Analytical Investigation of Response Reduction Factor (R) for R.C. Elevated Water Tank with Non-linear Static (Pushover) Analysis

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ABSTRACT

In the present work, an attempt is made to investigate response reduction factor (R) values of different soil types by using nonlinear static (Pushover) analysis for R.C. elevated rectangular water tank structure. All the parameters were investigated by varying properties of soft, medium and hard soils to cover a method of nonlinear static (Pushover) analysis. The zone factor (Z) kept constant Z – III for pandharpur site location and capacity of 150 m3 tank full in condition. This has resulted into SAP 2000 finite element software. The analysis of response reduction factor (R) value was done under three different soil conditions i.e. soft soil properties, medium soil properties, and hard soil properties. Response reduction factor (R) values indicate that R.C. elevated rectangular water tank structure without soil properties behaves quite the one value as per codal provisions.

Keywords: Response Reduction Factor (R), Non-Linear Static (Pushover) Analysis, Soil Conditions, SAP 2000, Seismic Design, R.C. Elevated Rectangular Water Tank.

1 Introduction

Elevated water tanks are commonly used in public water distribution system. Elevated water tanks structure also called as elevated service reservoirs (ESRs). Aim of the present study is to bring out the differences in response reduction factor (R) of column beam (staging) frame and variation of soil types frame in the post-elastic region and to quantify their ductility. In addition, nonlinear static analysis is also performed to bring out the differences in the response reduction factor (R) behavior of with types of soils There is only one value as 2.5 of response reduction factor (R) in Indian standard (IS) code for elevated water tank structure.

2 Purpose of Pushover Analysis

The realistic force demands on potentially brittle elements, such as axial force demands on columns, moment demands on beam to column connections, shear force demands in reinforced concrete beams, etc. Pushover Analysis option will allow engineers to perform pushover analysis as per FEMA-356 and ATC-40. Pushover analysis is a static, nonlinear procedure using simplified nonlinear technique to estimate seismic structural deformations.

3 Soil Structure Interaction

The soil structure interaction deals with interrelation with the structure and the soil respectively. The soil flexibility can be taken in this analysis and the three different soil types are used in this analysis to perform the nonlinear static (Pushover) analysis. We can use SAP 2000 finite element software to perform the analysis of RC elevated rectangular water tank structure. Soft soil of large fine particles such as silty, clayey

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soil located near or under water table. Medium soil of little fine particles such as mixture clay, silt, and humus located plants roots. Hard soil of many fine particles such as clay located near plant roots water logged areas.

4 Problem Definition

In the present case study elevated water tank is designed for Laxmi Township at Pandharpur. In the present work, efforts are made to calculate the response reduction factor (R) values for elevated water tank structure of different soil types. With the help of SAP 2000 software, displacement controlled non-linear pushover analysis is carried out to evaluate the base shear (V) of water tank. It is observed that the value of Response reduction factor (R) is affected by seismic zones, soil type, and time period (T) of the water tank. Three different types of soil conditions representatives of hard soil, medium soil and soft soil has been considered in this study.

5 Design and Description R.C. Elevated Rectangular Water tank: -

RC elevated rectangular water tank G+4 type frame designed using IS 456- 2000 concrete code. Frame type OMRF, Capacity: - 150 m3 (150000 lit.), Zone: - III – 0.16, Soil Type: - Soft soil (III), Medium soil (II), Hard soil (I). Wall Thickness of Container: - 300 mm, Top Slab and Bottom Slab Thickness of Container: - 170 and 200 mm, Size of Beam: - 280 X 500 mm, Size of Column: - 450 X 450 mm. Height of Column and storey: - 4.0 m. Tie Beam Levels c/c: - Plinth + @ 4.0 m, Type of concrete and support Condition: - R.C.C and Fixed Support at Base, Grade of concrete: - M 30, Grade of Steel: - Fe 415 (415 N/mm2), Modulus of Elasticity of Steel: - 210000 MPA (N/mm2), Modulus of Elasticity of Concrete: - 5000√fck - 27386.127 MPA (N/mm2), Ultimate Strain in Bending: - 0.0035.

Table 1: Information of soil properties

Serial No.	Soil Type	Modulus of Elasticity (E) Kn/m2	Poisson's Ratio (μ)	Unit Weight of Soil (y) Kg/m3
1.	Soft soil	15000	0.4	16
2.	Medium Soil	35000	0.4	16
3.	Hard Soil	65000	0.3	18

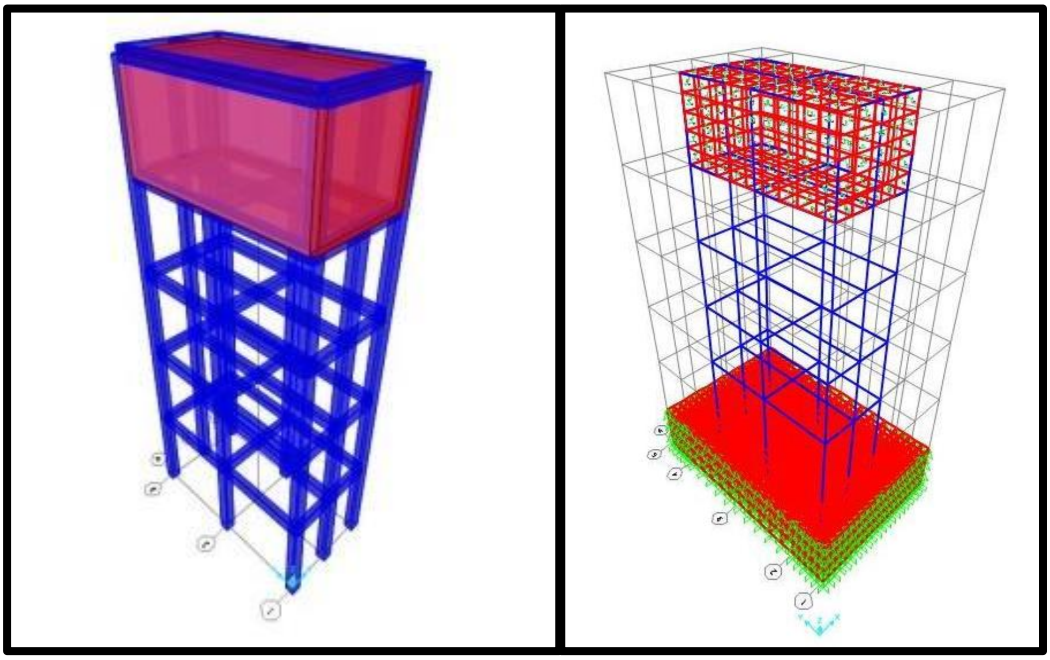

Figure 1: RC elevated rectangular water tank model in 3D and soil model.

6 Non-Linear Static (Pushover) Analysis Process Using SAP 2000 Software: -

In a nonlinear static analysis procedure, the structure model incorporates directly the nonlinear force-deformation characteristics of individual's components and elements due to inelastic material response. Create model with soil flexibility, implement loads and pushover load cases. Define properties and acceptance criteria for the pushover hinges M3 for beam; P-M2-M3 for column Locate the pushover hinges on the model by selecting one or more frame members and assigning them. Developing the pushover curve base shear (V) vs. roof displacement (δ) in soft, medium and hard soil. Plastic hinge formation as per life safety, collapse prevention etc.

7 Concept of Response Reduction Factor (R): -

The concept of response reduction factor(R) value 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 factor (R) values 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 (RR), Damping factor (Rἐ). According to ATC-19, it is described as

R = Rs x RR x Rμ x Rἐ.-------------------(1.1).

for Soft soil, medium soil and hard soil used in the pushover analysis of RC elevated rectangular water tank to find response reduction factor (R) values. Use SAP 2000 software. Here we use the defaults hinge property. When these hinge properties (default and user defined) are assigned to a frame element, the program automatically creates a new generated hinge property for each and every hinge. P-M2-M3 (PMM) hinge for column and M3 for beam. M3 and M2 uncoupled moment, axial force(P).

8 Study of Parameters Such as Lateral Displacement, Time Period, Base Shear (V): -

8.1 Time Period (T) Seconds: -

Find out the time period (T) values of the structure use SAP 2000 software. The time period (T) values, use to find response reduction factor (R) values.

Table 2: Time period (T) values in seconds for soft, medium and hard soil

Step Type	Steps Number	Time Period (T) Sec.	Time Period (T) Sec.	Time Period (T)Sec.
Text.	Unitless.	Soft soil.	Medium soil.	Hard soil.
Mode	1	0.9898	0.9495	0.9257
Mode	2	0.9281	0.8895	0.8665
Mode	3	0.7175	0.6863	0.6661
Mode	4	0.2093	0.1994	0.1932

8.2 Base Shear and Lateral Displacement: -

Base shear (V) is a one type of shear force obtained in unit of KN. It is act at the base of the structure. Lateral displacement is obtained in unit of meters. It is displacement taken by structure when lateral force acting on the structure.

Load Case	Step	Displacement	Base shear (V)
Text		m	KN
Push x	0	-0.000115	0
Push x	1	0.007185	267.252
Push x	2	0.014486	534.504
Push x	3	0.017044	628.16
Push x	4	0.023502	800.457
Push x	5	0.029393	881.686
Push x	6	0.040876	974.33
Push x	7	0.053391	1043.798
Push x	8	0.060691	1079.409
Push x	9	0.067992	1115.02
Push x	10	0.072886	1138.895

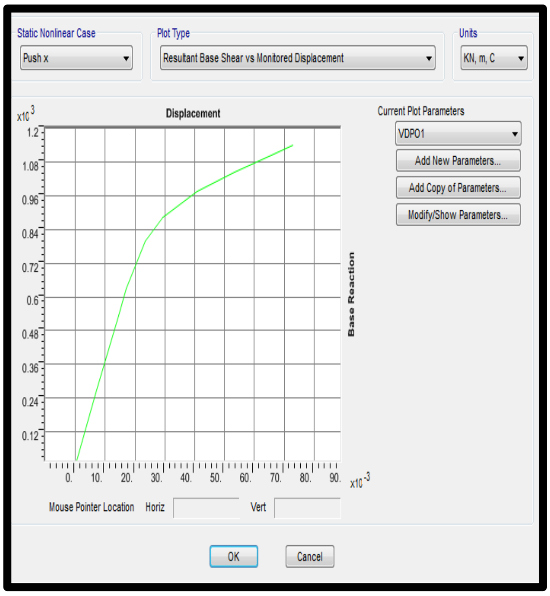

Table 3 & Figure 2: Displacement and base shear for push x in soft soil

9 Non-Linear Static (Pushover) Analysis in X-Direction for Soft Soil: -

Here soft soil condition used for the analysis of RC elevated rectangular water tank structure. Above curve gives pushover analysis in X direction to get base shear (V) in KN and displacement in meter. Use displacement modification curve to find out yield drift or yield displacement (Δy). This curve analyzed by SAP 2000software.

By using the displacement modification curve as per SAP 2000 software for Push x in soft soil. We get the result of yield drift (Δy) value for finding out response reduction factor (R) value. Yield drift Δy = 0.0235 m=23.5 mm for push x. Also, to study table for base shear (V) in KN and lateral displacement in meter.

10 Non-Linear Static (Pushover) Analysis in Y-Direction for Soft Soil: -

Here soft soil condition used for the analysis of RC elevated rectangular water tank structure. Above curve gives pushover analysis in Y direction to get base shear (V) in KN and displacement in meter.

Load Case	Step	Displacement	Base shear (V)
Text		m	KN
Push y	0	-0.000001339	0
Push y	1	0.007299	234.503
Push y	2	0.014599	469.006
Push y	3	0.020232	649.979
Push y	4	0.027469	818.595
Push y	5	0.03684	926.514
Push y	6	0.044282	988.184
Push y	7	0.057434	1067.147
Push y	8	0.064734	1105.175
Push y	9	0.072034	1143.201
Push y	10	0.072999	1148.225

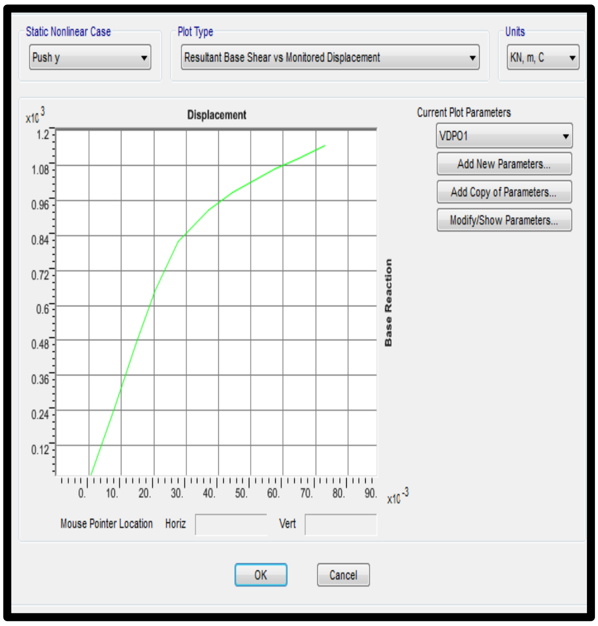

Table 4 & Figure 3: Displacement and Base shear for push y in soft soil

Use displacement modification curve to find out yield drift or yield displacement (Δy). This curve analyzed by SAP 2000 software. By using the displacement modification curve as per SAP 2000 software for Push y in soft soil. We get the result of yield drift (Δy) value for finding out response reduction factor (R) value. Yield drift Δy =0.02746 m = 27.46 mm for push y. Also, to study table for base shear (V) in KN and lateral displacement in meter. From the tables we study that our target displacement is 0.073m = 73 mm achieved. Curve represents the pushover analysis of structure.

11 Establish the Response Reduction Factor Values (R) of RC Elevated Rectangular Water Tank for Different Soil Types: -

The response reduction factor (R) value of RC rectangular elevated water tank structure for soft soil type. As per maximum condition we take values of push y curve for estimation of response reduction factor (R)value. Estimation of over strength factor (Rs): -

Rs = Vo/Vd---(1.2).

Vo - Maximum base shear value from soft soil pushover curve = 818.595 KN.

Vd - Design Base shear (as per EQ calculation) = 257.51 KN.

Rs = 818. 595 / 257. 51 = 3.178.

Rs= 3.178--(1.3).

Estimation of ductility factor(Rμ): -

Rμ = {(μ – 1 / Φ) +1} --(1.4).

Maximum drift capacity Δm (0.004H) = 0.004 x 18.4 = 0.0736m = 73.6 mm. Yield drift Δy (from pushover curve) = 0.02746 = 27.46 mm.

μ = Δm / Δy = 73.6 / 27.46 = 2.68. Rμ = {(μ – 1 / Φ) + 1}.

Φ for soft soil as Tg predominant period of ground motion. We can take T from software model and Tg = 1.25 sec. as per Professor Helmut krawinkler Stanford university California. T = 0.7175 sec. time period from software model table.

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Φ = 1 + {Tg/3T} – {(3Tg/4T) x e^– 3(ln (T/Tg) – 0.25) ^2}. Φ=1+{1.25/3x0.7175} – {(3x1.25/4x0.7175) x e^– 3(ln (0.7175/1.25) – 0.25) ^2}. Φ = 1+ 0.5807 – {1.3066 x 0.1430} = 1+ 0.5807 – 0.1868 = 1.3939. Rμ = {(2.68 – 1 / 1.3939) + 1} = 1.205.

Estimation of redundancy factor (RR): - Lines of vertical seismic framing for RC elevated rectangular water tank structure for principle Y direction is three (3) from table of redundancy factor in ATC-19 that we get RR=0.86----------------------------(1.5).

Estimation of damping factor (Rἐ) is usually assigned a value equal to 1.0 for 5% viscous damping. Rἐ=1.0---(1.6).

Response reduction factor (R) value find out by using the following equation of all factor of RC elevated rectangular water tank.

R = RS x RRx Rμx Rἐ--(1.7).

R = 3.178 x 1.205 x 0.86 x 1.0 = 3.29.

R = 3.29. (Soft soil) ---(1.8).

Follow the same process as above for the medium and hard soil by using the equations of it. For Medium soil T = 0.6863 second. For hard soil T = 0.6661 second. This time period (T) values takes place from above table no 2.

Φ = 1+ {1 / (12T –μT)} – {(2 / 5T) x e^ – 2(ln (T) –0.2) ^2} …… Medium soil.

Φ = 1+ {1 / (10T– μT)} – {(1 / 2T) x e^ – 1.5(ln (T) –0.6) ^2} …. Hard soil.

From above to find out response reduction factor (R) values for soil conditions. These response reduction factor (R) values indicate there is not any one value to use for all soil conditions.

Table 5: *Response reduction factor (R) values and soil type*

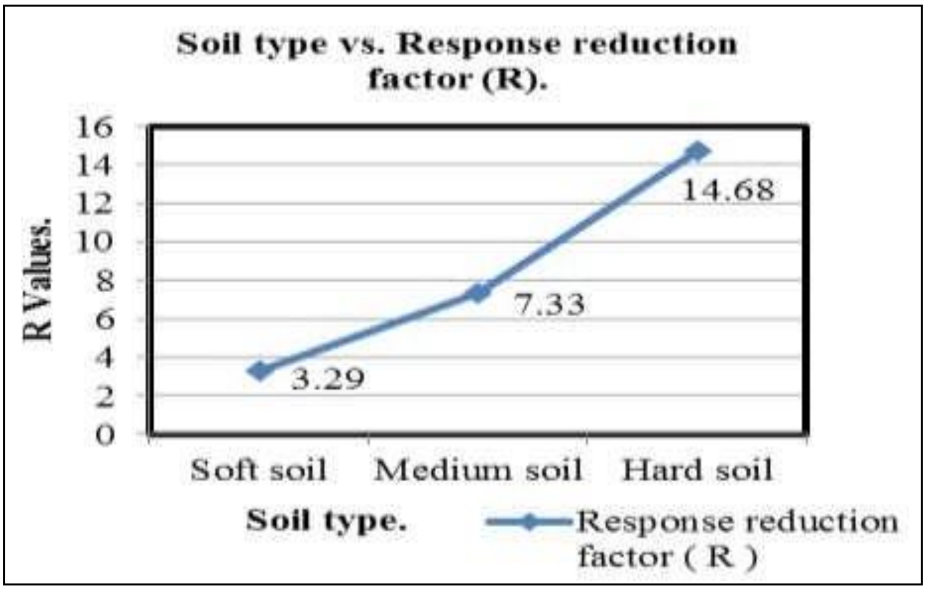
Text Type	Soil type (Tank full 150m3)		
	Soft soil	Medium soil	Hard soil
Zone	III	III	III
Time period	0.7175	0.6863	0.6661
Over strength factor (Rs)	3.178	4.005	6.087
Ductility factor (Rμ)	1.205	2.130	2.806
Redundancy factor (RR)	0.86	0.86	0.86
Damping factor (Rἐ)	1.0	1.0	1.0
Response Reduction factor (R) values	3.29	7.33	14.68

12 Comparison of the Response Reduction Factor (R) Values for RC Elevated Rectangular Water Tank Structure: -

In This Study the Validation of Results with Codal Provisions. Below Table Gives Comparison of Analyzed Response Reduction Factor (R) Values with The Codal Provision of Response Reduction Factor (R) Values.

Table 6: Comparison of response reduction factor (R) value with codal provision.

Serial no.	Text.	Structure frame type.	Response reduction factor values. (R).
1.	IS 1893 part 2 - 2002 / 2014.	OMRF frame type.	2.5.
2.	IBC 2000/ FEMA368.	OMRF frame type	1.5 - 3.0.
3.	ACI 350.3.	OMRF frame type.	2.0 - 4.75.
4.	ATC 19.	OMRF space frame type.	2.0 - 4.0.
5.	AWWA D110.	OMRF elevated frame type water tank.	2.0 - 2.75
6.	Soft soil.	OMRF elevated frame type water tank.	3.29.
7.	Medium soil.	OMRF.	7.33.
8.	Hard soil.	OMRF.	14.68.



Graph 1: *Soil type vs. Response reduction Factor (R) values*

13 Conclusion

- In case of RC elevated rectangular water tank structure there is significant difference between Response reduction factors (R) and IS code, other codal values. It varies from 3.29 to 14.68 for tank full condition in seismic zone III and for soft, medium, hard soil. There is no mathematical basis for the response reduction (R) factor tabulated in the Indian design codes. A single value of response reduction factor (R) for all the structure of a given framing type, irrespective of plan and vertical geometry cannot be justified. The percentage variation in the value of Response reduction factor (R) in the Y- direction for soft and medium is 55.11%. For medium and hard soil is 50.06 %. From the IS code 1893-2014 part 2 the values of response reduction factor (R) values are 2.5. So that us calculate values of response reduction factor (R) is proper and suitable.

- An accurate estimation of the fundamental time period is necessary for estimating a realistic response reduction factor (R) value for a structure. The conditions of the present study are limited by the facts that only a single plan configuration in one single seismic zone has been considered. The response reduction factor (R) values are increases while time period is decreases for fixed base and maximum time period achieved in the soft soil. So, it can observe that avoidance of soil flexibility effect might lead to mistaken and poor results of RC elevated rectangular water tank structure.
- Future scope: - For The investigation of response reduction factor (R) values, these results have to be quantified with Vulnerability assessment of RC elevated rectangular water tank structure using artificial soils data and analytical investigation.

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