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Study of height on response reduction factor of RC water tank in zone IV

MILAN H MANEK, PRAJIT C PATEL, SHARAD R GAJERA
M.E (STRUCTURE), M.E (WRM), M.E (WRM)
CIVIL ENGINEERING DEPARTMENT,
V.V.P ENGINEERING COLLEGE, RAJKOT, INDIA

Abstract - It Is Very Important To Consider Earthquake Load In Design Of Elevated Tank. Response Reduction Factor (R) Is Very Important To Find Out Earthquake Load. The Response Reduction Factor Reflects the Capacity of Structure to Dissipate Energy by Inelastic Behavior. The purpose of this paper is to explore a methodology for evaluation of the response modification factor, R, of reinforced concrete frame staging (supporting system) elevated tanks, which behave in a ductile manner under seismic loads and expectedly fail in flexural mode instead of shear mode. The Values Of Response Reduction Factor(R) Of RC Elevated Water Tank Are Given In IS1893 Draft Code, Which Is Calculated At Empirically Based On Engineering Judgment. In this paper we have calculate actual R factor by pushover analysis.

1.1 GENERAL:

Water Is Considered As The Source Of Every Creation And Is Thus A Very Crucial Element For Humans To Live A Healthy Life. High Demand Of Clean And Safe Drinking Water Is Rising Day By Day As One Can Not Live Without Water. It Becomes Necessary To Store Water. Water Is Stored Generally In Concrete Water Tanks And Later On It Is Pumped To Different Areas To Serve The Community.

One Of The Oldest Known Water Tanks In Kenya Was Built By The Railway At Makindu River In 1907. It Appears The Tank Was Connected To A Hydra Pump That Used The Power Of The Flowing Water In The River To Push Water Into The Tank From Where It Was Used By Steam Locomotives.

Water Tanks Can Be Classified As Overhead, Resting On Ground Or Underground Depending On Their Location. The Tanks Can Be Made Of Steel Or Concrete. Tanks Resting On Ground Are Normally Circular Or Rectangular In Shape And Are Used Where Large Quantities Of Water Need To Be Stored.

Overhead Water Tanks Are Used To Distribute Water Directly Through Gravity Flow And Are Normally Of Smaller Capacity. As The Overhead Water Tanks Are Opening To Public View, Their Shape Is Influenced By The Aesthetic View In The Surroundings.

1.2 NEED OF STUDY:

It Is Very Important To Consider Earthquake Load In Design Of Elevated Tank. Response Reduction Factor (R) Is Very Important To Find Out Earthquake Load. The Response Reduction Factor Reflects the Capacity of Structure to Dissipate Energy by Inelastic Behavior. The purpose of this paper is to explore a methodology for evaluation of the response modification factor, R, of reinforced concrete frame staging (supporting system) elevated tanks, which behave in a ductile manner under seismic loads and expectedly fail in flexural mode instead of shear mode.

The Values Of Response Reduction Factor(R) Of RC Elevated Water Tank Are Given In IS1893 Draft Code, Which Is Calculated At Empirically Based On Engineering Judgment. The Values Of Response Reduction Factor Of Elevated Water Tank Adopted By Difference Codes/Standards Are Summaries Below.

R As Per International Standards for Elevated Tanks:

Codes/standards	"R" Factor
BC 2000/ FEMA 368	1.5 to 3.0
ACI 350.3	2.0 to 4.75
IS:1893-2002(Part -2) RCC frame support (draft code)	1.8 (OMRF) 2.5 (SMRF)

The Value of R-Factor Is Fixed 2.5 for staging Supported RC Elevated Tank. One Constant R-Value For Elevated Water Tank Cannot Reflect The Expected Inelastic Behavior Of All Elevated Water Tanks Located In Different Seismic Zone And Having Different Capacities. So It Is Required to Find out Perfect Value of R factor For Various Type of RC Elevated Tank Individually.

1.3 OBJECTIVES:

- The Main Objective Of This Study Is To Verify The R factor Of Most Common Designed Elevated Intze Tank Through Comparing The Assumed R Factor During Design To Actual R Factor Obtained From Non-Linear Analysis. The Specific Objectives Of The Study Are To:
- Conduct Static Non-Linear (Pushover) Analysis And Calculate R Factor Of Elevated Intze Tank
- Prepare A Spreadsheet To Design Elevated Tank
- Compare The Calculated R factor With the Assumed R Factor.
- Evaluate Ductility, Redundancy And Over Strength Factor Of Elevated Intze Tank
- Study The Effect Of Staging Height And Staging Type On Response Reduction Factor (R).
- To Study Effect of Zone Factor on Response Reduction Factor (R).

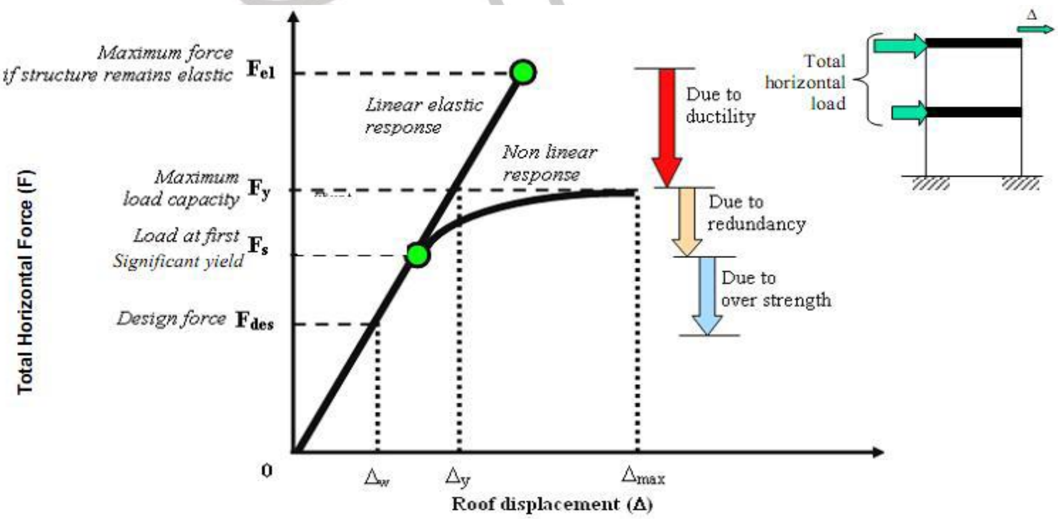
3.1Review of basic component about response reduction factor:

In the mid-1980s, data from experimental research at the University of California at Berkeley were used to develop base shear-roof displacement relationships for steel braced frames and a draft formulation for the response modification factor. The base shear-roof displacement relationships were established using data acquired from the testing of two code-compliant braced steel frames; one concentrically braced (Uang and Bertero, 1986) and one eccentrically braced (Whittaker et aI., 1987). The force-displacement curves were developed by plotting the roof displacement at the time corresponding to the maximum base shear force for each earthquake simulation and each model. Response reduction factor is the factor by which the actual base shear force should be reduced, to obtain the design lateral force. The response reduction factor reflects the capacity of structure to dissipate energy by inelastic behavior. This process is combined effect of over strength, redundancy and ductility. Response reduction factor is also known as ratio of maximum elastic force to designed force. Response reduction factor is depended on three factors.

1) Over strength factor
2) Ductility factor
3) Redundancy factor

- **R = Rs * RR * Rμ**

The Concept Of R factor Is Based On The Observations That Well Detailed Seismic Framing Systems Can Sustain Large Inelastic Deformations Without Collapse And Have Excess Of Lateral Strength Over Design Strength. Response Reduction (R) Factors Are Essential Seismic Design Tools, Which Are Typically Used To Describe The Level Of Inelasticity Expected In Lateral Structural Systems During An Earthquake. The Response Reduction Factor (R) Is Depends On Over Strength (RS), Ductility (Rμ), Redundancy.



Estimation of strength factor:

The steps in the procedure are as follows:

1. using nonlinear static analysis, construct the base shear-roof displacement relationship for the building.

2. At the roof displacement corresponding to the limiting state of response, calculate the base shear force Vo in the building. The reserve strength of the building is equal to the difference between the design base shear (Vd) and Vo')

3. Calculate the strength factor using the following expression:

- Strength factor is the ratio of Maximum Base Shear (from pushover curve) VO to Design Base shear (as per EQ calculation) Vd.
- $\mathbf{R_s = V_o / V_d}$

Estimation of ductility factor:

Equations for estimation of ductility factor is as below:

- **R μ = {(μ - 1 / Φ) + 1}**
- **Φ for rock sites: = 1+ {1 / (10T -μT)}–{(1 / 2T)*e^ (-2(ln (T) – 0.6) ^2)}**
- **Φ for alluvium sites: = 1+ {1 / (12T -μT)}–{(2 / 5T)*e^ (-2(ln (T) – 0.2) ^2)}**
- **μ = Δm / Δy**
- Δm = Maximum drift capacity (0.004 H)
- Δy = Yield drift (from pushover curve)

Estimation of redundancy factor:

The value of redundancy factor as suggested in ATC-19 is summaries in Table 3.

Lines of vertical seismic framing	Drift redundancy factor
2	0.71
3	0.86
4	1

Table-3 from ATC-19, For Redundancy factor.

Hinge formation:

The RC beams and columns are modeled as 3-D frame elements with centerline dimension. Wall and domes are modeled as shell elements. Column foundations are assumed to be fixed. Default 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 using the static pushover analysis.

Static nonlinear analysis of tank:

SAP software is used to perform the nonlinear static pushover analysis. The RC beams and columns are modeled as 3-D frame elements with centerline dimension. Wall and domes are modeled as shell elements. Column foundations are assumed to be fixed. Default 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 using the static pushover analysis. Figure shows the procedure of pushover analysis. Damping ratio is 0.5% considered.

4.3.1 Steps for Static nonlinear analysis of tank:

The following steps for the pushover analysis. Steps 1 through 4 discussing how to creating the computer model, step 5 runs the analysis, and steps 6 through 10 review the pushover analysis results.

1. Create the basic computer model (without the pushover data) in the usual manner use of graphical interface of SAP2000 makes this a quick and easy.

2. The program includes several built-in default hinge properties that are based on average values from ATC-40 for concrete members and average values from FEMA-273 for steel members. These built in properties can be useful for preliminary analyses, but user-defined properties are recommended for final analyses. Uses default properties.

3. Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and hinge locations, locate at 0 and 1.

4. Define the pushover load case. Pushover load case can start from the final conditions of other pushover load-case that was previously run in the same analysis. Typically the first pushover load case is used to apply gravity load and then subsequent lateral pushover load cases are specified to start from the final conditions of the gravity pushover. Pushover load cases can be force controlled, that is, pushed to a certain defined force level, or they can be displacement controlled, that is, pushed to a specified displacement. Typically, a gravity load pushover is force controlled and lateral pushovers are displacement controlled. SAP2000 allows the distribution of lateral force used in the pushover to be based on a uniform acceleration in a specified direction, a specified mode shape, or a user-defined static load case. Here how the displacement controlled lateral pushover case that is based on a user defined static lateral load pattern named PUSH is defined for this example.

5. Run the basic static analysis and, if desired, dynamic analysis. Then run the static nonlinear pushover analysis.

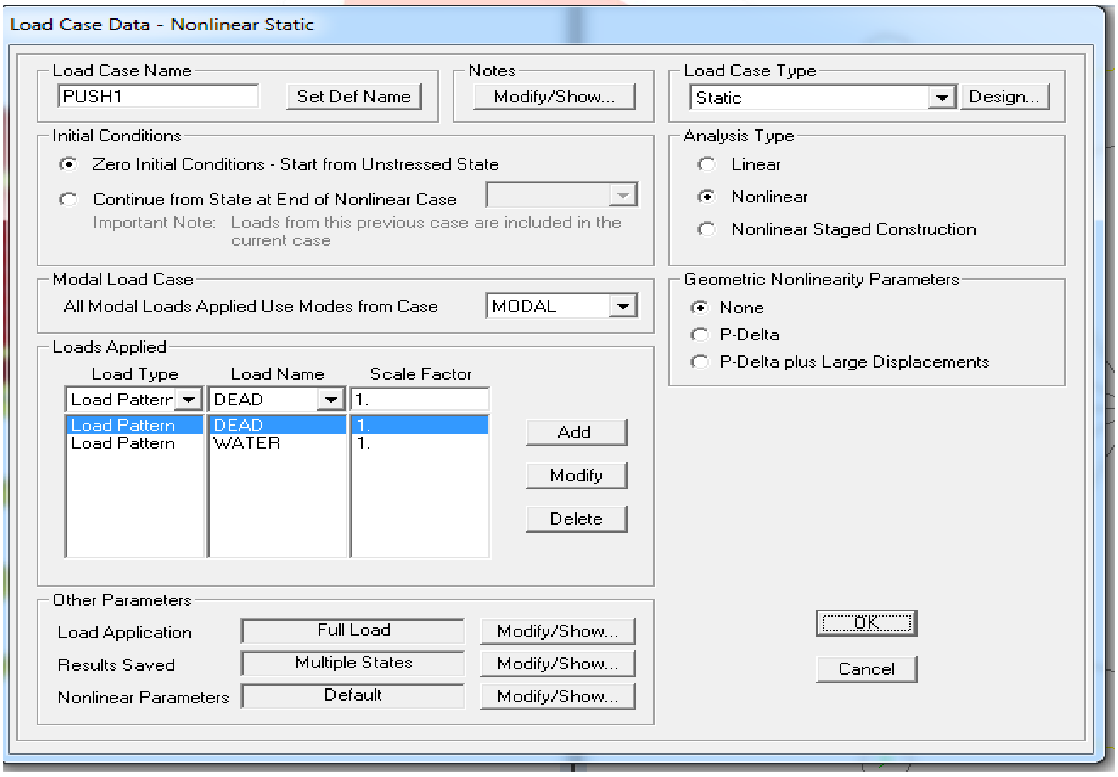
6. Display the pushover curve. The File menu shown in this display window allows you to view and if desired, print to either a printer or an ASCII file, a table which gives the coordinates of each step of the pushover curve and summarizes the number of hinges in each state.

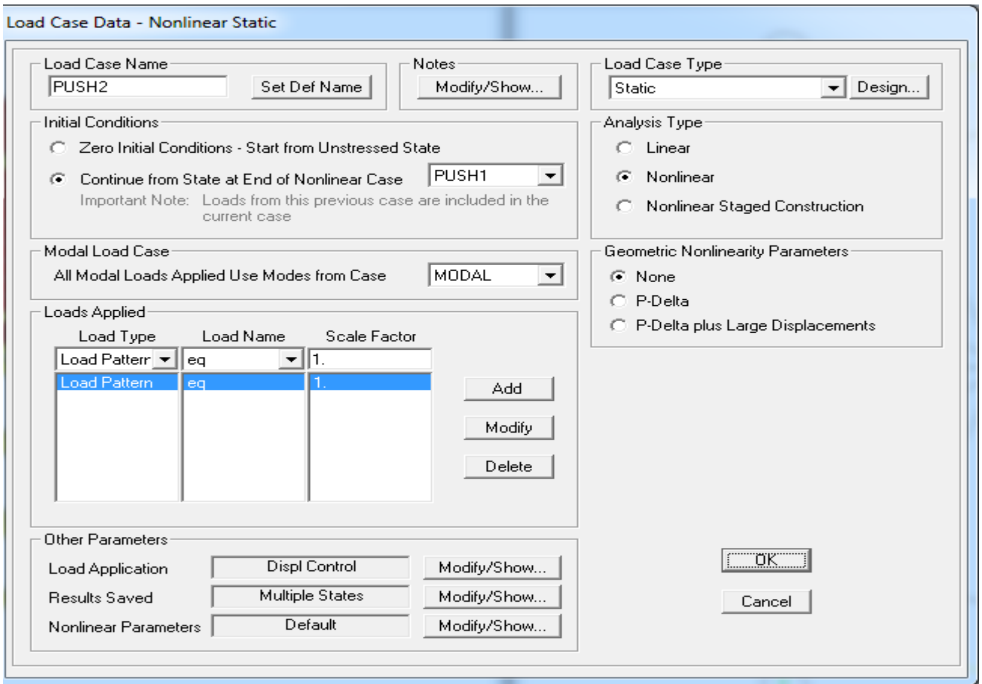
7. Display the capacity spectrum curve. Note that you can interactively modify the magnitude of the

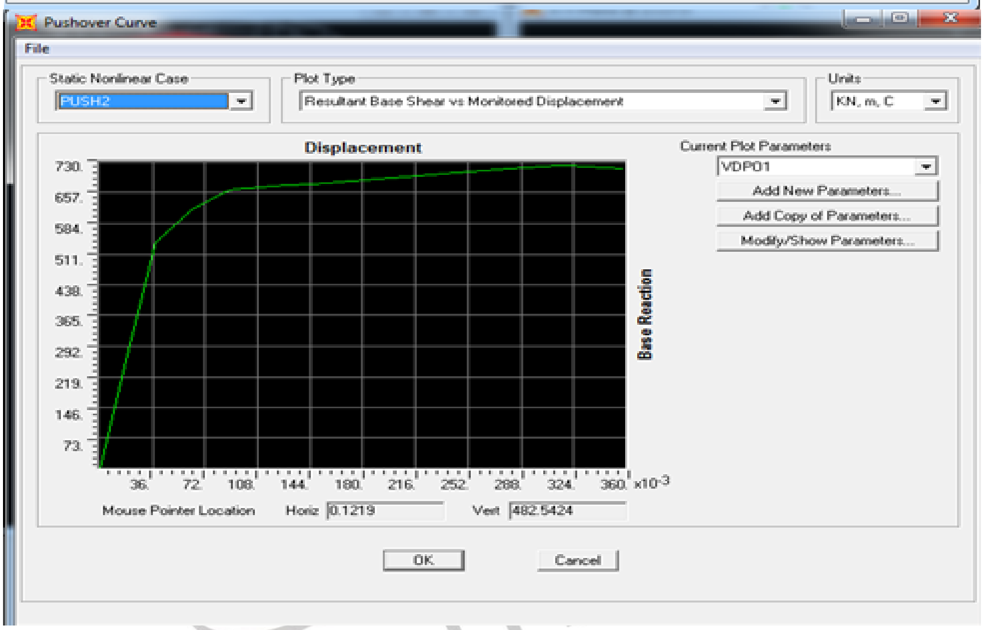
earthquake and the damping information on this form and immediately see the new capacity spectrum plot. The performance point for a given set of values is defined by the intersection of the capacity curve (green) and the single demand spectrum curve (yellow). Also, the file menu in this display allows you to print the coordinates of the capacity curve and the demand curve as well as other information used to convert the pushover curve to Acceleration-Displacement Response Spectrum format.

8. Review the pushover displaced shape and sequence of hinge formation on a step-by step basis. The arrows in the bottom right-hand corner of the screen allow you to move through the pushover step-by- step. Hinges appear when they yield and are color coded based on their state

9. Review member forces on a step-by-step basis. Often it is useful to view the model in two side-by-side windows with the step-by-step displaced shape in one window and the step-by-step member forces in the other. These windows can be synchronized to the same step, and can thus greatly enhance the understanding of the pushover results.







For 250m3 water tank:

Table below shows the Results of R factor, Time Period, Base Shear, Ductility Factor, Redundancy Factor, over strength Factor and R factor for 12m height, zone 4 for full and empty both condition:

Tank Type:Intz Tank	Column Size:650mm Dia	
Staging Type6 Col Circular	Zone IV	
Staging Height 12m	Full	Empty
Time Period	1.46	0.58
Base Shear	401	369.25
Ductility Factor	2.23	2.29
Redundancy Factor	0.86	0.86
Over strength Factor	1.827	1.28
R	3.51	2.52

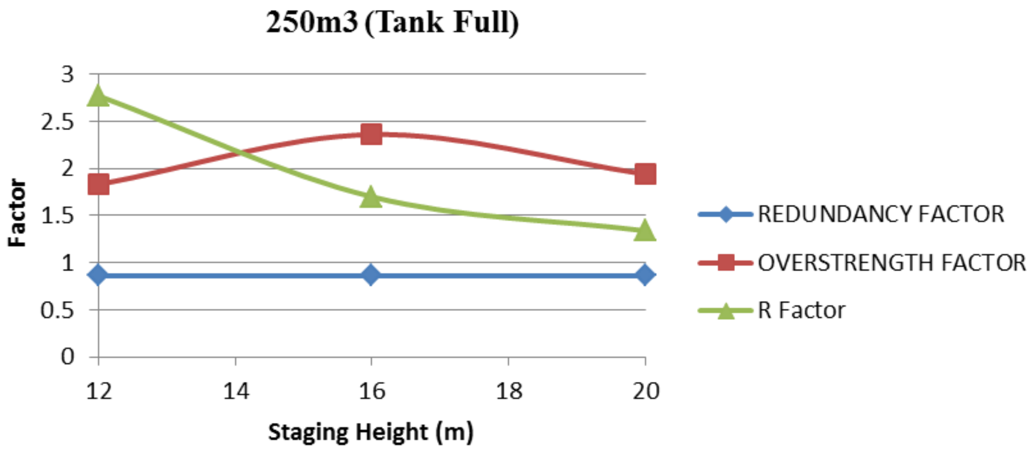
Table below shows the Results of R factor, Time Period, Base Shear, Ductility Factor, Redundancy Factor, over strength Factor and R factor for 16m height, zone 4 for full and empty both condition:

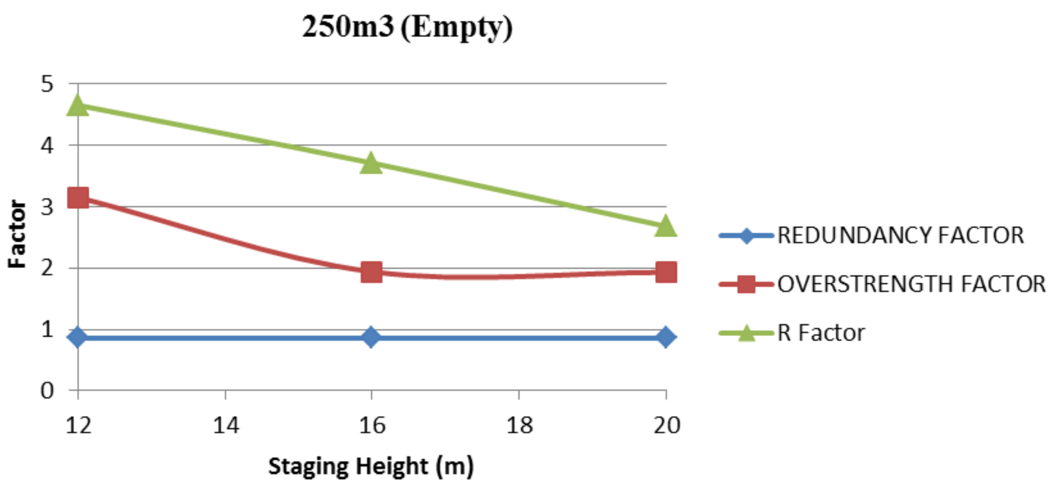
Tank Type:Intz Tank	Column Size:650mm Dia	
Staging Type6 Col Circular	Zone IV	
Staging Height 16m	Full	Empty
Time Period	1.68	0.82
Base Shear	356.17	298
Ductility Factor	1.11	2.54
Redundancy Factor	0.86	0.86
Overstrength Factor	1.92	1.89
R	1.83	4.13

Table below shows the Results of R factor, Time Period, Base Shear, Ductility Factor, Redundancy Factor, over strength Factor and R factor for 20m height, zone 4 for full and empty both condition:

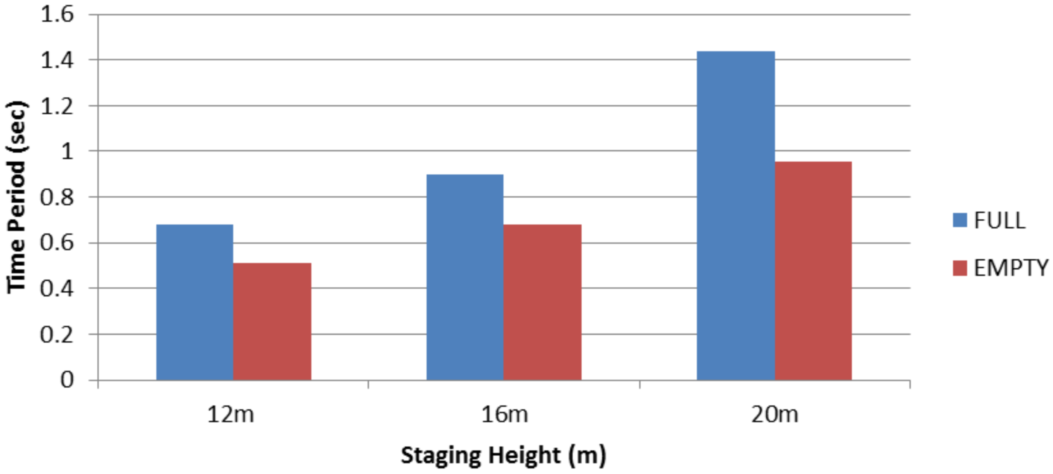
Tank Type:Intz Tank	Column Size:650mm Dia	
Staging Type6 Col Circular	Zone IV	
Staging Height 20m	Full	Empty
Time Period	2.015	1.05
Base Shear	304.5	237
Ductility Factor	1.49	1.83
Redundancy Factor	0.86	0.86
Overstrength Factor	1.45	1.91
R	1.87	3.01

Graph shows the comparison of staging height with three factors redundancy, ductility, and over strength. Results are taken for 250m3 full and empty condition. Results shows that R factor decrease with increase in staging height. Redundancy depends upon number of vertical framing, so Redundancy factor is remaining same for all height. Over strength factor is decreasing by increasing staging height. It shows that reserve strength of tank is decreasing by increasing height.

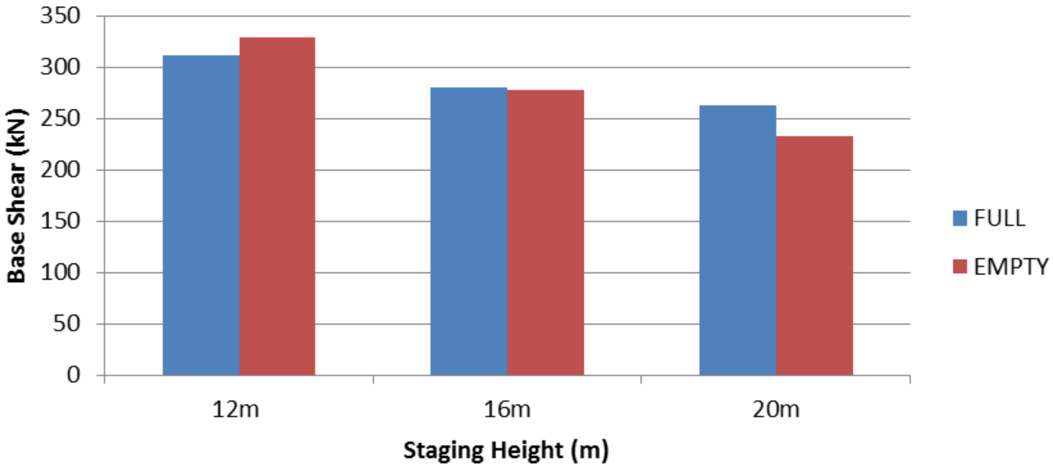




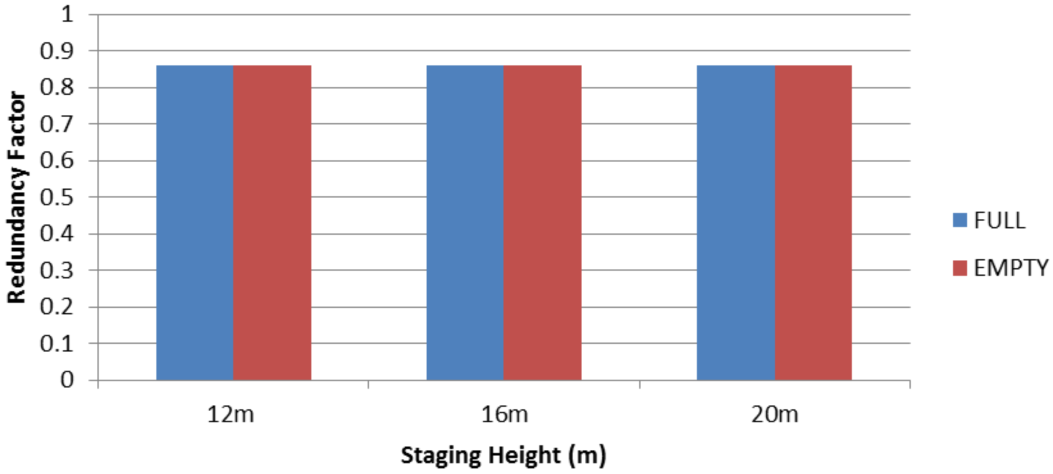
This graph shows the comparison of staging height to time period. This graph shows the comparison of staging height to time period. Graph shows that by increasing staging height time period will increase for full and empty condition of 250m 3 water tanks.



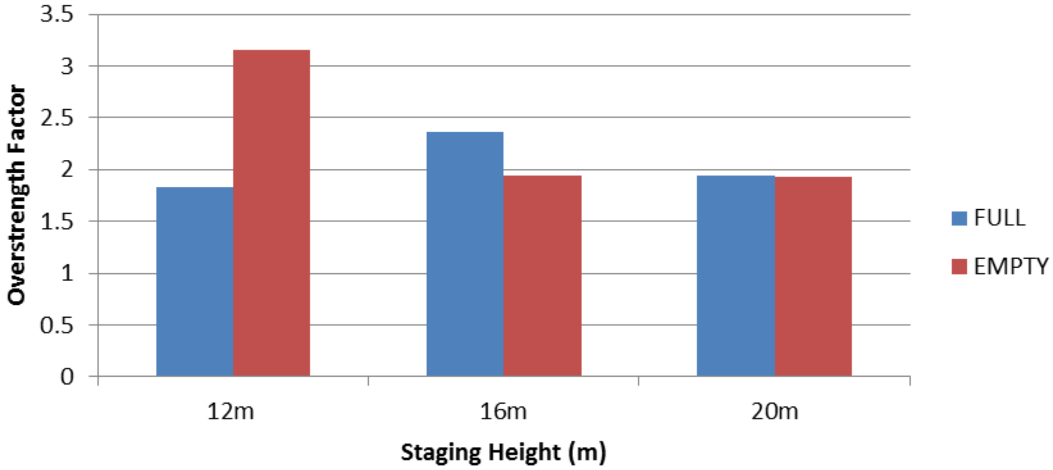
This graph shows the comparison of staging height to base shear. Graph shows that by increasing staging height base shear will decreasing for full and empty condition of 250m3 water tank.



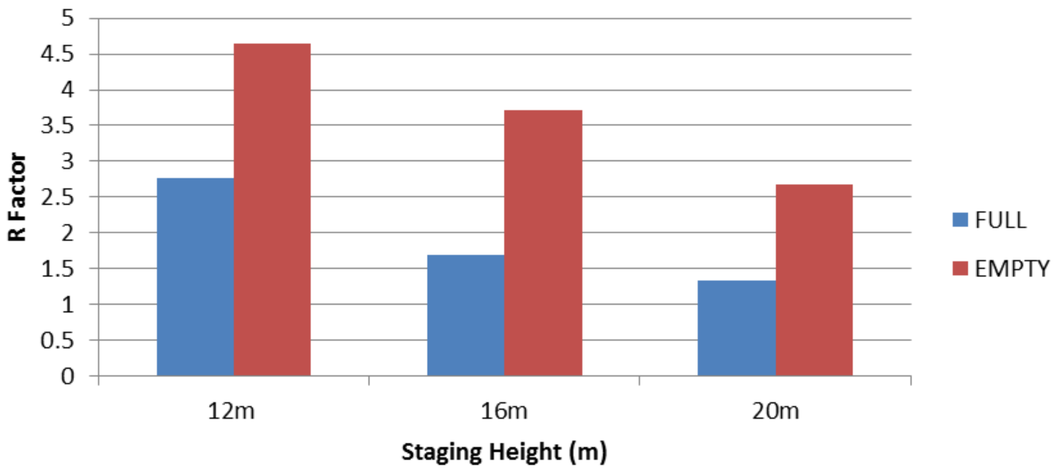
This graph shows the comparison of staging height to Redundancy factor. Graph shows that by increasing staging height Redundancy factor will same for full and empty condition of 250m3 water tank.



This graph shows the comparison of staging height to over strength factor. Graph shows that by increasing staging height over strength factor will decrease for full and empty condition of 250m3 water tank.



This graph shows the comparison of staging height to R factor. Graph shows that by increasing staging height R factor will decrease for full and empty condition of 250m3 water tank.



For 500m3 water tank:

Table below shows the Results of R factor, Time Period, Base Shear, Ductility Factor, Redundancy Factor, over strength Factor and R factor for 12m height, zone 4 for full and empty both condition:

Tank Type:Intz Tank	Column Size:650mm Dia	
Staging Type6 Col Circular	Zone IV	
Staging Height 12m	Full	Empty
Time Period	1.46	0.58
Base Shear	401	369.25
Ductility Factor	2.23	2.29
Redundancy Factor	0.86	0.86
Over strength Factor	1.827	1.28
R	3.51	2.52

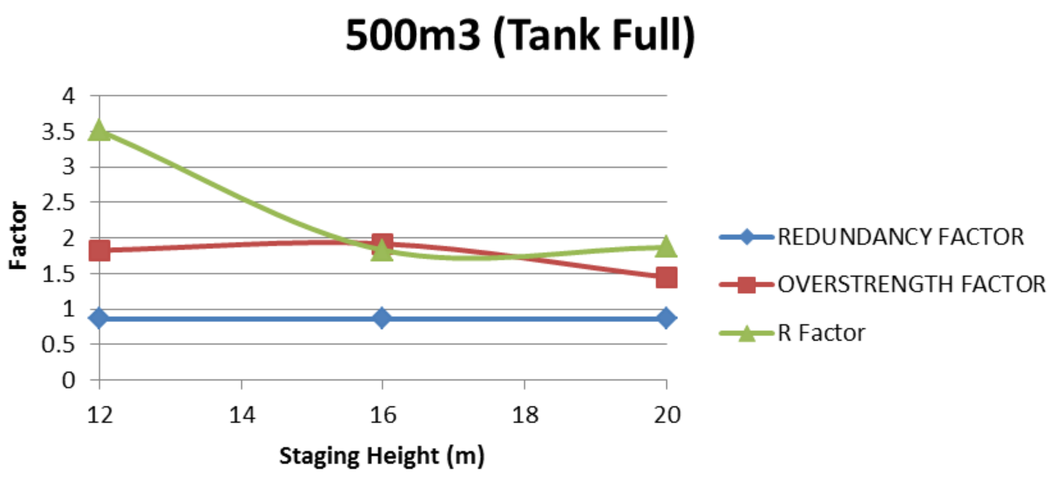
Table below shows the Results of R factor, Time Period, Base Shear, Ductility Factor, Redundancy Factor, over strength Factor and R factor for 16m height, zone 4 for full and empty both condition:

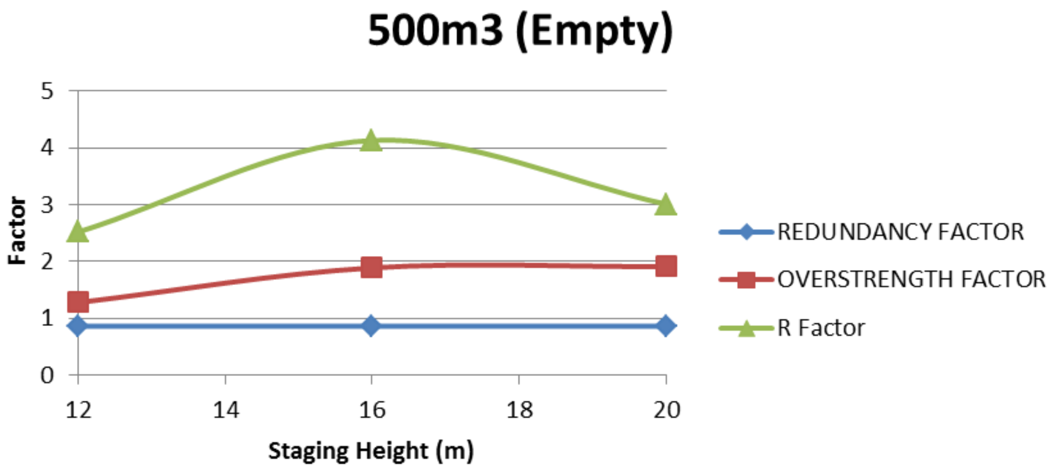
Tank Type:Intz Tank	Column Size:650mm Dia	
Staging Type6 Col Circular	Zone IV	
Staging Height 16m	Full	Empty
Time Period	1.68	0.82
Base Shear	356.17	298
Ductility Factor	1.11	2.54
Redundancy Factor	0.86	0.86
Overstrength Factor	1.92	1.89
R	1.83	4.13

Table below shows the Results of R factor, Time Period, Base Shear, Ductility Factor, Redundancy Factor, over strength Factor and R factor for 20m height, zone 4 for full and empty both condition

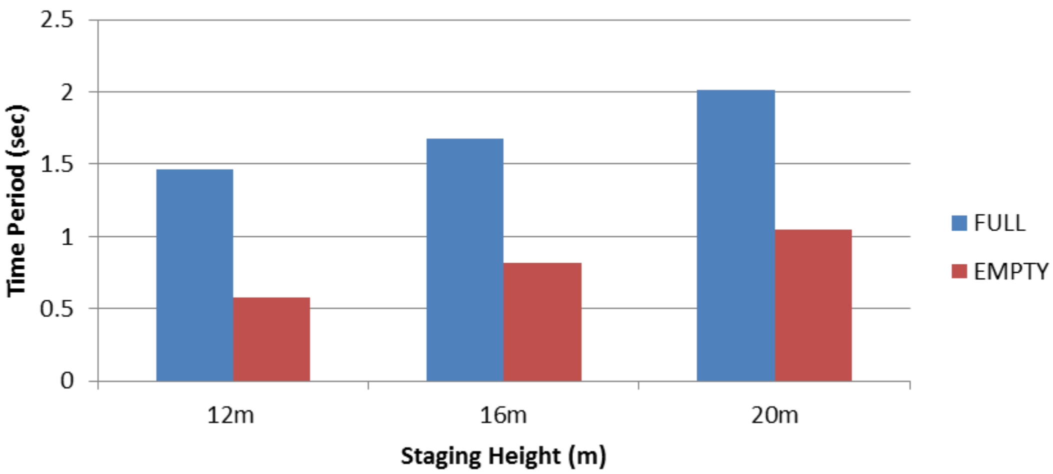
Tank Type:Intz Tank	Column Size:650mm Dia	
Staging Type6 Col Circular	Zone IV	
Staging Height 20m	Full	Empty
Time Period	2.015	1.05
Base Shear	304.5	237
Ductility Factor	1.49	1.83
Redundancy Factor	0.86	0.86
Overstrength Factor	1.45	1.91
R	1.87	3.01

Graph shows the comparison of staging height with three factors redundancy, ductility, and over strength. Results are taken for 500m3 full and empty condition. Results shows that R factor decrease with increase in staging height. Redundancy depends upon number of vertical framing, so Redundancy factor is remaining same for all height. Over strength factor is decreasing by increasing staging height. It shows that reserve strength of tank is decreasing by increasing height.

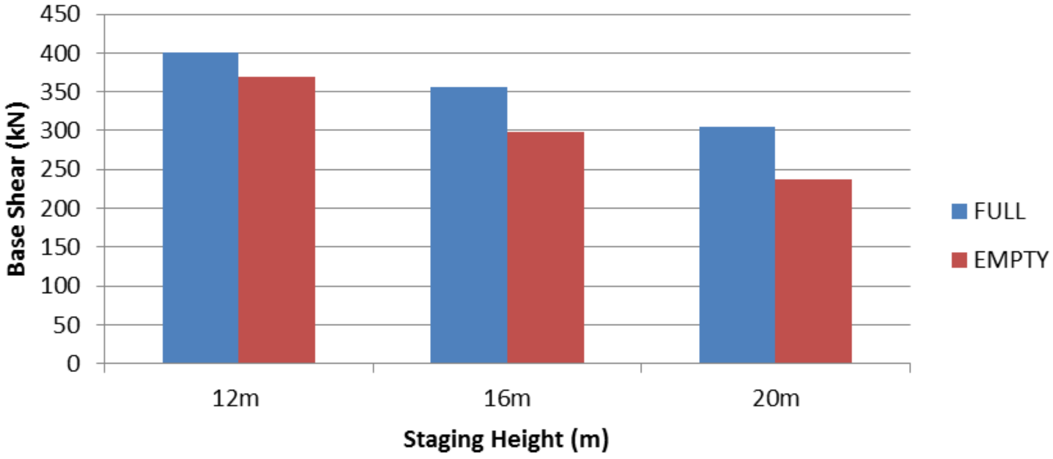




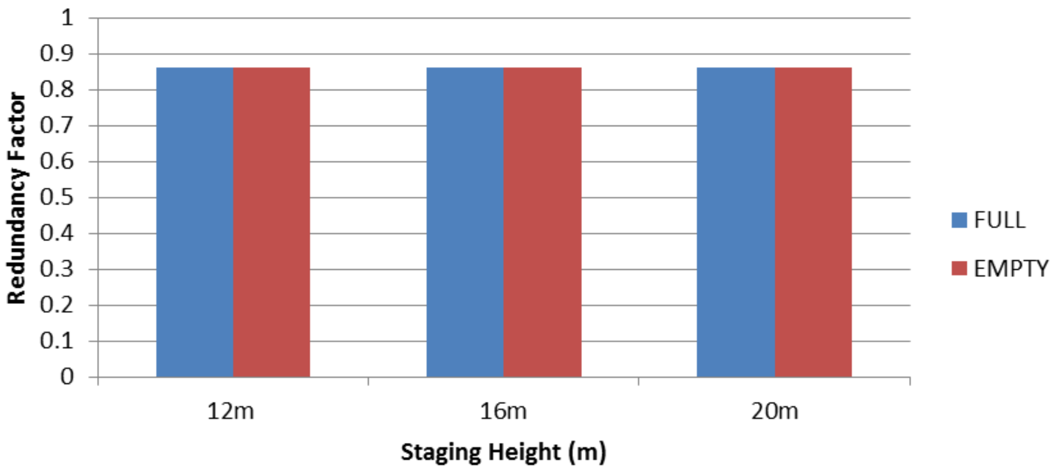
This graph given below shows the comparison of staging height to time period. Graph shows that by increasing staging height time period will increase for full and empty condition of 500m3 water tank.



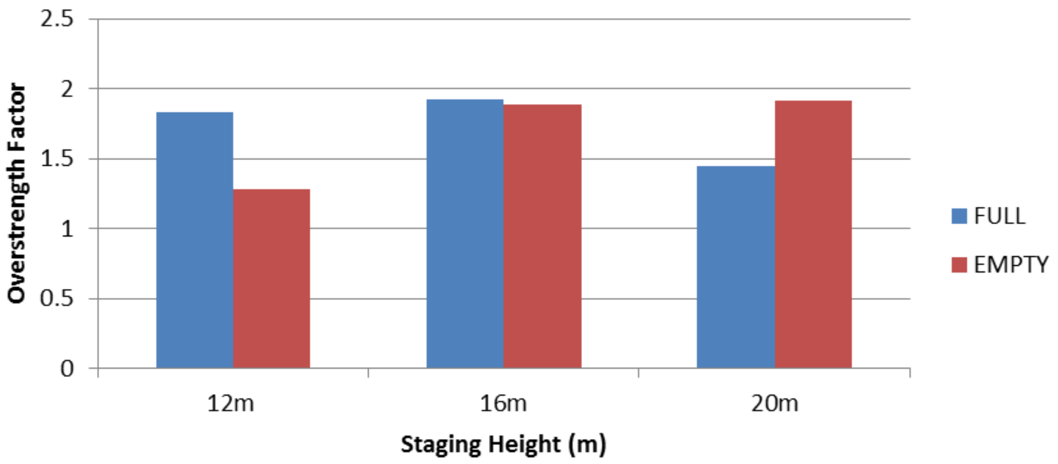
This graph given below shows the comparison of staging height to base shear. Graph shows that by increasing staging height base shear will decrease for full and empty condition of 500m3 water tank.



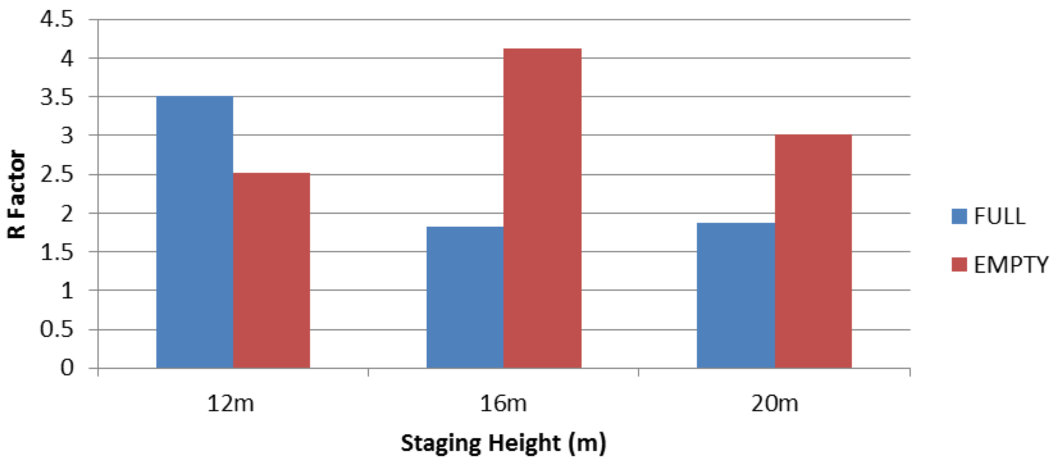
This graph given below shows the comparison of staging height to Redundancy factor. Graph shows that by increasing staging height Redundancy factor will saame for full and empty condition of 500m3 water tank.



This graph given below shows the comparison of staging height to over strength. Graph shows that by increasing staging height over strength will decreasing for full and empty condition of 500m3 water tank.



This graph given below shows the comparison of staging height to R factor. Graph shows that by increasing staging height R factor will decrease for full and empty condition of 500m3 water tank.



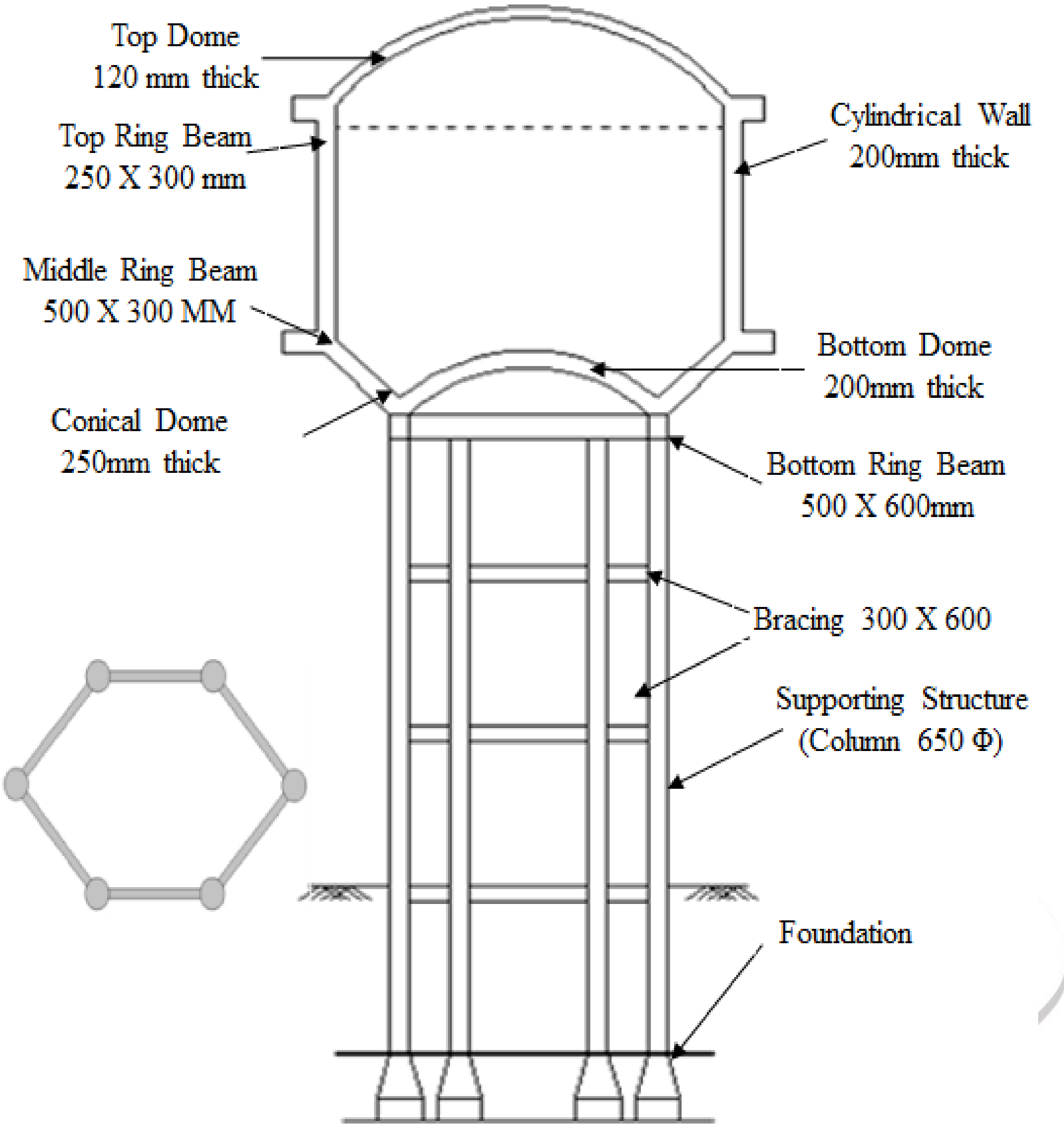
4.5 Formulation of response reduction factor:

Response reduction factor is product of three factor 1) over strength factor 2) ductility factor and 3) redundancy factor.

- **R = Rs * RR * Rμ**

For the formulation of R factor we take a 500m3(full condition) tank with 12m height, zone 4, and staging type 6 columns.

Dimensions of all members are shown in figure below:

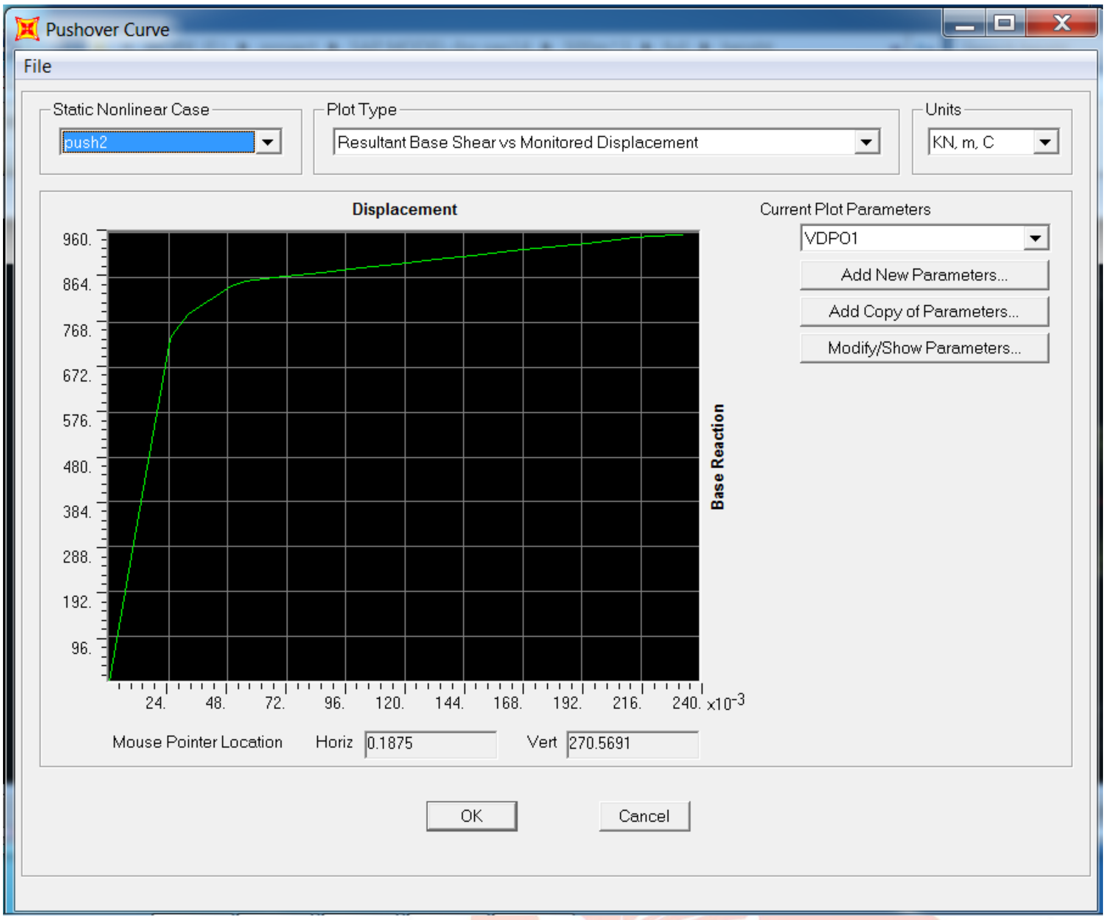


Elevated tank with all component

Static nonlinear analysis is done by using SAP with two nonlinear cases. Push 1and

Push 2. Push 1 includes dead load with full load control. Push 2 includes earthquake load with displacement control, including multiple state in both cases.

Figure shows the pushover curve for 500m3(full), 12m height of water tank, damping ratio is considered 5%.



From the pushover curve we can take yield drift (Δy) and maximum base shear (**V_o**):

Δy=0.024
Vo=733.65
Time period (t) = 1.45688
Design Base shear (as per EQ calculation) Vd = 401.5
Now, calculation for R:

Estimation of strength factor:

- Strength factor is the ratio of Maximum Base Shear (from pushover curve) VO to Design Base shear (as per EQ calculation) Vd.
- **$R_s = V_o / V_d = 1.827$**

Estimation of ductility factor:

- **R μ = {(μ - 1 / Φ) + 1}**
- **μ = Δm / Δy**
- Δm = Maximum drift capacity (0.004 H)
- Δy = Yield drift (from pushover curve)

- **Φ for rock sites: = 1+ {1 / (10T -µT)}–{(1 / 2T)*e^ (-2(ln (T) – 0.6) ^2)}**

Using this equations **R µ = 2.23**

Estimation of redundancy factor:

The value of redundancy factor as suggested in ATC-19 is summaries in Table 3.

Lines of vertical seismic framing	Drift redundancy factor
2	0.71
3	0.86
4	1

We have 3 lines of vertical framing so, RR is 0.86

- Now **R = Rs * RR * R**µ
- R=3.51

4.6 Summary:

In this chapter pushover analysis of 12m, 16m, and 20m height of water tank with 250m3 and 500m3 capacities with full and empty condition are done using SAP and R factor is calculated. Calculation of R factor of 500m3(full), 12m height is shown. Comparison of various result and its graphs are included and discussed. Effect of height on R is studied. Comparison of R with different factors is shown with graph and discussed about results.