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Seismic Response of Elevated Isolated Framed Staging Tank under Bi-Directional Excitation with Elastomeric Bearing

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ABSTRACT

A Common effective method i.e. base isolation systems is used to reduce the seismic response of liquid storage tanks. In this work a method for dynamic analysis of liquid storage tanks isolated by the lead rubber bearing to bi-directional earthquake motion which incorporates the interaction between the restoring forces of the bearings in two orthogonal directions is presented.it is concluded that. The peak response of base isolated liquid storage tanks is not much influenced by the bi-directional interaction of restoring forces of Lead LRB.

Introduction

Seismic response of elevated R.C.C. liquid storage tanks isolated by Lead laminated rubber bearings has been investigated and found that the isolation is effective to reduce the seismic response hence the design forces. In case of lead rubber bearing there exists bi-directional interaction due to yielding of the lead as soon as the resultant force exceeds the yield force. There had been some studies in the past for the response of building supported on the lead rubber-bearings to bi-directional excitation, duly considering the interaction of restoring forces in two horizontal direction. Therefore, it will be interesting to investigate the tanks isolated by lead rubber bearing, under bi-directional earthquake excitations.

In this work, seismic response of elevated liquid storage tanks isolated by the lead rubber bearing is investigated under two horizontal component of an earthquake ground motion.

The specific objectives of the study are summarize as

(i) To present a method for dynamic analysis of liquid storage tanks isolated by the lead rubber bearing to bi-directional earthquake motion which incorporates the interaction between the restoring forces of the bearings in two orthogonal directions.

(ii) To study the effect of bidirectional interaction of restoring forces on the seismic response of liquid storage tanks.

iii) To investigate the influence of important system parameters for effectiveness of the isolation system .the important parameters are isolation period, damping of the lead rubber bearings.

1.2 Structural Model of Liquid Storage Tank

Fig. 1.1 shows the idealized structural model of liquid storage tanks mounted on the isolation system. In order to isolate the tank the lead rubber –bearing is installed between the column and the foundation of the tank. The cylindrical base-isolated liquid storage tank is modeled using two different lumped mass mechanical analogs [4].

1) two-mass model (Model 1) proposed by Housner [1] and

2) three-mass model (Model 2) proposed by Haroun and Housner [7].

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1.2.1 Two-Mass Model (Model 1)

Figure 1.1(a) shows Two-Mass Model (Model 1). This model divides the liquid column into two layers. The upper layer, called convective mass, is considered to vibrate relative to the tank wall and resulting in the sloshing phenomenon, whereas the bottom layer, called impulsive mass, vibrates with the tank as rigid body and experience same earthquake acceleration as the base. The impulsive mass predominately contributes to the base shear and overturning moment of the tank. In this model, the convective mass (m_c) of the liquid is considered to be connected to the solid tank wall with certain stiffness (k_c) at a height Hc, whereas the impulsive mass (m_i) is connected rigidly to the tank wall at a height H_i. The sloshing is connected to the tank wall by corresponding equivalent springs having stiffness constants k_c. The damping constants of the sloshing and impulsive masses are cc and ci, respectively. The tank has four-degrees-of-freedom under bi-directional excitation as u_{cx}, u_{cy}, and u_{bx}, u_{by} which denote the absolute displacements of sloshing mass, bearing displacement, in x and y-direction, respectively.

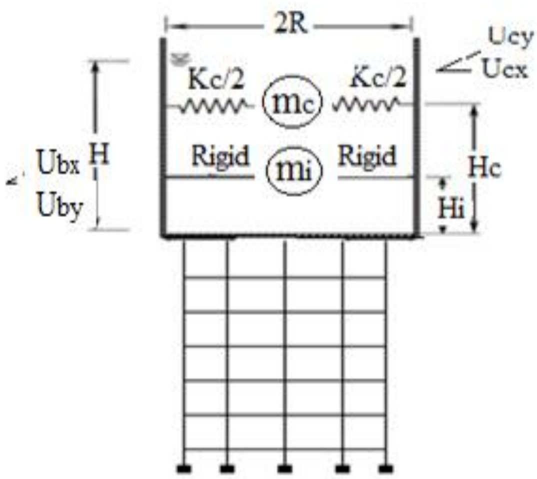

Figure 1.1a. Two-mass model (Model 1).

1.2.2 Three-Mass Model (Model 2)

Figure 1.1(b) shows Three-Mass Model (Model 2). In Three-Mass Model (Model 2) The continuous liquid mass is lumped as sloshing mass (convective mass), impulsive mass and rigid masses and referred to as m_c,m_i and m_r, respectively. The sloshing and impulsive masses are connected to the tank wall by corresponding equivalent springs having stiffness constants k_c and k_i, respectively. The damping constants of the sloshing and impulsive masses are c_c and c_i, respectively. The tank has six-degrees-of-freedom under bi-directional excitation as u_{cx},u_{cy}.u_{ix},u_{iy} and u_{tx},u_{ty} which denote the absolute displacements of sloshing mass, impulsive mass and tower drift, in x and y-direction, respectively. The lumped masses for shallow and slender tank are calculated [5], [6].

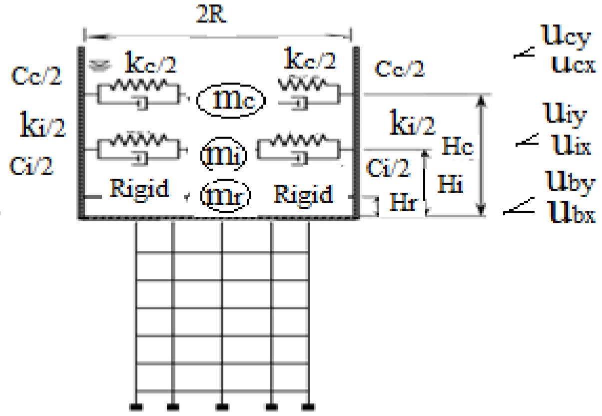

Figure 1.1 b. Three-mass model (Model 2).

Fig. 1.1 (c) shows 3-d model of elevated isolated liquid storage tank with lead rubber bearing placed in between foundation and column.

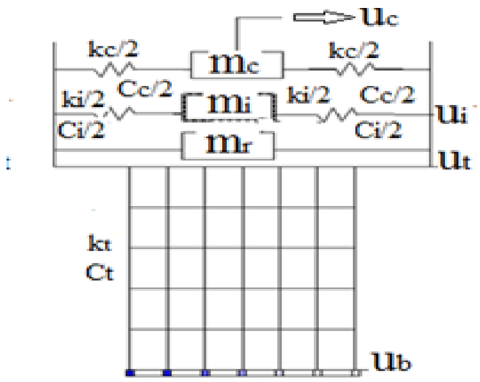

Fig. 1.1 c. Idealized 3-d model of elevated isolated liquid storage tank with lead rubber bearing placed in between foundation and column.

1.3 Force –Deformation Behaviour of the Bearing

The lead rubber-bearings consider consist of alternate layers of rubber and steel plates with central lead core and have isotropic property, which signifies same characteristics in all direction .the bearings is modelled such that it has bilinear force deformation behavior as shown in fig.1.2.The bearing are vertical stiff and have initial horizontal stiffness,k_b and viscous damping,c_b respectively .the vertical stiffness is derived from steel plates while parallel layers of rubber bearings provide horizontal flexibility. The lead core yields relatively at very low shear stress leadings to dissipation of seismic energy as shown in fig.4.4.and reduction of earthquake response. The nonlinear bi-directional hysteretic restoring force in the bearing are modeled by coupled differential equation as proposed by Nagarajaiah et al. [3] and T.K. Datta[2]the restoring force developed in the bearing are given by

$$\begin{Bmatrix} F_{bx} \\ F_{by} \end{Bmatrix} = \alpha \begin{bmatrix} k_b & 0 \\ 0 & k_b \end{bmatrix} \begin{Bmatrix} x_b \\ y_b \end{Bmatrix} + (1-\alpha) \begin{bmatrix} F_Y & 0 \\ 0 & F_Y \end{bmatrix} \begin{Bmatrix} Z_x \\ Z_y \end{Bmatrix} \quad (1.1)$$

Where F_{bx} and F_{by} are the bearing forces in x-and y-direction respectively, α is an index which represent the ratio of post to pre-yielding stiffness,kb is the pre yielding stiffness of the bearing.x_b and y_b are relative displacement in x- and y-direction respectively.F_y is the yield strength of isolator and hysteretic components of displacement Z_x and Z_y are computed from following non –linear first order differential equation as

$$q \begin{Bmatrix} \frac{dZ_X}{dt} \\ \frac{dZ_Y}{dt} \end{Bmatrix} = [G] \begin{Bmatrix} \dot{x}_b \\ \dot{y}_b \end{Bmatrix} \quad (1.2)$$

[G]=

$$\begin{bmatrix} (A-\beta sgn(\dot{x}_b)|Z_x|Z_x-\tau Z_x^2 & (-\beta sgn(\dot{y}_b)|Z_x|Z_x-\tau Z_x Z_y \\ (-\beta sgn(\dot{y}_b)|Z_x|Z_x-\tau Z_x Z_y & (A-\beta sgn(\dot{x}_b)|Z_y|Z_y-\tau Z_y^2 \end{bmatrix} \quad (1.3)$$

Where, q is the yield displacement,$\dot{x}_b$ and $\dot{y}_b$ are the relative velocities of the isolation bearings in the x- and y-direction ,respectively, and β,τ,A are non-dimensional parameters which controls the shape and size of force deformation loop of the bearing. The parameters are selected such that the predicted response from the models matched with the experiments results. It is to be noted that that the off diagonal terms of matrix [G] provide the coupling or interaction between the restoring forces of the lead rubber bearing in the two orthogonal direction.

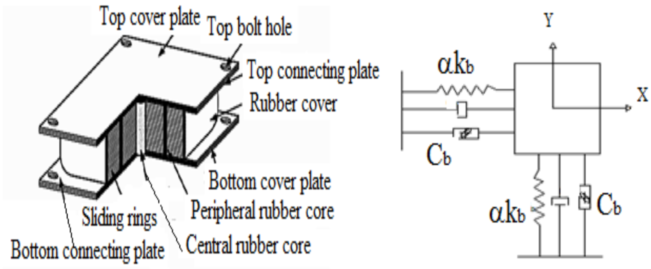

Fig1.2. base isolation system (a) lead rubber bearing (b) Schematic diagram

1.4. Governing Equation of Motion

The equation of motion of isolated liquid storage tank subjected to earthquake ground motion are expressed in the matrix form as

$$[m]\{\ddot{z}\}+[c]\{\dot{z}\}+[k]\{z\}+\{F\}=-[m][r]\{\ddot{u}_g\} \quad (1.4)$$

$$\{Z\} = \{x_c, x_I, x_b, y_c, y_I, y_b\}^T$$

And

$$\{F\} = \{0,0,(1-\alpha)Fy\ Zx, 0,0,(1-\alpha)FyZy\}^T$$

Are the displacement and restoring force vector, resp. $x_c = u_{cx}-u_{bx}$ and $y_c=u_{cy}-u_{by}$ are the displacement of the convective mass relative bearing displacement in x- and y-direction resp. $x_b=u_{bx}-u_{gx}$, $y_b=u_{by}-u_{gy}$ are the displacement of the bearing relative to ground in x- and y- direction respectively.[m],[k] and [c] are mass, stiffness and damping matrix of the system ;[r] is the influence coefficient matrix $\{\ddot{u}g\}=[\{\ddot{u}_{gx},\ddot{u}_{gy}\}]^T$is the earthquake ground acceleration vector $\ddot{u}_{gx}$,$\ddot{u}_{gy}$ are the earthquake ground accelerations in the x-and y-direction, respectively.

The matrix [m], [c], [k] and [r] are expressed as.

For Slender Tank-100kl

$$[m]=\begin{bmatrix} m_c & 0 & m_c & m_c & 0 & 0 & 0 & 0 \\ 0 & m_i & m_i & m_i & 0 & 0 & 0 & 0 \\ m_c & m_i & M+m_b & M+m_b & 0 & 0 & 0 & 0 \\ m_c & m_i & M+m_b & M+3m_b & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_c & 0 & m_c & m_c \\ 0 & 0 & 0 & 0 & 0 & m_i & m_i & m_i \\ 0 & 0 & 0 & 0 & m_c & m_i & M+m_b & M+m_b \\ 0 & 0 & 0 & 0 & m_c & m_i & M+m_b & M+3m_b \end{bmatrix} \quad (1.5)$$

$$[c]=\begin{bmatrix} c_c & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & c_i & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & c_t & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & c_b & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & c_c & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & c_i & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & c_t & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & c_b \end{bmatrix} \quad (1.6)$$

$$[k]=\begin{bmatrix} k_c & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & k_i & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & k_t & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & k_b & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & k_c & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_i & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & k_t & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & k_b \end{bmatrix} \quad (1.7)$$

$$[r]=\begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (1.8)$$

For shallow tank-50kl

$$[m]=\begin{bmatrix} m_c & m_c & m_c & 0 & 0 & 0 \\ m_c & M+m_b & M+m_b & 0 & 0 & 0 \\ m_c & M+m_b & M+3m_b & 0 & 0 & 0 \\ 0 & 0 & 0 & m_c & m_c & m_c \\ 0 & 0 & 0 & m_c & M+m_b & M+m_b \\ 0 & 0 & 0 & m_c & M+m_b & M+3m_b \end{bmatrix} \quad (1.9)$$

$$[c]=\begin{bmatrix} C_c & 0 & 0 & 0 & 0 & 0 \\ 0 & C_t & 0 & 0 & 0 & 0 \\ 0 & 0 & C_b & 0 & 0 & 0 \\ 0 & 0 & 0 & C_c & 0 & 0 \\ 0 & 0 & 0 & 0 & C_t & 0 \\ 0 & 0 & 0 & 0 & 0 & C_b \end{bmatrix} \quad (1.10)$$

$$[k]=\begin{bmatrix} K_c & 0 & 0 & 0 & 0 & 0 \\ 0 & K_t & 0 & 0 & 0 & 0 \\ 0 & 0 & K_b & 0 & 0 & 0 \\ 0 & 0 & 0 & K_c & 0 & 0 \\ 0 & 0 & 0 & 0 & K_t & 0 \\ 0 & 0 & 0 & 0 & 0 & K_b \end{bmatrix} \quad (1.11)$$

$$[r]=\begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (1.12)$$

Where $M=m_c+m_1+m_r$ is the total effective mass of the tank. The equivalent stiffness and damping of the convective and impulsive masses are expressed as

$$k_c = m_c\omega^2{}_c \quad (1.13)$$

$$k_i = m_i\omega^2{}_i \quad (1.14)$$

$$c_c = 2\xi_c m_c\omega_c \quad (1.15)$$

$$c_i = 2\xi_i m_i\omega_i \quad (1.16)$$

ξ_c, ξ_i are damping ratio of convective mass and impulsive mass, respectivelly.

4.4.1 Incremental Solution of Equation of Motion

The governing equation of motion of the isolated elevated liquid storage tank cannot be solved using the classical modal superposition technique due to

(i)The damping in the isolation system and liquid storage tank is different in nature, because of different material characteristics.

(ii)Force deformation behavior of the lead rubber bearing is nonlinear.

As a result, the governing equation of motion are solved in the incremental form using Newmark's step by step method assuming linear variation of acceleration over small time interval Δt the equation of motion in incremental form are expressed as

$$[m](\{\ddot{z}\}) + [c]\{\dot{z}\} + [k]\{z\} + \{F\} = -[m][r]\{\ddot{u}g\} \quad (1.17)$$

Where $\{\Delta z\} = \{\Delta x_c, \Delta x_i, \Delta x_b, \Delta y_c, \Delta y_i, \Delta y_b\}^T$ and

$$\{\Delta F\} = \{0,0,(1-\alpha)Fy\ \Delta Zx, 0,0,(1-\alpha)Fy\ \Delta Zy\}^T \quad (1.18)$$

Where ΔZx, ΔZy are the incremental hysteretic displacement component in x- and y- direction, respectively. The incremental acceleration and velocity vectors $(\{\Delta\ddot{z}\})$ and $\{\Delta\dot{z}\}$ respectively over in the time interval Δt are expressed as

$$\{\Delta\ddot{z}\} = a_0(\Delta z) + a_1\{\Delta\dot{z}\}^t + a_2\{\Delta\ddot{z}\}^t \quad (1.19)$$

$$\{\Delta\dot{z}\} = b_0(\Delta z) + b_1\{\Delta\ddot{z}\}^t + b_2\{\Delta\dot{z}\}^t \quad (1.20)$$

Where

$$a_0 = \frac{6}{\Delta t^2},\ a_1 = \frac{-6}{\Delta t}, a_2 = -3, b_0 = \frac{3}{\Delta t}, b_1 = -3, b_2 = \frac{-\Delta t}{2}$$

subscript 't'denotes time. The final equation of motion in the incremental form are expressed as

$$[k_{eff}]\{\Delta z\} = \{P_{eff}\} - \{\Delta F\} \quad (1.21)$$

Where $[\mathbf{k}_{eff}]$ is the effective stiffness matrix and $\{P_{eff}\}$ is the effectiveness excitation vector.

$$[k_{eff}] = a_0[m] + b_0[c] + [k] \quad (1.22)$$

$$\{P_{eff}\} = -[m]\{r\}\{\ddot{u}g\} - [m](a_1\{\Delta\dot{z}\}^t + a_2\{\Delta\ddot{z}\}^t) - [c](\ (b_1\{\Delta\ddot{z}\}^t + b_2\{\Delta\dot{z}\}^t) \quad (1.23)$$

The incremental restoring force vector involves the incremental hysteretic displacement components, ΔZx,ΔZy, which depend the bearing velocities at time t+$^{\Delta t}$ as a result an iterative procedure is required to obtain the required solution. The steps of the procedure as follows:

i) Assume $\Delta Zx = \Delta Zy = 0$ for iterative j=1 in equation 1.18 and solve for ΔZ by equation (1.21)

Calculate the incremental velocity vector using the equation (1.20) and find the velocity vector at time t+Δt by {Δż}^(t+Δt)={Δż}^t+{Δż} this velocity vector will provide the velocity of the base mass or rigid mass in the x- and y-directions, respectively (i.e.{ẋ_b }^(t+Δt) and {ẏ_b }^(t+Δt)).

Knowing the velocity of the mass in both the horizontal direction at time t+Δt compute the revised incremental displacement components ΔZx and ΔZy using the third order Runga –Kutta method are expressed as

$$\{\Delta Zi\} = \frac{k_{0i}+k_{2i}}{4} \quad (1.24)$$

$$k_{0i} = \Delta tf(\{\dot{x}_b\}^t, \{\dot{y}_b\}^t, Zi) \quad (1.25)$$

$$k_{1i} = \Delta tf\left(\dot{x}_b^{\frac{t+\Delta t}{3}}, \dot{y}_b^{\frac{t+\Delta t}{3}}, \frac{Zi}{3} + \frac{k_{0i}}{3}\right) \quad (1.26)$$

$$k_{2i} = \Delta tf\left(\dot{x}_b^{\frac{t+2\Delta t}{3}}, \dot{y}_b^{\frac{t+2\Delta t}{3}}, \frac{Zi}{3} + \frac{2k_{1i}}{3}\right) \quad (1.27)$$

v) Iterate further, until the following convergence criteria are satisfied for the incremental hysteretic displacement components of the bearing i.e.

$$\frac{|\Delta Z_x^{j+1}| - |\Delta Z_x^{j}|}{Z_m} \leq \varepsilon \tag{1.28}$$

$$\frac{|\Delta Z_y^{j+1}| - |\Delta Z_y^{j}|}{Z_m} \leq \varepsilon \tag{1.29}$$

Where ε is the small tolerance parameters the subscript denotes the iteration number and Z_m is the maximum value of hysteretic displacement of the bearing is expressed

$$Z_m = \sqrt{\frac{A}{\beta+\tau}} \tag{1.30}$$

After obtaining the final acceleration vector, the absolute acceleration of convective and impulsive masses in both x- and y- direction are obtained. The total base shear generated due to an earthquake ground motion in x- and y- direction respectively as

$$f_{bx} = m_c \ddot{u}_{cx} + m_i \ddot{u}_{ix} + (m_r + m_b)\ddot{u}_{tx} + 2(m_b)\ddot{u}_{bx} \tag{1.31}$$

$$f_{by} = m_c \ddot{u}_{cy} + m_i \ddot{u}_{iy} + (m_r + m_b)\ddot{u}_{ty} + 2(m_b)\ddot{u}_{by} \tag{1.32}$$

For Shallow tank (Model 1), appropriate masses, accelerations and heights are to be taken for the calculation of the base shear.

1.5 Parameters of Lead Rubber Bearing

The damping, stiffness and yield level of the bearing are designed to provide the desired value of three parameters namely, the T_b,ξ_b, and F0 expressed as

$$\alpha k_b = \left(\frac{2\pi}{T_b}\right)^2 (M + m_{Staging} + m_b) \tag{1.33}$$

$$F_0 = \frac{F_y}{W} \tag{1.34}$$

Where $\omega_b = 2\pi/T_b$ (isolation frequency) and W=Mg is the effective weight of the liquid storage tank. The parameters T_b,ξ_b and F0 are the design parameters for the isolation system and their values should be in a particular range, for effective isolation of the tanks .the time period T_b should be beyond the energy –containing periods of an earthquake motion, so that there is less transmission of the earthquake acceleration in to the tank. The parameters ξ_b corresponds to the damping ratio of the rubber in the isolation bearing. The parameters F0 is selected in such a way that the bearing does not yields during a minor earthquake or winds but the yielding must occur during a major earthquake to dissipate the seismic energy.

Parameters of the Lead Rubber Bearing used in this work are Yield displacement (q) =25cm, A=1, β=τ=0.5, the ratio of post to pre yielding stiffness of the bearing (α)=0.1

1.6 Numerical Study

The seismic response of base-isolated liquid storage tanks are investigated under two horizontal component of an earthquake ground motion .the bi-directional interaction between the restoring forces of the lead rubber bearing is duly considered. The details of earthquake ground motion considered are as below.

Sr. No.	Record	Notation	Component	Direction	PGA	Magnitude
1	Imperial Valley,1940,El-Centro	El-Centro	Normal (N)	x	0.26	6.95
			Parallel (P)	y	0.31	

To study the influence of bi-directional interaction and system parameters for the effectiveness of seismic isolation, slender tanks with varying capacity i.e. 50kl,100kl, with 12m,20m,28m staging heights are considered(properties are given in table 1.1(a))

Table 1.1a. Dimension of Elevated Water Tank Components

Sr.No.	Capacity	50Kl	100KL
1.	Diameter of container	4.65 m	5.04 m
2.	Depth of water in container	3.0 m	5.0 m
3.	Free board	0.3 m	0.3 m
4.	Roof slab	120 mm	140 mm
5.	Bottom slab	200 mm	270 mm
6.	Bottom beam	250 x 600 mm	300 x 700 mm
7.	Wall	200 mm	200 mm
8.	Bracing	300 x 450 mm	250 x 350 mm
9.	Column mm diameter	4 nos. - 450 mm	4 nos. - 500 mm
10.	Depth of footing below ground level	2.0 m c/c	3.0 m c/c
11.	distance between	3.43 m	4.31 m

1.6.1 Effect of Interaction of Bearing Forces

The peak response quantities for tank under different earthquake ground motion in x and y- direction are shown in table 1.2 under Imperial Valley 1940) earthquake ground motion. It is observed that isolation is quite effective in reducing the base shear and impulsive displacement of the Tank. Sloshing displacement is quite increasing in tank due to isolation. The similar effect of the bi-directional interaction is observed on force deformation behaviour.

Table1.2 a. Peak response of elevated Tank (shallow tank) in x-direction.

Earthquake/ Capacity of tank	Height of staging	Interaction/ No-interaction of bearing forces	Type of Tank	T_b=2sec, ξ_b=0.1 Shallow tank			
				F_{bx}/W	x_c (cm)	x_t (cm)	x_b (cm)
Imperial Valley (1940) 50kl	12m		Non-isolated	0.17	30.47	2.89	
		Interaction	Isolated (Lead-LRB)	0.04	35.37	0.59	9.2
		No-interaction	Isolated (Lead-LRB)	0.04	36.37	0.61	9.3
	20m		Non-isolated	0.09	35.63	2.95	
		Interaction	Isolated (Lead-LRB)	0.03	35.27	0.45	9.2
		No-interaction	Isolated (Lead-LRB)	0.03	37.17	0.49	9.4
	28m		Non-isolated	0.08	35.86	2.92	
		Interaction	Isolated (Lead-LRB)	0.02	61.14	0.44	6.4
		No-interaction	Isolated (Lead-LRB)	0.03	62.01	0.45	6.7

Earthquake/ Capacity of tank	Height of staging	Interaction/ No-interaction of bearing forces	Type of Tank	T_b=4sec, ξ_b=0.1 Shallow tank			
				F_{bx}/W	x_c (cm)	x_t (cm)	x_b (cm)
Imperial Valley (1940) 50kl	12m		Non-isolated	0.17	30.5	2.8	
		Interaction	Isolated (Lead-LRB)	0.04	59.1	1.1	9.62
		No-interaction	Isolated (Lead-LRB)	0.04	61.6	2.1	9.7
	20m		Non-isolated	0.09	35.3	2.9	
		Interaction	Isolated (Lead-LRB)	0.03	60.7	0.69	13
		No-interaction	Isolated (Lead-LRB)	0.03	61.23	0.71	14
	28m		Non-isolated	0.08	35.8	2.9	
		Interaction	Isolated (Lead-LRB)	0.03	55.1	0.27	23.2
		No-interaction	Isolated (Lead-LRB)	0.04	56.12	0.24	24.12

Table1.2 b. Peak response of elevated Tank (shallow tank) in Y-direction.

Earthquake/ Capacity of tank	Height of staging	Interaction/ No-interaction of bearing forces	Type of Tank	T_b=2sec, ξ_b=0.1 Shallow tank			
				F_{bx}/W	x_c (cm)	x_t (cm)	x_b (cm)
Imperial Valley (1940) 50kl	12m		Non-isolated	0.19	26.2	9.1	
		Interaction	Isolated (Lead-LRB)	0.02	24.6	0.4	8.60
		No-interaction	Isolated (Lead-LRB)	0.02	25.1	0.4	8.67
	20m		Non-isolated	0.08	28.6	9.2	
		Interaction	Isolated (Lead-LRB)	0.02	31.5	0.2	8.69
		No-interaction	Isolated (Lead-LRB)	0.02	32.1	0.2	8.69
	28m		Non-isolated	0.07	26.5	9.7	
		Interaction	Isolated (Lead-LRB)	0.01	47.5	0.5	6.12
		No-interaction	Isolated (Lead-LRB)	0.02	48.1	0.5	6.11

Earthquake/ Capacity of tank	Height of staging	Interaction/ No-interaction of bearing forces	Type of Tank	T_b=4sec, ξ_b=0.1 Shallow tank			
				F_{bx}/W	x_c (cm)	x_t (cm)	x_b (cm)
Imperial Valley (1940) 50kl	12m		Non-isolated	0.19	26.2	9.1	
		Interaction	Isolated (Lead-LRB)	0.03	48.5	0.2	5.25
		No-interaction	Isolated (Lead-LRB)	0.03	49.1	0.2	5.29
	20m		Non-isolated	0.08	28.6	9.2	
		Interaction	Isolated (Lead-LRB)	0.02	50.4	0.1	5.29
		No-interaction	Isolated (Lead-LRB)	0.03	51.2	0.1	5.31
	28m		Non-isolated	0.07	26.5	9.7	
		Interaction	Isolated (Lead-LRB)	0.02	49.3	0.2	5.29
		No-interaction	Isolated (Lead-LRB)	0.03	51.2	0.2	5.21

1.6.2 Effect of isolation damping

Figure 1.3 illustrates the influence of isolation damping on the seismic response of shallow and slender tank with varying staging height. The figure 1.3.and table 1.2 indicates that the base shear, tower drift reduces for effective damping ξ_b=0.1. It has been found that reduction in base shear is significantly decreases. The sloshing displacement gradually increases with increase in height of tank.

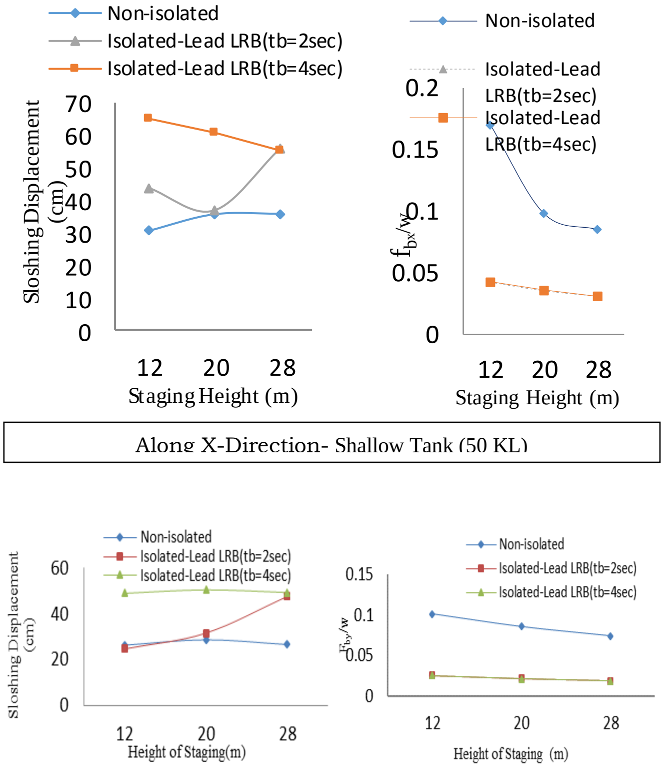

Fig 1.3. Base Shear & Sloshing Displacement Response of Shallow Tank (50 KL due to Imperial Valley (1940) Earthquake (ξ_b=0.1, F0=0.05).

1.6.3 Effect of Time period of framed staging

The effect of time period of tower structure T_t on the response of isolated tank such as base shear, sloshing displacement and bearing displacement for shallow and slender tank is illustrated under different earthquakes in fig.1.4.It has been found that the response of isolated tank is insensitive to variation of T_t .the response of isolated tank is compared with non-isolated tank and it is observed that base shear response is decreased over the entire range of T_t. And the sloshing displacement increase as compared to non-isolated tank.

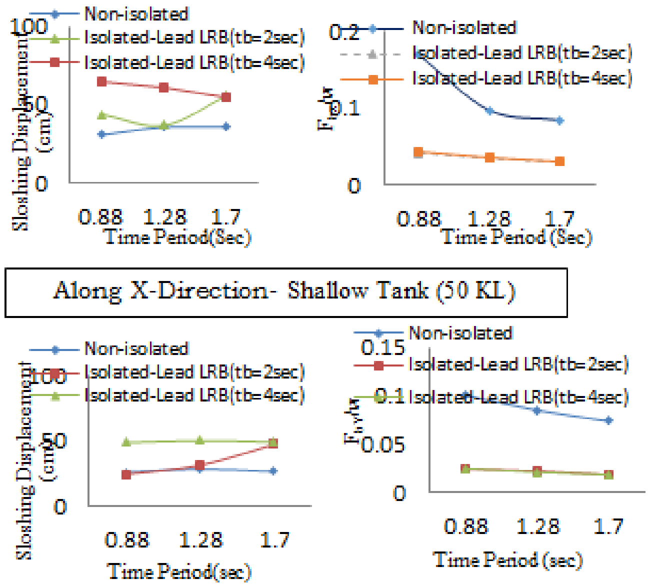

Fig1.4. Base Shear & Sloshing Displacement response against Time period For Shallow Tank (50kl) due to Imperial Valley (1940) Earthquake (ξb=0.1, F0=0.05)

1.6.4 Effect of flexibility of Isolation system

The influence of time period of isolation system on response of shallow tank and slender tank are investigated as shown in fig. 1.5 it is observed that due to increase of isolation period base shear is reduced significantly because of increased flexibility of the isolation system transmit less acceleration to liquid container, hence less dynamic forces are generated. The sloshing displacement marginally increases with increase of time period and further increase in time period increase the sloshing displacement.

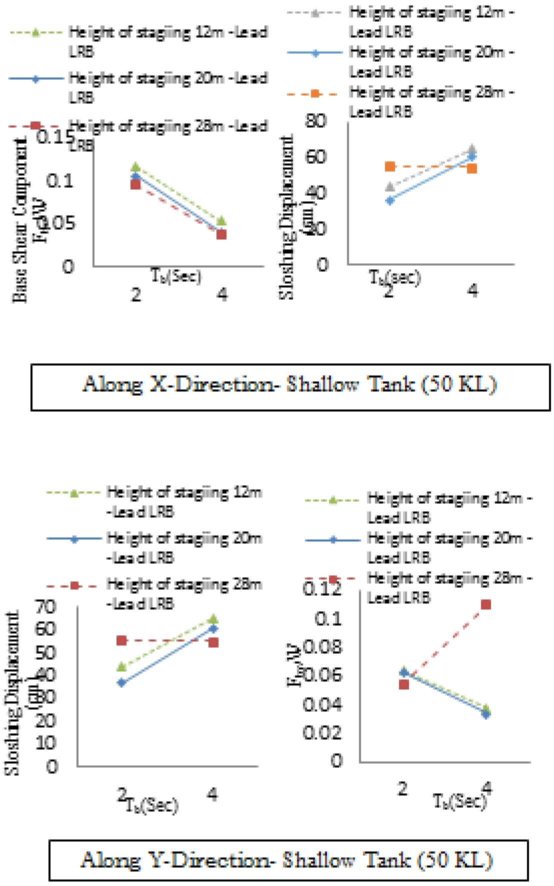

Fig 1.5. Base Shear & Sloshing Displacement response against Time period For Shallow Tank (50kl due to Imperial Valley (1940) Earthquake (ξ_b=0.1, F0=0.05).

Concluding Remark

Comparative performance of elevated liquid storage tanks by putting the base isolation system at bottom of the supporting tower is investigated using, the x and y -components of Imperial Valley (1940), earthquake ground motions. The earthquake response of isolated tanks is compared with non- isolated tanks to measure the effectiveness of the isolation. The following conclusions are drawn from the trends of the results of isolated elevated liquid storage tank:

1. It is observed that the base shear of elevated liquid storage tank is significantly reduced due to isolation. The base shear is mainly dominated by the impulsive and rigid mass components. It is also found that isolation effectively work in 12m staging height tank.
2. The peak response of base isolated liquid storage tanks is not much influenced by the bi-directional interaction of restoring forces of Lead LRB.
3. The drift of framed tower structure is also significantly reduced due to isolation. Further, the peak response of isolated tanks is insensitive to the period of the tower structure.

4. The effectiveness of seismic isolation increases with the increase of bearing flexiability and damping.

5. the contribution of sloshing mass increases with increase in staging height of the tank and base shear response decrease with increases in height of the tank as structure becomes more flexible due to increase of height.

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