PERFORMANCE BASED EVALUATION OF RESPONSE REDUCTION FACTOR FOR ELEVATED CIRCULAR WATER TANK

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ABSTRACT

The actual earthquake force in considerably higher than what the structures are designed for. We cannot design the structures for the actual value earthquake intensity because the cost of construction will be too high. The actual intensity of earthquake is reduced by a factor called response reduction factor ‘R’. The value of ‘R’ depends on how we design the frame members. From previous study it is noted that the ‘R’ factor depends on ductility factor (Rμ), strength factor (Rs), structural redundancy (RR) and damping associated with structure. The objective of this work is to evaluate the response modification factor (R) for To evaluate the response reduction factor of elevated water tank for various capacities using nonlinear analysis in CSI SAP2000 and To compare response reduction factor of elevated water tank having different capacities for different seismic zones, To evaluate the strength factor, ductility factor and redundancy factor for various seismic zones. To study the effect of base shear, maximum lateral displacement, fundamental time period of various zones to be carried out

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INTRODUCTION

The water tank is the one of the structure which is widely used in water distribution system and it is life line structure in earthquake prone area. Due to the past earthquake many structures have collapsed or damaged, it caused the life losses and property losses. So if the structure has to be constructed, it is required to check out the behaviour of structure under seismic loading. If the structure is existing, retrofitting work has to carried out.

The various factors contributing to the structural damage during earthquake are vertical irregularities, irregularity in strength and stiffness, mass irregularity, torsional irregularity etc.

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.

1.1 WATER TANK

A water tank is a container which is used to hold water. Water tanks are used in a wide variety of settings and for an assortment of purposes all over the world. Some tanks are designed as collectors. They may collect rainfall, or serve as a collection point for water pumped up from a well or piped out of a stream, river, or lake. Once collected the water can be transported in the tank or transferred to another tank for transport. Collection tanks can be made from steel, plastic, and concrete, depending on how they are used, and they may be attached to filtration systems for hygienic reasons.

ELEVATED WATER TANK

It’s also called as water tower.

“A water tower is an elevated structure supporting a water tank constructed at a height sufficient to pressurize a water supply system for the distribution of portable water and to provide emergency storage for fire protection”. There is one damper which is known as the visco elastic damp it has got two metals in-between of them there is a elastomer present. Because of the shearing of the metal plates energy is transferred.

Fig 1.1: Elevated water tank

1.2 TYPES OF WATER TANK

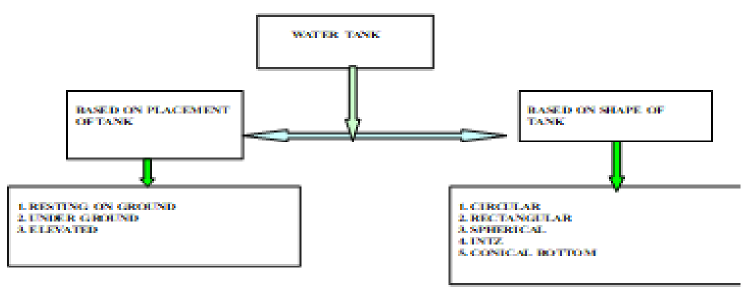


Fig 1.2: Types of water tank

In general water tanks are classified as

1) Ground water tank

2) Underground water tank

3) Elevated water tanks supported on staging.

1.2.1 Ground water tank

The tanks which are constructed at ground level or on the ground are called tanks resting on ground. Where the gravity flow is enough for supply of water by gravitational force i.e. the ground elevation is highest in that area. Its initial cost of construction is low, maintenance cost is low, the ease with which water quality can be tested, greater safety and a greater aesthetic value.

The primary disadvantage of a ground tank is lack of gravitational pressure to delivery water to destination point. The water in the tank is not put under significant amount of pressure unless the tank is located at a high elevation, such as on top of hill. The continuous pumping will become costly.

Fig 1.2: Ground water tank

1.2.2 Underground water storage tank

These are used for underground storage of portable drinking water, waste water, and rain water collection. So whatever we call it a water tank or water cistern, as long as we are storing water underground these are the storage tank for us. The ribbed design of water cistern tanks makes it capable of being buried underground, supporting the surrounding soil.

Fig 1.2.2: Underground water tank

1.2.3 Elevated water tanks supported on staging

This is one of the tank supported by columns is called elevated tanks. In this type of tanks the water is delivered by gravitational pressure but to fill the tank the pumping is required to uplift the water from ground level. But the elevated tanks are not safe in earthquake prone areas because the huge mass is resting on supported columns. Many of water tanks are collapsed or damaged, due to past earthquake, so study of seismic behaviour of structure is required to minimize the losses. Short term pump shot down does not affect the pressure in the distribution system since the pressure is maintained in the gravity. The pressure is also depends on the depth of water in the tank.

The optimal pressure achieved only at constant depth. The optimal depth of water for the purpose of producing the pressure is even more specific for stand pipes than tanks elevated on legs. The length of the stand pipes causes continuous and highly unequal pressure on the distribution system. In addition to this the significant quantity of water required to produce the required water pressure. The storage tanks should be impermeable or leakage proof.

Fig 1.2.3: Elevated water tank

1.3 OBJECTIVES OF THE STUDY.

The following are the main objectives of the present study

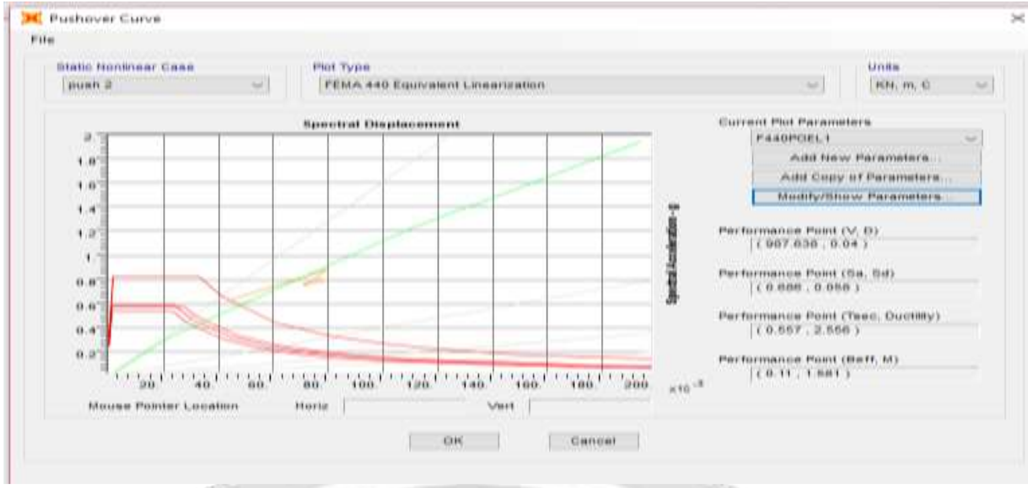
- To evaluate the response reduction factor of elevated water tank for various capacities using nonlinear analysis in CSI SAP2000.
- To compare response reduction factor of elevated water tank having different capacities for different seismic zones.
- To evaluate the strength factor, ductility factor and redundancy factor for various seismic zones.
- To study the effect of base shear, maximum lateral displacement, fundamental time period of various zones to be carried out.
- To the base shear of the elevated water tank modal results can be compared to the manual calculated results.

1.4 SCOPE OF THE PRESENT STUDY AND METHODOLOGY

The following are the scopes of present study are,

- Elevated water tank are modeled by using CSI SAP2000 software and also 3D modeling done with help of this software.
- The study was carried out with the nonlinear static analysis of the elevated water tank.
- Elevated water tank is fixed at support and soil structure interaction is not considered.
- Application of gravity loads, live load, water load etc.
- Type of the supporting structures (framed).
- Application of static lateral load induced due to earthquake, at CG of container.
- Type of earthquake loading is strictly as per IS 1893:2002.
- Pushing the structure using the load patterns of static lateral loads, to displacements larger than those associated with target displacement using static pushover analysis.
- Plastic hinges were assigned at predefined beam and column loadings.

2.1.1 Calculation of response reduction factor (Full tank)



- **(a) Estimation of strength factor [for zone II]**
- Maximum Base Shear (from pushover curve) Vo= 987 kN
- Design Base shear (as per EQ calculation) VB = 357 kN
- Using equation for strength factor, given in ATC –19 **Rs = Vo / VB**=987/357
- **Rs =2.8**
- **(b) Estimation of ductility factor**
- Maximum drift capacity Δm =107.8 mm (0.004 H)
- Yield drift Δy =40 mm
- Using equation for displacement ductility ratio, given in ATC-19 [1]
- **μ = Δm / Δy =107.8/40=2.6**
- 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 =1.32 seconds (From SAP model)
- Φ=0.46
- **Rμ=1.5**
- **(c) Estimation of redundancy factor**
- **RR = 0.86** (Redundancy factor (RR) from ATC-19)
- **(d) Estimation of response reduction factor R:**
- R= RS x Rμ x RR =2.8*1.5*0.86
- **R=3.6**
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- **(a) Estimation of strength factor [for zone III]**
- Maximum Base Shear (from pushover curve) Vo= 971 kN
- Design Base shear (as per EQ calculation) VB = 451 kN
- Using equation for strength factor, given in ATC –19 **Rs = Vo / VB**=971/451
- **Rs =2.0**
- **(b) Estimation of ductility factor**
- Maximum drift capacity Δm =107.8mm (0.004 H)
- Yield drift Δy =39mm
- Using equation for displacement ductility ratio, given in ATC-19 [1]
- **μ = Δm / Δy =107.8/39=2.7**
- 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 =1.32 seconds (From SAP model)
- Φ=0.42
- **Rμ=1.3**
- **(c) Estimation of redundancy factor**
- **RR = 0.86** (Redundancy factor (RR) from ATC-19)
- **(d) Estimation of response reduction factor R:**
- R= RS x Rμ x RR=2.0*1.3*0.86
- **R=2.2**
- **(a) Estimation of strength factor [for zone IV]**
- Maximum Base Shear (from pushover curve) Vo= 963 kN
- Design Base shear (as per EQ calculation) VB = 582 kN
- Using equation for strength factor, given in ATC –19 **Rs = Vo / VB**=963/582
- **Rs =1.58**
- **(b) Estimation of ductility factor**
- Maximum drift capacity Δm =107.8mm (0.004 H)
- Yield drift Δy =38mm
- Using equation for displacement ductility ratio, given in ATC-19 [1]
- **μ = Δm / Δy =107.8/38=2.8**
- 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 =1.32 seconds (From SAP model)
- Φ=0.35
- **Rμ=1.01**
- **(c) Estimation of redundancy factor**

- **RR = 0.86** (Redundancy factor (RR) from ATC-19)
- **(d) Estimation of response reduction factor R:**
- R= RS x Rμ x RR =1.58*1.01*0.86
- **R=1.35**
- **(a) Estimation of strength factor [for zone V]**
- Maximum Base Shear (from pushover curve) Vo= 949 kN
- Design Base shear (as per EQ calculation) VB = 646 kN
- Using equation for strength factor, given in ATC – 19 **Rs = Vo / VB**=949/646
- **Rs =1.46**
- **(b) Estimation of ductility factor**
- Maximum drift capacity Δm =107.8mm (0.004 H)
- Yield drift Δy =37mm
- Using equation for displacement ductility ratio, given in ATC-19 [1]
- $\mu = \Delta m / \Delta y$ **=107.8/37=2.9**
- Using equation for ductility factor, derived by Miranda and Bertero
- **R** $\mu = \{(\mu - 1 / \Phi) + 1\}$
- Φ for medium soil = **1+{1 /(12T -μT)}–{(2 / 5T)*e-2(ln(T) – 0.2)^2}**
- T =1.32 seconds (From SAP model)
- Φ=0.34
- **Rμ=0.87**
- **(c) Estimation of redundancy factor**
- **RR = 0.86** (Redundancy factor (RR) from ATC-19)
- **(d) Estimation of response reduction factor R:**
- R= RS x Rμ x RR =1.46*0.87*0.86
- **R=0.98**

- **20 mt height, full condition:**

Table 1: Comparing value of "R" factor for different zones of 500m^3 capacity of tank

Zone	**II**	**III**	**IV**	**V**
Time period	1.32	1.32	1.32	1.32
Base shear (KN)	357	451	582	646
Over strength factor (Rs)	2.8	2.15	1.58	1.46
Ductility factor(Rμ)	1.5	1.3	1.01	0.87
Redundancy factor (RR)	0.86	0.86	0.86	0.86
Response reduction factor(R)	3.6	2.2	1.35	0.98

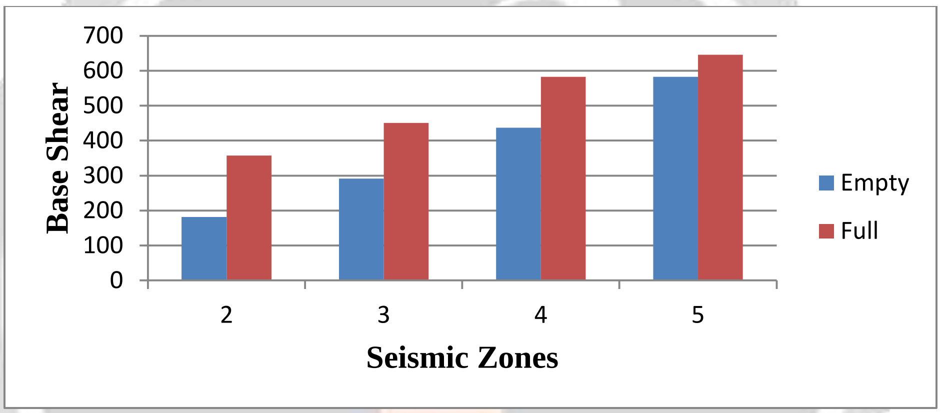


Fig 2.2: Base shear v/s seismic zones for different Tank condition

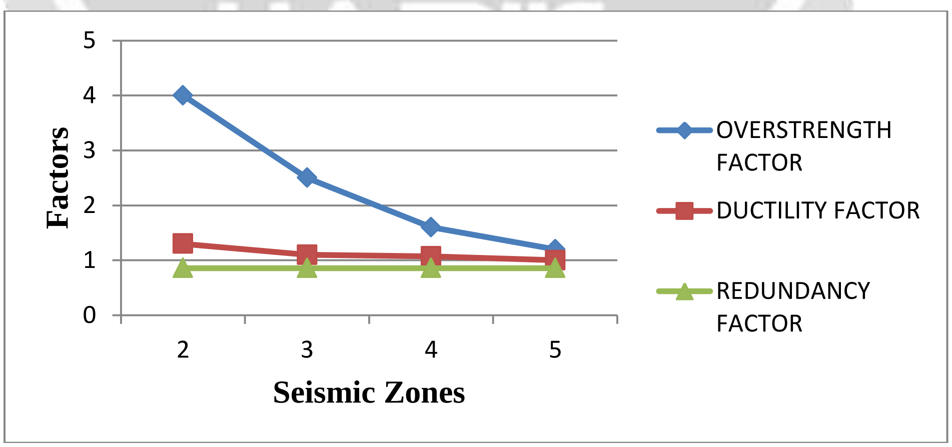
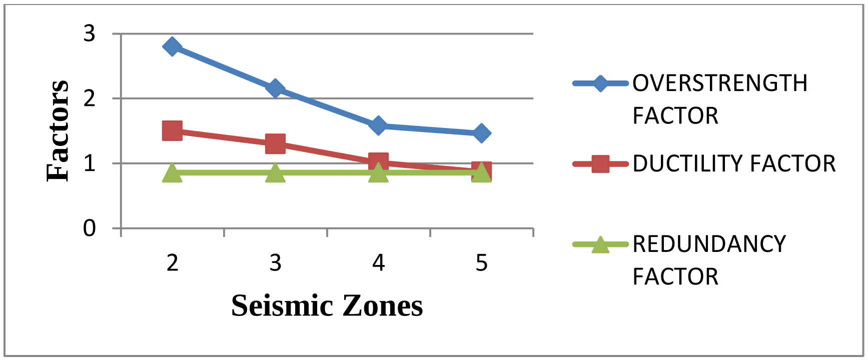


Fig 2.21: Factor's v/s seismic zones for Empty water tank.



➢ **Fig 2.22: Factor's v/s seismic zones for Full water tank**

RESULTS AND DISCUSSIONS

3.1 TIME PERIOD

3.1.1 Variation of Time Period for 250m³

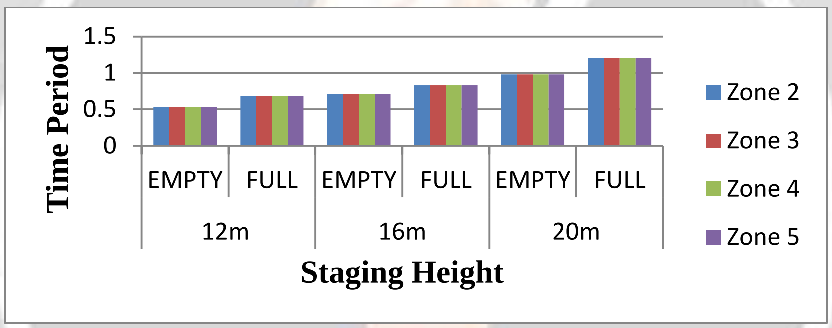


Fig 3.1: Time period v/s Different Staging for different zones and tank condition of water tank

3.1.2 Variation of Time Period for 500m³

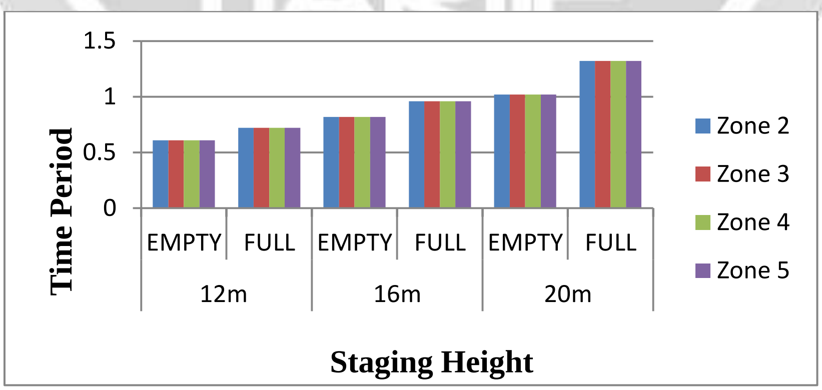


Fig 3.2: Time period v/s Different Staging for different zones and tank condition of water tank

3.2 RESPONSE REDUCTION FACTOR

3.2.1 Variation of Response reduction factor for 250m^3

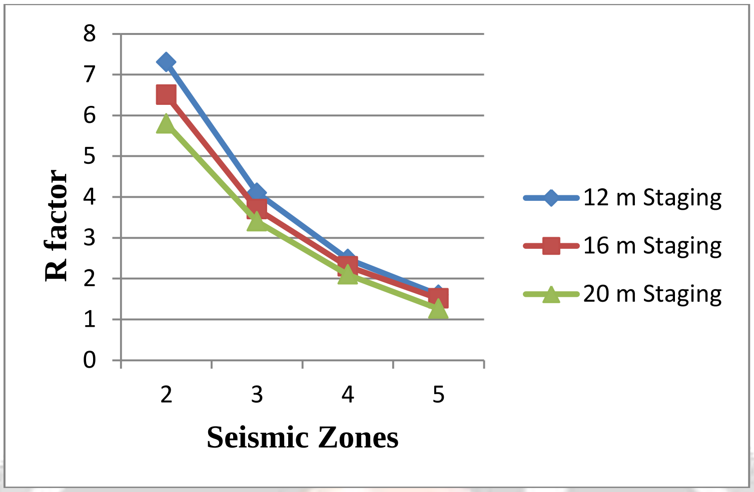


Fig 3.2.1: R factor v/s seismic zones for different staging of Empty water tank

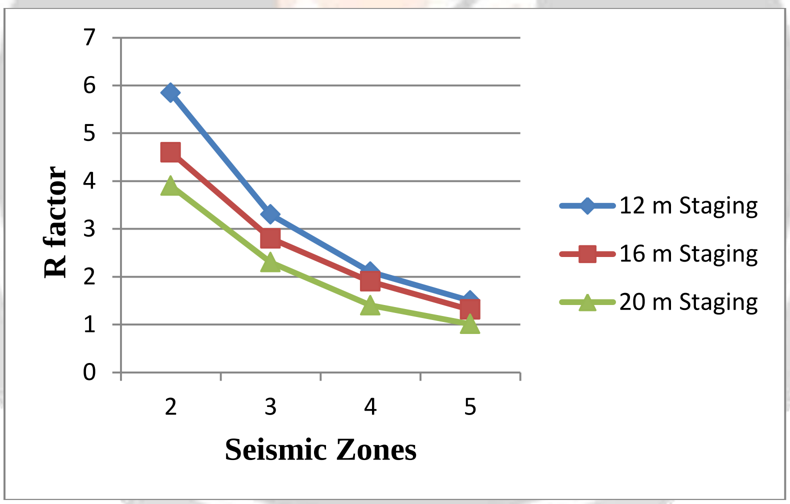


Fig 3.4: R factor v/s seismic zones for different staging of Full water tank

3.2.2 Variation of Response reduction factor for 500m^3

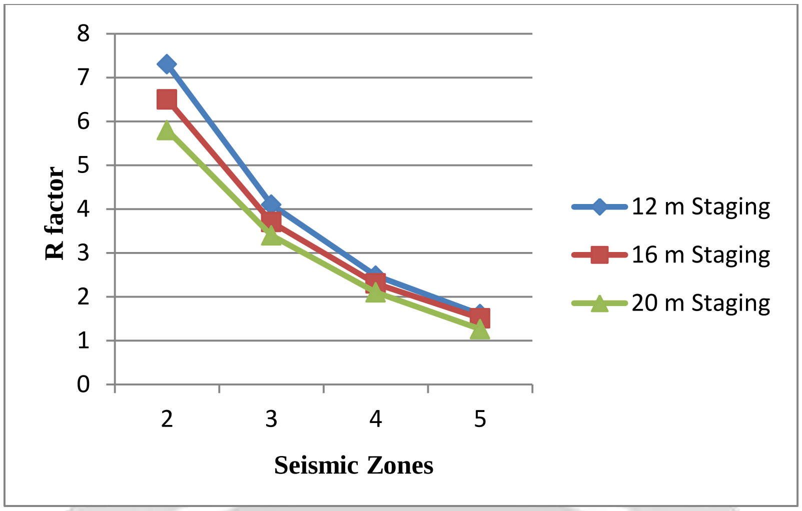


Fig 3.5: R factor v/s seismic zones for different staging of water tank

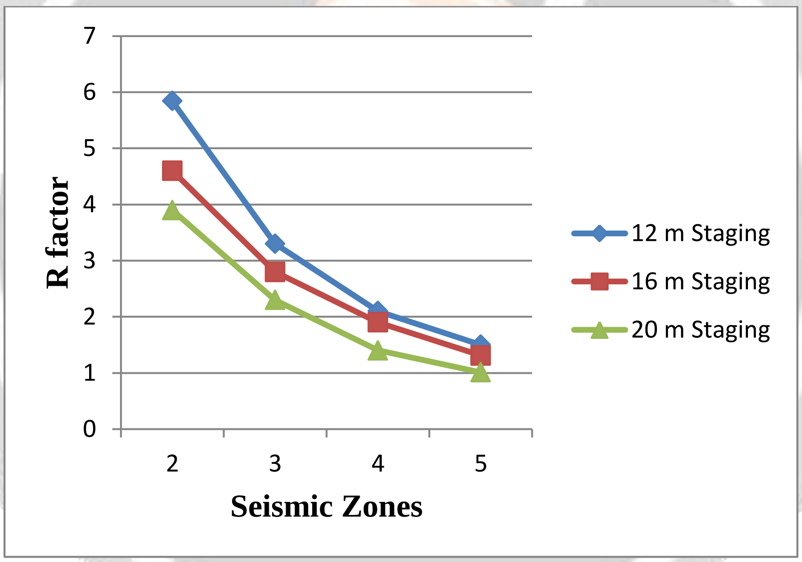


Fig 3.6: R factor v/s seismic zones for different staging of water tank

CONCLUSION

1) The response reduction factor is considerably affected by the staging height of water tanks. It reduces as the height of water tank is increasing.

2) R factor is highly dependent on seismic zones. For various seismic zones R factor also changes.

3) Time period and Redundancy of elevated tank will remain same for different zones of same height of tank.

4) Base shear is increased when the percentage of the filling in the storage tanks are increasing.

5) Base shear increases by changing the zone from II to V for the same height of elevated tank.

6) The Time period is considerably affected by the staging height of water tanks. It increases as the height of water tank is increasing.

7) Over strength factor of elevated tank is decreased by increasing zone factor. So, it shows that reserved strength of water tank is decreasing by increasing the zone factor.

8) R factor is decreasing by changing the condition of water tank from full to empty.

9) Time period and base shear of elevated tank is also increased in full condition of tank.

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