7th International Conference on Seismology & Earthquake Engineering
18-21 May 2015

SEISMIC ANALYSIS OF CONCRETE RECTANGULAR CONTAINERS ISOLATED BY DIFFERENT ISOLATION SYSTEMS

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Keywords: Rectangular Containers, Seismic Analysis, Base Isolation, Hydrodynamic Pressure

ABSTRACT

The liquid storage containers are one of the most important structures of the lifeline and industrials facilities in all over the world. These structures can be used as grounded, pneumatic and embedded containers. The grounded concrete tanks are widely used for the long-term storage of nuclear spent fuel assemblies. Hence, protection of these structures against severe seismic events has become crucial. Numerous studies have been done for the seismic analysis of fluid containers. Most of them are concerned with cylindrical or rectangular tanks with fixed-base. This paper focuses on analyzing the results of seismic responses of flexible rectangular tanks isolated by three types of outstanding isolation systems. The considered systems are high damping rubber-bearing (HDRB), lead-rubber bearing (LRB) and friction pendulum bearing (FPB). An equivalent mechanical model of rectangular tanks is used in this study which contains three lumped masses known as: convective mass, flexible mass and rigid mass. Eventually, the seismic isolation systems are found to be very effective in reducing the base shear and hydrodynamic pressures but usage of this technology found to have adverse or/and neutral effects on the sloshing height. An increase in displacements for all isolation systems in horizontally isolated tanks seems to be inevitable.

INTRODUCTION

Concrete rectangular containers play an important role in the rescue work after an earthquake. These structures are exposed to a wide range of seismic hazards and interaction with other sectors of the built environment too. Based on observation from previous earthquakes, it showed that the seismic response of a flexible tank may be substantially greater than that of a similar rigid tank. Consequently, the seismic response of liquid storage tanks can be strongly influenced by the interaction between the flexible tank and the fluid within it. Recently, Hashemi et al (2013) investigated the dynamic response of flexible 3D rectangular liquid storage tanks with flexible walls on all four sides, subjected to horizontal seismic ground motion and they developed an equivalent mechanical model for estimating the dynamic response of these structures. Flexibility of the walls is particularly expressed in their equivalent model.

Recent research shows that using a seismic isolation system under liquid storage tanks affects the efficiency of seismic behavior of these structures. Chalhoub and Kelly (1990) observed that the sloshing response increases slightly but the total hydrodynamic pressure decreases substantially due to the base isolation of the tanks. Kim and Lee (1995) experimentally investigated the seismic performance of liquid storage tanks isolated by laminated rubber bearings under unidirectional excitation and have shown that the isolation is effective in reducing the dynamic response. Malhotra (1997) investigated the seismic response of base isolated steel tanks and found that isolation was beneficial in reducing the response of the tanks over traditional fixed base tanks without any significant change in sloshing displacement. Shenton and Hampton (1999) studied the seismic response of isolated elevated tanks and found that seismic isolation is effective in reducing the tower drift, base shear, overturning moment and tank wall pressure for the full range of tank capacities. Shrimali and Jangid (2002) investigated the seismic response of tanks that were isolated by lead rubber bearing (LRB) under bi-directional earthquake excitation and observed that the seismic response of isolated tanks is insensitive to the interaction effect of the bearing forces. Jadhav and Jangid (2006) investigated the seismic response of liquid storage steel tanks isolated by elastomeric bearings and sliding systems under near-fault ground motions and found that both elastomeric and sliding systems were effective in reducing the earthquake forces of the liquid storage tanks. Although the above studies confirm that the seismic isolation is effective in reducing the earthquake response and show that the fluid-structure-isolator interaction effects in liquid storage tanks were studied extensively, the studies are limited principally to cylindrical tanks and investigations on the base isolation effect of flexible rectangular fluid containers are virtually rare. There is only a documentary experimental study of isolated rectangular tanks by high damping rubber-bearing and it was rendered by Park et al (2000).

In present study, seismic analysis of flexible rectangular fluid containers isolated by High Damping Rubber Bearing (HDRB), Lead Rubber Bearing (LRB) and Friction Pendulum Bearing (FPS) is investigated under horizontal seismic ground motion. In order to measure the effectiveness of the isolation system, the earthquake response of isolated tanks is compared with non-isolated tanks.

GEOMETRY AND MECHANICAL MODEL OF RECTANGULAR TANK

The tank is modeled by the lumped mass model suggested by Hashemi et al (2013). The contained continuous liquid mass is lumped as convective, flexible and rigid masses referred as m_c, m_f and m_0, respectively. The convective and flexible masses are connected to the tank wall by corresponding equivalent spring having stiffness k_c and k_f, respectively. The damping constant of the convective and flexible masses are c_c and c_f, respectively. Thus, the base-isolated tank system has three degrees of freedom under x excitation of ground motion. These degrees of freedom are denoted by u_c, u_f and u_b, which denote the absolute displacement of convective, flexible and rigid masses.

Three-dimensional shape of the fixed-base and equivalent mechanical model of base-isolated system is shown in Figure 1a and 1b respectively.

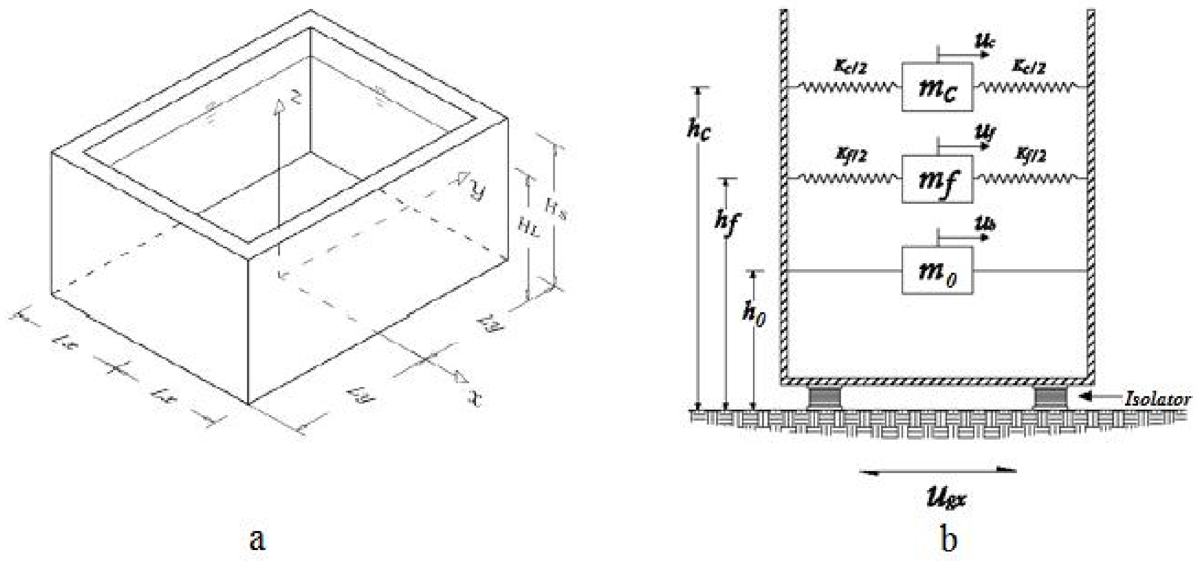

Figure 1. a) Geometry of flexible rectangular tank 1b) Mechanical model of flexible rectangular tank

BASE ISOLATION BEARINGS AND SIMPLIFIED MODEL

In order for isolating rectangular tanks, high damping rubber-bearing (HDRB), lead-rubber bearing (LRB) and friction pendulum bearing (FPB) are used in present study.

HDRB can provide lateral flexibility so that the period of vibration is lengthened sufficiently. This system also provides damping so that the relative displacements across the flexible mounting can be limited to a practical design level.

LRB consists of alternating layers of steel and rubber providing flexibility while maintaining sufficient vertical stiffness. The lead core in the canter of the bearing provides supplemental damping.

FPB is an axisymmetric concave sliding device that combines high energy dissipation characteristic, and a gravitational restoring force mechanism that allows minimizing residual displacements of the supported structure under ground shaking (Zayas et al., 1987).

Simplified model can be used for all isolation bearings used in practice (Naeim and Kelly., 1999). In this study, the behavior of isolation systems is represented by a simplified model as shown in Fig 3. It shows an idealized force-displacement relation of an isolation system. As seen in figure, three main parameters are needed to define the horizontal behavior of the bearings; namely the elastic stiffness (ke), the post elastic stiffness (kp) and the characteristic strength (Q_d). Generally, simplified bilinear hysteretic model can reflect the nonlinear characteristics of isolation systems.

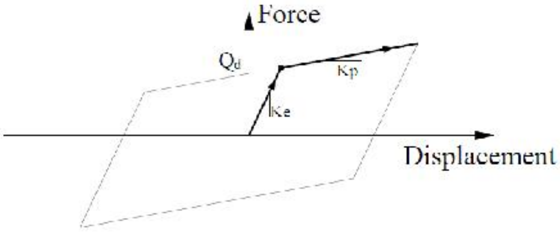

Figure 2. Simplified bilinear model of bearing behavior

NUMERICAL STUDY

Since rectangular tanks are used most often for the wet-type storage of nuclear spent fuel assemblies, a typical dimension for those tanks is selected for the following example. Therefore, height of the wall, H_s=10m; wall thickness, t_s=1.22m; water depth, H_L=12m; length of the short side wall, 2Lx=20m; and length of the long side wall, 2Ly=50m. The typical material properties for the concrete tanks; density, ρ_s=2400kg/m^3; Young's modulus, $E=2.1\times10^{10}$ N/m^2; and the Poisson's ratio, υ=0.17. The values of rigid, flexible and convective masses and stiffness and damping constants were have been extracted from the presented diagrams in study of Hashemi et al (2013).

The main properties of third considered isolation bearings for simulating their behavior by usage of simplified bilinear model are presented in table 1.

Table 1. Main properties of isolation bearings

Isolation System	Elastic Stiffness (kN/mm)	Plastic Stiffness (kN/mm)	Yield Strength (kN)
HDRB	413.6	104	16560
LRB	1105	130	14560
FPB	4800	160	14860

The time variation of base shear, bearing displacement and sloshing height isolated by the HDRB, LRB and FPB systems is shown in Figures 3, 4 and 5, respectively. It is observed that there is significant reduction in the base shear of the tank implying that the third isolation systems are quite effective in reducing the incoming acceleration by earthquake on storage tanks. It is because of this fact that the base shear relatively depends on acceleration due to ground motion. The maximum value of the bearings displacement of the HDRB, LRB and FPB are about 7.2, 5.8 and 3cm, respectively that is in allowable limitation of the displacement obtained by experimental study for considered isolation bearings. The seismic isolation bearings also give adverse or/and neutral effects on the sloshing height. However, grater amplification in sloshing height is noticed in the case of base-isolated tanks by HDRB and LRB systems as compared to use of FPB systems.

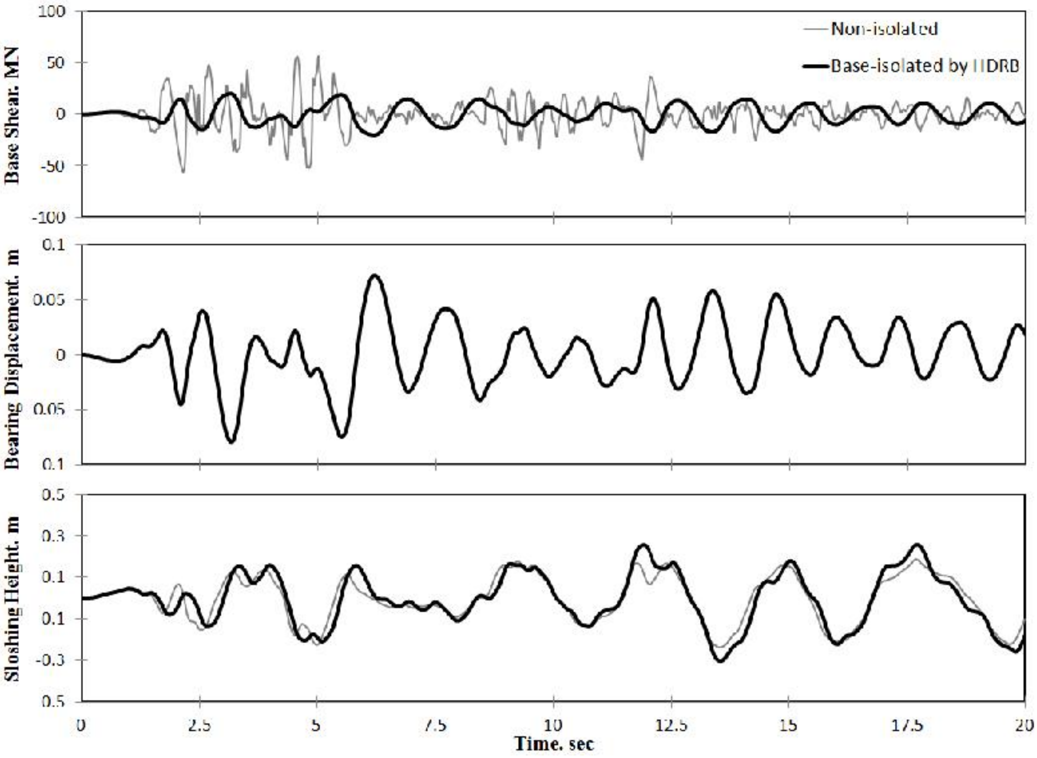

Figure 3. Seismic response of base-isolated flexible rectangular tank by HDRB

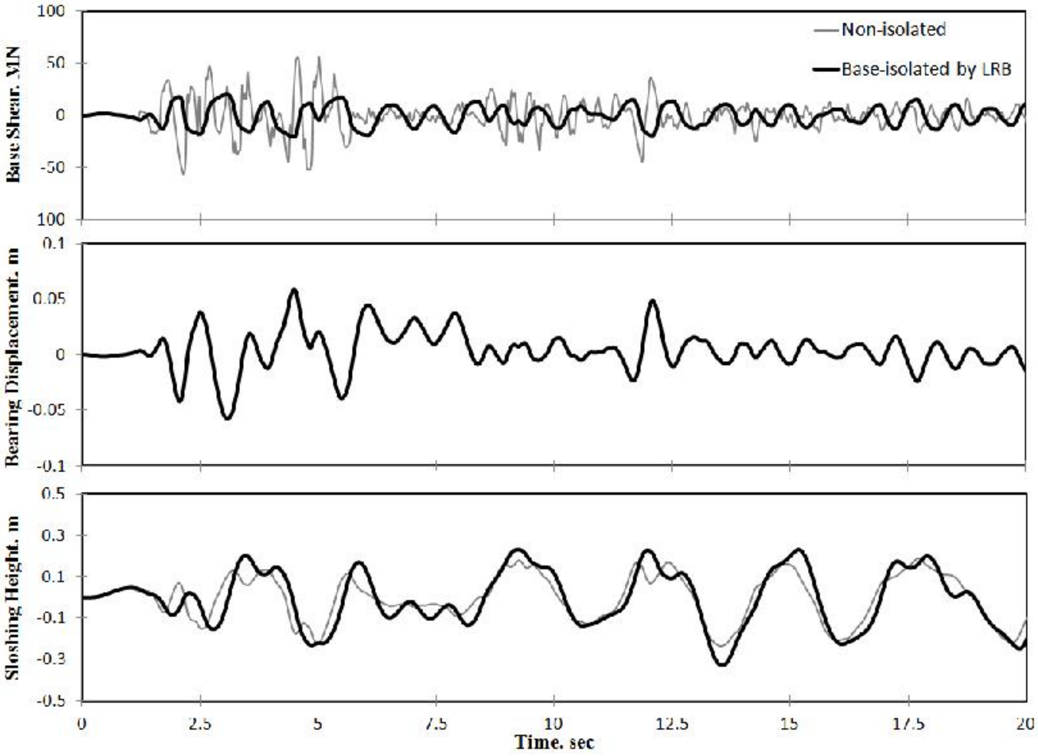

Figure 4. Seismic response of base-isolated flexible rectangular tank by LRB

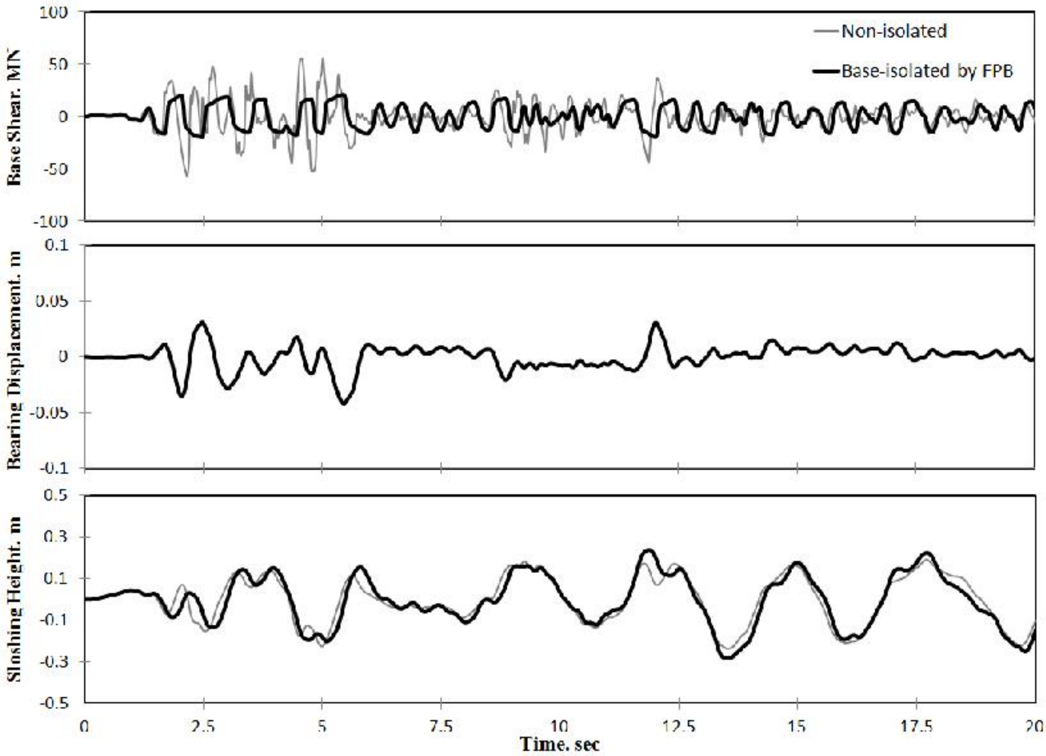

Figure 5. Seismic response of base-isolated flexible rectangular tank by FPB

Since the behavioral mechanism on the FPB systems is different and initial look at choosing mechanical properties and number of these bearings for isolating liquid storage tanks is very essential, in the rest of this investigation, influence of isolation period and friction coefficient of sliding surface are studied.

Comparison of the hydrodynamic pressure distributions along the height of the middle cross-section of the long side wall for the non-isolated and the base-isolated tanks are shown in Figure 6. The capability of third isolation systems in reducing the hydrodynamic pressure on the wall has been clearly demonstrated. The reduction of this response for tanks isolated by HDRB, LRB and FPB has shown the high effectiveness of these isolation systems. This response also has a good uniform distribution and its magnitude is drastically reduced for base-isolated tank. This is due to the fact that the base isolation system causes the tank to move as a rigid body.

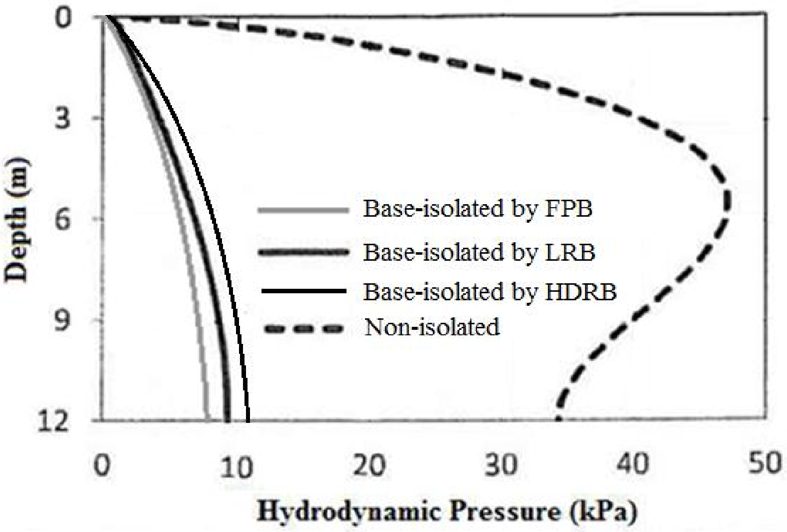

Figure 6. Comparison of hydrodynamic pressure distributions for non-isolated and base-isolated tanks

In Table 2, three important of seismic response for non-isolated and base-isolated conditions of considered rectangular tank is reported.

Table 2. Comparison of maximum seismic responses

		Base-isolated		
Variable	Non-isolated	HDRB	LRB	FPB
Base Shear (MN)	56.44	20.30	20.33	21.03
Hydrodynamic Pressure (KPa)	47	8.2	6.8	5.4
Bearing Displacement (mm)	NA	72.23	58.44	30.88

PARAMETRIC SURVEY OF BASE-ISOLATED TANK BY FPB

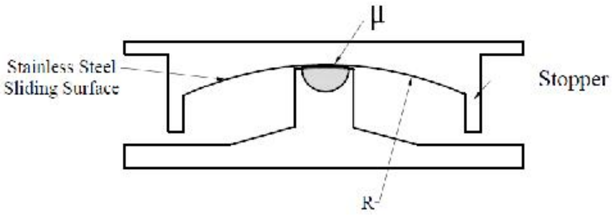

Figure 7. Cross section configuration for FPB

Movement of the slider generates a dynamic frictional force that provides the required damping to absorb the earthquake energy. The isolator period is a function of the radius of curvature of the surface, R. The natural period is independent of the mass of the supported structure and is determined from the pendulum isolator equation.

$$T=2\pi(R/g)^{1/2} \qquad (1)$$

Where g is the acceleration due to gravity.

The post-yielding isolator stiffness, *Kp* of the isolator system, which provides the restoring capability, is provided by equation 2.

$$Kp=W/R \qquad (2)$$

Where W is the total weight of the superstructure. The yield frictional force, Q_d, is defined as equation 3.

$$Q_d= \mu W \qquad (3)$$

The coefficient of friction μ is a function of the sliding velocity $\dot{U}$ and bearing pressure. The friction-velocity relationship, as determined by equation 4.

$$\mu=\mu_{max}-(\mu_{max}-\mu_{min}) \exp(-a|\dot{U}|) \qquad (4)$$

Where μ_{max} and μ_{min} are the maximum and minimum mobilized friction coefficient respectively and a is a parameter which controls the variation of friction with velocity.

EFFECT OF ISOLATION PERIOD AND FRICTION COFFICIENT

The variation of maximum response of base isolated rectangular tank (as seen base shear and bearing displacement) versus the isolation period T_b was shown in Figure 8a. This Figure indicates that the base shear decreases with the increase of flexibility of isolation system. This is due to the fact that increased flexibility of the isolation system transmits less acceleration to the tank. However, the bearing displacement increases with the increase of isolation period.

Figure 8b shows the variation of normalized base shear (base shear/ weight) and bearing displacement versus friction coefficient. The figure initially shows a decreasing trend in the base shear as the friction coefficient increases up to about 0.04 at which the minimum base shear is attained. Beyond this point, any further increase in friction coefficient result in increase in base shear ratio. As a result, it can be said that there is an optimum value for the friction coefficient of isolators leading to minimum value of seismic response. For the specific tank and earthquake record considered in this study, this optimum value is found to be about 0.04.

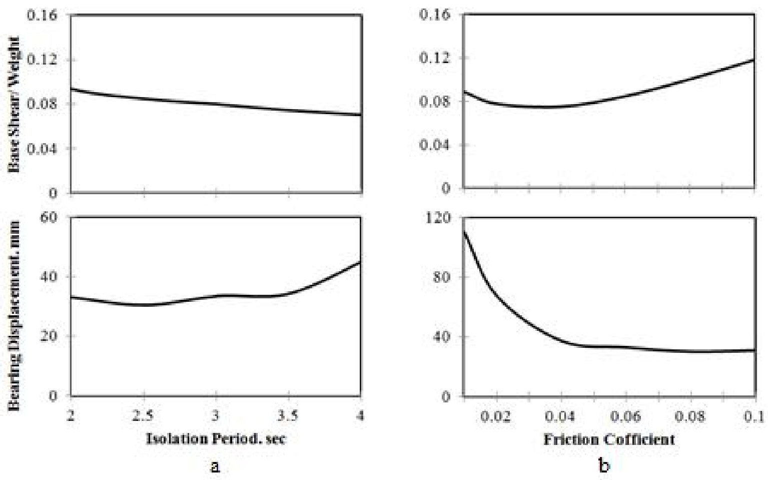

Figure 8. a) Effect of isolation period (μ=0.06) & b)Effect of friction coefficient (T_b=2.5sec)

CONCLUSIONS

Consequently, from the trends of the results of this study the following conclusions may be drawn:

1- Seismic base isolation can be an efficient way to reduce seismic responses, such as base shear and hydrodynamic pressure, but an increase in displacements for all isolation systems in horizontally isolated tanks seems to be inevitable and this factor increase as the isolator becomes more flexible.
2- The seismic isolation systems found to have adverse effects on the sloshing height. This seismic response is amplified more by usage of elastomeric systems and is not greatly influenced due to sliding system.
3- The effectiveness of seismic isolation of the liquid storage containers increase with the increase of the flexibility of isolation systems.
4- There is an optimum value for the friction coefficient of FPB system at which the base shear response of the tank reaches its minimum value. For the specific tank and seismic excitation used in this study, this optimum value is determined to be about 0.04.

Eventually, a careful selection of isolators with a certain limit on the mechanical properties of isolators is required for the optimal seismic isolation design of rectangular containers.

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