loads. In addition to the moment-rotation relationship, it is essential to define the axial force-moment (P-M) interaction relationship. A strip model, similar to the one used for moment hinges in beams, is employed, as illustrated in Figure 8. The total internal compressive and tensile forces across the column cross-section are determined using the same approach as that used for moment hinges in beams

3.3 Problem Statement:

The study focuses on evaluating the seismic performance of overhead water tanks through nonlinear static (pushover) analysis. Pushover analysis is a non-linear static analysis method used to evaluate the seismic performance of structures. The methodology involves several key steps that allow engineers to assess how a structure will respond to seismic forces and identify potential failure mechanisms. Damping ratio of 5 percent is assumed. Flexural (M3), axial biaxial moment (P – M2- M3) plastic hinges are assigned to each ends of the beams and columns respectively, where the resultant moments under gravity and lateral loads are maximum. In Pushover analysis, first a ‘’gravity push’’ was applied with full dead load, convective mass, impulsive mass and 25% of live load. Next a ‘lateral push’ was applied at the C.G. of the container to obtain the push over curve. The objective is to assess the structural response through force displacement curve, hinge formation pattern and time period of the tank for variable staging heights of tank.

A circular tank with 200Cu.m capacity is considered for Nonlinear Static pushover analysis. Pushover analysis is performed in FEA software ETABS. Figure 9 shows the plan and staging configurations for the tank.



(a) Plan (b) Elevation

Figure 9: Plan and Staging configurations for 200m^3 capacity ESR

Details of tank are presented in Table 2.

Table 2: Details for 200m^3 ESR

Tank Capacity	200 Cu. m.
Container Diameter	7.5 m
Height of container	5 m
Freeboard	0.3 m
Wall thickness	200 mm
Roof slab thickness	150 mm
Floor slab thickness	200 mm
Varying staging height	18m, 14m & 10 m
Depth of foundation	2 m below G.L
Column diameter	600mm
Floor Beams	300 mm x 600 mm
Brace	300mm x 450mm
Length of column	3m
No. of Columns	6

4. Results and Discussion:

The results obtained from pushover analysis for different staging heights of eater tank like 18m, 14m and 10m are discussed in this section. Maximum base shear, displacement, hinge formation pattern, time period of water tank is observed. Pushover curve starts from unloaded condition. Pushover curves for the tank model signify the global behavior of the frame with stiffness and ductility. For all heights of tank, it can be seen that there is no significant failure of structural members of the tank. From the formation of hinges pattern, it can be seen that hinges are within immediate occupancy to life safety performance level and life safety to collapse prevention level. Table 3, 4, 5 and Fig. 10, 12, 14 shows the pushover results for 18m, 14m and 10m staging height of tank.

4.1 Pushover Analysis of 18m staging height Tank:

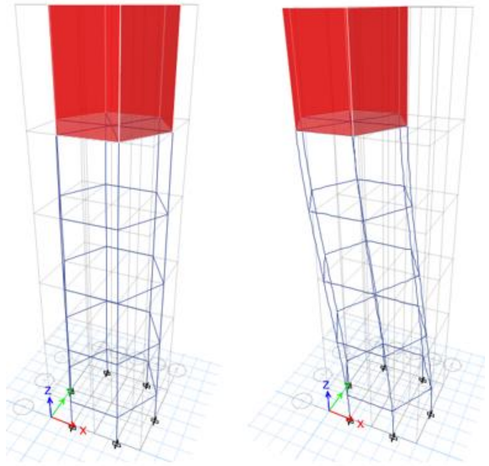


Table 3: Pushover results for 18m staging height Tank

Step	Monitored Displacement (mm)	Base Force (kN)
0	0.00	0.00
1	16.44	396.82
2	23.23	528.23
3	89.95	1355.96
4	159.92	2198.95
5	170.71	2329.33
6	170.71	2153.75
7	252.29	3114.54
8	252.30	3020.72
9	280.42	3351.92
10	280.43	3326.35
11	327.61	3867.47
12	327.61	3838.50
13	330.46	3875.37

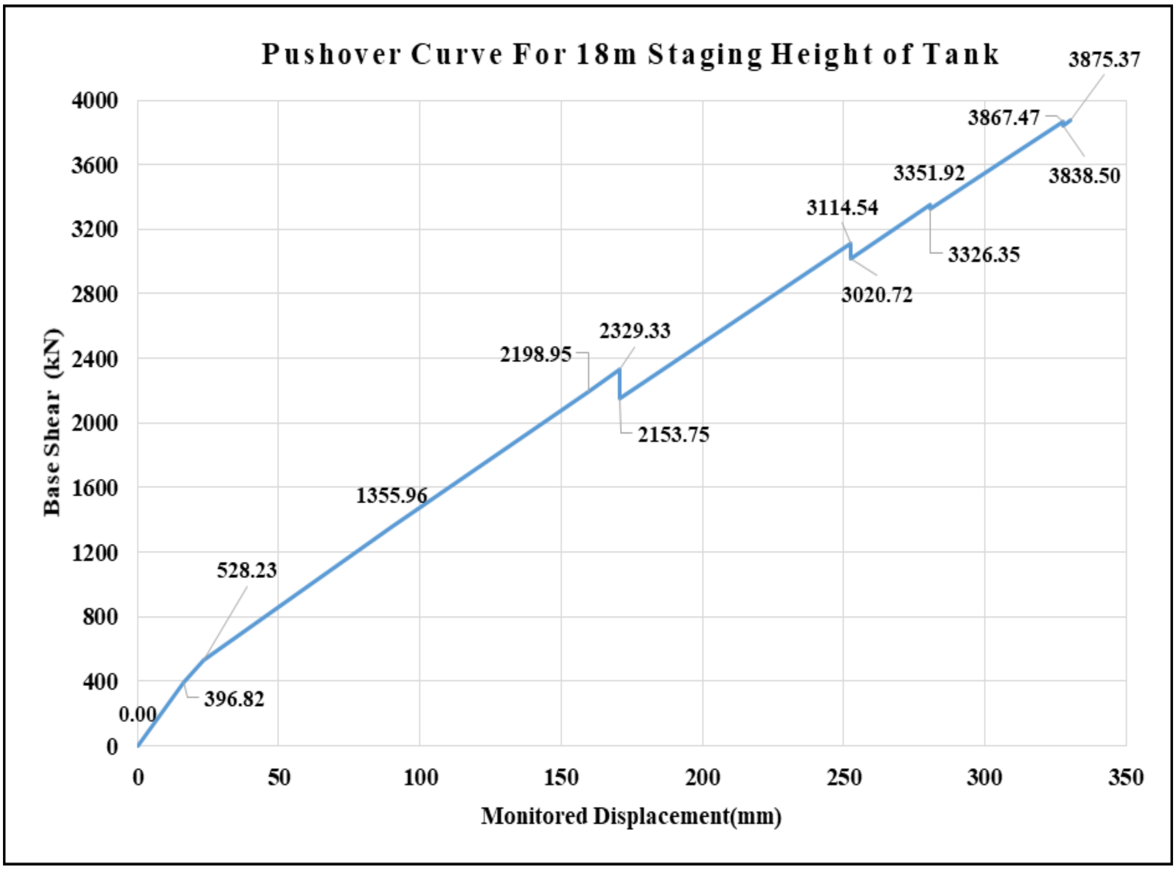
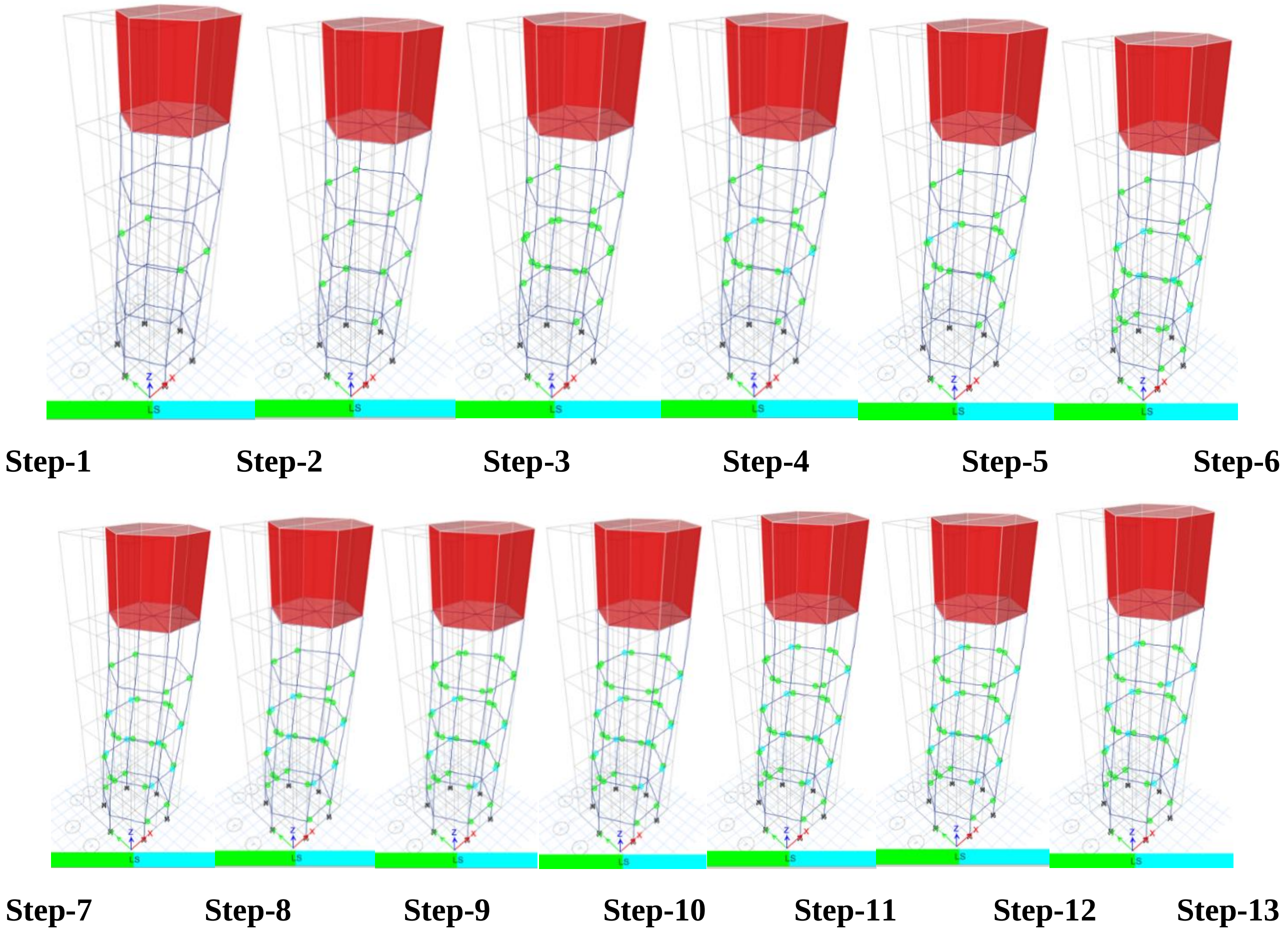


Figure 10: Pushover Curve for 18m Staging Height

From Table 3 and Figure 10, it can be seen that for 18m staging height, a higher base shear value is observed due to increased mass and dynamic effects compared to shorter tanks.

4.2 Step by step Formation of hinges for 18m staging height Tank:


Step-1 **Step-2** **Step-3** **Step-4** **Step-5** **Step-6**

Step-7 **Step-8** **Step-9** **Step-10** **Step-11** **Step-12** **Step-13**

Figure 11: Formation of hinges for 18m staging height Tank

Figure 11 represents the formation of hinges for 18m height of tank. It can be observed that, in step-1 hinges are formed in bracings at storey-3. In step-2 hinges are formed in bracings at storey-3 as well as storey-2 and 4. More hinges are formed in step-3 at the same levels. Until step-3 all hinges formed are within immediate occupancy performance level (green colour). In step-4, at storey-3 hinges formed goes in life safety performance level (blue colour). As we move further more hinges are formed in bracings at different levels of staging. It can be seen that, all hinges which are formed are within immediate occupancy [IO] performance level (green colour) and life safety [LS] performance level (blue colour).

4.3 Pushover Analysis of 14m staging height Tank:

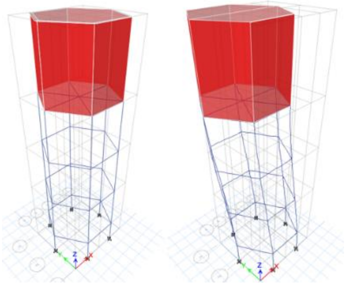


Table 4: Pushover results for 14m staging height Tank

Step	Monitored Displacement (mm)	Base Force (kN)
0	0.00	0.00
1	25.19	378.82
2	29.50	429.86
3	142.04	1034.18
4	**226.84**	**1494.78**
5	226.85	1418.09
6	229.88	1449.48
7	232.86	1468.73
8	232.87	1409.47
9	235.06	1429.21
10	230.17	1353.11

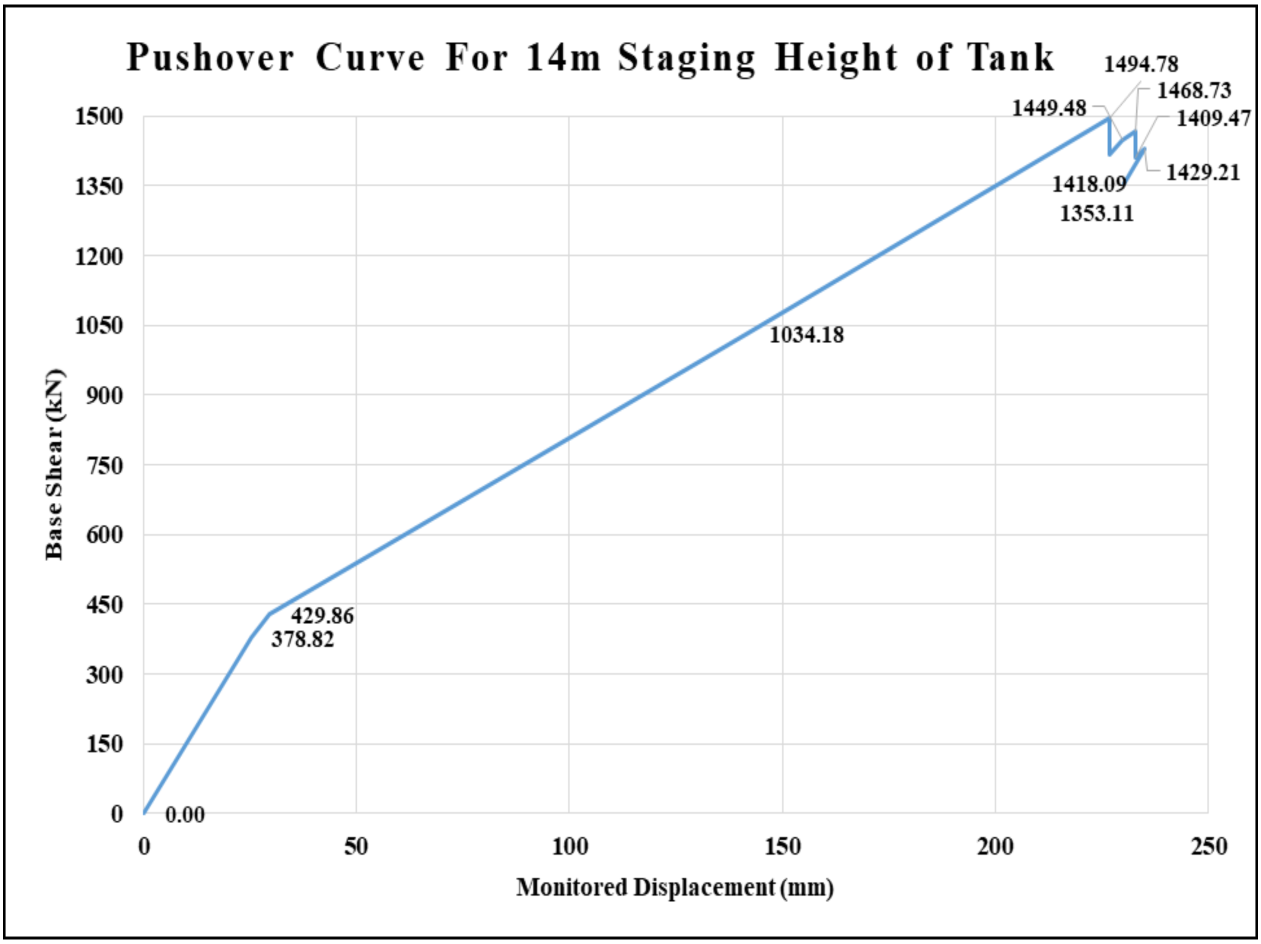
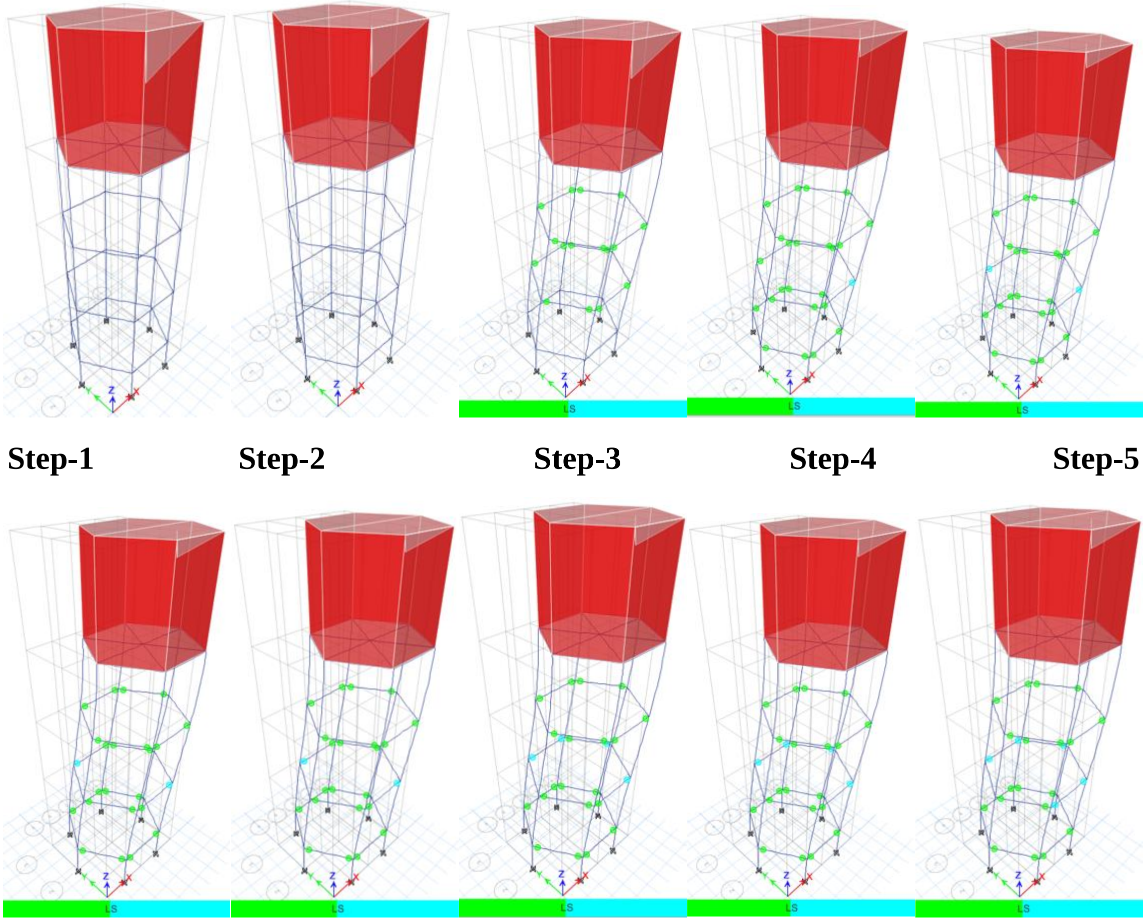


Figure 12: Pushover Curve for 14m Staging Height

From Table 4 and Figure 12, it can be seen that for 14m staging height, the base shear is lower than that of an 18m tank but still significant due to its considerable height.

4.4 Step by step Formation of hinges for 14m staging height Tank:



Step-1 **Step-2** **Step-3** **Step-4** **Step-5**

Step-6 **Step-7** **Step-8** **Step-9** **Step-10**

Figure 13: Formation of hinges for 14m staging height Tank

Figure 13 represents the formation of hinges for 14m height of tank. It can be observed that in step-1 and 2 there is no hinge formation. In step-3, hinges are formed at storey-2 and 3 and within immediate occupancy performance level (green colour). As we move further more hinges are formed in bracings at different levels of staging. At storey-2 hinges formed goes in life safety performance level (blue colour). It can be seen that, all hinges which are formed are within IO performance level (green colour) and LS performance level (blue colour).

4.5 Pushover Analysis of 10m staging height Tank:

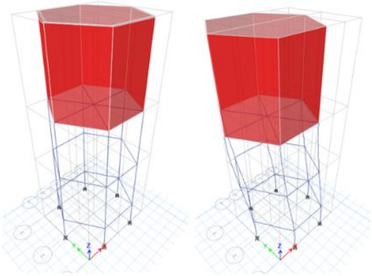


Table 5: Pushover results for 10m staging height Tank

Step	Monitored Displacement (mm)	Base Force (kN)
0	0.00	0.00
1	11.16	27.70
2	111.18	272.17
3	160.53	392.95
4	160.54	286.13
5	164.55	306.09
6	197.51	386.35
7	197.52	282.23
8	210.58	327.68
9	290.72	504.20
10	267.02	298.24

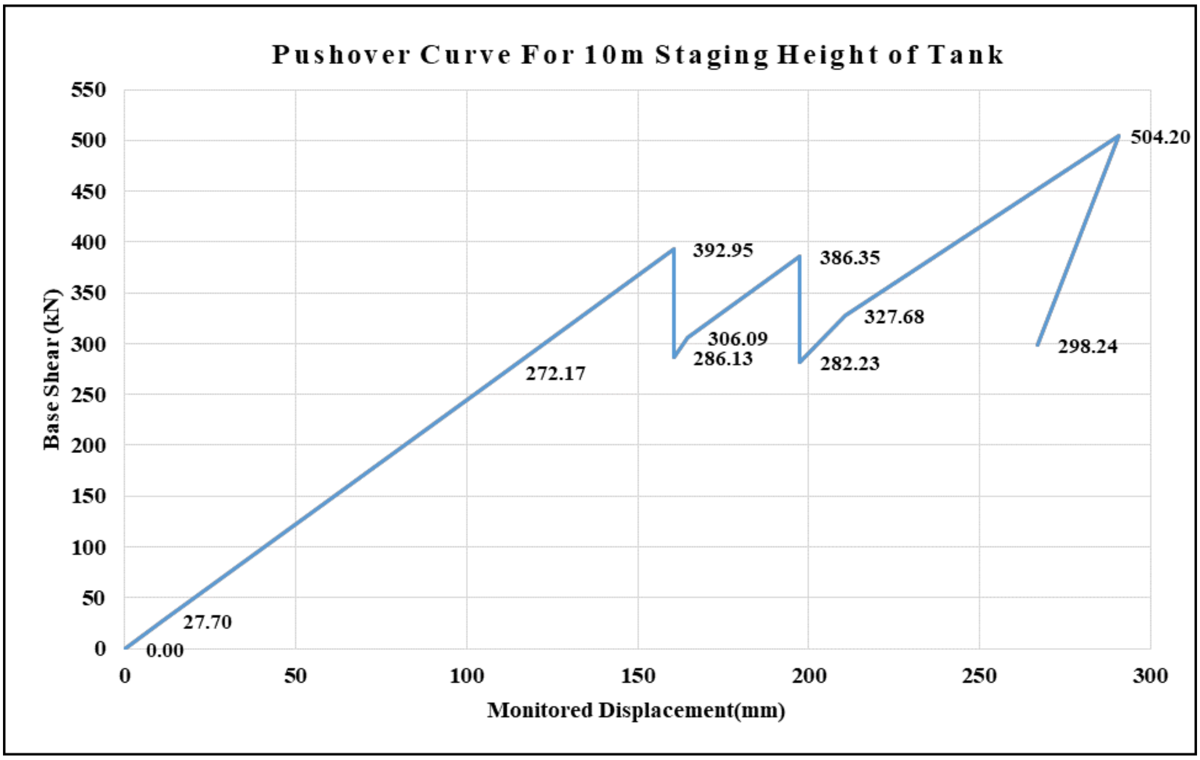
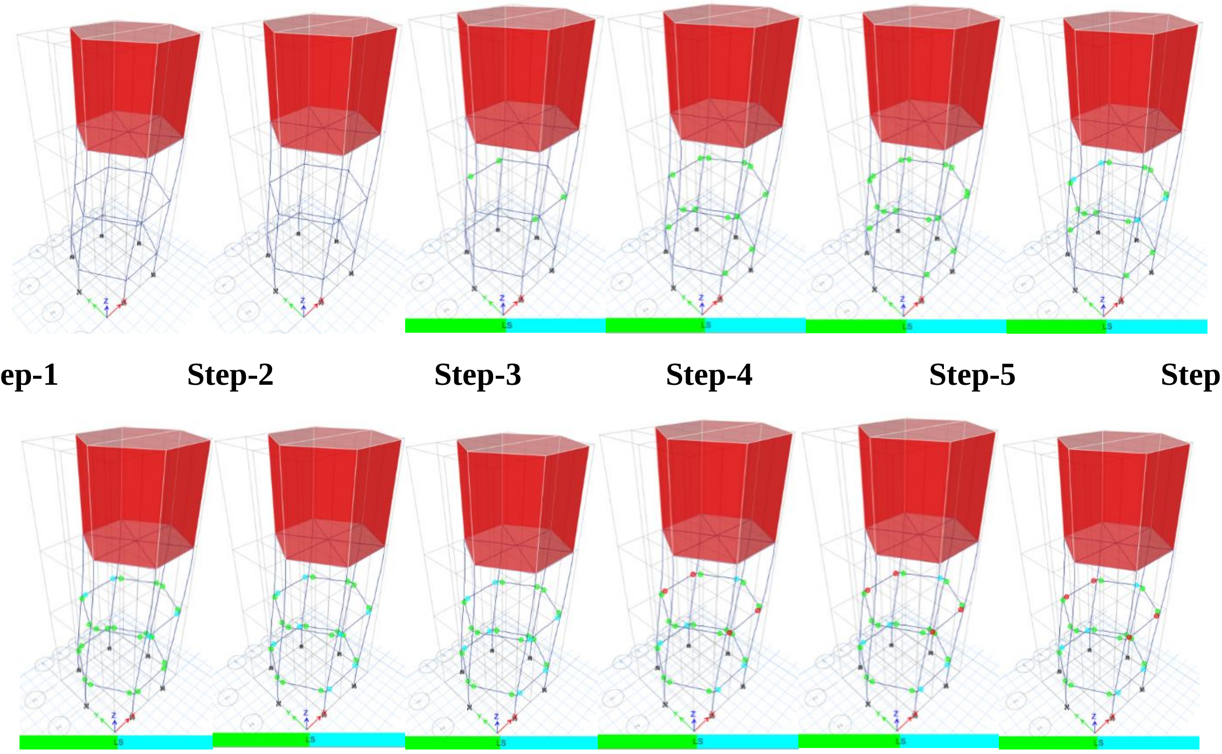


Figure 14: Pushover Curve for 10m Staging Height

From Table 5 and Figure 14, it can be seen that for 10m staging height, the tank exhibit the lowest base shear value among the three due to reduced mass and shorter time period.

4.6 Step by step Formation of hinges for 10m staging height Tank:



Step-1 **Step-2** **Step-3** **Step-4** **Step-5** **Step-6**

Step-7 **Step-8** **Step-9** **Step-10** **Step-11** **Step-12**

Figure 15: Formation of hinges for 10m staging height Tank

Figure 15 represents the formation of hinges for 10m height of tank. It can be observed that in in step-1, 2 there is no hinge formation. In step-3, hinges are formed in bracings at storey-2. More hinges are formed at storey- 1 and 2. Until step-9, all the formed hinges are within life safety [LS] performance level (blue colour). In further steps, hinges formed are in the collapse prevention [CP level (red colour). All the hinges which are formed are in bracings

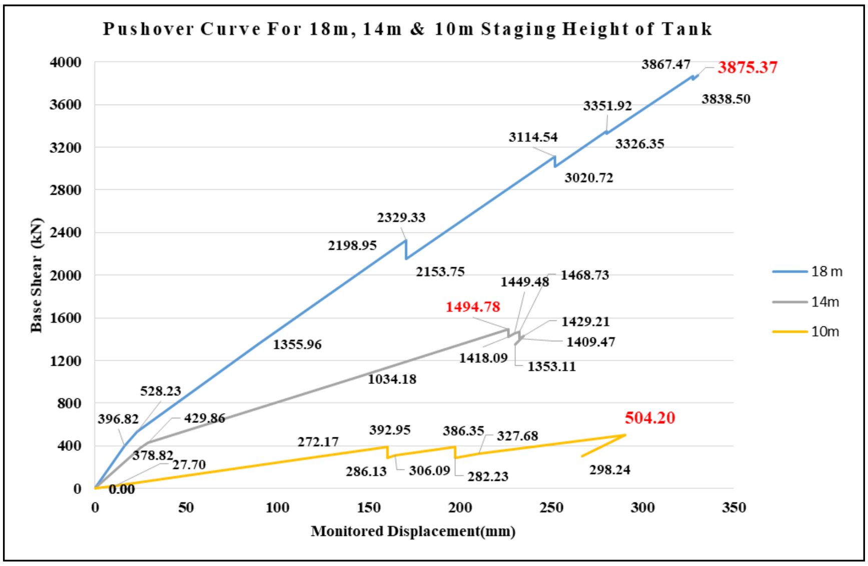
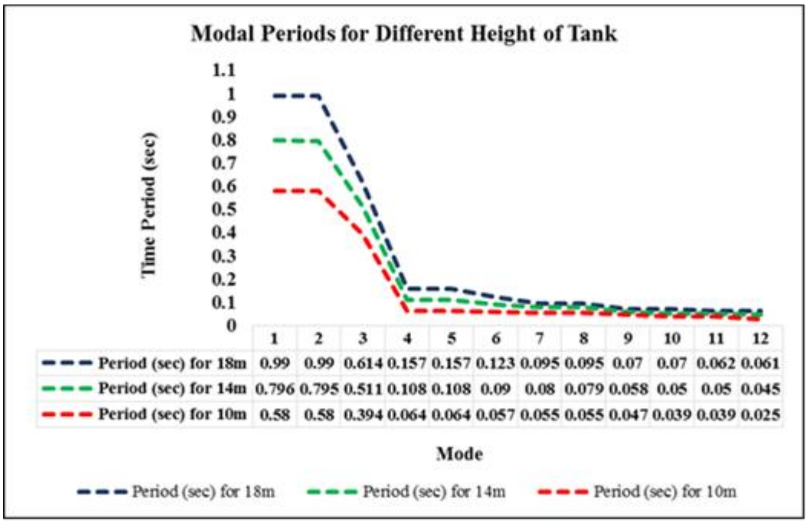


Figure 16: Pushover Curve for 18, 14m and 10m Staging Height

From Figure 16, it can be observed that pushover curve starts from unloaded condition. Pushover curves for the tank model describes global behavior of the frame with ductility and stiffness. Subsequently yielding of members start. There is drop in the curve showing initial failure of members. The structure experiences stiffness loss at every step of analysis resulting in gradual decrease of slope of pushover curve. Some elements of structure may yield in sequence under increment of loads. Structure experiences a change in stiffness at each event subsequently. Values of base shear increases as the height of tank reduces. Value of base shear for 14m staging height tank is around three times of 10m staging height tank and for 18m staging tank it is around eight times. From pushover curve for 18m, 14m and 10m it can be observed that sufficient ductility is achieved. For all heights of tank, it can be seen that there is no significant failure of structural members of the tank. The variation of base shear values in pushover analysis for tanks with staging heights of 18m, 14m, and 10m shows that taller tanks generally experience higher base shears due to increased mass and dynamic effects associated with their height.

Table 6: Modal Periods for Different Staging Height of Tank

Mode	**Period (sec) for 18m**	**Period (sec) for 14m**	**Period (sec) for 10m**
1	0.990	0.796	0.580
2	0.990	0.795	0.580
3	0.614	0.511	0.394
4	0.157	0.108	0.064
5	0.157	0.108	0.064
6	0.123	0.090	0.057
7	0.095	0.080	0.055
8	0.095	0.079	0.055
9	0.070	0.058	0.047
10	0.070	0.050	0.039
11	0.062	0.050	0.039
12	0.061	0.045	0.025



	1	2	3	4	5	6	7	8	9	10	11	12
Period (sec) for 18m	0.99	0.99	0.614	0.157	0.157	0.123	0.095	0.095	0.07	0.07	0.062	0.061
Period (sec) for 14m	0.796	0.795	0.511	0.108	0.108	0.09	0.08	0.079	0.058	0.05	0.05	0.045
Period (sec) for 10m	0.58	0.58	0.394	0.064	0.064	0.057	0.055	0.055	0.047	0.039	0.039	0.025

Figure 17: Combined Modal Periods for Different Height of Tank

From Table 6 and Fig. 17, it can be seen that modal period of tank reduces with reduction in tank height. Increased tank height leads to longer modal periods. Taller tanks are more flexible, leading to lower stiffness and higher flexibility. This increased flexibility results in longer modal periods. As the tank height increases, more of the tank's mass participates in the dynamic response, leading to longer modal periods.

5. Conclusion & Discussion:

Pushover analysis for 18m, 14m and 10m staging height of tank is performed. Maximum base shear and displacement are observed. Time period of tank for all cases is found out. Step by step formation of hinges for all the cases are observed.

The study focuses on using nonlinear static analysis to address seismic risks associated with overhead circular water tanks. Nonlinear static analysis is an advanced method that provides a more accurate assessment of structural behavior under seismic loads compared to linear methods. Overhead circular water tanks are critical infrastructure, and their failure during earthquakes can lead to significant consequences. The methodology involves evaluating the tank’s performance through pushover analysis for 18m, 14m and 10m staging height of tank, which simulates the effect of seismic forces.

The study emphasizes the need for detailed modeling of the tank’s geometry and material properties to achieve reliable results. Nonlinear static analysis contributes to a better understanding of dynamic interactions between water and tank structures during earthquakes

From pushover analysis, it can be observed that pushover curve starts from unloaded condition. Pushover curves for the tank model describes global behavior of the frame with ductility and stiffness. Subsequently yielding of members start. There is drop in the curve showing initial failure of members.

The structure experiences stiffness loss at every step of analysis resulting in gradual decrease of slope of pushover curve. Some elements of structure may yield in sequence under increment of loads. Structure experiences a change in stiffness at each event subsequently.

Value of base shear for 14m staging height tank is around three times of 10m staging height tank and for 18m staging tank it is around eight times. From pushover curve for 18m, 14m and 10m it can be observed that sufficient ductility is achieved. For all heights of tank, it can be seen that there is no significant failure of structural members of the tank. The variation of base shear values in pushover analysis for tanks with staging heights of 18m, 14m, and 10m shows that taller tanks generally experience higher base shears due to increased mass and dynamic effects associated with their height.

In summary, as the staging height of an elevated water tank increases from 10m to 18m, there is a corresponding increase in base shear values observed during pushover analysis due to factors such as increased mass and altered dynamic behavior. Therefore, the variation of base shear values in pushover analysis for tanks with staging heights of 18m, 14m, and 10m shows that taller tanks generally experience higher base shears due to increased mass and dynamic effects associated with their height.

For all heights of tank, it can be seen that there is no significant failure of structural members of the tank. From the formation of hinges pattern, it can be seen that hinges are within immediate occupancy to life safety performance level and life safety to collapse prevention level. It can be seen that no substantial damage to structural members are happened and are within immediate occupancy and life safety acceptance criteria. No hinges are formed in column portion. Strong column-weak beam theory is satisfied as per philosophy of seismic design.

Modal period of tank reduces with reduction in tank height. Increased tank height leads to longer modal periods. Taller tanks are more flexible, leading to lower stiffness and higher flexibility. This increased flexibility results in longer modal periods. As the tank height increases, more of the tank's mass participates in the dynamic response, leading to longer modal periods.

The findings underscore the importance of adopting nonlinear static analysis advanced analytical tool to mitigate risks associated with seismic events and ensure the structural reliability of overhead water tanks in earthquake-prone regions. The study calls for collaboration between engineers and policymakers to implement improved design codes for water tanks in seismic zones.

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