An Investigation of Response Reduction Factor of RCC framed staging elevated water tank using Nonlinear Pushover Analysis

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Abstract*— The basic principal of earthquake resistance design of structures is that the structure should not collapse but damage to the structural elements is permitted. Water tank is very valuable structure. Staging type of tanks is generally collapse during earthquake, so it is required to calculate earthquake load properly. Past evidence had shown that the elevated tanks are susceptible. due to earthquake. The tanks are designed based on linear elastic methods which are considered only elastic range. Factor shows the reserved strength of water tank in IS 1893-2016(Part-2) value of R factor for RC elevated shaft supported tank is 2.5 and for column supported 4. One constant R-value for elevated water tank cannot reflect the expected inelastic behavior of all elevated water tanks located in different seismic zone, different soil condition, and having different height. So it is requisite to find out absolute value of R factor for various type of RC elevated tank individually. The present study efforts are made to evaluate the response reduction factor of RC framed staging elevated water tank having varying staging height, capacities, soil condition and zones. 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.

***Index Terms*— SAP2000, R-Factor, Time Period, Ductility Factor, Redundancy Factor**

I. INTRODUCTION

Water is considered as the source of every creation and is thus a very decisive element for humans to live a healthy life. High demand of clean and safe drinking water is rising day by day as one cannot 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.

1.1 Need of the study

Generally staging support system type causes over head tanks collapse in earthquake. 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 values of response reduction factor(r) of RC elevated water tank are given in is 1893 draft code, which is arrived at empirically based on engineering judgment. The value of r-factor is fixed 4 for frame 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.

1.2 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 pushover Analysis. In this study, 250 m^3 and 500 m^3 liters of water tanks are taken for the analyzing of response reduction factor.

II. CONCEPT OF RESPONSE REDUCTION FACTOR

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 (Rr). Over strength factor (Rs) accounts for the yielding of a structure at load higher than the design load due to various partial safety factors, strain hardening, oversized members, confinement of concrete. Non-structural elements also contribute to the over strength. Ductility factor (Rμ) is a ratio of ultimate displacement or code specified permissible displacement to the yield displacement. Higher ductility implies that the structure can withstand stronger shaking without collapse. Redundancy factor (Rr) depends on the number of vertical framing participate in seismic resistance. Yielding at one location in the structure does not imply yielding of the structure as a whole. Hence the load distribution, due to redundancy of the structure, provides additional safety margin.

The response reduction factor or force modification factor R reflects the capacity of structure to dissipate energy through inelastic behavior. It is a combined effect of over strength, ductility and redundancy represented as

$$\mathbf{R = R_S * R_R * R_\mu.}$$

A) R_s=Over strength factor
B) R_μ=Ductility factor
C) R_R=Redundancy factor

The key components of R – factor, reserved strength and ductility can be worked out on the basis of pushover curve as shown in fig. 1.

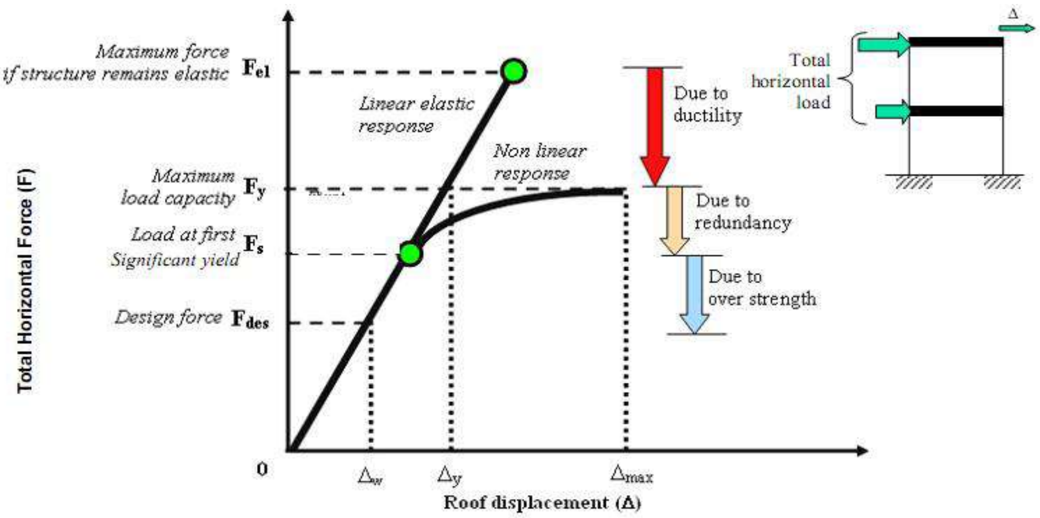


Figure 1 Concept of response reduction factor

Code	Values
IBC 2000 / FEMA 368	1.5 to 3.0
AWWA D110	2 to 2.75
ACI 350.3	2.0 to 4.75
RCC frame support IS:1893 – 2002 (Part – 2) SMRF	**2.5**
RCC frame support IS:1893 – 2014 (Part – 2) SMRF	**4**

- 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.

III. RESULTS AND DISCUSSION

In the results redundancy factor remain same for the all zones and soil conditions which is 0.86.

3.1 For 250000 litters:

- Effects of variation in heights on Over strength factor, Ductility factor and Redundancy factor for 250 m^3-zone 4.

Over strength factor		
Height	**Hard**	**medium**
12	3.164088	2.780538
14	3.936262	3.936262
16	3.737214	2.28791
18	3.142239	2.591592
20	2.889832	2.403859

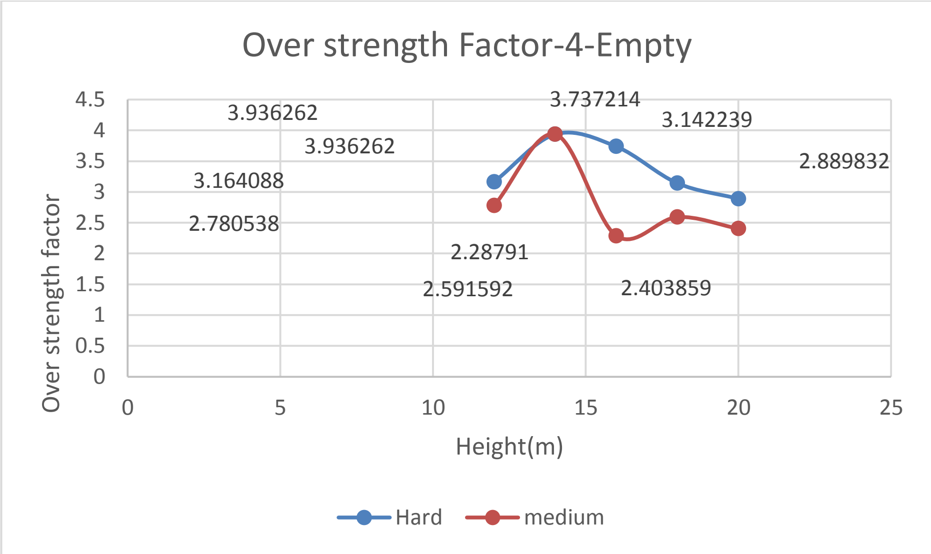
Ductility factor		
Height	**Hard**	**medium**
12	2.605097	3.18471
14	2.435998	3.130311
16	2.226161	2.067897
18	2.011656	2.048144
20	1.946504	1.950556

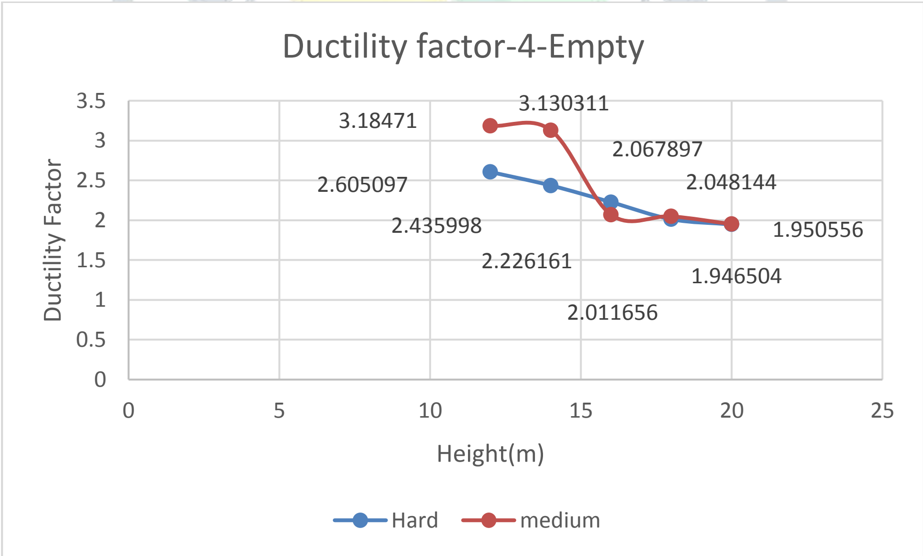
- Effects of variation in heights on over strength factor, Ductility factor and Redundancy factor for 250 m^3-zone 5.

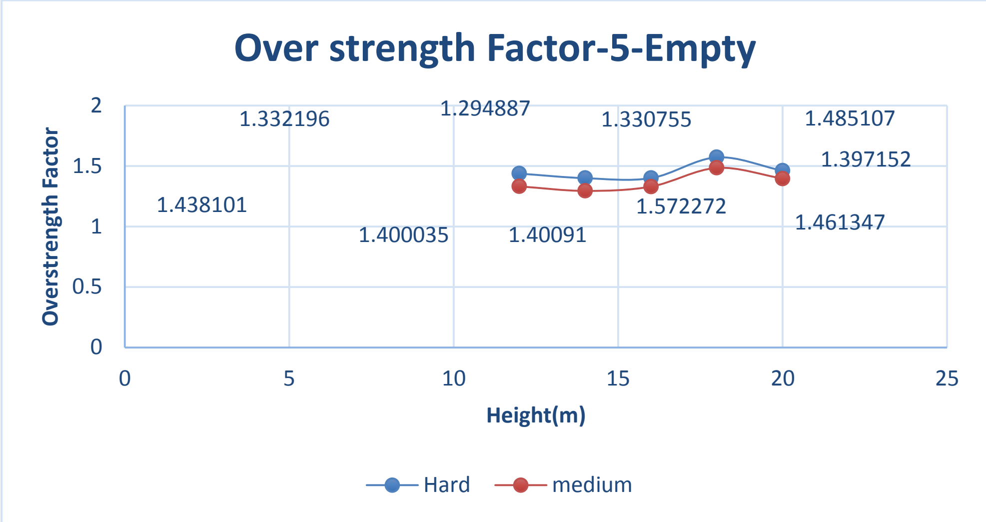
Over strength factor		
Height	**Hard**	**medium**

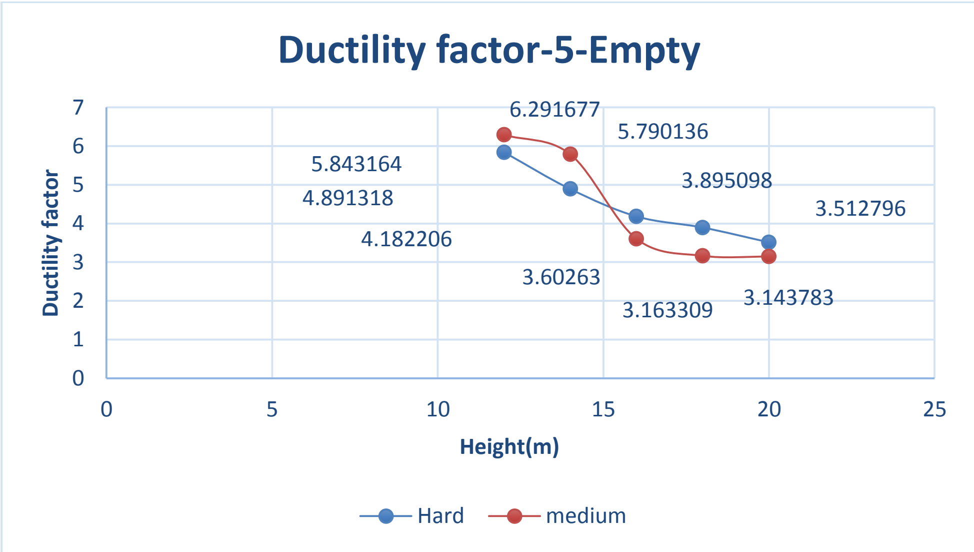
12	1.438101	1.332196
14	1.400035	1.294887
16	1.40091	1.330755
18	1.572272	1.485107
20	1.461347	1.397152

Ductility factor		
Height	**Hard**	**medium**
12	5.843164	6.291677
14	4.891318	5.790136
16	4.182206	3.60263
18	3.895098	3.163309
20	3.512796	3.143783





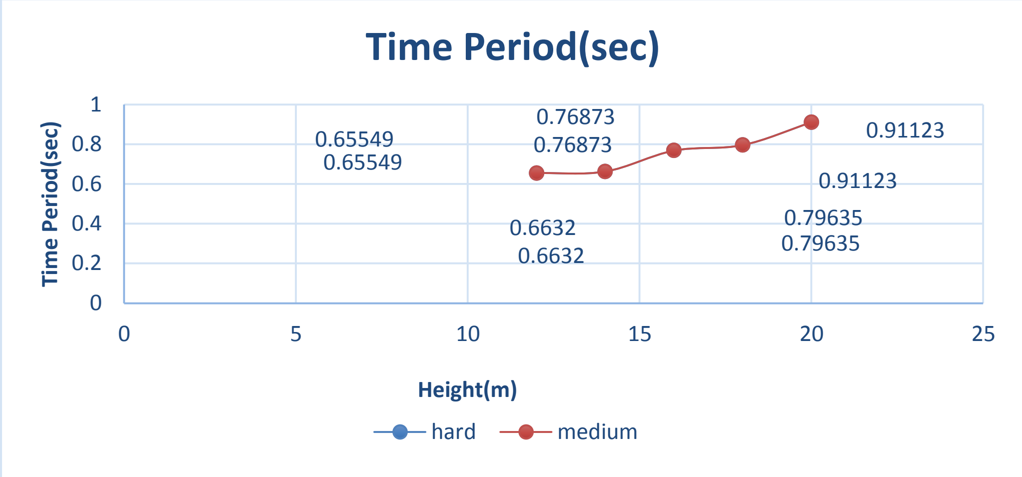




- The above results shows that ductility and over strength factor decreases as height increases which affect the structure. Ductility factor decreases which is harmful for the tank because more ductility factor is good for the structure.

➢ **Time period for zone 4 and 5, and the time period remains same for both zones and soil conditions.**

Height	Time period	
	hard	medium
12	0.65549	0.65549
14	0.6632	0.6632
16	0.76873	0.76873
18	0.79635	0.79635
20	0.91123	0.91123

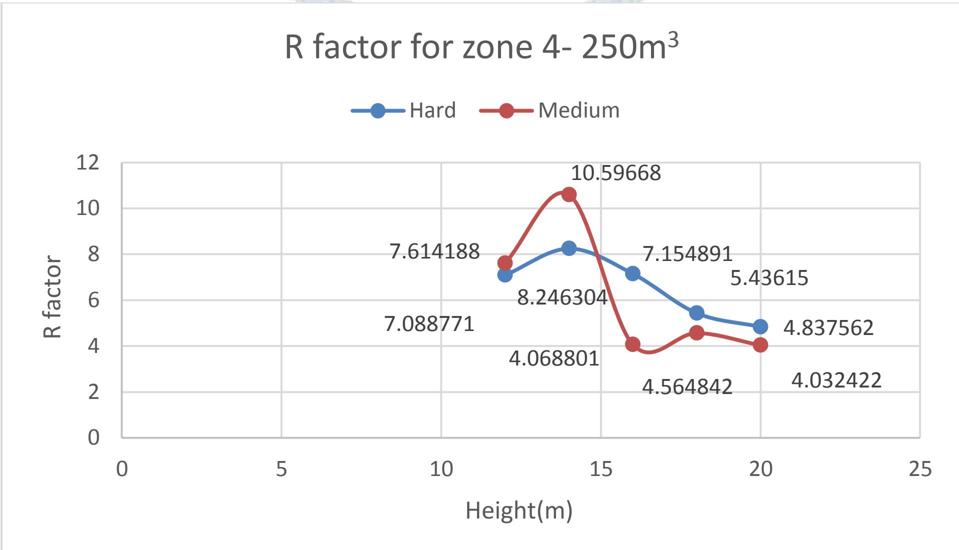


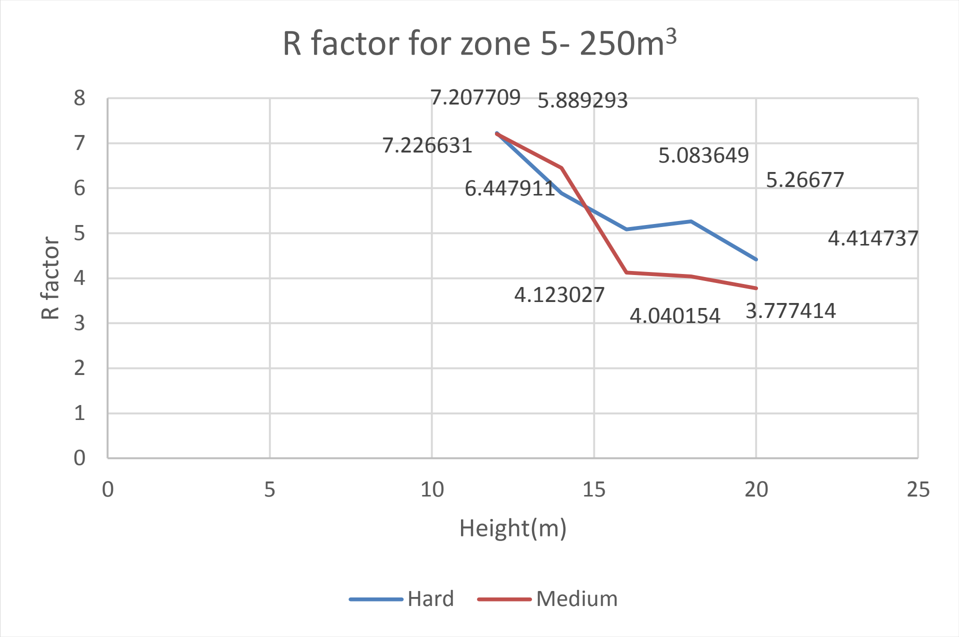
- The results shows that the time period increases as height increases this is because the stiffness of the structure decreases as the height increases.

➢ **R factor**

Height	R factor for zone 4 Empty	
	Hard	**Medium**
12	7.088771	7.614188
14	8.246304	10.59668
16	7.154891	4.068801
18	5.43615	4.564842
20	4.837562	4.032422

Height	R factor for zone 5 Empty	
	Hard	**Medium**
12	7.226631	7.207709
14	5.889293	6.447911
16	5.083649	4.123027
18	5.26677	4.040154
20	4.414737	3.777414





➢ R factor decreases as height increases. Lesser R factor needs higher design lateral loads and less detailing expenses.

3.2. For 500000 litters:

➢ Effects of variation in heights on Over strength factor, Ductility factor and Redundancy factor for 500 m^3-zone

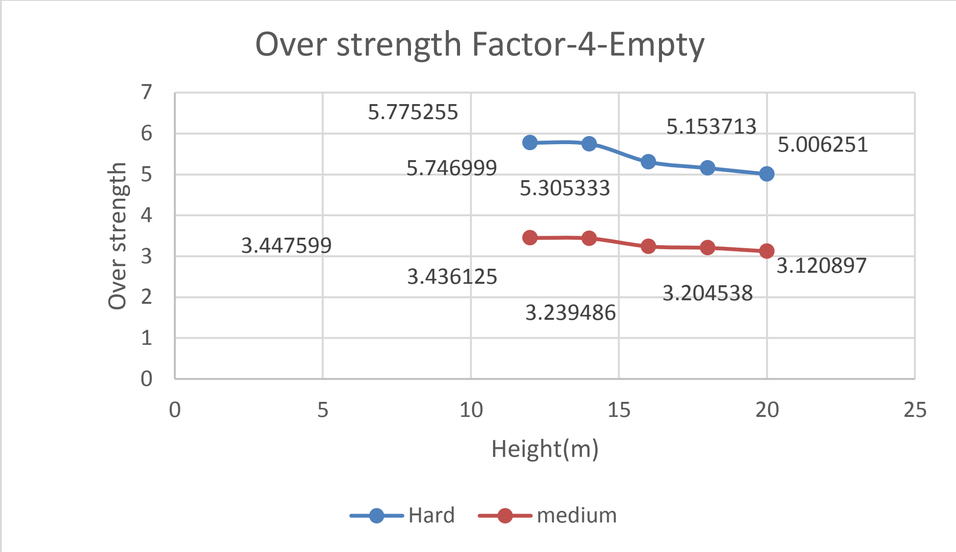
Over strength factor		
Height	**Hard**	**medium**
12	5.775255	3.447599
14	5.746999	3.436125
16	5.305333	3.239486
18	5.153713	3.204538
20	5.006251	3.120897

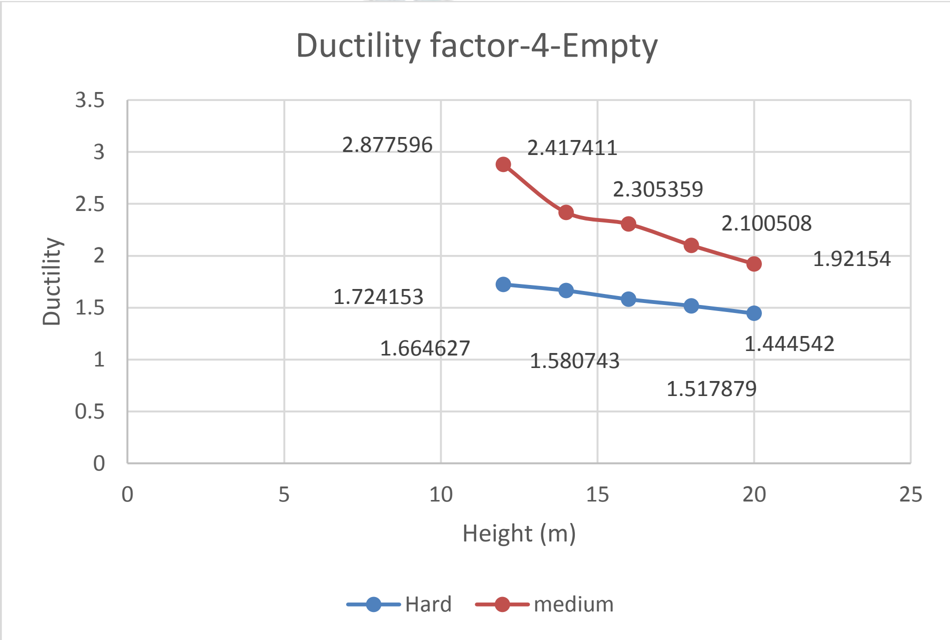
Ductility factor		
Height	**Hard**	**medium**
12	1.724153	2.877596
14	1.664627	2.417411
16	1.580743	2.305359
18	1.517879	2.100508
20	1.444542	1.92154

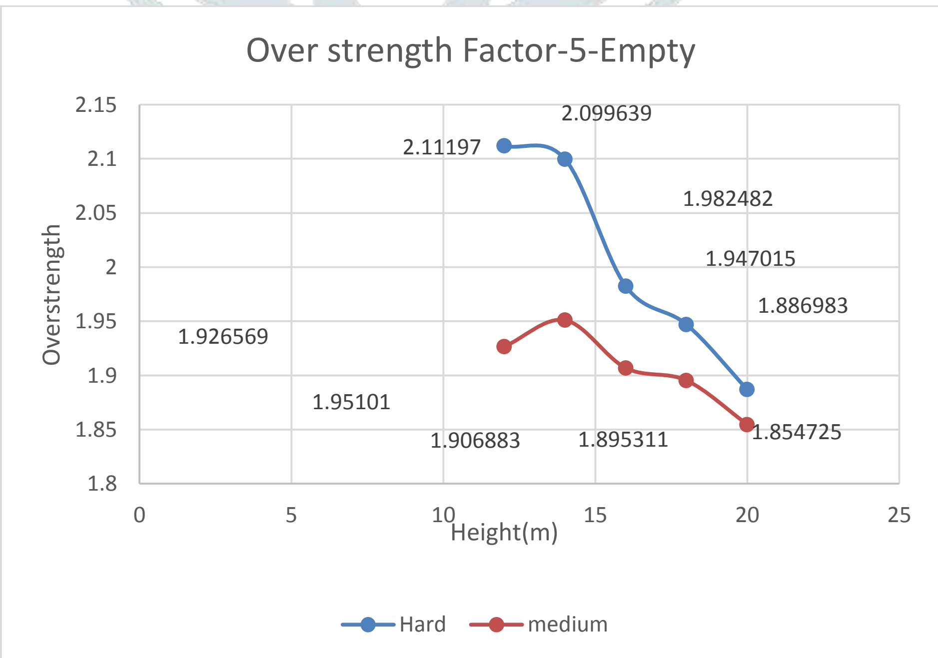
➢ Effects of variation in heights on Over strength factor, Ductility factor and Redundancy factor for 500 m^3-zone 5.

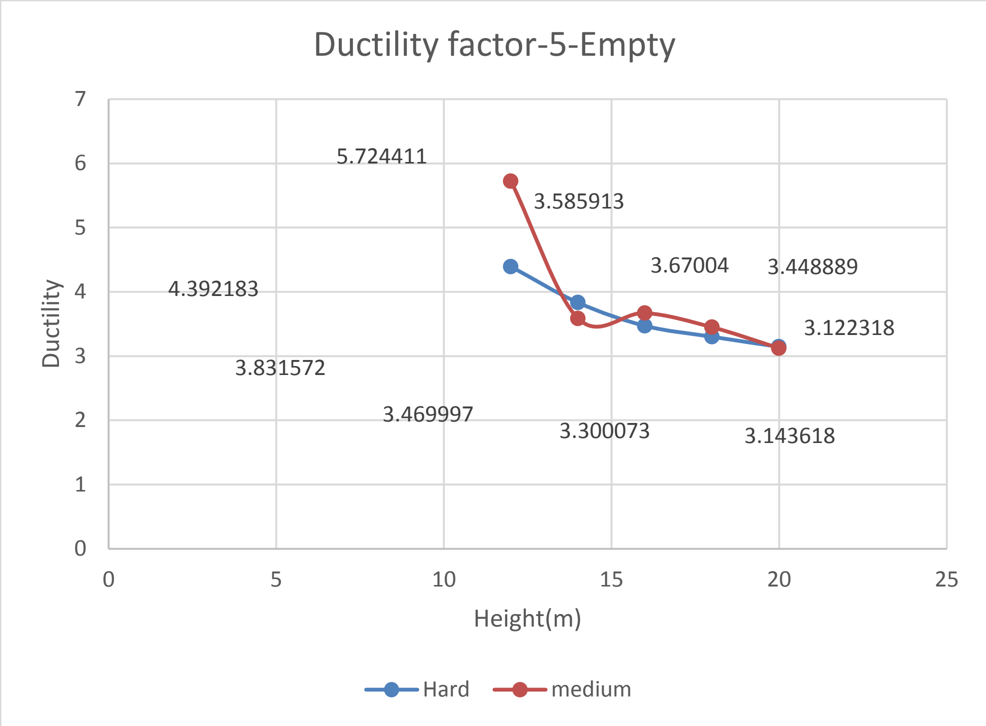
Over strength factor		
Height	**Hard**	**medium**
12	2.11197	1.926569
14	2.099639	1.95101
16	1.982482	1.906883
18	1.947015	1.895311
20	1.886983	1.854725

Ductility factor		
Height	**Hard**	**medium**
12	4.392183	5.724411
14	3.831572	3.585913
16	3.469997	3.67004
18	3.300073	3.448889
20	3.143618	3.122318


Over strength Factor-4-Empty
Over strength
Height(m)
5.775255
5.153713
5.006251
5.746999
5.305333
3.447599
3.436125
3.120897
3.204538
3.239486
Hard
medium


Ductility factor-4-Empty
Ductility
Height (m)
2.877596
2.417411
2.305359
2.100508
1.92154
1.724153
1.664627
1.580743
1.444542
1.517879
Hard
medium

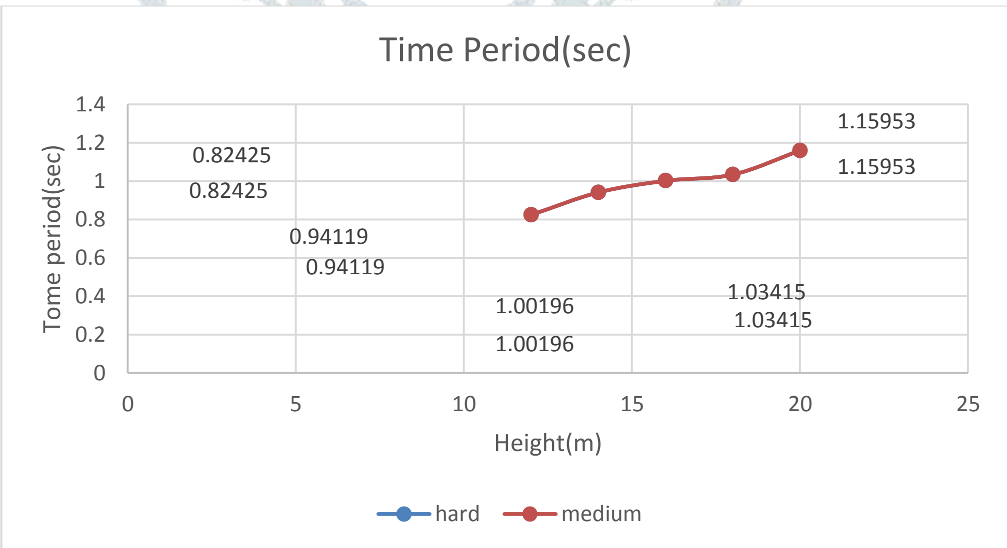

Over strength Factor-5-Empty
Overstrength
Height(m)
2.099639
2.11197
1.982482
1.947015
1.886983
1.926569
1.95101
1.906883
1.895311
1.854725
Hard
medium



- The above results shows that ductility and over strength factor decreases as height increases which affect the structure. Ductility factor decreases which is harmful for the tank because more ductility factor is good for the structure.

➢ **Time period for zone 4 and 5, and the time period remains same for both zones and soil conditions.**

zone 4 & 5	time period 500 m^3 empty	
height	hard	medium
12	0.82425	0.82425
14	0.94119	0.94119
16	1.00196	1.00196
18	1.03415	1.03415
20	1.15953	1.15953

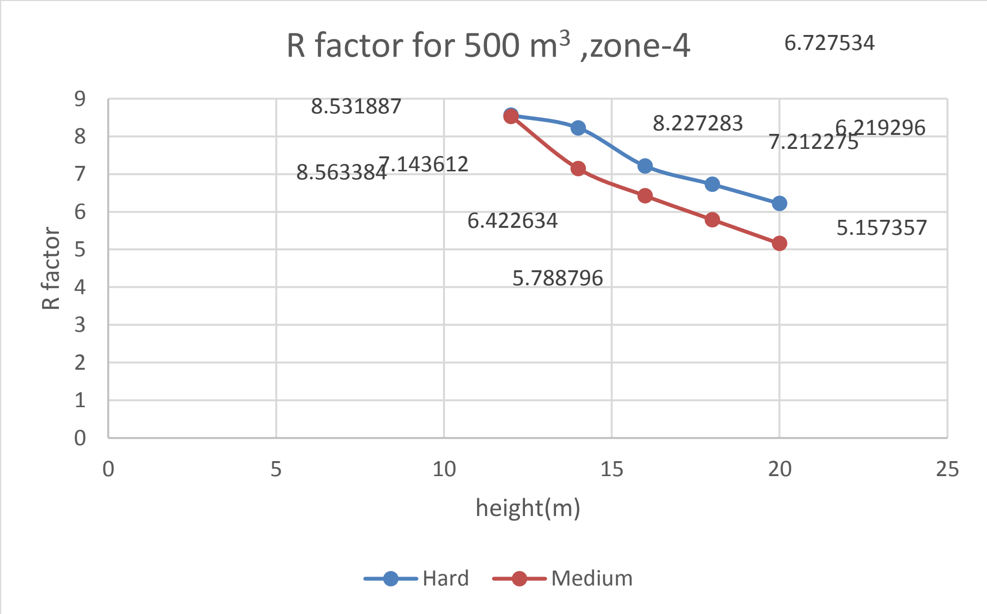


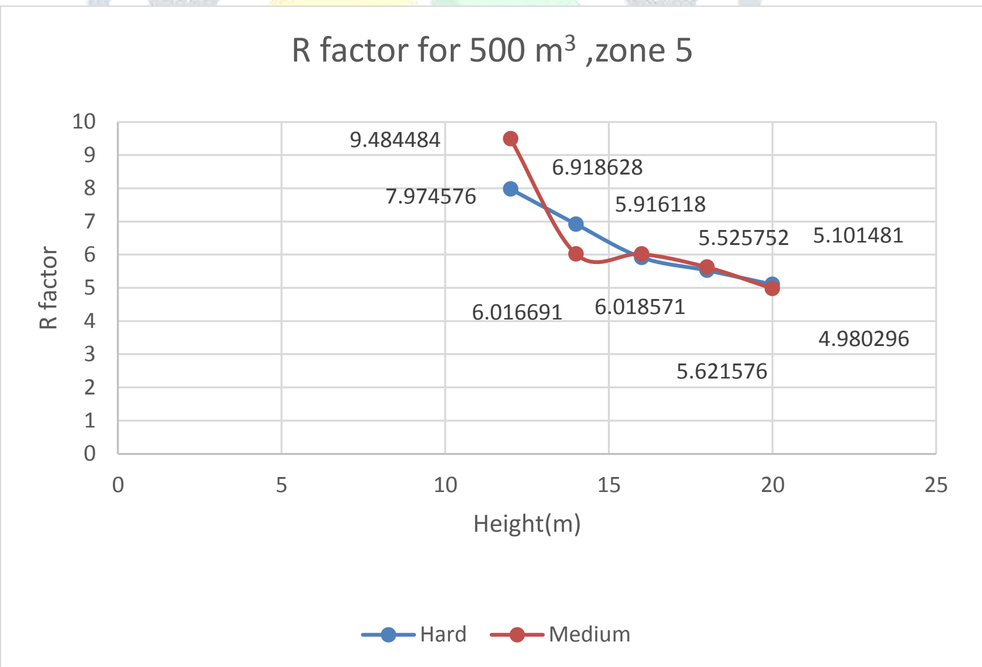
➢ **R factor**

Height	R factor for zone 4 Empty	
	Hard	Medium
12	8.563384	8.531887
14	8.227283	7.143612
16	7.212275	6.422634

18	6.727534	5.788796
20	6.219296	5.157357

Height	R factor for zone 5 Empty	
	Hard	**Medium**
12	7.974576	9.484484
14	6.918628	6.016691
16	5.916118	6.018571
18	5.525752	5.621576
20	5.101481	4.980296





- R factor decreases as height increases. Lesser R factor needs higher design lateral loads and less detailing expenses.

IV. CONCLUSION

- The elevated tanks Fundamental time period increases with increase in tank staging height.
- The Overstrength and ductility factor decreases as height increases.
- Base shear decreases as the staging height increases that is due to increase in Time period.
- The response reduction factor is considerably affected by the fundamental time period of water tanks.
- R factor varies from 5 to 110 for tank empty condition.
- Estimation of response reduction factor with exact analysis will help in an economical design.

V. REFERENCES

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[4] ATC19 structural response modification factor
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