RESEARCH ARTICLE OPEN ACCESS

Seismic Analysis of Reinforced Concrete Shaft Support Water Storage Tank

Bharti Tekwani*, Dr. Archana Bohra Gupta**
*(Department of structural engineering, MBM collage,JNVU University, jodhpur)
** (Department of structural engineering, MBM collage,JNVU University, jodhpur)

ABSTRACT
This paper compares the results of Seismic Analysis of Reinforced Concrete Shaft Support Water Storage Tank carried out in accordance with IS: 1893- 1984 and IS: 1893-2002 (Part-2) draft code. The analysis is carried out for shaft supported water tank of 500,750 and 1000 Cu.m capacity, located in four seismic zones (Zone-II, Zone -III, Zone-IV, Zone-V) and on three different soil types (Hard rock, Medium soil, Soft soil). Further, 1000 kl tank for conditions - tank full, tank empty are also considered in this study. The analysis was performed using MAT LAB. The parameters of comparison include base shears, base moments and time history analysis. The above models are analyzed for different time history data such as El Centro, Kobe, Ji-Ji, Erzincan. The comparison is made between the structural responses of one mass and two mass models of above capacity.
Keywords : One mass model, two mass model, shaft staging, time history

I. INTRODUCTION

During the 30 September 1993, Killari earthquake and 26 January 2001, Bhuj earthquake large number of water tower structures were severely damaged This has developed an active interest in the field so as to rationalize the ideas of the dynamic behavior of water tanks with particular reference to earthquake effects on them. Muzaffarabad earthquakes (2005) Kuch and Bhuj earthquakes (2001) are the recent example.

1.1 Shaft Type Staging

Shaft Staging – It is a tower in the form of shaft is called shaft staging .Staging consisting of shell like a circular or polygonal cylinder or hollow prism. The tower may be in the form of single shaft circular or polygonal in plan and may be tapering. The area enclosed within the shafts may be used for providing the pipes, stairs, electrical control panels, valves, etc. The shaft
staging is to be designed for vertical load due to the weight of the container, the weight of the water and the self weight as well as horizontal forces due to wind or earthquakes.

Types of shaft staging
1. Polygonal Shaft
2. Circular shaft

1.2Failure of Shaft Staging

Hollow circular shaft is the most popular type of staging to support a tank container. The height of the shaft varied from a minimum of about 10m to a maximum of 20m whereas the shape and size of the tank container largely depended on the storage capacity and required head for the water supply. The affected tanks varied in their storage capacity from 80 kL to 1000 kL. The diameter of the staging generally increases with increase in the capacity of the tank; however, the thickness of the staging section is usually kept between 150 and 200 mm.

1.3 Time History Analysis

Time History analysis is a step by step analysis of the dynamic response of the structure at each increment of time when its base is subjected to specific ground motion time history. To perform such an analysis a representative earthquake time history is required for a structure being evaluated. It is used to determine the seismic response of a structure under dynamic loading of representative earthquake.

II. METHODOLOGY

2.1 Procedure For Calculation of Seismic Responses Using IS: 1893-2002(Part 2) Draft Code.

Step-1: Based on capacity of water tank, fix the approximate dimensions for each component of water tank.

Step-2: Compute the seismic weight of the water tank with staging (W*)*.

Step-3: Determine the c.g of empty container from top of footing.

Step-4: Find the parameters of spring mass model based on h/D ratio of water tank. i.e. (mi, mc, hi, hi*, hc, hc*).

Step-5: Compute the lateral stiffness of staging. [Clause 4.3.1.3 of IS: 1893-2002(Part-2) draft code]

Step-6: Compute the impulsive and convective time period for water tank.

$T_i = 2\pi\sqrt{(m_i+m_s)/k_s}$ [Clause 4.3.1.3 & 4.3.2.2(a) of IS: 1893 - 2002(Part-2) draft code]

Step-7: Compute design horizontal seismic coefficient for impulsive & convective mode.

(Ah) i=ZI (Sa/g)/ (2R) [Clause 4.5 & 4.5.1 of IS: 1893- 2002 (Part-2) draft code]
(Ah)i = Design horizontal acceleration spectrum value
Z= Zone factor in Table 2 of IS: 1893-2002(Part-1),
I= Importance factor given in Table 1 of IS: 1893-2002(Part-2) draft code,
R=Response reduction factor given in Table 2 of IS: 1893-2002(Part-2) draft code,
Sa/g= Average response acceleration coefficient as given by Fig.2 and Table 3 of IS: 1893-2002(Part -1) [Clause 4.5.1 & 4.5.4 of IS: 1893-2002 (Part-2) draft code]

Step-8: Compute base shear (V) at the bottom of staging for elevated water tank in impulsive & convective mode

$V_i = (Ah)_i(mi+ms)g$,

$V_c = (Ah)_c\,(mi+ms)g$ &

$V = \sqrt{(Vi^2)+(Vc^2)}$

Step-9: Compute base moment in impulsive and convective mode (M*).

M*=√ (Mi*) + (Mc*)

Step-10: compute sloshing wave height

$d_{max} = (A_h)_c R \frac{D}{2}$ for circular tank

2.2 Procedure For Calculation of Seismic Responses Using IS: 1893-1984.

Step-1: The elevated water tank is idealized as single degree of freedom system with their mass Concentrated at their centre of gravity.

Step-2: Damping is considered as 2% of critical for free steel structure and 5% for concrete structure.

Step-3: Time period in second can be calculated as

$$T = 2\Pi\sqrt{(\Delta/g)}$$

Were, Δ = Static horizontal deflection at the top of the tank under static horizontal force equal to Weight W acting at C.G. of tank.

g = acceleration due to gravity.

When empty: the weight W used in the design shall consist of dead load of the tank and 1/3 the
Weight of the staging.

When Full : The weight of content is to be added to the weight under empty condition using period T & appropriate the spectral acceleration shall be read off from avg. Acceleration spectra. **Step-4:** The design horizontal seismic Coefficient 'αh' shall be calculated.

β = Coefficient depending upon soil foundation system calculated from table 3 clause 3.4.3

I = Factor depending upon importance of structure calculated from table 4 clause 3.4.4

Fo = seismic zone factor for average acceleration spectra from table 2

Sa/g = avg. acceleration coefficient for appropriate natural period & damping of the structure from fig 2

$$\alpha_h = \beta\, I\, F_0 \frac{S_a}{g}$$

Step-5: According to clause 5.2.6 The lateral force shall be taken as = α_h x W.

This force shall be assumed to be applied at the CG of tank horizontally in the plane in which the structure is assume to associate for purpose carried out the lateral load analysis.

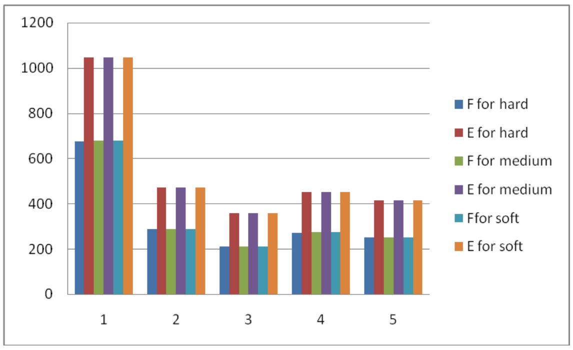

Fig- 1 %Increase in Base Shear

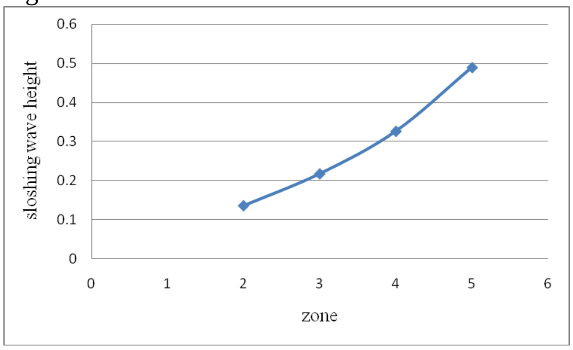

Fig-2 Sloshing Wave Heigh

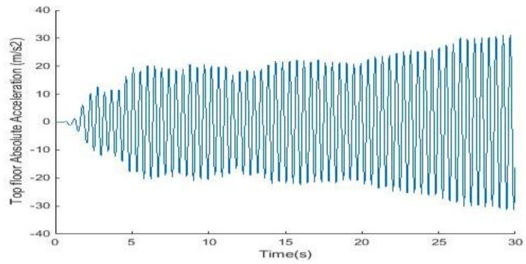

Fig-3 Response of 1000 KL for two mass model for El Centro

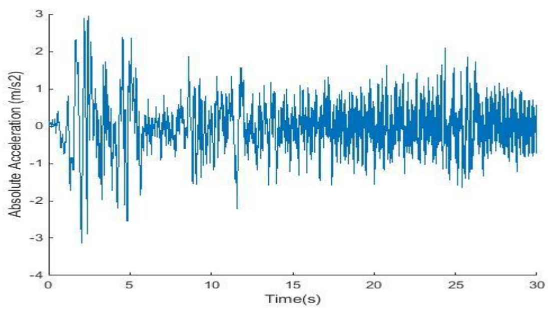

Fig-4 Response of 1000 KL for one mass model for El Centro

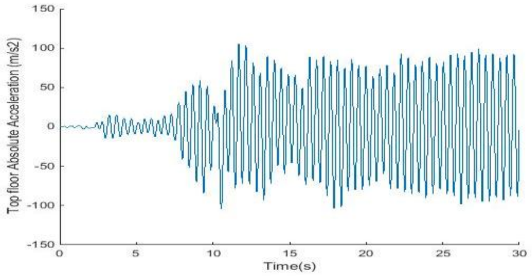

Fig-5 Response of 1000 KL for two mass model for ji-ji

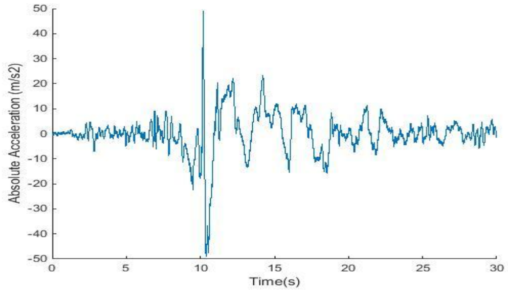

Fig-6 Response of 1000 KL for one mass model for ji-ji

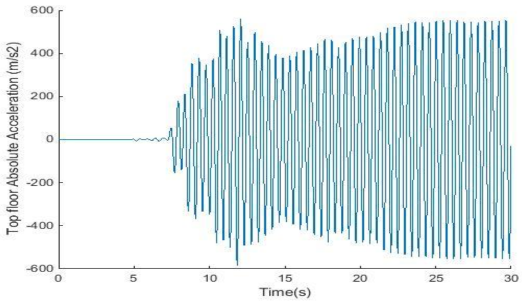

Fig-7 Response of 1000 KL for two mass model for kobe

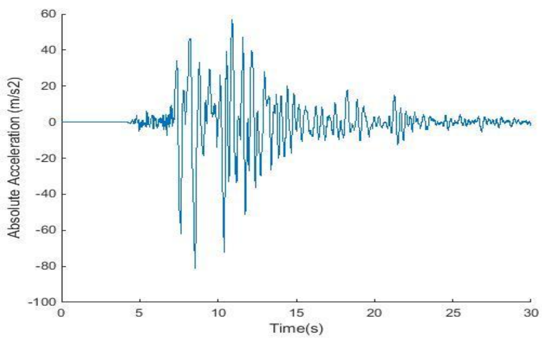

Fig-8 Response of 1000 KL for one mass model for kobe

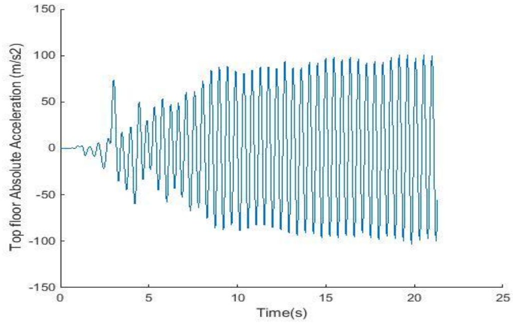

Fig-9 Response of 1000 KL for two mass model for Erzincan

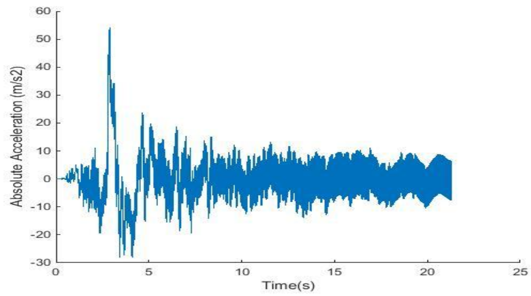

Fig-10 Response of 1000 KL for one mass model for Erzincan

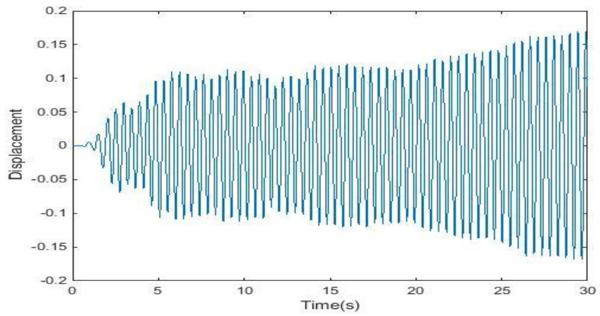

Fig:-11 Response of 1000 KL for two mass model for El Centro

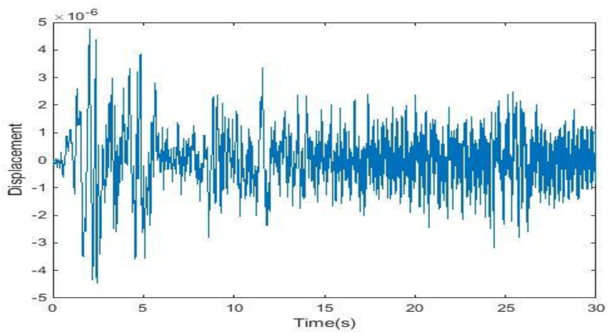

Fig:-12 Response of 1000 KL for one mass model for El Centro

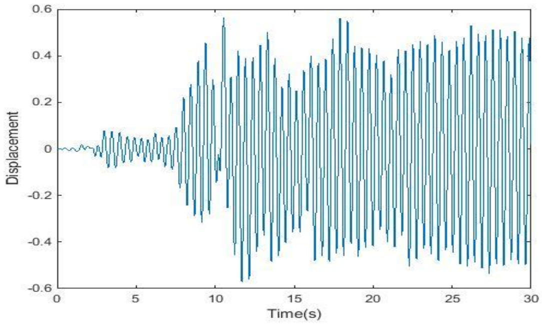

Fig:-13 Response of 1000 KL for two mass model for jiji

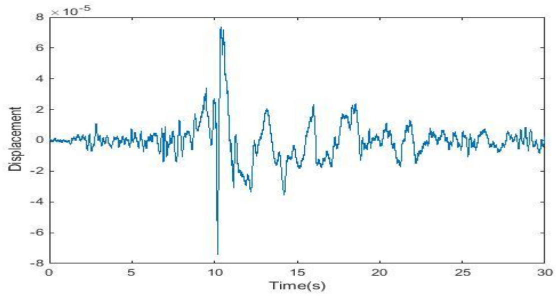

Fig:-14 Response of 1000 KL for one mass model for jiji

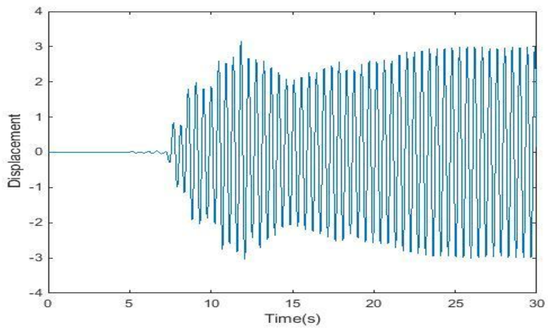

Fig:-15 Response of 1000 KL for two mass model for kobe

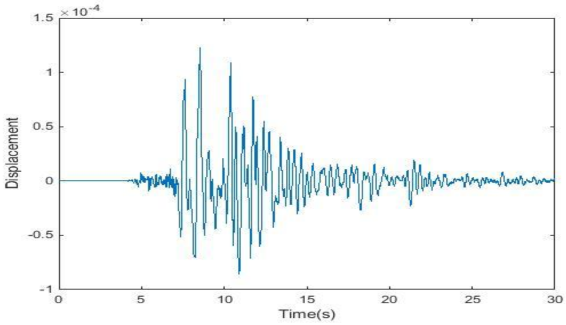

Fig:-16 Response of 1000 KL for one mass model for kobe

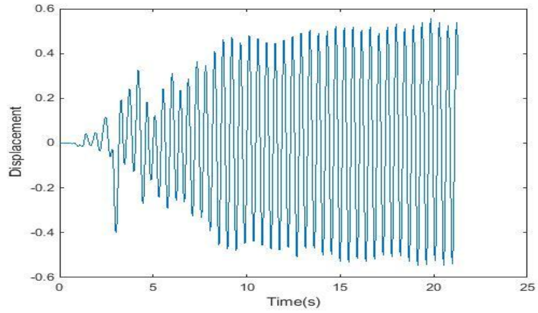

Fig:-17 Response of 1000 KL for two mass model for Erzincan

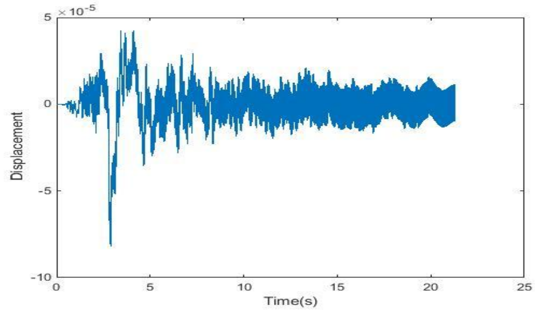

Fig:-18 Response of 1000 KL for one mass model for Erzincan

I. CONCLUSION

- The base shear values calculated by IS: 1893 (Part 2) draft code are more than those obtained by IS: 1893-1984. The increase in forces when the revised draft code is applied shows that earlier design was for lesser forces, meaning the existing tanks designed according to earlier code provisions are now deficient according to the revised code hence must be redesigned and retrofitted.
- The percentage increase in base moments for empty tank is more than those for full tank hence empty tanks become more vulnerable in the event of an earthquake.
- There is a major increase (677%) in base shear values for tanks which were located earlier in zone I now upgraded to zone II.
- Sloshing wave height is proportional to inner diameter of container and horizontal seismic coefficient for convective (A_{hc}) mode. Maximum value of sloshing wave height (d_{max}) is 0.8165, having in case of soft soil for V zone.
- Order of obtained value of sloshing wave height for same zone factor

$d_{max(}$hard soil) < $d_{max(}$medium soil) < $d_{max(}$soft soil)

- The percentage increase in base moments for empty tank is more than those for full tank. This is because for empty tank the centre of gravity shifts upwards. So the distance of lateral force from the base of tank increases. The moments calculated at the base of the tank thus increase. Hence empty tanks become more vulnerable in the event of an earthquake.

- With reference to figures3&4 maximum absolute acceleration response for 1000 KL capacity for two mass model & for one mass model are 31.334 m/s^2, 3.1465 m/s^2 at 25 to 30 seconds and 3 to 4 sec respectively.
- With reference to figures 11 & 12, maximum displacement for 1000 KL capacity for two mass model and for one mass model are 0.1696 m, 0.000 m at 25 to seconds and 3 to 4 seconds respectively.
- With reference to figures 5 &6 maximum absolute acceleration response for 1000 KL capacity for two mass model & for one mass model are 105.4526 m/s^2, 49.0499 m/s^2 at 10 to 11 seconds and 10 to 11 seconds respectively.
- With reference to figures 13 & 14, maximum displacement for 1000 KL capacity for two mass model and for one mass model are 0.5706 m, 0.0001 m at 10 to 12 seconds and 10 to 11 seconds respectively.
- With reference to figures 7 & 8 maximum absolute acceleration response for 1000 KL capacity for two mass model & for one mass model are 584.47 m/s^2, 81.0575 m/s^2 at 12 to 13 seconds and 8 to 9 sec respectively. Response approximately increases 8 times from one mass model to two mass.
- With reference to figures 15 & 16, maximum displacement for 1000 KL capacity for two mass model and for one mass model are 3.1622 m, 0.0001 m at 12 to 13 seconds and 8 to 9 seconds respectively.
- With reference to figures 9 &10 maximum absolute acceleration response for 1000 KL capacity for two mass model & for one mass model are 103.0292 m/s^2, 54.2711 m/s^2 at 21 to 22 seconds and 3 to 4 sec respectively.
- With reference to figures 17 & 18, maximum displacement for 1000 KL capacity for two mass model and for one mass model are 0.5574 m, 0.0001 m at 18 to 19 seconds and 2 to 3 seconds respectively.
- There is no response appear up to 5 seconds for both models because values for ground motion acceleration for Kobe earthquake record is zero during in this time period.
-
- From the all above results for same capacity of tank sequence of maximum absolute acceleration response as follows

  Kobe > Ji-Ji > Erzincan > El Centro

  It shows that for same capacity of tank magnitude of Kobe earthquake is higher than the other earthquake in case one mass model as well as two mass model although time of response is different.
- Response obtained in case of two mass model is average and confine for all four type of earthquake thus it is more realistic representation of tank.
- Sequence of Time of response for same capacity of tank is

  Ji-ji > Kobe > Erzincan > El Centro
- The revised draft code which recommends a two degree of freedom system, is a more realistic representation of the tank structure.

REFERENCES

[1] American Concrete Institute ACI, 2001,"Seismic Design of Liquid Containing Concrete Structures", ACI 350.3, Farmington Hills, MI.

[2] BIS 1976 IS:4326-1976 "Earthquake resistant design and construction of buildings",Code of practice, Bureau of Indian Standards, New Delhi.

[3] BIS 1984 IS:1893-1984 "Criteria for earthquake resistant design structures", Bureau of Indian Standards, New Delhi.

[4] BIS 1993 IS:13920-1993 "Ductile detailing of reinforced concrete structures subjected to seismic forces" Code of Practice, Bureau of Indian Standards, New Delhi.

[5] Chirag N. Patel, H. S. Patel (Oct.-Dec.,2012) "Supporting systems for reinforced concrete elevated water tanks" International Journal of Advanced Engineering Research and Studies, Vol. II, Issue I, , pg no-68-71

[6] Hirde Suchita, Banjare Asmita, Hendaoo Manoj (October-December, 2011) "Seismic Performance of Elevated Water Tanks" International Journal of Advanced Engineering Research and Studies.

[7] Housner, G. W., (1963), "The Behavior of Inverted Pendulum Structures during Earthquakes" Bulletin of Seismological Society of America, 53(2), pp 381–387.

[8] Housner. G.W., and Jennings, P.C., (1982), Earthquake Design Criteria, Earthquake Engineering Research Institute, Oakland, California, USA

[9] IITK-GDMA, (2005), IITK-GSDMA Guidelines for Proposed Draft Code and Commentary on Indian Seismic Code IS:1893 (Part 1), IITK-GSDMA-EQ05-V4.0, August 2005, Indian Institute of Technology Kanpur and Gujarat State Disaster Mitigation Authority, Gandhinagar, India

[10] IS 1893 (Part 1): (2002), "Criteria for earthquake resistant design of structures", BIS, New Delhi, (2002).
[11] IS: 11682-1985, Criteria for Design of RCC Staging For Overhead Tanks (1985),Bureau of Indian Standards, New Delhi
[12] Malhotra, P. K., (2004) "Seismic Analysis of FM-Approved Suction Tanks", draft, FM Global, Norwood, MA.
[13] Malhotra, P. K., (2005). "Sloshing loads in liquid-storage tanks with insufficient freeboard", Earthquake Spectra 21(4),pp 1185–1192.
[14] Malhotra, P. K., Wenk, T., and Weiland, M., (2000), "Simple Procedure of Seismic Analysis of Liquid Storage Tanks", Structural. Engineering. 10(3), pp. 197–201.
[15] Murty C.V.R. February (2003), IITK-BMTPC Earthquake Tip 11 (eqtips@iitk.ac.in.)
[16] M. Moslemia, M.R. Kianoush, W. Pogorzelski, (2011) "Seismic response of liquid-filled elevated tanks" (Elsevier) Engineering Structures 33 2074–2084
[17] Neeraj Tiwari and M. S. Hora February (2015) "Transient Analysis of Elevated Intze Water Tank-Fluid- Soil System."ARPN Journal of Engineering and Applied Sciences vol. 10, no. 2.
[18] Rai, D. C. Nov 26-30, (2012), "Seismic Force Estimation IS 1893-2002."
[19] Pravin B.Waghmare, Atul M. Raghatate & Niraj D.Baraiya (2012) "Comparative Performance of Elevated Isolated Liquid Storage Tanks (With Shaft Staging)" International Journal of Advance technology in civil engineering, ISSN:2231-5721, Volume 1.
[20] Rai, D. C. September (2003) "Performance of elevated tanks in Mw7.7 Bhuj earthquake of January 26th, 2001." Indian Acad. Sci. (Earth Planet. Sci.),112, No. 3, pp. 421{429}
[21] Rai, D. C. and Jaiswal, O. R. and Jain, S. K., (2007), "Review of Code Provisions on Design Seismic Forces for Liquid Storage Tanks" Earthquake Spectra 23(1), 239–260.
[22] S. C. Duta, S. K. Jain and C. V. R. Murty, (2000) "Assessing the seismic torsional vulnerability of elevated tanks with RC frame-type staging, Soil Dynamics and Earthquake Engineering (ELSEVIER)" Vol. 19, pp. 183-197
[23] S. C. Duta, S. K. Jain and C. V. R. Murty, (2000) "Alternate tank staging configurations with reduced torsional vulnerability, Soil Dynamics and Earthquake Engineering (ELSEVIER)" Vol. 19, pp. 199- 215
[24] S.K. Jain, U.S. Sameer, (December 14-16) "Seismic Design of Frame Staging for Elevated Water Tanks‖, Ninth Symposium on Earthquake Engineering" Roorkee 1990, Vol.1.
[25] S.K.Jain & et al., (4 January 1994) " proposed provision of a seismic design of a liquid storage tank" , journal of structural engineering, vol 20 no. pp. 167-175.
[26] Syedd Saifuddin , (7-8 January, 2013) "Seismic analysis of liquid storage tank", International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013) Special Issue of ICACSE 2013 - Held in Lords Institute of Engineering and Technology, Hyderabad.
[27] USGS U.S Geological Survey (http://www.usgs.gov/)