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Comparative Performance of Elevated Isolated Liquid Storage Tanks (With Shaft Staging)

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Abstract - Liquid storage tanks are important components of lifeline and industrial facilities. They are critical elements in water supply scheme and fire fighting system, and extensively used for storage and processing of variety of liquid like material such as petroleum product, liquefied natural gas, chemical fluid and wastage of different forms. In this paper, the seismic response of base isolated cylindrical liquid storage tanks is investigated under real earthquake ground motion. The isolation systems considered is elastomeric bearings (without lead core), the specific objectives of the study are to carry out the comparative performance of the tanks with isolation and without isolation (i.e. Fixed tanks) also to investigate the response of the tanks for varying capacity with varying heights. For this study forty tanks of varying heights such as 8m,10m,11m,11.5m,12.5m,14m,16m with varying capacities of 500kl,265kl,200kl,100kl,50kl are considered. For this a time history analysis has been carried out by using a three time history of varying magnitude with varying peak ground acceleration. It is observed that the base shear of elevated liquid storage tanks supported on shaft is significantly reduced due to isolation. The drift of the tank relation to base of shaft is also significantly reduced due to isolation. The earthquake response of isolated short tanks is relatively more, i.e. Isolation is not effective for stiffer shafts, and however in general, the effectiveness of base isolation is achieved for tall tanks. Although the effectiveness of seismic isolation increases with the increase of bearing flexibility and damping these properties needs to be modified for desired response.

Keywords*- liquid storage tanks, shaft, earthquake ground motion, elastomeric rubber bearing*

I. INTRODUCTION

The tanks come under variety of configuration; it may be ground supported, elevated or partly buried. In recent years the number, the size and importantance of these structure have been increased and there is need to understand their seismic behavior and to formulate rational and efficient method of their analysis and design to resist earthquake ground motion. Over period of times failure of large number of tanks has attributes the need of more clear understanding and assessment of behavior of tanks during an earthquake ground motion.

Reinforced concrete circular shafts type support (staging) is widely used for elevated tanks of low to a very high capacity for its ease of construction and more solid form it provides compared to frame construction. In recent past earthquakes Bhuj,Gujarat (2001)and Jabalpur (1997)thin shell of circular shaft have perform unsatisfactory, thin shaft shell when used as a column (or pedestal)are vulnerable because they not only possess a very low ductility but also lack redundancy of alternate load path that are present in framed structure. For structure in high Seismicity regions earthquakes loading is considered the most significant and possibly the most destructive external loads, particularly for low to medium rise tanks. Seismic isolation consist essentially the installation of mechanism which decouple the tanks and or its content from particularly damaging earthquakes induces ground or support motion. This decoupling is achieved by increasing the flexibility of the system, together with providing appropriate damping to resist the amplitude of the motion caused by the earthquakes. The advantages of seismic isolation includes the ability to significantly reduces structural and non structural damage to reduce seismic design forces. The past studies of the dynamics behavior. This includes (i) the effect of aspect ratio on for further study of base isolated liquid storage tanks to understand tanks reducing the earthquake response of tanks. However, there is need. Liquid storage tanks confirm the effectiveness of base isolation in (ii) the effectiveness of isolation System for liquid storage tanks.

II. MODEL OF SEISMIC ISOLATED LIQUID STORAGE TANKS

For the presents study, a practical range of tanks is considered. Five practical capacities of tanks viz, 50kl, 100kl, 250kl, 256kl, 500kl are considered for the analysis's height of the tanks is varied from 8m to 14m(various parameters of tanks are given in table No.3.1).Thus 8 tanks for each capacities are considered. Thus, in alls the performance of 40 tanks is examined using time history for each fixed base and isolated tanks.

Each of 40 tanks is designed to evaluate their geometrical parameters. The shaft and container is modeled as shell in SAP-2000. The isolation system, i.e. laminated rubber bearings (LRB) installed below the tower to decouple the structure from the ground.

A. Spring mass model for seismic analysis

It was observed that tank liquid vibrates in two distinct pattern[1] (a) The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall, this mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base (b) Liquid mass in the upper region of tank undergoes sloshing motion, this mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented. In the present work convective mass is shown by spring with a mass at a height [h_c] and impulsive mass attach with the wall is shown by a mass at a height [h_i] of the container.

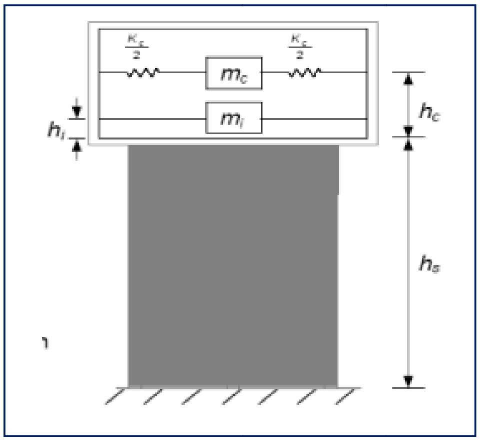
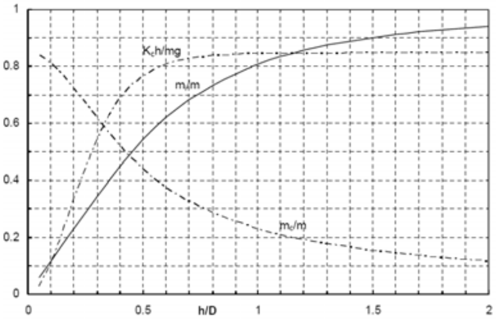


Fig.1.1 Mathematical Model of Tank with Various Masses



Fig, 1.2 Impulsive and Convective Masses and convective spring stiffness

Where, S =H/D (i.e. ratio of the liquid height to diameter of the tank) [1]

$$Y_c = m_c/m \tag{3.1}$$

$$Y_i = m_i/m \tag{3.2}$$

$$m = \pi R^3 H \rho_w \tag{3.3}$$

Time period of impulsive mode [47].

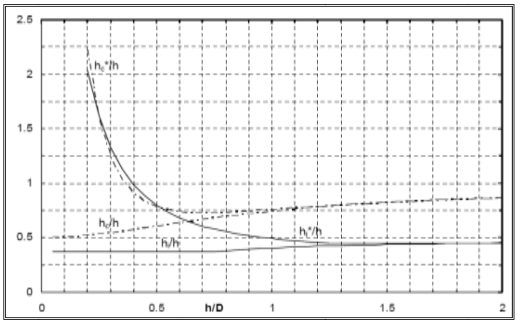
$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}} \tag{3.4}$$

Where m_s- mass of container and one third mass of staging, m_i-impulsive mass of liquid,K_s- Lateral stiffness of staging.

Time period of convective mode [1].

$$T_c = 2\pi\sqrt{\frac{m_c}{K_c}} \tag{3.5}$$

Where, m_c- convective mass of liquid, Kc- stiffness of convective mass



Fig, 1.3 Heights of Impulsive and Convective Masses

The effective heights H_c,H_i, in terms of liquid height are expressed as [fig.1.3].

$$H_c = \mu_c H \tag{3. 6}$$

$$H_i = \mu_i H \tag{3. 7}$$

Design Horizontal Seismic Coefficient:-

The Design horizontal seismic coefficient for impulsive mode,[47]

$$A_{hi} = (Z/2)\,(I/R)\,(S_a/g)_i \tag{3. 8}$$

Where,

Z-zone factor=0.24, I-importance factor=1.5

Damping 5%, T_i-time period of impulsive mode.

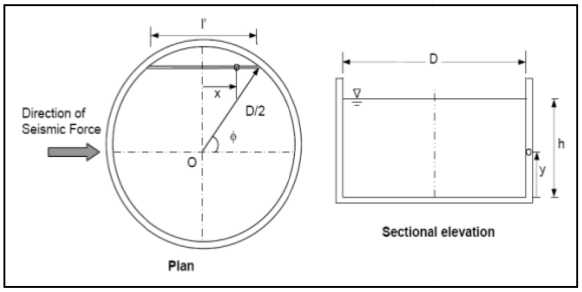
$(S_a/g)_i$-spectral acceleration coefficient.

Design horizontal seismic coefficient for convective mode,[47]

$$A_{hc} = (Z/2)\,(I/R)\,(S_a/g)_c \qquad (3.9)$$

Shaft is considered to have reinforcement in two curtains both horizontally and vertically. Hence, *R* – Response reduction factor is taken as 1.8. Damping 0.5% T_c-time period of convective mode.

A multiplication factor of 1.75 is used to get $(S_a/g)_c$ for 0.5% damping from that of 5% damping.



Impulsive hydrodynamic pressure on wall [1].

$$p_{iw}(y) = Q_{iw}(y)\,(A_h)_i\,\rho g h \cos\varnothing \qquad (4.0)$$

where,

$$Q_{iw}(y) = 0.866[1-(y/h)^2]\tanh(0.866D/h) \qquad (4.1)$$

Maximum pressure will occur at φ=0, at base of wall y=0, Impulsive hydrodynamic pressure in vertical direction, on base slab (y=0) on a strip of length l',is given by[1].

$$p_{ib} = 0.866\,(A_h)_i\,\rho g h \sinh(1.732\,x/h)/\cosh(0.866l'/h)\ . \qquad (4.2)$$

Where,

ρ = Mass density of liquid,φ = Circumferential angle, and

y = Vertical distance of a point on tank wall from the bottom of tank wall.

x=horizontal distance of a point on base of tank in the direction of seismic force, from centre of tank

Lateral Convective hydrodynamic pressure on wall [1].

$$p_{cw} = Q_{cw}(y)\,(A_h)_c\,\rho g D\,(1-1/3\cos^2\varnothing)\cos\varnothing \qquad (4.3)$$

Where,

$$Q_{cw}(y) = 0.5625\cosh(3.674y/D)/\cosh(3.674h/D) \qquad (4.4)$$

Convective hydrodynamic pressure in vertical direction on base slab (y=0) [1].

$$p_{cb} = Q_{cb}(x)\,(A_h)_c\,\rho g D \qquad (4.5)$$

Where

$$Q_{cb}(x) = 1.125[(x/D)-4/3(x/D)^3]\,\mathrm{sech}\,[3.674\,h/D] \qquad (4.6)$$

Pressure on tank wall due to inertia is given by[47].

p-(wall inertia) = $(A_h)_i$ x mass density of wall x wall thickness

B. *Governing equation of motion*

Structure has been model by finite element method using SAP-2000 (version 9i).The equation of motion of elevated liquid storage tanks subjected to unidirectional earthquake ground motion are expressed in the matrix form as [3]

$$[m]\{\ddot{x}\} + [c]\{\dot{x}\} + [k]\{x\} = -[m]\ddot{u}_g \qquad (4.7)$$

Where {x}-displacement vector,

[m]-mass matrix

[c]-damping matrix

[k]-stiffness matrix

$\ddot{u}_g$ -earthquake acceleration

The convective and impulsive masses are calculated by using eq. (3.1) to (3.3) the self weight of tank and shaft is calculated automatically by the software at appropriate nodal points. The convective and impulsive masses lumped at appropriate heights by using equation (3.6) to (3.7).For non isolated tanks the bottom nodal points are given zero degrees of freedom i.e. fixed.

For isolated tanks L.R.B. types of isolation has been used, the time period of isolation is considered as 2 sec in horizontal motion. The total stiffness of isolation is equally divided among all nodal points.

C. *Earthquake ground motion*

The seismic response of isolated liquid storage tanks is investigated for near fault earth quake ground motions recorded on rock. For the present study, three recorded earthquake ground motions considered are Kern Country (1952/07/21), Imperial Valley (1979/10/15) and Sanfracisco (1957/03/22). For the purpose of the seismic behavior of the tanks, ground motions records are put in X-component. Records of acceleration for Kern Country (1952/07/21), Imperial Valley (1979/10/15), and Sanfracisco (1957/03/22) are as below [2].

Earthquake	Magnitude	Record/Component	PGA
Kern-Country (1952/07/21)	M(7.5)	KERN/HOL-UP	0.022(g)
Imperial-Valley (1979/10/15)	M6.5)	IMPAVAL/ H-AEP045	0.327(g)
Sanfracisco (1957/03/22)	M(5.3)	SANFRAN/GGP-UP	0.112(g)

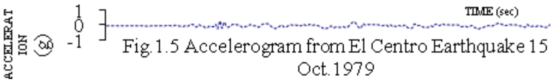


Fig.1.5 Accelerogram from El Centro Earthquake 15 Oct.1979

Fig1.6 Accelerogram from San francisco Earthquake 22 March 1957

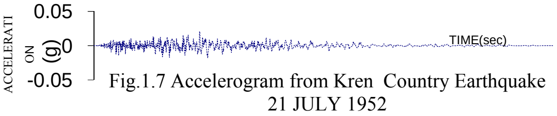


Fig.1.7 Accelerogram from Kren Country Earthquake 21 JULY 1952

III. DESIGN OF ISOLATORS

A practical seismic isolation system should meet the fallowing requirements.

1. Sufficient horizontal flexibility to increase the structural periods and spectrum demands accepts for very soft soil sites
2. Sufficient energy dissipitation capacity to limit the displacement across the isolators to a practical level.
3. Adequate rigidity to make the isolated structure not much different from a fixed base structure under general service loading.

Based on above mentioned requirements and codal procedure, as per UBC -1997, LRB isolator design properties like damping, hardness, modulus of rigidity, and poissoins ratio for rubber are considered from UBC 1997.

Tanks under consideration here requires different size of isolators, as gravity loads acting on the column are different for different sizes of tanks, different sizes of bearings are required.

The basic equation of LRB is as fallows [4].

The effective horizontal stiffness of the isolators is [4]

$$k_{eff}=(W/g)(2\pi/T_D)^2=GA/t \quad (4.7)$$

Where W- total weight of the tank,

G-gravitational force and taken as $9.81 m/s,^2$

T_D- effective isolation period,

G- Shear modulus of the rubber,

A-cross sectional area of the bearing,

t- total thickness of rubber layer.

The design displacement D_D of the isolation system along each main horizontal axis at design basis earthquake level is calculated according to the UBC97 [5]

$$D_D=(g/4\pi^2)(C_{VD}T_D)/B_D \quad (4.8)$$

C_{VD}- Seismic coefficient C_D as set forth in Table 16-R [5],

B_D - Numerical coefficient related to the effective damping of the isolation system at the design displacement $ß_D$ as set forth in Table A-16-C [5],

The total design displacement including additional displacement due to accidental torsion is calculated according to the UBC [5]

$$D_{TD}=D_D[1+(12ey/b^2+d^2)] \quad (4.9)$$

e-actual eccentricity plus accidental eccentricity which is taken as maximum tank direction perpendicular to the direction of force under consideration,b-shortest plan dimension, d -longest plan dimension, y- distance between the center of rigidity of the isolation system[6]. The characteristics force Q is [7]

$$Q = (\pi/2)k_{eff}ß_D D_D \quad (5)$$

$ß_D$ – damping of the isolation system

The post yield horizontal stiffness k_2 is [7]

$$k_2=k_{eff}-(Q/D_D) \quad (5.1)$$

Post yield to pre yield stiffness ratio is taken as 0.1

i.e. $k_2 /k_1 = œ$

The yield displacement D_Y [7]

$$D_Y = Q/ (k_2- k_1) \quad (5.2)$$

The yield force F_Y [7]

$$F_Y=Q+k_2D_Y \quad (5.3)$$

The pre-yield horizontal stiffness k_1 [7]

$$k_1 =F_Y / D_Y \quad (5.4)$$

The vertical stiffness of the laminated rubber bearings is expressed by

$$k_v =E_rA / t \quad (5.5)$$

E_r– compression modulus of elasticity of rubber [7],

A-c/s area of LRB, t_- total thickness of LRB. [7],

$$E_r=[1/(6GS_H^2)]+1.333K \qquad (5.6)$$

K- Bulk modulus. For circular LRB, shape factor is taken as [7]

$$S_H=Ø/(4t_r) \qquad (5.7)$$

where Ø- diameter of LRB, t_r- thickness of each rubber layer in LRB.The details calculations of base isolators are omitted here and final design parameters are listed in table no 1.5-1.6. It is important to note that analysis and design of all different types of base isolator was done using excel spread sheet

Table1.1 (A) Geometric Properties of All Water Tank

.		Geometry of shaft support		Bottom slab		Vertical slab		
Sr No	Capacity	thickness	height	Diameter	thickness	height	Diameter	thickness
	KL	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	50 KL	2.628	0.175	8	4.38	0.1	3.285	4.38
2		2.628	0.175	10	4.38	0.1	3.285	4.38
3		2.628	0.175	10.5	4.38	0.1	3.285	4.38
4		2.628	0.175	11	4.38	0.1	3.285	4.38
5		2.628	0.175	11.5	4.38	0.1	3.285	4.38
6		2.628	0.175	12.5	4.38	0.1	3.285	4.38
7		2.628	0.175	14	4.38	0.1	3.285	4.38
8		2.628	0.175	16	4.38	0.1	3.285	4.38

Table1.1 (B) Geometric Properties Of All Water Tanks

.		Geometry of shaft support		Bottom slab		Vertical slab		
Sr No	Capacity	thickness	height	diameter	thickness	height	diameter	thickness
	(KL)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	100 KL	3.312	0.15	8	5.52	0.2	4.14	5.52
2		3.312	0.15	10	5.52	0.2	4.14	5.52
3		3.312	0.15	10.5	5.52	0.2	4.14	5.52
4		3.312	0.15	11	5.52	0.2	4.14	5.52
5		3.312	0.15	11.5	5.52	0.2	4.14	5.52
6		3.312	0.15	12.5	5.52	0.2	4.14	5.52
7		3.312	0.15	14	5.52	0.2	4.14	5.52
8		3.312	0.15	16	5.52	0.2	4.14	5.52

Table1.1(C) Geometric Properties Of All Water Tanks

.		Geometry of shaft support		Bottom slab		Vertical slab		
Sr. No	Capacity	thickness	height	diameter	thickness	height	diameter	thickness
	(KL)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	200 KL	4.176	0.16	8	6.96	0.2	5.22	6.96
2		4.176	0.16	10	6.96	0.2	5.22	6.96
3		4.176	0.16	10.5	6.96	0.2	5.22	6.96
4		4.176	0.16	11	6.96	0.2	5.22	6.96
5		4.176	0.16	11.5	6.96	0.2	5.22	6.96
6		4.176	0.16	12.5	6.96	0.2	5.22	6.96
7		4.176	0.16	14	6.96	0.2	5.22	6.96
8		4.176	0.16	16	6.96	0.2	5.22	6.96

Table1.1 (D) Geometric Properties Of All Water Tanks

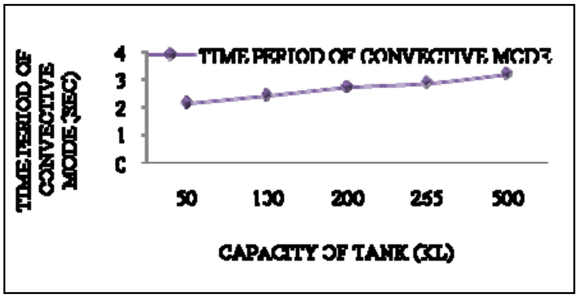
.		Geometry of shaft support		Bottom slab		Vertical slab		
Sr. No	Capacity	thickness	height	diameter	thickness	height	diameter	thickness
	(KL)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	265 KL	4.59	0.16	8	7.65	0.23	5.737	7.65
2		4.59	0.16	10	7.65	0.23	5.737	7.65
3		4.59	0.16	10.5	7.65	0.23	5.737	7.65
4		4.59	0.16	11	7.65	0.23	5.737	7.65
5		4.59	0.16	11.5	7.65	0.23	5.737	7.65
6		4.59	0.16	12.5	7.65	0.23	5.737	7.65
7		4.59	0.16	14	7.65	0.23	5.737	7.65
8		4.59	0.16	16	7.65	0.23	5.737	7.65

Table 1.1 (E) Geometric Properties Of All Water Tanks

	Geometry of shaft support		Bottom slab		Vertical slab		
Capacity	thickness	height	diameter	thickness	height	diameter	thickness
KL	(m)	(m)	(m)	(m)	(m)	(m)	(m)
500 KL	5.676	0.2	8	9.46	0.2	7.095	9.46
	5.676	0.2	10	9.46	0.2	7.095	9.46
	5.676	0.2	10.5	9.46	0.2	7.095	9.46
	5.676	0.2	11	9.46	0.2	7.095	9.46
	5.676	0.2	11.5	9.46	0.2	7.095	9.46
	5.676	0.2	12.5	9.46	0.2	7.095	9.46
	5.676	0.2	14	9.46	0.2	7.095	9.46
	5.676	0.2	16	9.46	0.2	7.095	9.46

Table 1.2 Time Period Of Convective Mass

Capacity KL	E_c (KN/m^2)	ρ_s (KN/m^3)	k_c kg/m	T_c sec	H_c (m)	H_i (m)	Mass of container (kg)
50KL	22.3 x10^6	25	121928	2.1	2.29	1.23	17.87 x10^3
100KL	22.3 x10^6	25	193680	2.4	2.8	1.55	47.80 x10^4
200KL	22.3 x10^6	25	307814	2.7	3.6	1.95	59.83 x10^4
265KL	22.3 x10^6	25	372240	2.9	4.01	2.14	71.93 x10^4
500KL	22.3 x10^6	25	567720	3.2	4.9	2.65	109.6 x10^4



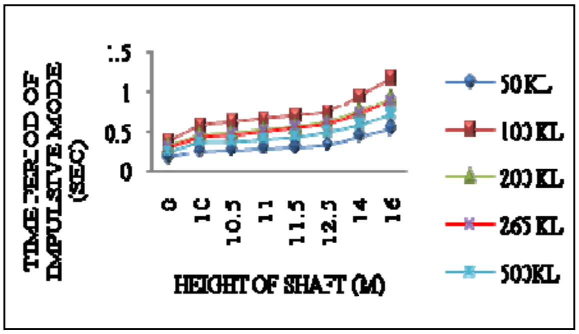


Fig.1.9 Time Period Of Impulsive Mass of All Tanks

Table 1.4 Properties Of Lrb (As Per Ref. [7])

Capacity (KL)	Height of staging (m)	k_{eff} (KN/m)	D_{TD} (m)	Q (KN)	k_2 (KN/m)	k_1 (KN/m)	F_Y (KN)	D_Y (mm)
50 KL	8m	989	0.2	46.	787.1	7871	51.	6
	10m	1057.3	0.2	49.	841.	8415.	55.5	6
	10.5m	1073.4	0.2	50.	854.	8543.	55.3	6.5
	11m	1092.4	0.2	51.	865	8695.	56.3	6.5
	11.5m	1107.5\\	0.2	51.	881.5	8815.	57	6.5
	12.5m	1134.7\	0.2	53.	903	9031	59	6.5
	14m	1190.9	0.2	55	947.9	9479	62	6.5
	16m	1258.3	0.2	59.	1001.	1001	651	6.5
100 KL	8m	1826.1	0.26	85	1453.	1453	95.8	6.5
	10m	1860.	0.2	87.	1480.	1480	97	6.5
	10.5m	1878.	0.2	88.	1495.	1495.	99	6.5
	11m	1900.5	0.26	89.	1512.	1512	99	6.5
	11.5m	1915.6	0.26\	89.	1524.	1524	99.4	6.5
	12.5m	1947.7	0.26	91.	1550.	1550	101.5	6.5
	14m	2007.0	0.26	94.	1597.	1597	107	6.5
	16m	2079.4	0.26\\	97.6	1655.0	16550	108	6.6
200 KL	8m	3001.0	0.2	140	2388	2388	152	6.5
	10m	3108.6	0.26	145	2474	2474	162.1	6.5
	10.5m	3120.6	0.26	146	2483	2483	162.7	6.5
	11m	3156.8	0.26	148	2512.	2512	164.6	6.5
	11.5m	3192.0	0.26	149	2540.5	25405	166.49	6.5
	12.5m	3260.4	0.26	153	2594	2594	170.0	6.5
	14m	3315.6	0.26	155	2638.	2638	172.9	6.5
	16m	3415.1	0.26	160	2718	2718	178.	6.5

Table 1.4(B) Properties Of Lrb (As Per Ref. [7])

Capacity KL	Height of staging (m)	k_{eff} (KN/m)	D_{TD} (m)	Q (KN)	k_2 (KN/m)	k_1 (KN/m)	F_Y (KN)	D_Y (mm)
265 KL	8m	3827.	0.26	179	3046.	30461	199	6.5
	10m	3935.	0.26	184	3132.	31325	205	6.5
	10.5m	3962.	0.26	186	3154.	31541	206	6.5
	11m	3991	0.26	187	3176.	31764	208	6.5
	11.5m	4018.	0.26	188	3198	31980	209	6.5
	12.5m	4072.	0.26	191	3241.	32412	212	6.5
	14m	4153	0.26	194	3306	33060	216	6.5
	16m	4235	0.26	198	3370.	33708	220	6.5
500 KL	8m	6782	0.26	318	5397.	53978	353.	6.5
	10m	6954	0.26	326	5535.	55354	362.	6.5
	10.5m	7044	0.26	330	5606.	56066	367.	6.5
	11m	7051	0.26	330	5608	56088	367	6.5
	11.5m	7065	0.26	331	5623.	56234	368	6.5
	12.5m	7178	0.26	336	5713.	57130	374	6.5
	14m	7278	0.26	341	5793.	57930	379	6.5
	16m	6782	0.26	348	5913	59138	387	6.5

TABLE 1.5 Properties of LRB

Capacity (KL)	Height Of Staging (m)	K_v (KN/m)	S_H	A (m^2)	t (m)	t_r (m)
50 KL	8	131633	14	0.24725	0.25m	0.01
	10	141758	14	0.26433	0.25m	0.01
	10.5	144143	14.	0.26835	0.25m	0.01
	11	146977	14.	0.273124	0.25m	0.01
	11.5	149215	15	0.276893	0.25m	0.01
	12.5	15324	15	0.28367	0.25m	0.01m
	14	16160	15	0.29774	0.25m	0.01
	16	17161	14	0.31458	0.25m	0.01
100 KL	8	256301	19	0.456547	0.25m	0.01
	10	261405	19	0.46509	0.25m	0.01
	10.5	264108	19.	0.469612	0.25m	0.01
	11	267412	19.	0.47514	0.25m	0.01
	11.5	269665	19	0.478909	0.25m	0.01
	12.5	274471	19	0.48695	0.25m	0.01
	14	283334	19	0.501774	0.25m	0.01
	16	294153	20	0.519865	0.25m	0.01
200 KL	8	432082	24	0.750274	0.25m	0.01
	10	448188	24	0.77716	0.25m	0.01
	10.5	449994	25	0.780175	0.25m	0.01
	11	455414	25	0.78922	0.25m	0.01
	11.5	460683	25	0.798015	0.25m	0.01
	12.5	470920	25	0.8151	0.25m	0.01
	14	479200	25.	0.82892	0.25m	0.01
	16	494106	26	0.853795	0.25m	0.01
265 KL	8	555848	27.600	0.956813	0.25m	0.01
	10	572114	27.989	0.98395	0.25m	0.01
	10.5	576180.6	28.085	0.990734	0.25m	0.01
	11	580397.9	28.185	0.997769	0.25m	0.01
	11.5	584464.6	28.28	1.004554	0.25m	0.01
	12.5	592598.2	28.471	1.018122	0.25m	0.01
	14	604798.9	28.754	1.038474	0.25m	0.01
	16	617000.1	29.034	1.058827	0.25m	0.01
500KL	8	998822.8	36.741	1.69553	0.25m	0.01
	10	1024745	37.206	1.738747	0.25m	0.01
	10.5	1038158	37.445	1.761109	0.25m	0.01
	11	1039123	37.123	1.761109	0.25m	0.01
	11.5	1041323	37.501	1.766386	0.25m	0.01
	12.5	1058203	37.798	1.794528	0.25m	0.01
	14	1073275	38.062	1.819654	0.25m	0.01
	16	1096033	38.457	1.857595	0.25m	0.01

IV. RESPONSE OF TANKS ISOLATED BY ELASTOMERIC BEARINGS SUBJECTED TO REAL EARTHQUAKES

The seismic response of isolated and fix base tanks system is investigated for the three real earthquakes excitation. The time history analysis is carried out by giving excitation in lateral direction of tank (shaft).

A. *Maximum Bearing Displacement*

The bearing displacement increases with increase of isolation period. It becomes more flexible leading to more displacement. In the present study, time period of isolation system (target period) is T_D=2 sec, damping ratio i.e. $ß_D$=0.13and normalized yield strength i.e. F_O= F_Y/W is equal to 0.05.It is found that the maximum displacement of the bearing depends upon the stiffness properties of the bearing, in present work stiffness properties of the bearings varies due to increase in the total seismic weight of the structure. Also, the vertical to horizontal stiffness ratio for 50kl, 100kl,200kl, 265kl,500kl,increase to 134,140,144,147, 148 respectively, there is a slight difference in maximum displacement in the bearing which is under the permissible limits. The maximum permissible limits for the lateral displacement of the bearing are equal to the height of the bearing. All the bearing for all the tanks did perform as desired i.e. the displacement of the bearing are well controlled by the design of the bearing.

B. Maximum Acceleration Response

Response of both fixed base (non isolated tanks) and isolated tanks are investigated for three different earthquakes having different characteristics. The normalized response gives a clear idea of effectiveness of isolation for the given tanks in fig 2.4 to fig 2.6. It is observed that tanks with fixed base attracted greater ground acceleration. It is also found that all the isolated tanks performed as desired i.e. they attracted lesser ground acceleration as compared to fixed base(normalized acceleration value below 1). Isolation tanks especially the shorter height did not perform well i.e. the ground acceleration were amplified after isolation.

C. Base Shear Response

Each earthquake record considered for the time history are having properties like peak ground acceleration (PGA), frequency composition and duration varying significantly so that the inherent variability of earthquake can be accounted in the analysis. In the present study, time period of isolation system (target period) is T_D=2 sec,damping ratio i.e. $ß_D$=0.13 and normalized yield strength i.e. $F_O= F_Y/W$ is equal to 0.05, From above study it is observed that the percentage reduction of base shear under Imperial Valley (1979/10/15) earthquake for 50kl tank of height 8m, 10m, 10.5m, 11m, 11.5m, 12.5m, 14m,16m are 72,73,68,67,70,71, 78,77 which are less as compared to base shear 81,81,79,82,80,82,82,87 under Kern-Country (1952/07/21) and base shear 84,82,84,84,82,80,81,86 under Sanfracisco(1957/3/22) earthquake.

In 100kl tank the percentage reduction of base shear under Imperial Valley (1979/10/15) earthquake for 8m,10m,10.5m,11m,11.5m,12.5m,14m,16m,are,64,68,70, 74,74,78,81,83 which are less as compared to base shear,88,89,88,89,89,88,88,90,under,Kern-Country, (1952/7/21)earthquake,and,base shear, 94,87,90,87,87, 87,91,95,under. Sanfracisco-(1957/03/7) earthquake.

In 200kl tank the percentage reduction of base shear under Imperial Valley (1979/10/15) earthquake for 8m, 10m, 10.5m, 11m, 11.5m, 12.5m,14m,16m,are 71,66,66,78,78,78,77,80 which are less as compared to base shear, 89, 89, 89, 87, 90, 90, 92,87under,Kern-Country (1952/07/21)earthquake&base-shear, 85, 89, 85, 89 88,89,92,94 under Sanfracisco (1957/03/22) earthquake.

In 265kl tank the percentage reduction of base shear under Imperial Valley (1979/10/15) earthquake for 8m,10m,10.5m,11m,11.5m,12.5m,14m,16m,are,81,83, 83,85,83,83,81,75 which are less as compared to base shear 90,93,86,84,90,91,91,94 under Kern-Country (1952/07/21) earthquake and base shear 90,93,92, 93,95, 95, 95, 95 under Sanfracisco (1957/03/22) earthquake.

In 500kl tank the percentage reduction of base shear under Imperial Valley (1979/10/15) earthquake for 8m,10m,10.5m,11m,11.5m,12.5m,14m,16m,are,81,88, 89,91,89.4,89.5,88.2,87.7which are less as compared to base shear,93,94,95,95,94,94,94,95,under,Kern-Country (1952/07/21)earthquake,and,base-shear,93,96, 96, 95,94, 95, 94, 95 under Sanfracisco(1957/03/22) Earthquake.

Base shear values for all the tanks are considerably reduced after isolation. It is found that all the tanks behave satisfactory under Kern-Country (1952/07/21) earthquake, and Sanfracisco (1957/03/22) earthquake as compared to Imperial Valley (1979/10/15) earthquake. It is also observed that the designed isolation system decreases the base shear value as damping of the isolation system maintains constant. In fig. 2.7 to fig. 2.9 shows the comparative graphs with height and normalized base shear for considered time history**.**

In fig. 3 to fig.4.1 shows the comparative graphs with time and base shear values of isolated and fixed base tanks for considered time history.

V. CONCLUDING REMARKS

1. Comparative performance of elevated liquid storage tanks supported on shafts by putting the base isolation system at bottom of the supporting shaft is investigated using real earthquake motions. The earthquake response of isolated tanks is compared with the non isolated (fixed base) tanks to measure the effectiveness of the isolation.
2. It is observed that the base shear of elevated liquid storage tanks supported on shaft is significantly reduced due to isolation.
3. The drift of the tank relation to base of shaft is also significantly reduced due to isolation.
4. The earthquake response of isolated short tanks is relatively more, i.e. isolation is not effective for stiffer shafts, and however in general, the effectiveness of base isolation is achieved for tall tanks.
5. Although the effectiveness of seismic isolation increases with the increase of bearing flexibility and damping these properties needs to be modified for desired response.

REFERENCES

[1] Jain S.K., Jaiswal O. R. IITK-GSDMA Guidelines for seismic design of liquid storage tanks.

[2] http://peer.berkeley.edu/research/motions

[3] Shrimali M. K. And Jangid R.S. Earthquake response of isolated elevated liquid storage steel tanks, Dept.Of Civil Engg. IIT, Bombay.

[4] 4.Cenk A. and Metin A. Performance of non linear base isolation systems designed according to uniform building code, 5th international advanced technologies symposium (IATS'09) May13-15, 2009, Karabuk, Turkey.

[5] International building code, UBC 1997

[6] IS 3370-1967-PART I, "Code of practice for concrete structure for storage of liquids" Bureau of Indian standards, New Delhi.

[7] Kelly, J.M., Earthquake resistant design with rubber, Springer Publishers, New York, USA (1997).

[8] SAP-2000 Version-9 COMPUTRS AND STRUCTURES, INC, Berkeley, California

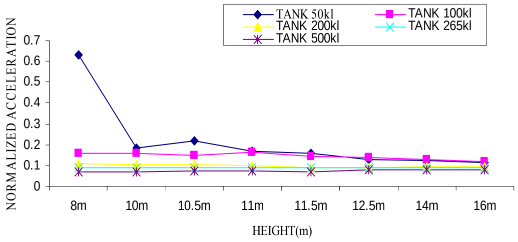


Fig.2.4 Normalized Acceleration Response Spectra for Imperial Valley (1979/10/15) Earthquake

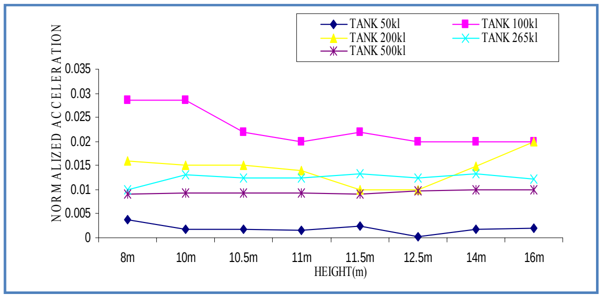


Fig.2.5 Normalized Acceleration Response Spectra for Kern Country (1952/7/21) Earthquake

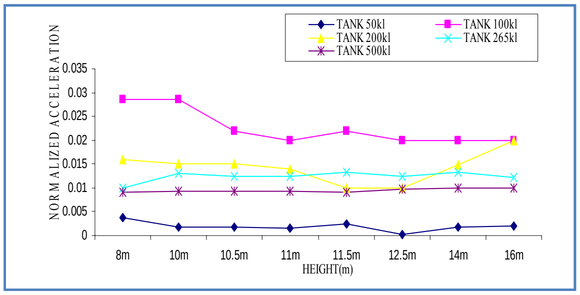


Fig.2.6 Normalized Acceleration Response Spectra for Sanfracisco (1957/03/22) Earthquake

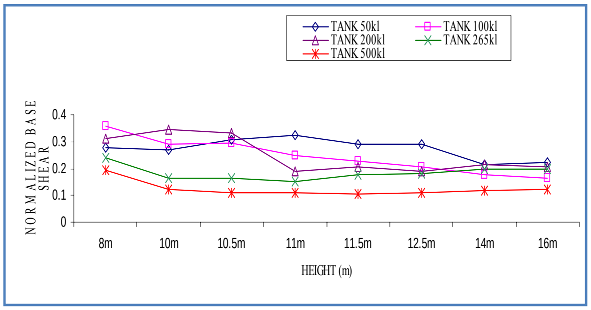


Fig.2.7 Normalized Base Shear Response Spectra for Imperial Valley (1979/10/15) Earthquake

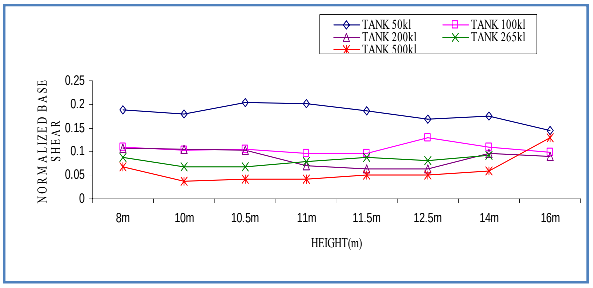


Fig.2.8 Normalized Base Shear Response Spectra for Kern Country (1952/7/21) Earthquake

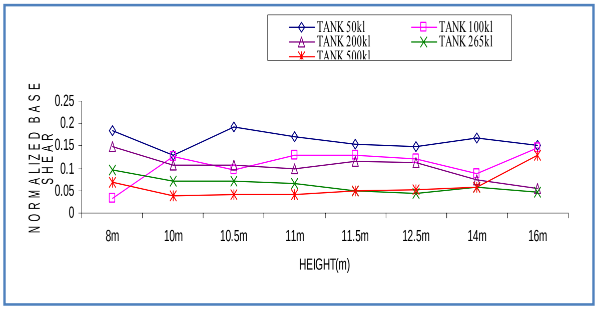


Fig.2.9 Normalized Base Shear Response Spectra for Sanfracisco (1957/03/22) Earthquake

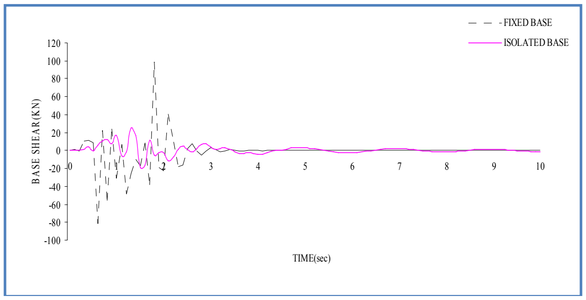


Fig.3 Variation of Base Shear Response Spectra against Time of 50kl Tank (Height 8m) For Imperial Valley (1979/10/15) Earthquake

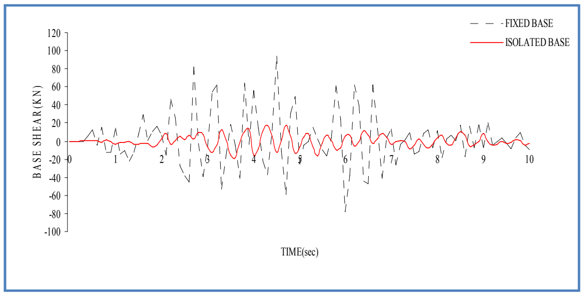


Fig.3.1 Variation of Base Shear Response Spectra against Time of 50kl Tank (Height 8m) For Kern Country (1952/7/21) Earthquake

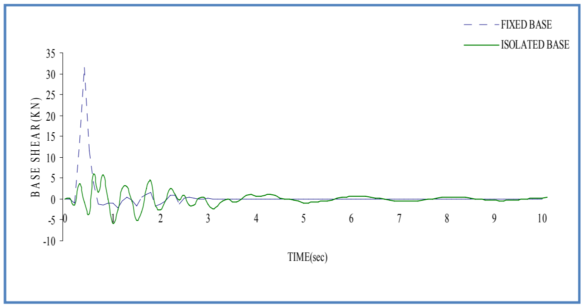


Fig.3.2 Variation of Base Shear Response Spectra against Time of 50kl Tank (Height 8m) For Sanfracisco (1957/03/22) Earthquake

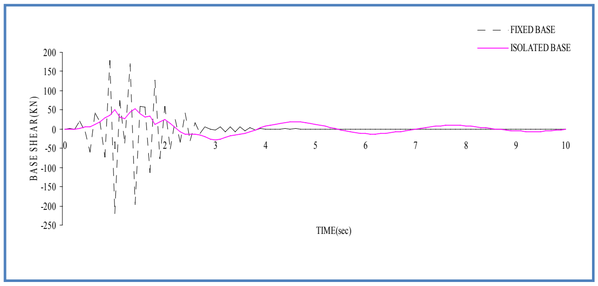


Fig.3.3 Variation of Base Shear Response Spectra against Time of 100kl Tank (Height 10m) For Imperial Valley (1979/10/15) Earthquake

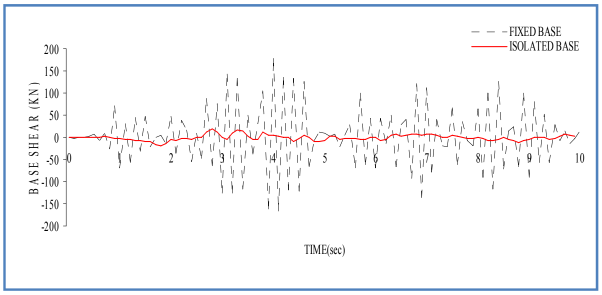


Fig.3.4 Variation of Base Shear Response Spectra against Time of 100kl Tank (Height 10m) For Kern Country (1952/7/21) Earthquake

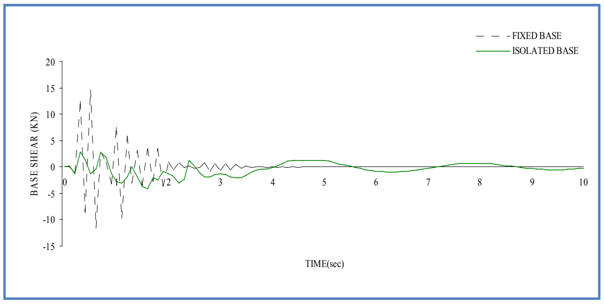


Fig.3.5 Variation of Base Shear Response Spectra against Time of 100kl Tank (Height 10m) For Sanfracisco (1957/03/22) Earthquake

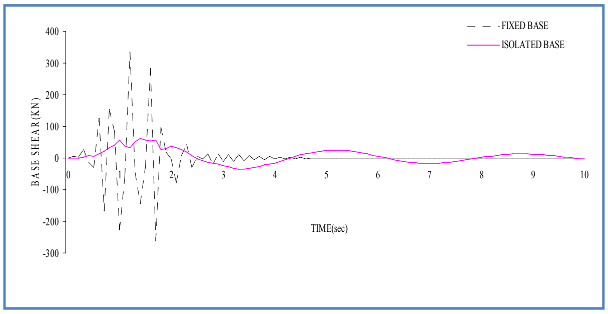


Fig.3.6 Variation of Base Shear Response Spectra against Time of 200kl Tank (Height 11m) For Imperial Valley (1979/10/15) Earthquake

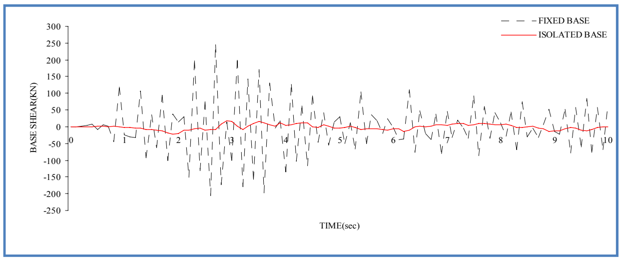


Fig.3.7 Variation of Base Shear Response Spectra against Time of 200kl Tank (Height 11m) For Kern Country (1952/7/21) Earthquake

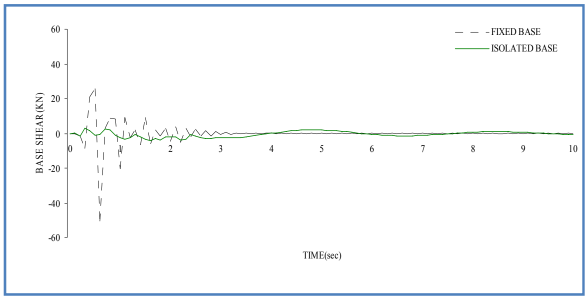


Fig.3.8 Variation of Base Shear Response Spectra against Time of 200kl Tank(Height 11m) For Sanfracisco (1957/03/22) Earthquake

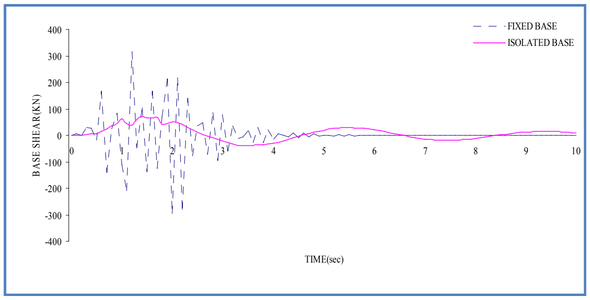


Fig.3.9 Variation of Base Shear Response Spectra against Time of 265kl Tank (Height 12.5m) For Imperial Valley (1979/10/15) Earthquake

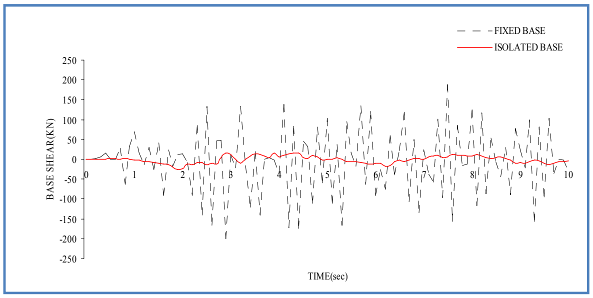


Fig.4 Variation of Base Shear Response Spectra against Time of 265kl Tank (Height 12.5m)For Kern Country (1952/7/21) Earthquake

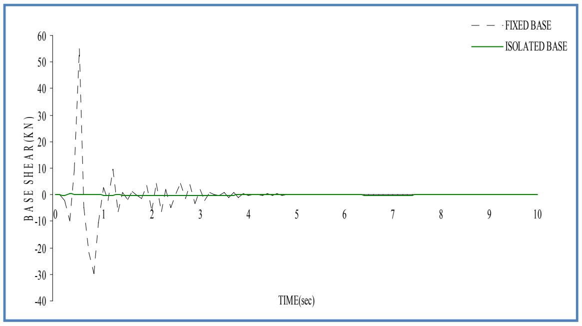


Fig4.1 Variation of Base Shear Response Spectra against Time of 265kl Tank (Height 12.5m) For Sanfracisco (1957/03/22) Earthquake

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