Seismic Analysis of Base Isolated Liquid Storage Tank

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Abstract- *Base-isolation belongs to the passive vibration control device family installed at the base of the structure which dissipates the external excitation energy by reducing the transmitted acceleration into the structure. The earthquake response of the liquid storage tank isolated by sliding and elastomeric bearings systems is studied under ten real existent earthquakes. The continuous liquid mass of the tank is modeled as lumped masses known as impulsive mass, convective or sloshing mass and rigid mass. The coupled dynamic equations of motion for both non-isolated and isolated tanks are solved by using Newmark's-Beta method considering time interval 0.02 s with iterations. The seismic response of the isolated tank is compared with non-isolated tank to study the effectiveness of base isolation system. The tank isolated by three different isolation systems LRB, Z-N system and R-FBI systems are studied and comparative study also carried between these three systems. A parametric study is also carried out to study the effect of various important system parameters on the effectiveness of seismic isolation for liquid storage tanks.*

Keywords- Liquid storage tank, Seismic response, Base-isolation, Elastomeric bearing, Sliding isolation ,Earthquakes, Spring mass model, System parameters.

I. INTRODUCTION

Liquid storage tanks are strategically very important structures, since they have vital uses in industries, nuclear power plants for storage and processing of materials like

liquids (petroleum product, chemical fluids)
Gases (liquefied natural gas, LPG)

The earthquake damage of tank has been due to several causes:

buckling of tank wall
failure of piping system and
uplift of the anchorage system

The integrity of any structure can be protected from the attack of severe earthquakes either through the concept of

1.Resistance.
2.Isolation.

Base isolation is one of the most widely accepted seismic protection systems in earthquake prone areas. It mitigates the effect of an earthquake by essentially isolating the structure from potentially dangerous ground motions. Principle of the base isolation is separate the structure from the ground. The ground will move but the structure will not move. Seismic isolation is a design strategy, which uncouples the structure for the damaging effects of the ground motion. The term isolation refers to reduced interaction between structure and the ground. When the seismic isolation system is located under the structure, it is referred as “base isolation”.

II. OBJECTIVES&SCOPE

- To study the effect of presence of Base-Isolations in mitigating the response of the structure when subjected to dynamic excitation
- To re-centre the structure after earthquake.
- To ensure the safety of human life & assets.
- Scope of the study is carrying outfinite element modeling (FEM) study on two identical storage tanks with different base-isolation condition.
- To study the influence of various system parameters on effectiveness of base isolation for liquid storage tanks , the system parameters are :

Aspect ratio of the tank
The time period of isolation
The damping of isolation.

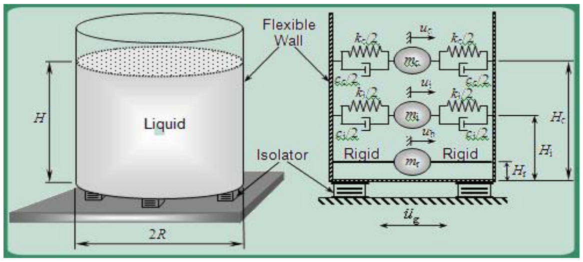
Assumptions of Study

- The fluid assumed as homogeneous, irrotational and incompressible.
- The vertical members of base-isolation systems are assumed to be inflexible or rigid.
- Structure reaction acts as an external force to the damper and thus altering the sloshing mechanism and its energy dissipation capacity. On the contrary, structural response is affected by nutation damping.
- Top surface of liquid remains smooth during sloshing.

- The structure behavior is assumed as linear. The pressure on the free surface of water is assumed to be constant.

Mechanical models were first studied for tanks with rigid walls later on Haroun, Veletsos and Hasner expanded mechanical models for flexible tanks and Malhotra simplified this flexible model.

Structural model of liquid storage tank: In addition to hydrostatic forces, hydrodynamic forces also considered in the analysis which are exerted by liquid on tank wall. These hydrodynamic forces are evaluated with the help of spring mass model of tanks



The parameters of the tank: H is the liquid height, R is the radius and t_h is the average thickness of the tank wall. The lumped masses are expressed in terms of the liquid mass (m) and it is taken from Haroun's model.

$$
\begin{aligned}
m &= \pi R^2 H \rho_w \\
m_c &= Y_c m \\
m_i &= Y_i m \\
m_r &= Y_r m
\end{aligned}
$$

Where ρ_w is the liquid mass density, Y_c , Y_i and Y_r are the mass ratios which are function of tank wall thickness and aspect ratio of the tank.

III. METHODOLOGY

- Structural model of liquid storage tank.
- Develop a liquid-structure interaction model and structure-base isolation interaction model to study the dynamic behaviour.
- Mechanical models were first analysis for liquid tanks.
- Develop Finite element method for the liquid storage tank.
- Newmark's-Beta method is selected as numerical method to solve the discretized Finiteelements differential equations.

Non linear force deformation relations in base isolation. Non classical damping.

IV. NUMERICAL STUDY AND DISCUSSIONS

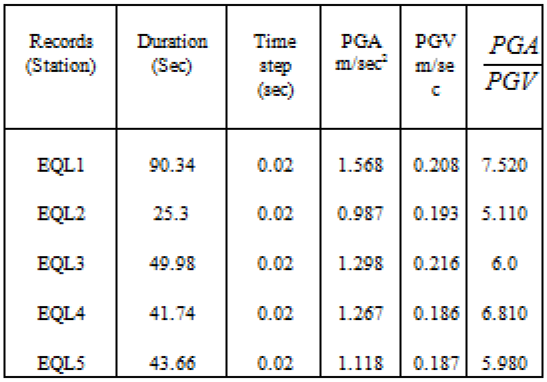
The seismic response of liquid storage tanks isolated by Laminated rubber bearing (LRB) systems, Lead rubber bearing (N-Z) system and Resilient friction base isolation (R-FBI) systems are studied under real Low-frequency and High-frequency earthquake ground motions. The response quantities are base shear (F_b), convective or sloshing displacement (x_c) and impulsive displacement (x_i).The parameters, which characterize the model of liquid storage tank.

Parameter	Value
Density of water ρ_w	1000 kg/m^3
Density of steel ρ_s	7900 kg/m^3
Modulus of elasticity E	200 Gpa
Height of liquid H	14.6 m
Damping ratio for sloshing ξ_c	0.5 %
Damping ratio for impulsive ξ_i	2 %

Low Frequency Content Earthquakes:

1. EQL1 or Lower California Earthquake (DEC 30, 1934)
2. EQL2 or San Fernando Earthquake at station 0600 PST 2500 Wilshire BLVD (FEB 9, 1971).
3. EQL3 or San Fernando Earthquake at station 0600 PST 3550 Wilshire BLVD (FEB 9, 1971).
4. EQL4 or San Fernando Earthquake at station 0600 PST 222 Wilshire BLVD (FEB 9, 1971).
5. EQL5 or San Fernando Earthquake at station 0600 PST 3470 Wilshire BLVD (FEB 9, 1971).

Ground Motion Record for PGA/PGV < 8

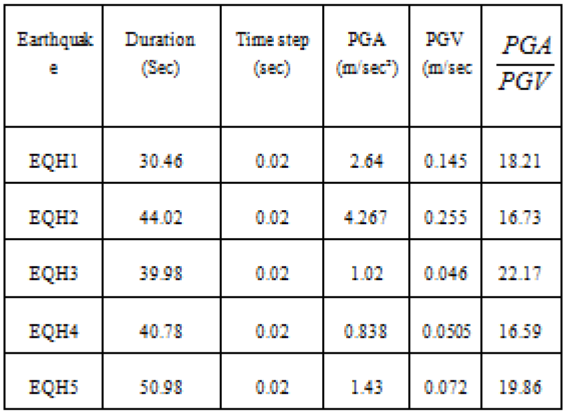


Records (Station)	Duration (Sec)	Time step (sec)	PGA m/sec^2	PGV m/sec	$\frac{PGA}{PGV}$
EQL1	90.34	0.02	1.568	0.208	7.520
EQL2	25.3	0.02	0.987	0.193	5.110
EQL3	49.98	0.02	1.298	0.216	6.0
EQL4	41.74	0.02	1.267	0.186	6.810
EQL5	43.66	0.02	1.118	0.187	5.980

HIGH FREQUENCY EARTHQUAKES:

1. EQH1 or California Earthquake at station 2026 PST Temblor (JUNE 27, 1966)
2. EQH2 or California Earthquake at station 2026 PST Cholame , Shandon (JUNE 27, 1966)
3. EQH3 or San Fernando Earthquake at station 1144 PST IA015 (MAR 22, 1957)
4. EQH4 or San Fernando Earthquake at station 1144 PST IA016 (MAR 22, 1957)
5. EQH5 or Helena , Montana Earthquake at station 1138 MST Helena (OCT 31 ,1993)

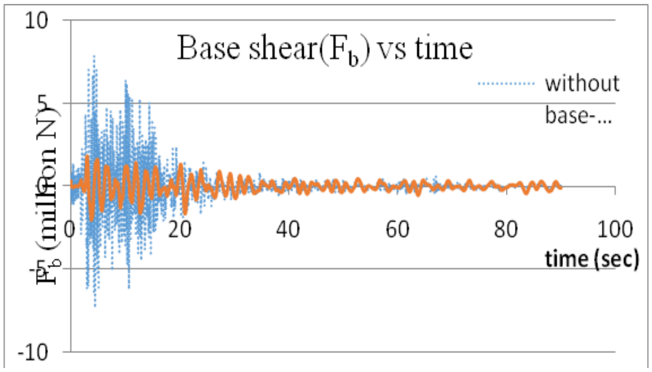
Ground Motion Record for PGA/PGV > 12



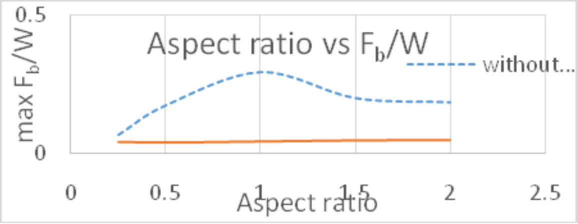
Earthquake	Duration (Sec)	Time step (sec)	PGA (m/sec^2)	PGV (m/sec	$\frac{PGA}{PGV}$
EQH1	30.46	0.02	2.64	0.145	18.21
EQH2	44.02	0.02	4.267	0.255	16.73
EQH3	39.98	0.02	1.02	0.046	22.17
EQH4	40.78	0.02	0.838	0.0505	16.59
EQH5	50.98	0.02	1.43	0.072	19.86

Parametric study on Time period of base-isolation :

The peak response of tanks isolated by the LRB , N-Z and R-FBI system is plotted against the isolation damping, ξ_b. it is observed that, as the flexibility of isolation system increases the peak base shear reduces. This is due to the fact that with an increase of isolation period the system becomes more flexible and, as a result, transmits less earthquake acceleration into the tanks leading to a reduction in the base shear. Moreover, for a relatively short isolation period (say less than 2.5 sec) the base shear reduces rapidly and after that it become nearly flat for Tb > 2.5 sec .Thus the effectiveness of sling systems for tanks increses with the increased flexibility.



Similarly it can be observed the impulsive displacement decreases with time period of Base-isolation system. Moreover, for a relatively short isolation period (say less than 2.2 s) the base shear reduces rapidly and after that it become nearly flat for Tb > 2.5 sec



It can be observed The convective displacements of the tank are earthquake dependent and generally decrease with the increase of the period of the isolation system

V. CONCLUSION

1. There is a moderate increase (20–70%) in the convective displacement when the tank is isolated especially for high aspect ratios. Nevertheless, the clear height over the liquid surface should be provide to overcome such disadvantage.
2. Performance of N-Z system proved to be better as compared to LRB and R-FBI systems.
3. By observing results we concluded that base isolation systems are more effective for High-frequency earthquakes comparing with Low-frequency earthquakes.
4. For the non-isolated tanks, the base shear and the impulsive displacement are significantly affected by the aspect ratio and the exciting earthquake also.
5. There exists an optimum value of isolation damping for which the base shear and impulsive displacement in the liquid storage tanks attains the minimum value under earthquake ground motion. However, the convective displacement decreases with increase in isolation damping.

REFERENCES

[1] M.S. Chalhoub and J.M. Kelly, Shake table test of cylindrical water tank in base isolated structures,Journal of Structural Engineering, ASCE116(7) (1990), 1451–1472.

[2] N.S. Kim and D.G. Lee, Pseudo-dynamic test for evaluation of seismic performance of base isolatedliquid storage tanks, Engineering Structures17(3) (1995), 198–208.

[3] P.K. Malhotra, New method for seismic isolation of liquid storage tanks, Earthquake Engineering andStructural Dynamics 26(1997), 839–847.

[4] Y.P. Wang, M.C. Teng and K.W. Chung, Seismic isolation of rigid cylindrical tanks using frictionpendulum bearing, Earthquake Engineering and Structural Dynamics30(2001),1083–1099.

[5] M.K. Shrimali and R.S. Jangid, Seismic response of liquid storage tanks isolated by slidingbearings,Nuclear Engineering and Design217(2002), 1–20.

[6] M.K. Shrimali and R.S. Jangid, A comparative study of performance of various isolation systems forliquid storage tanks, International Journal of Structural Stability and Dynamics2 (2002), 573–591.

[7] Shrimali MK, Jangid RS. Seismic analysis of base-isolated liquid storage tanks. Journal of Sound andVibration 2004;275(1–2):59–75.

[8] D.P. Sonia, B.B. Mistry, V.R. Panchal. Double variable frequency pendulum isolator for seismic isolation of liquidstorage tanks .Journal of Nuclear Engineering and Design241 (2011) 700–713

[9] Sandip Kumar Saha, Vasant Matsagar, Subrata Chakraborty. Uncertainty quantification and seismic fragility ofbase-isolated liquid storage tanks using response surface models Journal of Probabilistic Engineering Mechanics43 (2016) 20–35