Proceedings of the World Congress on Engineering 2010 Vol III
WCE 2010, June 30 - July 2, 2010, London, U.K.

Formulation of Response Reduction Factor for RCC Framed Staging of Elevated Water Tank using Static Pushover Analysis

Mr. Bhavin Patel[1] and Mrs. Dhara Shah[2]

Abstract **- The present study investigates the formulation of key factors for seismic response modification factor of RCC framed staging of elevated water tank. The analysis revealed that three major factors, called reserved strength, ductility and redundancy affects the actual value of response modification factor and therefore they must be taken into consideration while determining the appropriate response modification to be used during the seismic design process. The evaluation of response modification factor is done using static nonlinear pushover analysis. Pushover analysis is an advanced tool to carry out static nonlinear analysis of framed structures. It is used to evaluate non linear behavior and gives the sequence and mechanism of plastic hinge formation. Here displacement controlled pushover analysis is used to apply the earthquake forces at C.G. of container. The pushover curve which is a plot of base shear versus roof displacement, gives the actual capacity of the structure in the non linear range.**

Index Terms **- Response reduction factor, Seismic design, Static nonlinear pushover analysis.**

I. Introduction

Earthquake can induce large horizontal and overturning forces in elevated water tanks. Such tanks are quite vulnerable to damage in earthquakes due to their basic configuration involving large mass concentrated at top with relatively slender supporting system. When the tank is in full condition, earthquake forces almost govern the design of these structures in zones of high seismic activity. It is important to ensure that the essential requirement such as water supply is not damaged during earthquakes. In extreme cases, total collapse of tanks shall be avoided. However, some repairable damage may be acceptable during shaking not affecting the functionality of the tanks.

Severe damages were observed in buildings, public utility structures like water tanks and hospitals during 26th January 2001 Bhuj earthquake. IS:1893–1984 does not count the convective hydrodynamic pressures in the analysis of tank wall and assumes the tank as a single degree of freedom idealization. The accurate approach for analysis of water tank is to model the tank with two masses representing the impulsive as well as convective components of liquid. Lots of research has been made in two mass model of ESR and hydrodynamic analysis of the container. It has also been observed that a well designed and well constructed water tank can withstand more lateral loads than it is designed for due to three reasons:

- Over strength (R_S)
- Redundancy (R_R)
- Ductility (R_μ)

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

$$R = R_S * R_R * R_\mu.$$

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. The strength factor is a measure of base shear force at design level and at yielding. The ductility factor is a measure of roof displacement at yielding and at code specified limit. The redundancy factor depends on the number of vertical framing participated in seismic resistance.

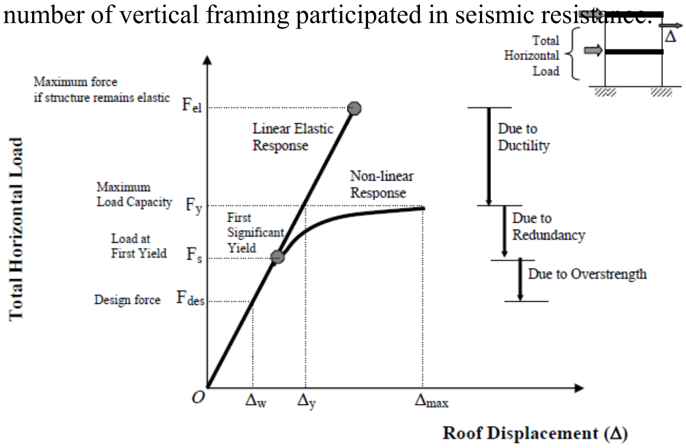

Fig.1. Definition of Response Reduction Factor

$$\text{Response reduction factor} = \frac{\text{Maximum elastic force } F_{el}}{\text{Design force } F_{des}}$$

R as per international standards for elevated tanks:

- IBC 2000 / FEMA 368 - R = 1.5 to 3.0
- AWWA D110 - $R_c = 1$, $R_i = 2$ to 2.75
- ACI 350.3 - R = 2.0 to 4.75
- IS:1893 – 2002 (part – 2)
  - RCC shaft support - R = 1.8
  - RCC frame support - R = 2.5

[1] Structural Engineer, VMS Engineering and design services (P) Ltd., Ahmedabad, Gujarat, India, (e– mail: bhavinpatel@vmsconsultants.com).
[2] Faculty of Technology, Structural Design Department, CEPT University, Ahmedabad, Gujarat, India, (e– mail: dhara@hasolon.com).

ISBN: 978-988-18210-8-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

II. CASE STUDY

In the present work, an existing water tank having rectangular container and supported on staging has been taken. The description and image of the tank is given below:

Location : Lalan College, Bhuj, Gujarat, India
Seismic zone : V (highest seismic zone)
Capacity of tank : 2.25 Lac liters ESR
Staging configuration: RCC framed staging
Staging geometry : 4 x 4 grid, total 16 columns
Staging height : 15 m
Tie beam levels : Plinth + 4 levels @ 3.0 m c/c
Column size : 350 x 350 mm
Beam size : 350 x 350 mm
Top slab thickness : 125 mm
Bottom slab thickness: 230 mm
Side wall thickness : 230 mm
Soil Type : Medium

Fig.2. Image of selected ESR located at Bhuj, Gujarat

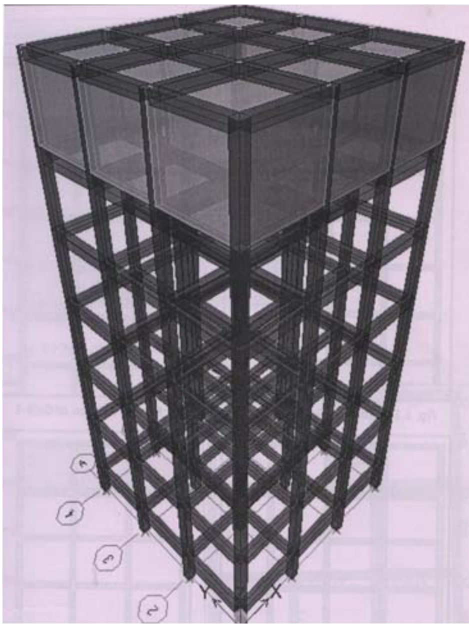

Fig.3. 3D view of Tank modeled in ETABS

In order to achieve the objective, the following procedure was adopted:

- Developing a three dimensional model of existing RCC Trestle
- Application of gravity loads, live loads, water load, etc.
- Application of static lateral load induced due to earthquake, at CG of container
- Developing *M-θ* & V- *δ* relationship for RCC Trestle
- Pushing the structure using the load patterns of static lateral loads, to displacements larger than those associated with target displacement using static pushover analysis
- Developing pushover curve and estimating the force and deformations in each element at the level of displacement corresponding to target displacement
- The element force and deformation demands of last step are then compared with the element capacities

Due to the proximity of highly seismic area, the tank was designed and detailed in accordance with the codal provisions of IS:1893 – 1984 and IS: 13920 – 1993. The container and framing system is modeled in ETABS for performing static pushover analysis. The analysis and design of container and framing members are skipped. The earthquake forces are estimated as per IS:1893 – 2002 (part – 2).

Moment-rotation (M-θ) and Axial load – Bending Moment (P-M) relationships for flexural and compression members have been developed using Kaustubh Dasgupta's software.

After assigning hinge properties to the structure, the static pushover cases were defined. Typically, the gravity loads were applied first and then subsequent lateral static pushover load cases were specified to start from the final conditions of the gravity pushover. In the gravity case, the structure was loaded with the dead load and 25% of the live load. The application of gravity loads was force-controlled whereas the application of lateral loads was displacement-controlled. The first mode response of the structure was assigned as the load pattern for the lateral push applied to the structure.

The procedure involves applying horizontal loads, in a prescribed pattern, to a computer model of the structure, incrementally; i.e., "pushing" the structure; and plotting the total applied shear force and associated lateral displacement at each increment [1]. From the analysis, the base shear (V) versus roof displacement (Δ_{roof}) curve of the structure, usually called static pushover curve, is obtained.

The nonlinear static procedure requires prior estimation of target displacement. The target displacement serves as an estimate of the maximum displacement of the selected point (node) in the subject structure during the design earthquake. The node associated with the center of mass at CG of container is often the target point or target node selected for comparison with target displacement.

The maximum limit for the roof displacement is specified as **0.004H**, where H is the height of the structure [2]. The

ISBN: 978-988-18210-8-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

base shear and roof displacement is recorded at every step. The final output is the static pushover curve.

In the present case, the height from the base to CG of container is 18 m and hence target displacement is set to 72 mm. The displacement is applied step-by-step to the structure in an incremental manner. The base shear and roof displacement is recorded at every step.

Due to plan symmetry of structure, the pushover analysis is carried out in X direction only. Hence, earthquake loads of tank full condition is given in X-direction only.

III. ANALYSIS AND RESULTS

Table 1. State of hinge formation

Step	Displacement mm	Base Force KN
0	0	0
1	4.9	142.78
2	9.9	285.55
3	13.8	397.9
4	19.2	549.03
5	24.5	686.2
6	29.9	799.94
7	31.1	821.25
8	31.1	848.75
9	36.3	979.58
10	41.3	1088.3
11	47.1	1182.2
12	52.4	1250.6
13	59.2	1319.4
14	65.4	1371.3
15	71.2	1413.6
16	77.2	1451.4

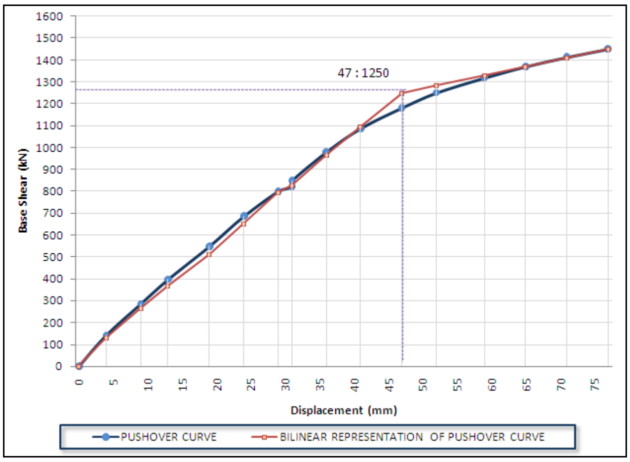

Fig.4. Pushover curve for the modeled tank

As shown in the table 1. above, the assigned hinges start yielding at a displacement value of 13.8 mm. There is no indication of strength degradation at any displacement value within the range of target displacement. Even after step 16, mechanism is not formed. However, here the limiting target displacement which is 72 mm is achieved.

1. *Estimation of strength factor:*

Maximum Base Shear V_0 = 1250 KN (from pushover curve)
Design Base shear V_d = 562 KN (as per EQ calculation)
Using equation for strength factor, given in ATC – 19
$R_S = V_0 / V_d = 1250 / 562 = 2.22$
$\mathbf{R_S = 2.22}$

2. *Estimation of ductility factor:*

Maximum drift capacity Δ_m = 72 mm (0.004 H)
Yield drift Δ_y = 47mm (from pushover curve)
Using equation for displacement ductility ratio, given in ATC – 19
$\mu = \Delta_m / \Delta_y = 72 / 47 = 1.53$

Using equation for ductility factor, derived by Miranda and Bertero
$R_\mu = \{(\mu - 1 / \Phi) + 1\}$
Φ for medium soil $=1+\{1 /(12T - \mu T)\}-\{(2 / 5T)*e^{-2(\ln(T) - 0.2)^2}\}$
T = 0.851 seconds (From ETABS model)
$\Phi = 0.66$
$\mathbf{R_\mu = 1.80}$

3. *Estimation of redundancy factor:*

Table 2. From ATC - 19

Lines of vertical seismic framing	Drift redundancy factor
2	0.71
3	0.86
4	1.00

$\mathbf{R_R = 1.00}$

4. *Estimation of response reduction factor R:*

$R = R_S \cdot R\mu \cdot R_R$

R = 2.22 x 1.80 x 1.00

R = 4.0

Hence the value of response reduction factor can be estimated as 4.0 for the selected model of RCC framed staging of ESR.

IV. CONCLUSION

1. There is no mathematical basis for the response reduction factor tabulated in Indian design codes.

2. A single value of R for all buildings of a given framing type, irrespective of plan and vertical geometry, cannot be justified. But for ESR staging (beam – column frame or shaft), where the basic system of framing and behavior is more or less common, the

ISBN: 978-988-18210-8-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

method can be derived to evaluate R – factor. Similar effort has been made here.

3. To ensure the consistent level of damage, values of R should depend on both fundamental period of the staging and the soil type.

4. The values assigned to R for a given framing system should vary between seismic zones. Also detailing requirements vary by zone.

REFERENCES

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

[2] I.S. 1893 (2002): “Indian Standard Criteria for Earthquake Resistant Design of Structures Part 1: General Provisions and Buildings”, Bureau of Indian Standards, New Delhi.

[3] ATC 19 (1995) “Structural Response Modification Factors”, Applied technology council, Redwood city, California.

[4] Andrew Whittker, Gary hart and Christopher Rojahn, “Seismic Response Modification Factors”, journal of structural engineering, vol. 125, april 1999.

[5] Chopra, A.K. (2001): “Dynamics of Structures – Theory and Applications to Earthquake Engineering”, Pearson Education (Singapore) Pte. Ltd.

[6] Dasgupta, P. (2000): “Effect of confinement on strength and ductility of large RC Hollow Sections”, M. Tech. Thesis, I.I.T. – Kanpur.

[7] FEMA 273 (1997): “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.

[8] Habibullah, A. and Pyle, S. (1998): “Practical Three Dimensional Nonlinear Static Pushover Analysis”, Published in Structure Magazine, Winter, 1998.

[9] I.S. 456 (2000): “Indian Standard Code of Practice for Plain and Reinforced Concrete”, Bureau of Indian Standards, New Delhi.

[10] Jain, S.K. and Murty, C.V.R. (2003): “Two-day Workshop on IS:1893 (1) – 2002”, Ahmedabad, 19-20 April, 2003.

[11] Kim, S. and D’Amore, E. (1999): “Pushover Analysis Procedure in Earthquake Engineering”, Earthquake Spectra, The Professional Journal of the Earthquake Engineering Research Institute, Volume 15, No. 3, August 1999.

[12] Moghadam, A.S. and Tso, W.K. (2000): “Seismic Assessment of Buildings using Pushover Analysis”, Advances in structural dynamics, Vol. II, J.M. Ko and Y.L. Xu (Eds.), 2000, Published by Elsevier Science Ltd.

[13] Park, R. and Paulay, T. (1975): “Reinforced Concrete Structures”, John Wiley & Sons, Inc., 605 Third Avenue, New York.

ISBN: 978-988-18210-8-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)