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Evaluation of Response Reduction Factor of an Elevated Water Tank Using Pushover Analysis for Different Soil Types

Sumukha R A[1], Rajalaxmi M Megadi[2]

[1] *PG Student, M.Tech in CADS, Department of Civil Engineering, SDM College of Engineering & Technology, Dharwad, sumukhajois@gmail.com*

[2] *Assistant Professor, Department of Civil Engineering, SDM College of Engineering & Technology, Dharwad, Rajalaxmi.megadi85@gmail.com*

Abstract

Earthquake ground motions are one of the most dangerous natural hazards due to which there is heavy economic and life loss. Most of the losses are due to collapse of buildings, bridges, liquid retaining structures etc. Elevated water tanks are vital structures in water supply systems. Their protection presentation is an important task during strong earthquakes. Response reduction factor ('R' factor) is defined as the factor by which the actual base shear force should be reduced to obtain the design lateral force. In the present work, efforts are made to calculate the 'R' factor for elevated overhead water tank of 12m staging height and having different soil types (20m^3, 30m^3, 40m^3, 50m^3 and 70m^3). The influence of soil types, time period and seismic zones on response reduction factor are studied. With the help of ETABS13 software, displacement controlled non-linear pushover analysis is carried out to evaluate the base shear and ductility factor of water tank. It is observed that the value of Response reduction factor is affected by seismic zones, soil type, and ductility of tank, time period and capacity of the water tank.

Keywords- *Pushover Analysis, Soil Types, Water Tank, Response Reduction.*

I. INTRODUCTION

Earthquakes are one of the most dangerous natural hazards causing damage and collapse to livelihood and they are the result of ground shaking caused by sudden release of energy in earth's lithosphere. Due to Earthquake ground motions, there is heavy economic and life loss. Most of the losses are due to collapse of structures such as buildings, bridges, water retaining structures, etc.

Elevated water tanks are vital structures in water supply systems. Their protection presentation is an important task during strong earthquakes. They should not fail after earthquake, so that they can be used in important necessities like providing drinking water and quenching fire. Many studies focused on seismic behavior, analysis and design of water tanks, mainly on ground water tanks. Earthquake can provoke large horizontal and overturning forces in elevated water tanks. Such tanks are quite susceptible to damage during and after earthquakes due to their fundamental configuration involving large mass concentrated at top with relatively slender supporting system. When the tank is in full condition, earthquake forces more or less govern the design of these structures in zones of highly seismic activity. It is significant to ensure that the essential needs such as water supply is not damaged during earthquakes. In the severe cases, total collapse of structure shall be avoided. However, some repairable damage might be tolerable during shaking but not disturbing the functionality of the water tanks.

Response reduction factor is defined as the factor by which the actual base shear force should be reduced to obtain the design lateral force. It represents the ratio of the maximum lateral force V_B (Design seismic base shear) which would develop in a structure to the Design base shear calculated using the approximate fundamental period T_a. Base shear force is the force that would be generated at the base of the structure if the structure were to remain elastic during its response to the design basis earthquake (DBE).

II. PUSHOVER ANALYSIS

As per ATC40-1996, Pushover analysis is defined as the process of pushing horizontally with prescribed loading pattern incrementally until the structure reaches a limit state. The main purpose of pushover analysis is to compare the strength and deformation capacity with the demands at the corresponding performance level by using a static nonlinear analysis algorithm. The analysis considers geometrical non-linearity and material inelasticity as well as internal force redistribution. It is carried out under constant gravity loads and monotonically increased lateral forces, applied at the location of the masses in the structural model to simulate the inertia forces. The method is able to describe the evaluation of plastic mechanism and structural damage as a function of lateral forces since they are increased monotonically. The roof displacement is plotted with base shear to get the global capacity curve.

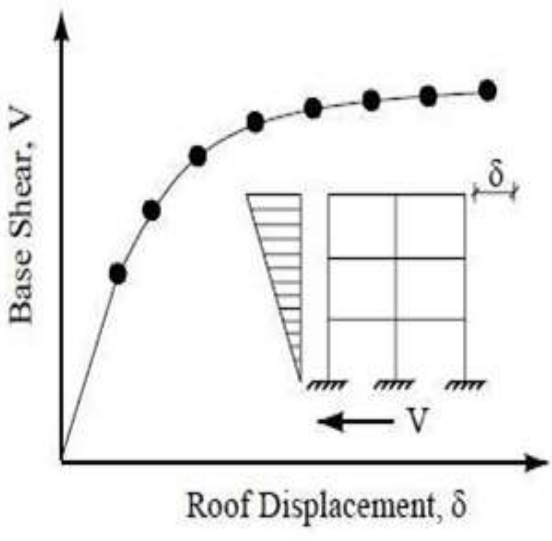

Figure 1. Global capacity (Pushover) curve of a structure

III. PROBLEM DEFINITION

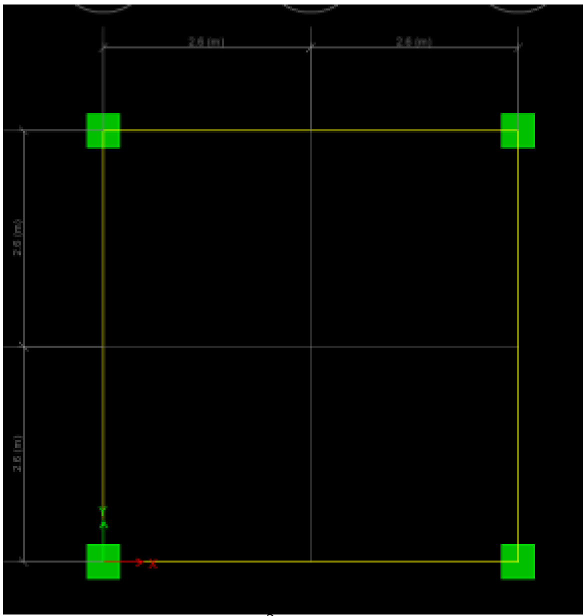

Figure 2. The plan of $70m^3$ capacity rectangular overhead water tank

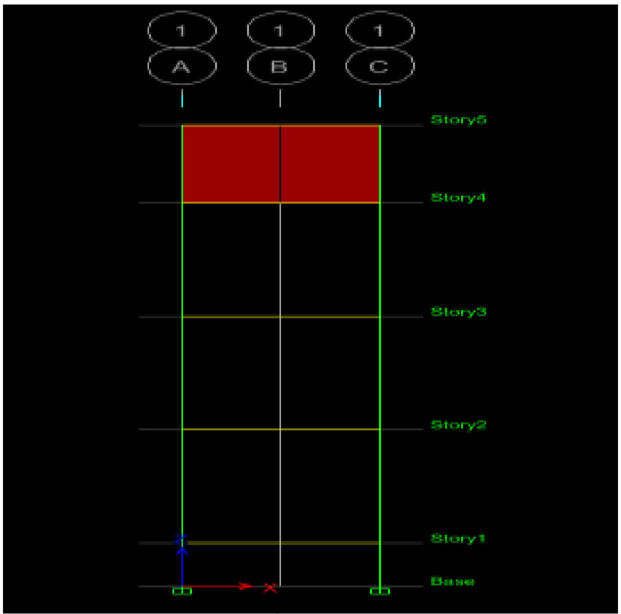

Figure 3. Elevation $70m^3$ capacity rectangular overhead water tank

Table 1: Description of rectangular overhead water tank for seismic analysis

Capacity	$20m^3$	$30\ m^3$	$40\ m^3$	$50\ m^3$	$70\ m^3$
Seismic Zone	III	III	III	III	III
length and width of Container	3.8	4	5	5	5.2
Height of container(m)	2.73	2.58	2.22	3	3.25
Wall Thickness of Container (mm)	150	150	150	150	150
Top slab Thickness of container (mm)	120	125	125	120	125
Bottom slab container thickness(mm)	200	200	200	200	200
Height of staging(m)	12	12	12	12	12
Column size(mm)	350x350	350x350	350x350	350x350	400x400
Size of Plinth beam(mm)	230x450	230x450	230x450	230x450	300x450
Size of top slab beams (mm)	230x450	230x450	230x450	230x450	230x450
Size of Bottom slab beam(mm)	300x500	300x500	300x600	300x700	300x700
No of column	4	4	4	4	4
height of column(m)	4	4	4	4	4

IV. STRUCTURAL MODELLING AND ANALYSIS

The modeling and analysis of the considered elevated over head water tank is carried out using ETABS13 software package. ETABS, which stands for Extended Three Dimensional Analysis of Building Structures, the graphical user interface is developed by computers and structures Inc., Berkeley, California, USA, which can handle most complex building models with even non-linear behaviors.

The efforts are made to study the seismic loads and behaviors on them and which is evaluated using nonlinear static pushover analysis guidelines according to ATC-40.

In the present study the values such as zone factor, Importance factor and analysis such as gravity and lateral load analysis is done as per seismic codal provisions IS 1893-2002 (part 1) are considered.
'R' value = 2.5[as per IS 1893-2002 (Part 2)] is considered.

For the present study a three dimensional model of 20m3 capacity of water tank with 2 bays along x direction and 2 bays in y direction is considered. The material for columns, beams and slab is taken to be M20 grade concrete

V. LOAD CONSIDERATION AND ANALYSIS

For static behavior purpose, the dead load of building is considered and live load as 1.25Kn/M^2. Lateral seismic load was considered confirming IS 1893(Part 1)-2002. The following parameters are been taken zone II (Z=010), zone III (Z=0.16), zone IV (Z=0.24), zone V (Z=0.36), soil type is medium (Type II), Importance factor (I = 1), Response reduction factor (R=2.5) as per IS1893 is taken and the time period (T) is program calculated. Apply gravity loads water pressure and live loads to the structure. After assigning the loads set model to gravity analysis.

After gravity analysis assign hinge properties to the beams and columns. For beams and braces default hinges upon flexure (M3) is assigned. For column default hinges up on interaction of the axial force and bending moment (P-M2-M3) is assigned. After assigning the hinge properties the static pushover cases are defined. Typically after the application of gravity loads the pushover cases are specified. Basically structure was loaded with dead load and 25% of live loads. Here gravity load application was force controlled whereas lateral load displacement is controlled.

The procedure involves pushing the structures using load patterns to the displacement larger than those associated with target displacement with the help of pushover analysis. The final output is the graph of base shear v/s monitored displacement curve.

VI. RESULTS AND DISCUSSIONS

Pushover curves for 20m^3, 30m^3, 40m^3, and 50m3 and 70m^3 for different soil types

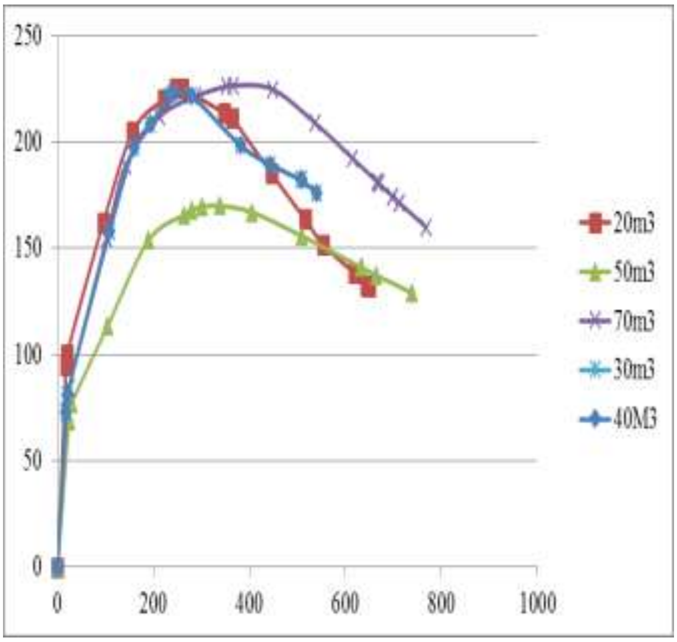

Figure 4: Pushover curves: - graph of base shear v/s monitored displacement for soil type I

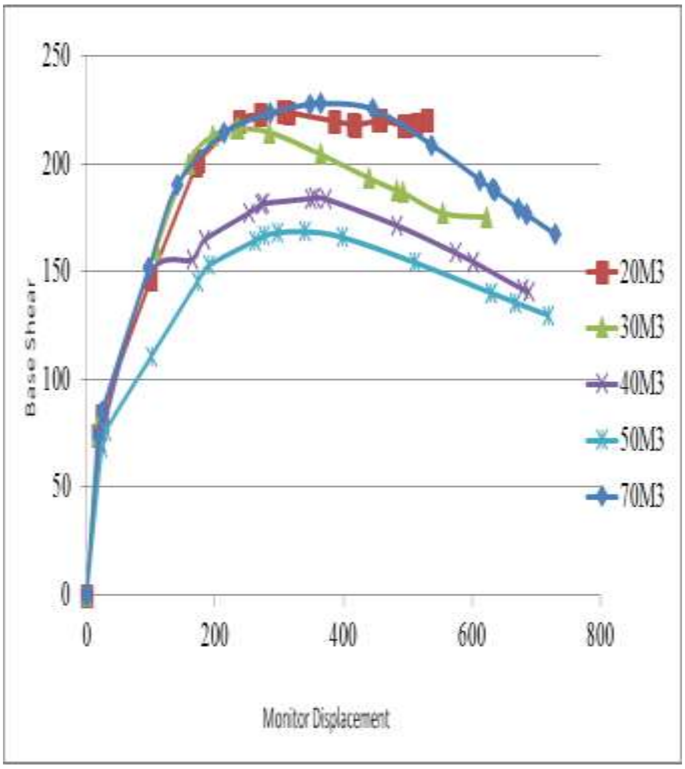

Figure 5: Pushover curves:- graph of base shear v/s monitored displacement for soil type II

A.Calculation of R Factor for 70m^3 Capacity

Estimation of strength factor [for soil type I]:

Maximum Base Shear (from pushover curve) Vo=225.3

Design Base shear (as per EQ calculation) Vd =139.71

Using equation for strength factor, given in ATC – 19 **Rs = Vo / Vd** =226.6/139.71

Rs =1.63

Estimation of ductility factor

Maximum drift capacity Δm =61mm (0.004 H)

Yield drift Δy =23.8mm

Using equation for displacement ductility ratio, given in ATC-19 [1]

μ = Δm / Δy =61/23.8=3.08

Using equation for ductility factor, derived by Miranda and Bertero

R μ = {(μ - 1 / Φ) + 1}

Φ for medium soil = **1+{1 /(10T -μT)}–{(1 / 2T)*e-1.5(ln(T) – 0.6)^2}**

T =1.92 seconds (From ETABS model)

Φ=0.810

Rμ =2.92

Estimation of redundancy factor

R_R = 0.71 (Redundancy factor (RR) from ATC-19)

Estimation of response reduction factor R:

R= RS x Rμ x RR =1.63*2.92*0.71

R=3.37

Table 2: "R" factor of 20m^3, 30m^3, 50m^3 and 70m^3 for soil type I and soil type II

capacity	20m^3		30m^3		40m^3		50m^3		70 m^3	
ZONE	III	III	III	III	III	III	III	III	III	III
Soil type	I	II	I	II	I	II	I	II	I	II
Time period	1.4	1.672	1.486	1.595	1.81	1.858	1.522	2.22	1.92	2.25
Over strength factor (RS)	3.2	3.18	2.7	2.63	1.8	1.8	1.55	1.53	1.63	1.63
Ductility ratio (μ)	3.08	2.54	2.91	2.8	2.064	1.94	2.068	2.061	2.56	2.3
Ductility factor (Rμ)	3.66	2.77	3.46	3.11	2.341	2.04	2.388	2.1	2.92	2.36
Redundancy factor (RR)	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Response reduction factor	8.31	6.34	6.62	6.1	2.95	2.62	2.63	2.3	3.37	2.8

B.CALCULATION OF RESPONSE REDUCTION FACTOR(Soil Type II)

Maximum Base Shear (from pushover curve) Vo=228kN

Design Base shear (as per EQ calculation) V_B =139.7kN

Using equation for strength factor, given in ATC – 19 **Rs = Vo / V_B** =228/139.7

Rs =1.63

Estimation of ductility factor

Maximum drift capacity Δm =61mm (0.004 H)

Yield drift Δy =26.5mm

Using equation for displacement ductility ratio, given in ATC-19 [1]

μ = Δm / Δy =61/26.5=2.3

Using equation for ductility factor, derived by Miranda and Bertero

R μ = {(μ - 1 / Φ) + 1}

Φ for medium soil = **1+{1 /(12T -μT)}–{(2 / 5T)*e-2(ln(T) – 0.2)^2}**

T =2.25 seconds (From ETABS model)

Φ=0.960

Rμ =2.36

Estimation of redundancy factor

R_R = 0.71 (Redundancy factor (R_R) from ATC-19)

Estimation of response reduction factor R:

R= R_S x Rμ x R_R =1.63*2.36*0.71

R=2.8

The above tables compares the 'R' values with two different soil types for different capacities of tank for seismic zone III. The % variation of 'R' value for soil type I as compared to that of II for 20m^3 capacity tank is 76.2%.

Similarly,

For 30m^3 capacity tank it is 92.1%

For 40m^3 capacity tank it is 88.8%

For 50m^3 capacity tank it is 87.4%

For 70m^3 capacity tank it is 83.085%

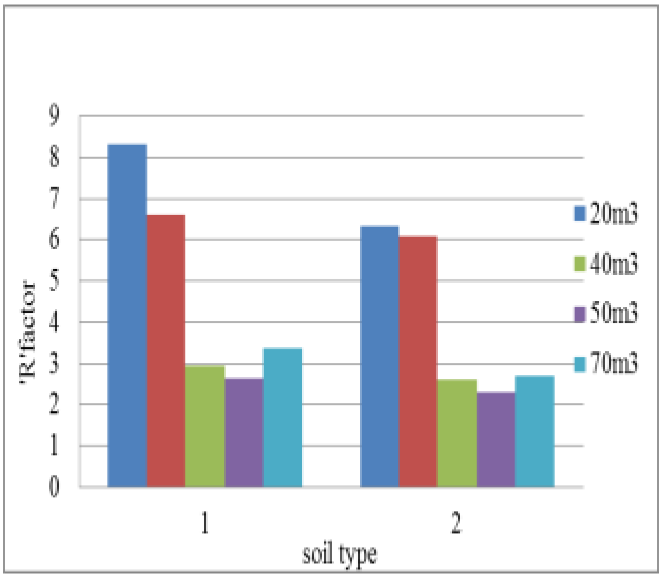

Figure 6: Bar graph of R factor v/s soil type for different capacities of water tank

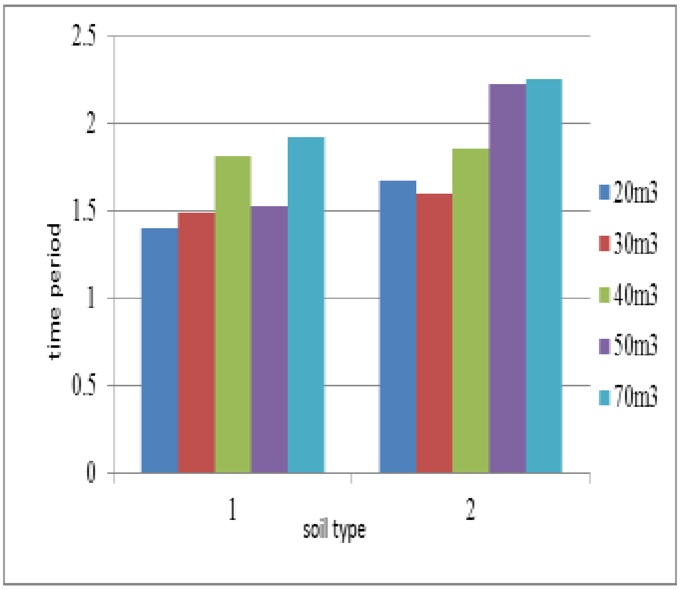

Figure 7: Bar graph of time period v/s soil type for different capacities of water tank

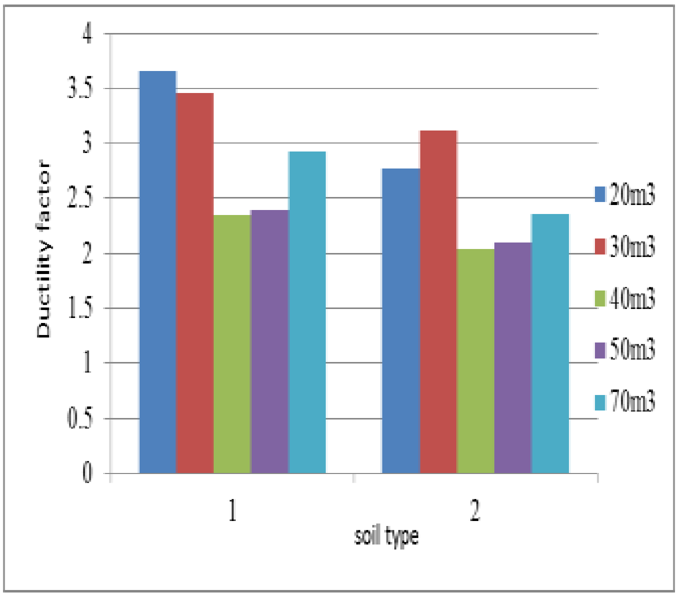

Figure 8: Bar graph of Ductility factor v/s soil type for different capacities of water tank

The above graphs from figures 6, 7 and 8 compares the 'R' values v/s soil types, time period v/s soil types and ductility factor v/s soil types respectively for different capacities of elevated overhead water tank. It is observed that the value of natural time period increases with soil type increases. The both ductility factor and 'R' factor reduces with soil type increases.

VII. CONCLUSIONS

Based on the results from pushover analysis following conclusions are arrived.

Pushover curves for different capacities elevated water tank shows the max base shear and corresponding displacement values for different seismic zones.

It is observed that Response reduction factor is directly proportional to the fundamental time period of water tank that is to say it is increase with time period.

4 The contributing factor while evaluating 'R' factor i.e. Rμ is also increases with time period.

5 It is observed from the study on soil types that the time period for soil type II is higher than that of soil type I.

6 Value of response reduction factor for soil type I is more than that of soil type II.

- The % variation of 'R' value for soil type I as compared to that of II for 20m^3 capacity elevated water tank is decreased by 76.2%. similarly
- For 30m^3 capacity elevated water tank is decreased by 92.1%
- For 40m^3 capacity elevated water tank is decreased by 88.8%
- For 50m^3 capacity elevated water tank is decreased by 87.4%
- For 70m^3 capacity elevated water tank is decreased by 83.085%

Under seismic design consideration the exact analysis of evaluation of 'R' factor will help in economical design. To know the consistent level of damage the value of R should be dependent on both type of soil and fundamental time period of staging.

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