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Review on Modification of Response Reduction Factor of Elevated Liquid Storage Tank

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Abstract: The Response Reduction Factor (R) means for the capacity of any structure to dissipate energy through its inelastic Behaviour. Elevated tank carries large mass at its top in the container. Due to this Elevated tank will have large overturning moments at its base under the action of lateral forces. Tanks of different capacities will dissipate different amount of energy through inelastic Behaviour. Similarly tanks of same capacity under different magnitude of lateral forces will dissipate different amount of energy. Our Indian code suggest a single value of Response Reduction Factor for all type of water tank of single supporting system, irrespective of height of staging or shaft, plan geometry, soil condition/Flexibility and locality cannot be justified. In the latest Indian standard codal provision of IS 1893 (Part 2): 2014 for a single type of framing system only one value of Response Reduction Factor is mentioned for all above parameters. Response Reduction Factor is an Important factor using it, the actual value of base shear of the structure should be reduced to obtained design horizontal or lateral force. The various Components of Response Reduction Factor are Ductility factor, over strength factor and Redundancy factor.

Keywords: Pushover analysis: Seismic analysis; Elevated liquid storage tank; Response Reduction factor; Parametric Study.

1. Introduction

Water is one of the prime requirements in everyday life. For storage of water, wide varieties of water tanks are constructed. Water supply is a lifetime facility. A different type of water tank adorns the skyline of developing areas and industrial complexes. The shape of tank, its height above ground level, the supporting structure, soil condition, seismic zone etc. are dictated by functional requirements, construction facilities, and pleasing appearance. Design of water tank is a very challenging and prime work for structural engineer. High level tank normally consists of an assembly of shells such as cylinder, Conical and Spherical shell segment and are supported on a framed concrete Tower with inclined or vertical legs or on a vertical cylindrical Shaft. The supporting Tower can also be a large skirt in varied shapes. Elevated concrete water tanks are located at point of considerable height are and thus conspicuous objects. Structurally the tank floor is supported on a grid work of beams or a dome and supported on a numbers of column or on a vertical cylindrical shaft. The majority of reinforced concrete water tank are circular in plan. Intze water tank is most commonly used nowadays. Due to its special shape it imparts many advantages in the design and construction. The main benefit of the Intze tank is that the radial inward thrust of the conical bottom counteract the radial outward thrust of the Spherical. Response Reduction Factor plays very vital role in the earthquake analysis of tank. ‘R’ is the factor using it the actual base shear is reduced to obtain the design horizontal or lateral force. The various Components of ‘R’ are over strength, Ductility Factor and Redundancy factor. The paper includes review of the work of selected 10 research paper out of study carried out on about 40 papers..

2. Literature Review

Many Research papers has been published in the form of technical papers and Projects till date on the Modification of ‘R’ for the Elevated liquid storage tank. Different method of analysis and various parametric studies are covered in that analysis i.e. Sloshing effect on tank, pushover analysis, capacity of tank, staging height, soil condition, dynamic response of ground motion, dynamic response of framed staging etc. Some of those are given below.

2.1 Dr. O. R. Jaiswal, Dr. Durgesh C Rai, Dr. Sudhir K Jain

This paper presents for the analysis of design seismic force of elevated tanks compare to the design seismic force of buildings as mentioned in different International codal provisions: IBC 2000, ACI Standards ACI 371: 1998) and ACI 350.3: 2001, AWWA D-100:1996, AWWA D-103:1997, AWWA

D-110:1995 and AWWA D-115:1995, API 650:1998, Eurocode 8:1998, NZSEE guidelines and NZS 4203:1992. Parameters like base shear coefficients vs time period, ductility factors, 'R' of all the codes are compared. Most of the above documents emphasized consideration of components like convective mass and height and impulsive mass and height in seismic analysis of tanks. Base shears of tanks are compared to buildings, it is concluded that different shape spectrum should be used for tanks and buildings. Based on the comparisons done from other codes values of R for the draft code of IS1893- part2: 2014 are suggested.

2.2 Mostafa Masoudi, Sassan Eshghi, Mohsen Ghafory Ashtiany

In this paper the Effects of multicomponent earthquake, interaction of structure with fluid and effects of P-delta on inelastic response have been used to analyse the linear and non-linear response time history analysis for a given locality up to failure of shaft supported and staging supported water tanks. P-delta effects are considered as it has considerable effects on the moments in the staging during non linear states. R value is evaluated by reversing as per the procedure of design explain in FEMA450. Ae=I.F/R (A475), Ae=design PGA. The calculated value of Response reduction factor was coming out to be less than values recommended in various codes like Euro code 8, ASCE / SEI (7-10) and ACI:371 R-08. As water tanks carry large mass at top most portion of the supporting system will enter inelastic range so the ductility requirements of the staging will be very high unlike buildings. Fluid structure interaction also affects the performance based on the frequency of earthquake acceleration.

2.3 C. T. Kevit and A. A. Liepins

In this paper a pushover analysis is carried out got the existing RCC hollow cylindrical pedestal of an elevated water storage tank. The analysis is carried out using finite element analysis model incorporated with LS-DYNA. 'R' value is calculated based on the procedure given in ATC-19. For different heights and capacities R value is directly proportional to its time period. The pedestals for the given concrete and composite tanks are considered tall hollow cylindrical reinforced concrete structures. The steel tan consists of four or more cross-braced steel legs. The results calculated from the analysis include stresses at the failure surface of concrete at first damage and at the lateral-load deflection curve and maximum load. The pushover result is used to estimate the response modification factor in seismic response analysis. The coming value of response modification factor is much higher than value suggested by Code.

2.4 R Ghateh, M. R. Kianoush, W Pogorzelski

In this paper FEA was used to investigate nonlinear seismic response. Pushover curves and cracking propagation of various models were developed and over strength factor and ductility factors were calculated. Results showed that tanks having same capacity, taller ones had less base shear compared to shorter ones. Tanks with same height and different capacity, heavier ones undergo larger deformation. As the seismicity region level decreases (1 to 4) over strength factor increases. There is no significant change in ductility factor with seismicity of region as it mostly depends on geometry and material properties. Increase in fundamental time period and H/Dw ratio will increase over strength factor and reduce ductility factor.

2.5 Chintha. Ravichandra, R. K. Ingle

The author of this paper aims to provide the different effective load case for ESR. Like wind load or earthquake force. Earthquake analysis is carried out as per the guidelines of IS1893 Part 1 & 2 (latest codes), Wind analysis is carried out as per the IS875:1987 (Part III) & IS875:draft (Part III). All three soil conditions are considered i.e. soft, medium, and hard. All four types of seismic zones are considered. Wind load analysis is carried out for different wind speeds like 39m/sec, 44m/sec, 47m/sec and 50m/sec. For soft soil the effect of wind force for 50 m/s wind speed is quite significant as compared with the earthquake forces in Zone II, III, and IV. In medium soil for wind speeds 47, 50 m/s is more effective as compared with the earthquake forces in Zone II, III, and IV. For hard soil with wind speeds of 47, 50 m/s is more significant as compared with the earthquake forces in Zone II, III, IV, and V.

2.6 Jignesh A. Amin and D. P. Soni

In the presented paper authors concentrated on the Calculation of ‘R’ for the elevated Tanks with Replacement of different RC Frame Staging Arrangements. Radial Beam and column at center, two concentric row of column and diagonal bracing. Two performance limits for the analysis i.e. local element limits and global structural limits are defined in the calculation of ‘R’ for the water tanks. Uniformly distributed load is assigned on a top ring beam as a self-weight. The center of gravity of the container is used as target node to assign the pushover loading. It is increasing gradually until the structure fails. The ductility factor in the pattern two concentric row of column and diagonal bracing is increased around 9.75% and 16% respectively as compared to staging pattern Radial Beam and column at center. The supporting structural system having more redundancy i.e. two concentric rows of columns or that with diagonal braces having more strength factor, ductility factor and response reduction factor as compared to basic staging configuration.

2.7 Tam Larkin

In this paper different types of soil conditions (soft, medium and hard) has been considered for the study. After performing the analysis and result, it has been detected that the properties of supporting soil below the structure has extensive effect on ductility, time period and overall performance of the structures. Fixity at below the structures may be extremely harmful in soft soils. Soil Structure Interaction effects may influence on the time period extension and loss of energy by foundation soil damping. The effects of Soil Structure Interaction for tanks are shown to reverse the trend of force and moment reduction under earthquake loading which is most common phenomenon. The impact of comparison with fixed base condition in case of soft and medium soil reduces ductility around 22% & 38% respectively as compared to fixed support condition for the tank for analysis. The impact of the flexibility is minimum for the hard soil condition. The impact of the Soil Structure Interaction for soft and medium soil decreases displacement up to 3% and 11% respectively as compared to fixed base condition for analysis.

2.8 Virendra Prabhakar Dehadrai1 and R. K. Ingle

This paper presents a study of the Behaviour of cylindrical liquid tanks supporting on non-uniform soil base mean Soil with changing stiffness. The most of the tanks supported on ground soil having all properties are varying with the location and area. The author considered two different stages of stiffens

i.e. Soil Stiffness along the Diameter Varied in Three Stages and Soil Stiffness along the Diameter Varied in Two Stages. For the study and detailed analysis it has been concluded that the critical design forces (i.e., hoop and meridional) of tank in the wall resting on soil with varying strata are more than the obtained for containers resting on soil strata with uniform stiffness. It has been observed a tank resting on soil with varying stiffness, the axisymmetric nature of the hoop and meridional bending forces in the wall of the tank become distorted. The most visible portion of the tank is the wall near the junction of the change in soil condition. This portion will have considerably large hoop and meridional bending moment forces as compared with those calculated from PCA (1993) tables or results for tanks placed on uniform soil strata.

2.9 Vishva K. Shastri and Jignesh A Amin

In the mentioned paper a Reinforced Concrete framed supporting elevated tank is used to determine the ‘R’ without and with considering flexibility of soil and its effect on structure. The existing elevated Reinforced Concrete Elevated liquid storage tank is investigated with non-linear static displacement controlled pushover analysis to determine the ductility and base shear capacity of tank without and with considering soil-flexibility.

It has been perceived that a tank supported on soil, that flexibility of soil has considerable effect on ‘R’, other important properties and the Behaviour of tank signifying the effect of fixity at base may be seriously erroneous in soft soils and less for hard soil. As the time period increases from fixed base soil to soft base soil the ‘R’ decreases, So it is observed that avoidance of effect of soil flexibility might lead to erroneous and incorrect results. The amount of base shear is reduced about 20% in case of soil with soft base to fixed base condition.

2.10 Kashyap N Patel and Jignesh A Amin

In the given study, efforts are made to conclude the ‘R’ for the existing Reinforced Concrete Elevated liquid storage tanks for four different staging systems. The design of tanks are carried out as per draft Indian standard codes for Seismic Analysis code, Seismic design of liquid storage tank code, Reinforced Concrete design code, and code of ductile detailing considering the effects of flexibility of soil at base. The analysis of the elevated Reinforced Concrete water tanks has been carried out using non-linear static pushover analysis (displacement controlled). The base shear of tank capacity and its ductility are calculated considering soil flexibility. The ‘R’ is found for the Elevated Reinforced Concrete water tanks having various capacities at various performance levels for four realistic designs. The study results of the analysis show that the flexibility of supporting soil has extensive effect on ‘R’, time period and overall behavior of water tank. This representing that idealism of base fixity may be extremely erroneous for soft soils.

3. Findings

- There is no mathematical equation is defined which is based for the ‘R’ in Indian design codes IS1893 (Part 2):2014. A single value of Response reduction factor for all types of Elevated liquid storage tank of single framing type, irrespective of its height, Zone, Soil condition and Geometry cannot be justified.
- For understanding the behavior of response reduction factor subjected variation in

staging height, tank capacity, time-period, SSI effects and geometric configuration of framing system.

- Indian standards dose provide the linear method of analysis and design of structural member but it does not contains nonlinear analysis approach of analysis which gives the realistic Behaviour of the structure and it is useful for the performance based design structure as well as the seismic damage assessment to the structure.
- Ductility of the supporting system and its relationship with mass of container as per IS1893 (Part 2):2014 and IS13920:2016.
- Behaviour of different staging arrangements under different earthquake time history.
- Study of seismic design methodology of ESR incorporating soil-structure interaction effects.

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