Evaluation of Ductility factor for the Elevated Water tank

Vimlesh V. Agrawal[1], Dr. (Prof.) Indrajit N. Patel[2],

[1]Research Scholar,
Gujarat Technological University
Ahmedabad, India
E-mail: vvagrawal@bvmengineering.ac.in
[2]Professor, Structural engineering department,
Birla Vishvakarma Mahavidyalaya Engineering College,
Vallabh Vidyanagar,
Inpatel34@gmail.com

Abstract*: *In the current procedures of design and analysis for seismic forces, base shear is calculated by the elastic strength demand divided by the strength reduction factor. This calculated factor is known as the Response Reduction factor 'R', which means for ductility, redundancy, Over-strength, and damping of a structural configuration. In the present study, the Response reduction factor accounting for ductility is known as the Ductility factor (Rμ). The Ductility factor is defined as the ratio of elastic strength capacity imposed on the single degree of freedom system to inelastic strength capacity for a given ductility ratio. The Ductility factor allows a system to behave in-elastically within the target ductility ratio during the design level earthquake ground. The objective of this study is to determine the ductility factor considering different parameters. It generally requires study to determine the Ductility factor. In the present study, the Ductility factor is determined for different parameters. For this purpose, statistical studies are carried out using different parameters such as the height of the tank, capacity of the tank, tank full and empty condition, and different earthquake zone. The Ductility factor is assumed to be a function of each of the above parameters. The effects of each parameter on the Ductility factor are also discussed at the end.

***Keywords*: Ductility factor, Pushover analysis, SAP2000, Two mass model**

(Article history: Received: 23/08/2022 and accepted 21/06/2023)

I. INTRODUCTION (*HEADING 1*)

As per the Review of Code Provisions on Design Seismic Forces for Liquid Storage Tanks by Dr. O. R. Jaiswal, Dr. D. C. Rai, and Dr. S. K. Jain, "It is well recognized that liquid storage tanks possess low ductility and energy absorbing capacity as compared to the conventional buildings." After a study of various design codes for seismic analysis of tanks, it is concluded that various design codes provide higher levels of design seismic forces for tanks. Wozniak and Mitchell (1978) state that "the high value of the lateral seismic coefficient for tanks in comparison with buildings is appropriate because of the low damping inherent for storage tanks, the lack of nonstructural load-bearing elements, and lack of ductility of the tank shell in longitudinal compression". The majority of the design codes follow the approach of assigning higher design seismic action for tanks compared to buildings. By what value the design action should be more that may be decided based on past earthquakes or failures. Ductility Factors Tanks should be designed for the displacement ductility factors. Ductility Factors appropriate to various tank materials, structural form and type of support are specified. The intention is to ensure that all tanks retain their contents under a level of earthquake shaking for the appropriate risk factor and return period. In general, it depends on the ductility of the tank and the energy-absorbing capacity of tank can provide. For elevated storage tanks, ductility, redundancy, and energy-absorbing capacity are mainly governed by the staging system. Due to low ductility and energy-absorbing capacity, liquid storage tanks are generally designed for higher seismic forces as compared to the force of conventional buildings. For elevated tanks, Whittaker and Jury (2000) do not provide specific information on ductility factor, Rμ. However, it mentions that for elevated tanks, ductility factor as appropriate for support structure should be considered. This may imply that if supporting structure is quite ductile then value of μ can be as high as for buildings (i.e., $\mu = 6$ to 10). In this article, statistical studies are carried out to determine ductility factors for different parameters such as the height of the tank, capacity of the tank, tank full and empty condition, and different earthquake zone.

II. METHODOLOGY

The response Reduction factor 'R', which means for ductility, redundancy, Overstrength, and damping of a structural configuration. Ductility Factor (Rμ) is defined as the capacity to undergo large inelastic deformations without significant loss of strength or stiffness. As per ATC 19, ductility factor can be calculated as follows.

$$R\mu = \{(\mu - 1 / \Phi) + 1\}$$

μ= ductility ratio = Δm/ Δy

Where, Δm=Maximum drift capacity,

Δy=Yield drift

Following Parameters are selected to determine the value of ductility factor

- Zone: II, III, IV &V
- Height: 20m, 30m & 40m
- Capacity of tank: 5 lakh, 7.5 lakh & 10 lakh litre
- Empty and Full tank
- Shape of thank.

The Pushover Analysis is carried out for each of above parameters under permanent gravity loading and gradually increasing lateral loading to calculate the displacement as well as pattern of damage. A plot (Capacity Curve) of the total base shear of the structure and top displacement in a structure is obtained by this analysis that would indicate any premature weakness. For developing modelling parameters, performance level of the structure and measures of pushover analysis the guidelines of ATC-19 and FEMA356 has been followed. Two action of forces are used to govern the inelastic behaviour of the member during the pushover analysis that is force controlled or deformation-controlled. Figure 1 shows Elevated water tank model analysed for pushover analysis.

For each of the above category and parameters individual tank has been design as shown in table 1. For each category size of each member for different staging heights and for capacities are different. Area of steel for each member are also assigned. All analysis has been carried out using SAP software. Total 72 models are prepared for this analysis. This paper is to propose a new pushover procedure to evaluate seismic responses of elevated water tanks supported on the concrete columns in the form of dynamic capacity curves (i.e. base shear versus top displacement). In this regard, a series of concrete supported elevated water tanks are analysed for different parameters considering fluid-structure interactions. As there are many pushover curves has been developed for the analysis, here only two pushover curves are shown in figure 2 and figure 3 for 20m height, 1000000 liters capacity and zone 4 and 5 respectively. One sample calculation is also shown here. The analysis based on shape of container is also has been carried out for many parameters, for zone V only included here.

For hard Soil

$$\emptyset = 1 + \left(\frac{1}{10T - \mu T}\right) - \frac{1}{2T} * e^{-1.5(\ln(T) - 0.60)^{\wedge}2}$$

For Medium Soil

$$\emptyset = 1 + \left(\frac{1}{12T - \mu T}\right) - \frac{2}{5T} * e^{-2.0(\ln(T) - 0.20)^{\wedge}2}$$

For soft soil

$$\emptyset = 1 + \left(\frac{T_g}{3T}\right) - \left(\frac{3T_g}{4T}\right) * e^{-3.0(\ln(T/T_g) - 0.25)^{\wedge}2}$$

- Maximum drift capacity Δm =0.004H=74.4 mm
- Yield drift Δy =23.89mm (from pushover curve)
- μ= ductility ratio = Δm / Δy = 3.11
- time period T =1.02 sec
- Φ=3.1029
- Rμ = {(μ - 1 / Φ) + 1} = 1.68

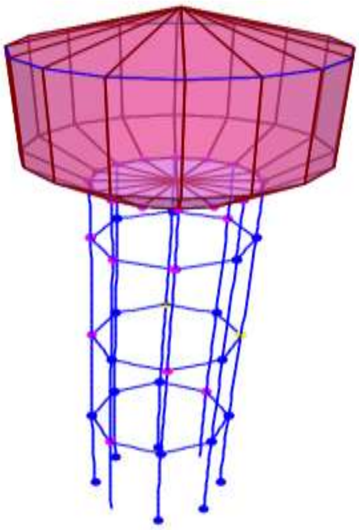


Figure 1: Elevated water tank model of pushover analysis.

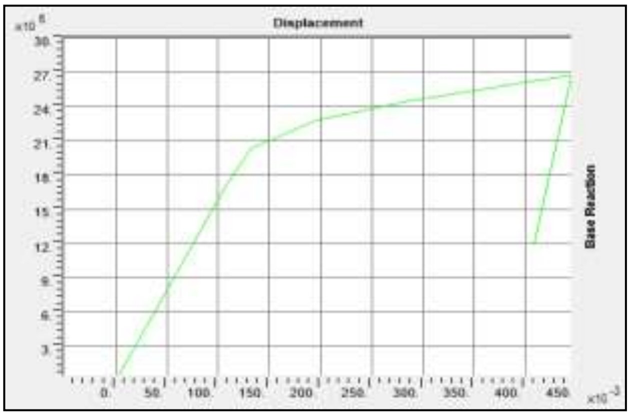
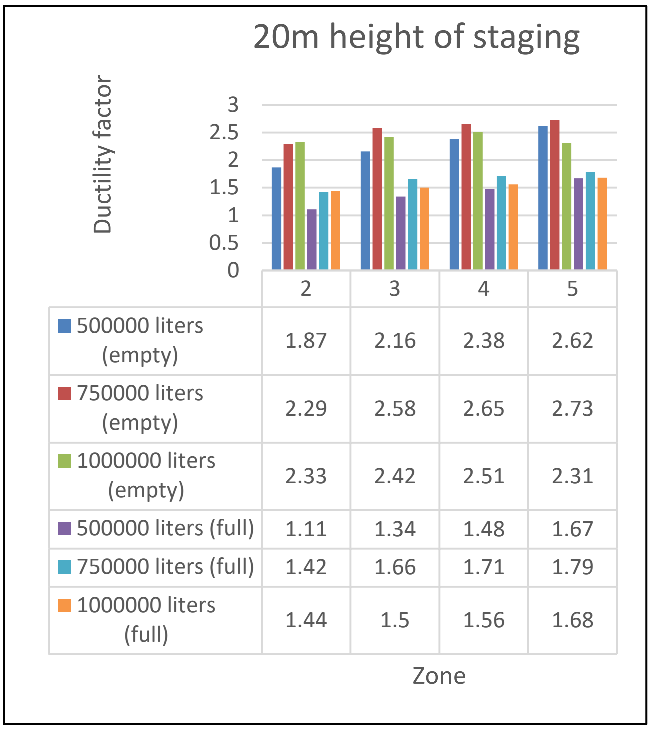


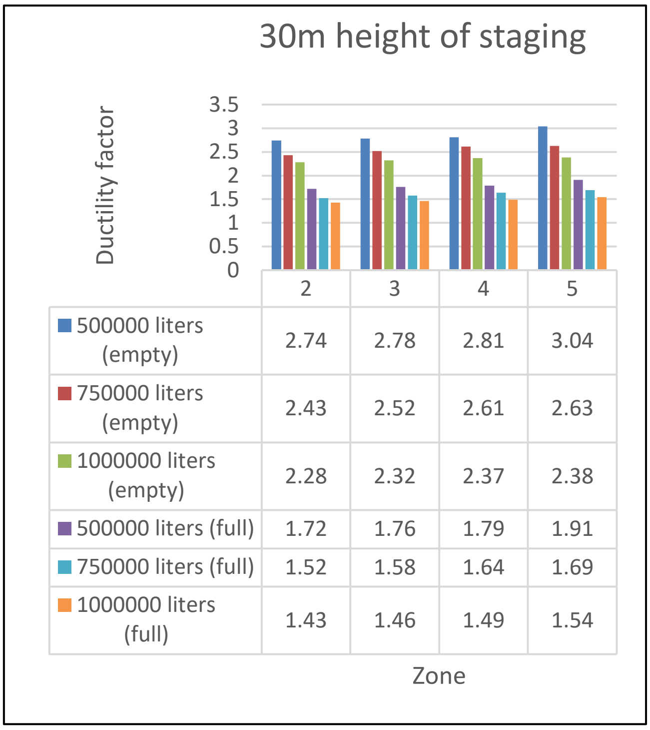
Figure 2: Pushover curve for 20m, 1000000 liters, Z-4

Figure 3: Pushover curve for 20m, 100000 liters, Z-5



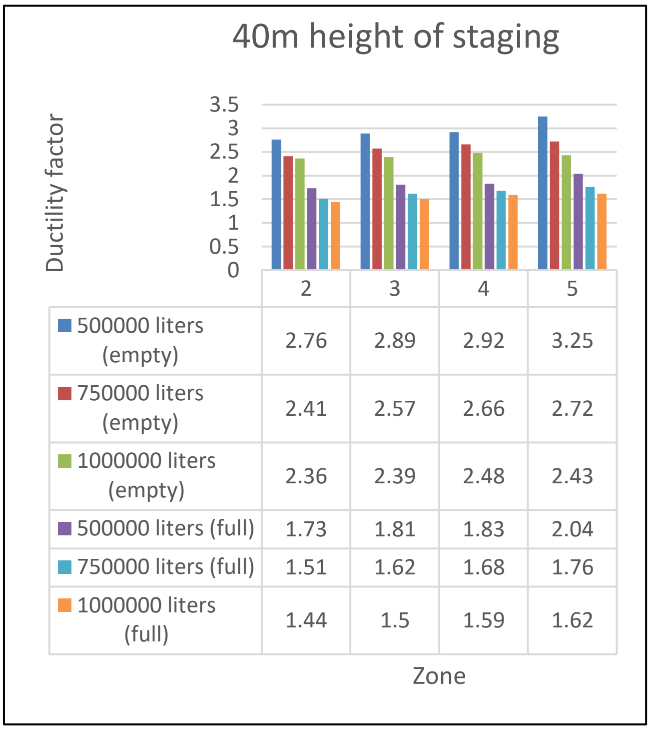
	2	3	4	5
■ 500000 liters (empty)	1.87	2.16	2.38	2.62
■ 750000 liters (empty)	2.29	2.58	2.65	2.73
■ 1000000 liters (empty)	2.33	2.42	2.51	2.31
■ 500000 liters (full)	1.11	1.34	1.48	1.67
■ 750000 liters (full)	1.42	1.66	1.71	1.79
■ 1000000 liters (full)	1.44	1.5	1.56	1.68

Figure 4: Ductility factor for 20m height of staging for different Capacity and Zone



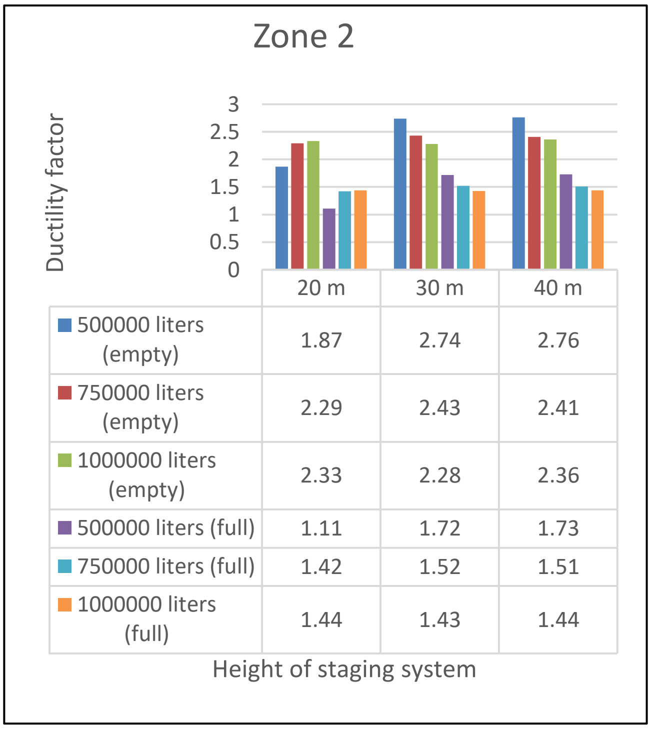
	2	3	4	5
■ 500000 liters (empty)	2.74	2.78	2.81	3.04
■ 750000 liters (empty)	2.43	2.52	2.61	2.63
■ 1000000 liters (empty)	2.28	2.32	2.37	2.38
■ 500000 liters (full)	1.72	1.76	1.79	1.91
■ 750000 liters (full)	1.52	1.58	1.64	1.69
■ 1000000 liters (full)	1.43	1.46	1.49	1.54

Figure 5: Ductility factor for 30m height of staging for different Capacity and Zone



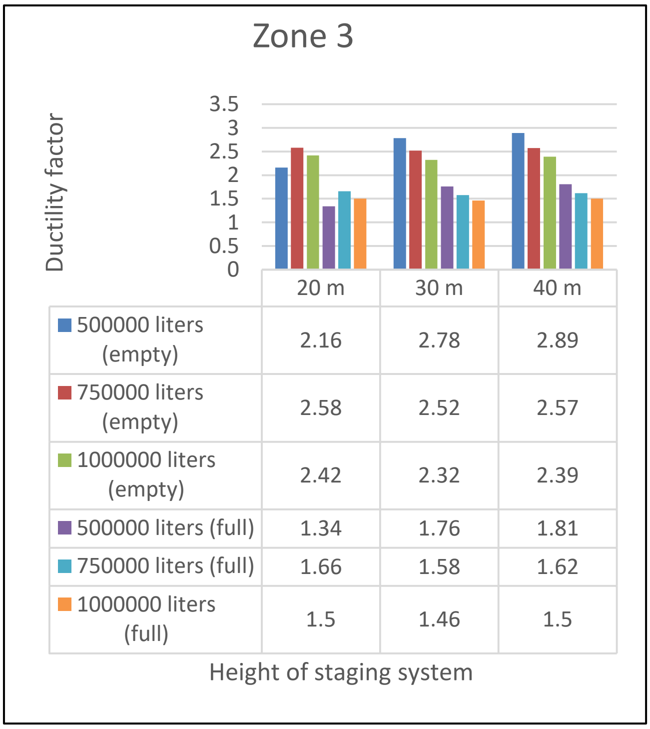
	2	3	4	5
■ 500000 liters (empty)	2.76	2.89	2.92	3.25
■ 750000 liters (empty)	2.41	2.57	2.66	2.72
■ 1000000 liters (empty)	2.36	2.39	2.48	2.43
■ 500000 liters (full)	1.73	1.81	1.83	2.04
■ 750000 liters (full)	1.51	1.62	1.68	1.76
■ 1000000 liters (full)	1.44	1.5	1.59	1.62

Figure 6: Ductility factor for 40m height of staging for different Capacity and Zone



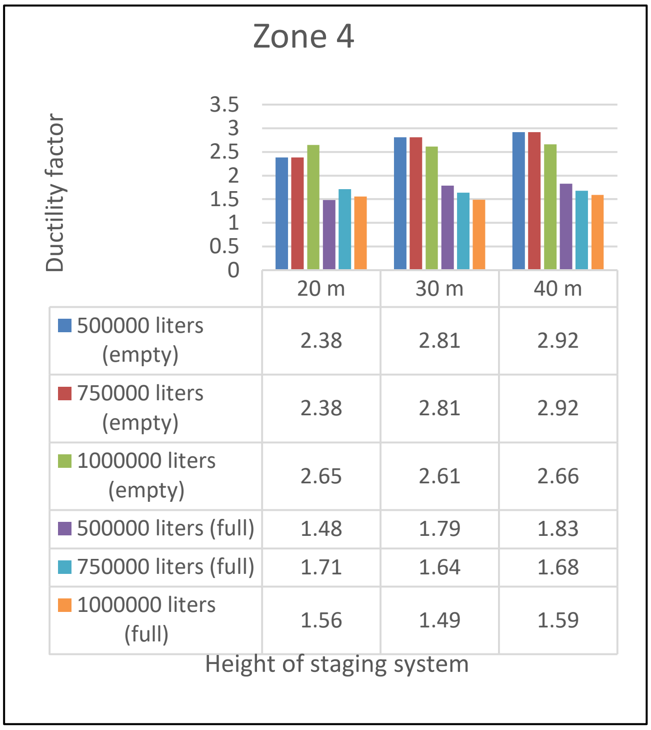
	20 m	30 m	40 m
■ 500000 liters (empty)	1.87	2.74	2.76
■ 750000 liters (empty)	2.29	2.43	2.41
■ 1000000 liters (empty)	2.33	2.28	2.36
■ 500000 liters (full)	1.11	1.72	1.73
■ 750000 liters (full)	1.42	1.52	1.51
■ 1000000 liters (full)	1.44	1.43	1.44

Figure 7: Ductility factor for Zone 2 and height of staging for different Capacity



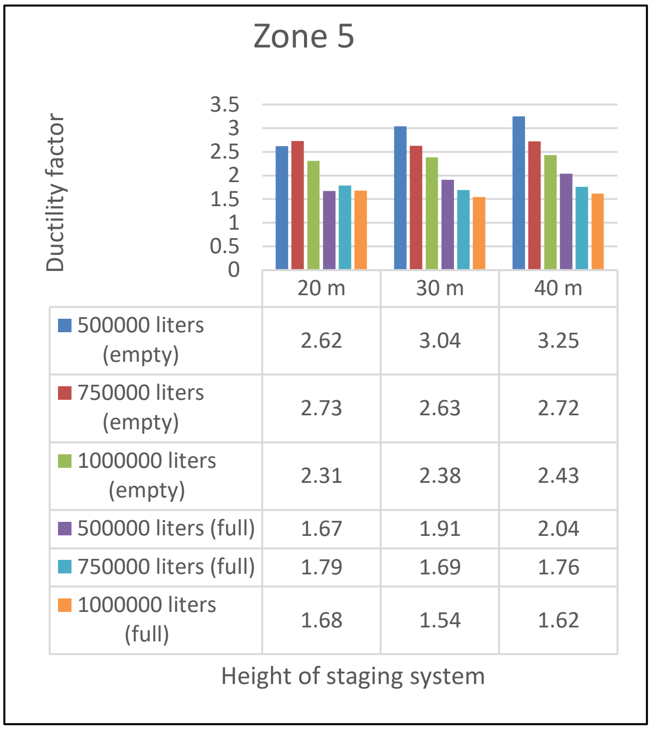
	20 m	30 m	40 m
■ 500000 liters (empty)	2.16	2.78	2.89
■ 750000 liters (empty)	2.58	2.52	2.57
■ 1000000 liters (empty)	2.42	2.32	2.39
■ 500000 liters (full)	1.34	1.76	1.81
■ 750000 liters (full)	1.66	1.58	1.62
■ 1000000 liters (full)	1.5	1.46	1.5

Figure 8: Ductility factor for Zone 3 and height of staging for different Capacity



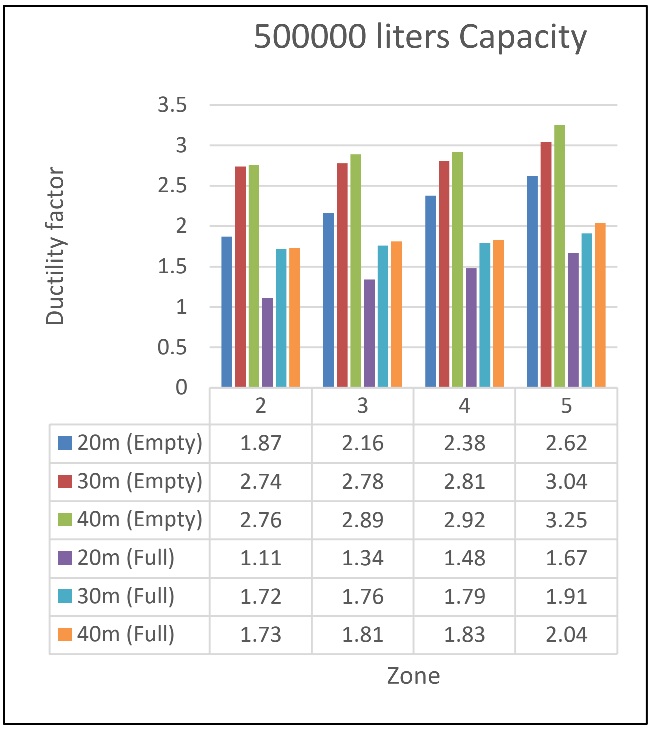
	20 m	30 m	40 m
■ 500000 liters (empty)	2.38	2.81	2.92
■ 750000 liters (empty)	2.38	2.81	2.92
■ 1000000 liters (empty)	2.65	2.61	2.66
■ 500000 liters (full)	1.48	1.79	1.83
■ 750000 liters (full)	1.71	1.64	1.68
■ 1000000 liters (full)	1.56	1.49	1.59

Figure 9: Ductility factor for Zone 4 and height of staging for different Capacity



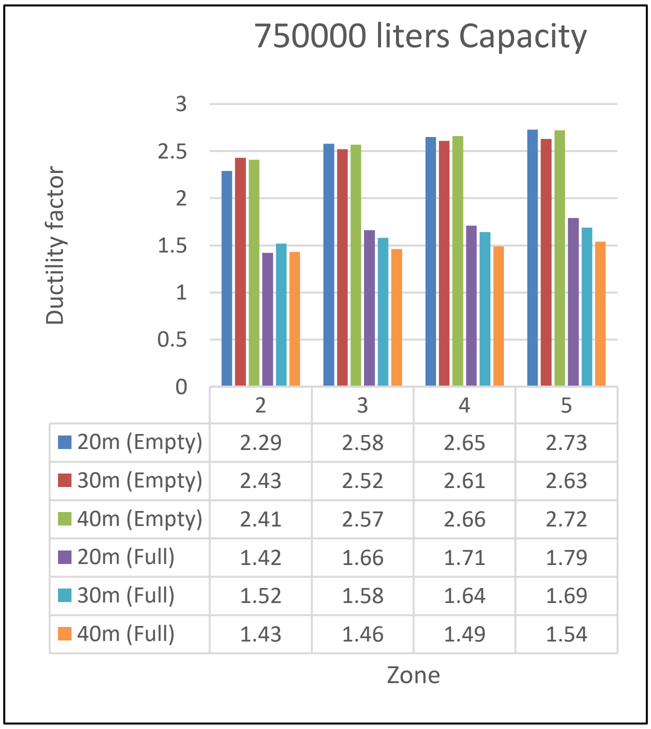
	20 m	30 m	40 m
■ 500000 liters (empty)	2.62	3.04	3.25
■ 750000 liters (empty)	2.73	2.63	2.72
■ 1000000 liters (empty)	2.31	2.38	2.43
■ 500000 liters (full)	1.67	1.91	2.04
■ 750000 liters (full)	1.79	1.69	1.76
■ 1000000 liters (full)	1.68	1.54	1.62

Figure 10: Ductility factor for Zone 5 and height of staging for different Capacity



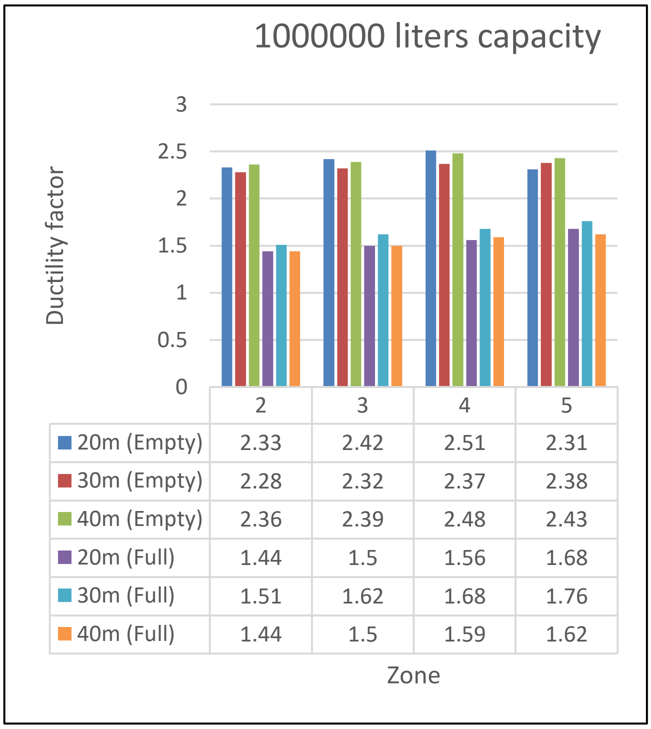
	2	3	4	5
■ 20m (Empty)	1.87	2.16	2.38	2.62
■ 30m (Empty)	2.74	2.78	2.81	3.04
■ 40m (Empty)	2.76	2.89	2.92	3.25
■ 20m (Full)	1.11	1.34	1.48	1.67
■ 30m (Full)	1.72	1.76	1.79	1.91
■ 40m (Full)	1.73	1.81	1.83	2.04

Figure 11 Ductility factor for 500000 liters capacity of container and for different Staging height and Zone



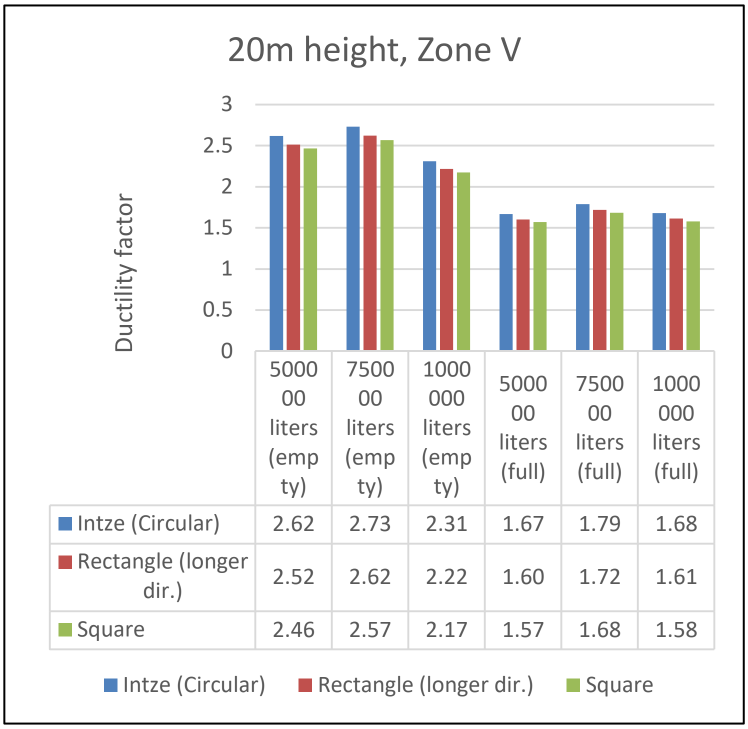
	2	3	4	5
🟦 20m (Empty)	2.29	2.58	2.65	2.73
🟥 30m (Empty)	2.43	2.52	2.61	2.63
🟩 40m (Empty)	2.41	2.57	2.66	2.72
🟪 20m (Full)	1.42	1.66	1.71	1.79
🟦 30m (Full)	1.52	1.58	1.64	1.69
🟧 40m (Full)	1.43	1.46	1.49	1.54

Figure 12 Ductility factor for 750000 liters capacity of container and for different Staging height and Zone



	2	3	4	5
🟦 20m (Empty)	2.33	2.42	2.51	2.31
🟥 30m (Empty)	2.28	2.32	2.37	2.38
🟩 40m (Empty)	2.36	2.39	2.48	2.43
🟪 20m (Full)	1.44	1.5	1.56	1.68
🟦 30m (Full)	1.51	1.62	1.68	1.76
🟧 40m (Full)	1.44	1.5	1.59	1.62

Figure 13 Ductility factor for 1000000 liters capacity of container and for different Staging height and Zone

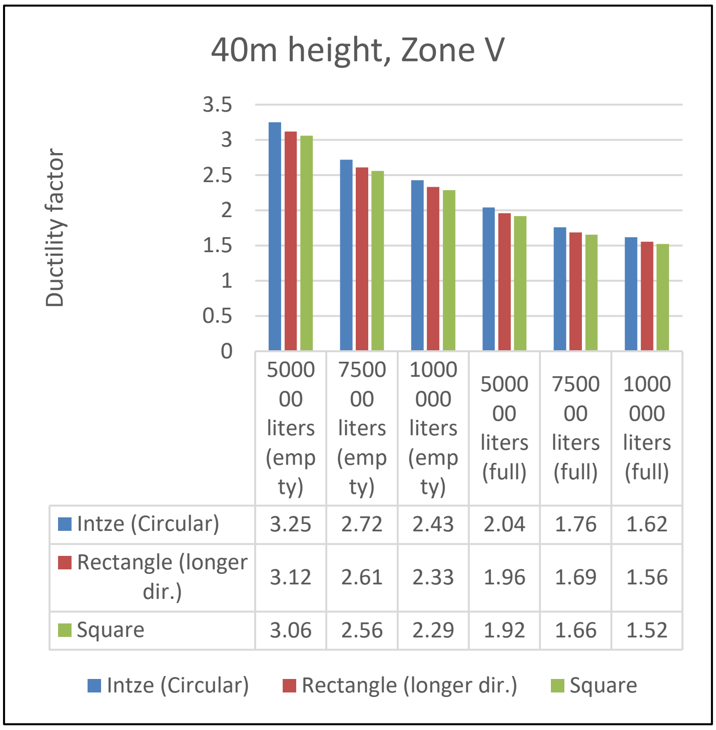


	500000 liters (empty)	750000 liters (empty)	1000000 liters (empty)	500000 liters (full)	750000 liters (full)	1000000 liters (full)
🟦 Intze (Circular)	2.62	2.73	2.31	1.67	1.79	1.68
🟥 Rectangle (longer dir.)	2.52	2.62	2.22	1.60	1.72	1.61
🟩 Square	2.46	2.57	2.17	1.57	1.68	1.58

Figure 14: Ductility factor for 20m height, Zone V for different capacity and shape of container

	500000 liters (empty)	750000 liters (empty)	1000000 liters (empty)	500000 liters (full)	750000 liters (full)	1000000 liters (full)
🟦 Intze (Circular)	3.04	2.63	2.38	1.91	1.69	1.54
🟥 Rectangle (longer dir.)	2.92	2.52	2.28	1.83	1.62	1.48
🟩 Square	2.86	2.47	2.24	1.80	1.59	1.45

Figure 15: Ductility factor for 30m height, Zone V for different capacity and shape of container



	500000 liters (empty)	750000 liters (empty)	1000000 liters (empty)	500000 liters (full)	750000 liters (full)	1000000 liters (full)
🟦 Intze (Circular)	3.25	2.72	2.43	2.04	1.76	1.62
🟥 Rectangle (longer dir.)	3.12	2.61	2.33	1.96	1.69	1.56
🟩 Square	3.06	2.56	2.29	1.92	1.66	1.52

Figure 16: Ductility factor for 40m height, Zone V for different capacity and shape of container

III. DISCUSSION OF FIGURES AND RESULT

For the largest capacity and largest height of the water tank, the variation in the Ductility factor is less, which is around 1% to 11%. While for the smallest capacity and smallest height the variation in the Ductility factor is more, which is around 9% to 30%. For small heights, large variation in the Ductility factor which is around 11% to 42% for different zone and tanks empty and full in condition, as height increased variation is described to 2% to 16%. It is also observed that by keeping height constant more variation in empty tank condition compare to tank full condition. As height increases the Ductility factor is also increased. As the Seismic zone increases the Ductility factor is also increased. More difference was observed for lesser capacity compared to large capacity. For lesser capacity, it is around 40% to 50%, while for large capacity it’s 2% to 8%. For law seismic zone variation in the Ductility factor more, as seismic zone increased variation in the value of the Ductility factor less. As the capacity of the tank increased the Ductility factor decreased, this is the only parameter for which the ductility factor decreased with the increase in capacity. The variation in value is around 2 to 14 %. There is less effect of shape of container on the ductility factor. As circular shape container is having more value compare to container rectangle and square in shape. The variation in ductility factor due to shape is around 5 to 10%. The value of the Ductility factor for the tank empty condition is more compared to the tank in full condition for each parameter. i.e. height of the tank, capacity of the tank, and Earthquake zone. (Refer to figure 4 to figure 16 for all the above justifications).

IV. CONCUSSION

Hence, from the above discussion, we can conclude that,

- For the largest capacity and largest height, the variation in the Ductility factor is less.
- For the smallest capacity and smallest height the variation in the Ductility factor is more.
- For small heights, large variation in the Ductility factor, as height increased less variation
- By keeping height constant more variation in empty tank condition compare to the tank full
- As height increases the Ductility factor also increased
- As the Seismic zone increases the Ductility factor also increased
- For law seismic zone variation in the Ductility factor more, as seismic zone increased variation in the Ductility factor less.
- As the capacity of the tank increased the Ductility factor decreased.
- There is less effect of shape of container on the ductility factor. The value of ductility factor is more for circular shape in compare with others.
- The Ductility factor for tank empty condition is more compared to tank in full condition for each parameter. i.e. height of the tank, capacity of the tank, and Earthquake zone.

ACKNOWLEDGMENT

Each and every work that one completes successfully stands on the good will and support of the people around. And thus, I am thankful to all those who created an extremely auspicious ambience for my study.

I would like to thank my guide Dr. Indrajit N. Patel, Structural Engineering Department, BVM, Vallabh Vidyanagar, for providing a vision about the. I have greatly benefited from the regular critical reviews and inspiration. His technical and editorial advices were essential. Sir explained me valuable lessons and insights of academic research in general. Working under his supervision has been a stimulating and rewarding experience. I would also like to thank my parent university Gujarat Technological University-Ahmedabad for giving me support.

REFERENCES

[1] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. (references)

[2] Dr. Durgesh C Rai Dr. Sudhir K Jain, “Review of Code Provisions on Design Seismic Forces for Liquid Storage Tanks”.

[3] Mostafa Masoudi, Sassan Eshghi, Mohsen Ghafory Ashtiany, “Evolution of response modification factor (R) for elevated concrete water tanks,” Rose School, IUSS Pavia, Italy, Engineering Structures vol. 39, pp. 199–209, 2012.

[4] Chintha. Ravichandra, R. K. Ingle, “Analysis of cylindrical Water tanks- Wind or Earthquake,” International Journal of Mechanical And Production Engineering, Volume- 3, Issue-7, pp 96-100, July-2015.

[5] Jignesh A. Amin and D.P.Soni, “Assessment Response Reduction Factor of Elevated Tanks with Alternate RC Frame Staging Configurations”, International Journal of Engineering Technology Science and Research, Vol. 04, Issue No. 12, December 2017.

[6] Kamila Kotrasova, “Study of hydrodynamic pressure on wall of tank,” Science Direct, Procedia Engineering, vol. 190, pp 2 – 6, 2017.

[7] Roja M, T.S Sahana, Dr Naveen G M, Sagar S, “Performance Based Evaluation Of Response Reduction Factor For Elevated Rectangular Water Tank,” International Research Journal of Engineering and Technology, Volume: 03 Issue: 06, June-2016.

[8] Jinkoo Kim, Hyunhoon Choi., “Response modification factors of chevron-braced frames” by Engineering Structures vol. 27, pp 285–300, 2005

[9] Tejash Patel, Jignesh Amin, Bhavin Patel, “Evaluation response reduction factor of RC framed staging elevated water tank using static pushover analysis,” International Journal of Civil and Structural Engineering Volume 4, No 3, 2014.

[10] Latesh T.Patil, Prof. Dr. Rajashekhar Talikoti, “Comparison of Seismic Behaviour of Rectangular Elevated Water Tank,” International Journal for Scientific Research & Development, Vol. 3, Issue 05, pp 558-561, 2015.

[11] Kashyap N. Patel, Jignesh A. Amin, “Performance based assessment of response reduction factor of RC elevated water tank considering soil flexibility: a case study,” International Journal of Advanced Structural Engineering, vol 10, pp 233–247, 2018.

[12] Nishigandha R.Patil, Dr. R. S. Talikoti, “Seismic Analysis of Elevated Water Tank,” International Journal of Civil and Structural Engineering Research, Vol. 3, Issue 1, pp: 90-94, Month: April 2015 - September 2015.

[13] Dutta, S., Chandra, S. & Roy, R. (2009) “Dynamic behavior of RC elevated tanks with soil – structure interaction. Engineering Structures”, 31(11), 2617–2629. https://doi.org/10.1016/j.engstruct.2009.06.010

[14] Ghateh, R., Kianoush, M. R., & Pogorzelski, W. (2015) “Seismic response factors of reinforced concrete pedestal in elevated water tanks”, Engineering Structures, 87, 32–46. https://doi.org/10.1016/j.engstruct.2015.01.017

[15] Gondalia, M. R., Prof, A., & Patel, D. (2017) “Non-linear static Pushover analysis on elevated storage reservoir (ESR)”International Journal of Advance Engineering and Research 656–666.

[16] Omidinasab, F., & Shakib, H. (2008) “Seismic Vulnerability of Elevated water tanks using Performance Based-Design”

[17] Sandeep T D(2017) “A comparative studies on elevated water tank due to dynamic loading” ,international research journal of engineering and technology (irjet), 4 (05), 2000-2004

[18] George W. Housner (1963) “The dynamic behavior of water tanks” Bulletin of the Seismological Society of America”, Vol.53, No. 2, pp. 381-387.

[19] Sajjad Sameer U and Sudhir K. Jain (1994) “Lateral-Load Analysis of Frame Staging’s for Elevated Water Tanks”, American Society of Civil Engineers, Journal of Structural Eng. 120, pp.1375-1394.

[20] Jain Sudhir K., Sameer U.S., 1990, “Seismic Design of Frame Staging For Elevated Water Tank”, Ninth Symposium on Earthquake Engineering (9SEE-90), Roorkey, December 1416, Vol-1.

[21] Sudhir K. Jain and M. S. Medhekar, October-1993, “Proposed provisions for a seismic design of liquid storage tanks”, Journals of structural engineering Vol.-20, No.-03

[22] ATC -19 “Structural Response modification factors” ATC-19 Report, Applied Technology Council Redwood City California, 1995

[23] ATC 40 (1996): “Seismic Evaluation and Retrofit of Concrete Buildings”, Volume 1, ATC-40 Report, Applied Technology Council, Redwood City, California.

[24] FEMA-356, Federal Emergency Management Agency, Prestandard and commentary for seismic rehabilitation of buildings. Washington (DC); 2000.

[25] FEMA 273 “NEHRP Guidelines for the seismic Rehabilitation of Buildings”, developed by the Building seismic safety council for the federal Emergency Management agency (Report NO. FEMA 273), Washington D.C. 1997.

[26] IITK-GSDMA guidelines for seismic design of liquid storage tanks.

[27] IS 456: “Indian standard code of practice for plain and Reinforced Concrete”, Bureau of Indian standards, New Delhi, 2000.

[28] IS 1893, “Criteria for Earthquake Resistance Design of Structures-Part 1; General Provisions and Buildings (Sixth Revision)”, Bureau of Indian Standards, New Delhi, 2016.

[29] IS 1893, “Criteria for Earthquake Resistance Design of Structures-Part 2; Liquid Retaining Tanks (Fifth Revision)”, Bureau of Indian Standards, New Delhi, 2014.

[30] IS 3370, “Code of Practice Concrete Structures for Storage of Liquids (First Revision)”, Bureau of Indian Standards, New Delhi, 2009.

[31] IS 11682 (1985): “Criteria for design of RCC staging for overhead water tanks” [CED 38: Special Structures].

AUTHOR PROFILE

Vimleshkumar V. Agrawal

He is currently a Ph. D research scholar at Gujarat Technological University-Ahmedabad, India. He is working as an Assistant Professor at Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, Gujarat. He has 19 years of teaching experience. He has published more than 30 research papers. His area of interest is Earthquake Engineering, Structural analysis and Design etc.

Email:
vvagrawal@bvmengineering.ac.in