Seismic Response of Elevated Liquid Storage Steel Tanks Isolated by VCFPS at Top of Tower under Near-Fault Ground Motions

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Abstract— Seismic response of two elevated liquid storage steel tanks—one slender and one broad—is investigated under normal Component of near-fault ground motions isolated by variable curvature friction pendulum systems (VCFPS) at top of tower. The elevated liquid storage tanks isolated with the VCFPS are idealized with three-degrees-of-freedom associated with convective, impulsive and rigid mass under uni-directional earthquake excitation. The governing equations of motion of liquid storage tanks isolated with the VCFPS at base are derived and solved in the incremental form using Newmark's step-by-step method assuming linear variation of acceleration over small time interval, as the force-deformation behavior of the VCFPS is non-linear. For comparative study, the seismic response of elevated liquid storage tanks isolated with the VCFPS at base is compared with that of the same elevated liquid storage tanks isolated by friction pendulum systems (FPS), also to measure effectiveness of isolation system, the seismic response of elevated isolated liquid storage tanks is compared with that of the non-isolated tanks.

Keywords: Base isolation, elevated Liquid storage steel tanks variable concave friction pendulum system near-fault ground motions Friction Pendulum system.

I. INTRODUCTION

In recent times major cause of destruction to life and property due to natural calamity is earthquake. Earthquake can be termed as tectonic movement of plates. Large amount of energy is released from ground due to earthquake which is then transferred to structure. There have been number of catastrophic failures of liquid storage tank such as Kobe earthquake in japan 1995, Chi-Chi earthquake in Taiwan 1999 due to various causes but the most common cause is buckling of tank, so protection of liquid storage tank against severe seismic events has become crucial. Various authors have investigated seismic response of liquid storage tank. Haroun and Housner, 1981; Haroun, 1983 and base isolated liquid storage tanks Malhotra, 1997; Shenton and Hampton, 1999; investigated seismic response of elevated liquid storage tank. Shrimali and Jangid, 2002 investigated seismic response of liquid storage tank isolated by lead rubber bearing. Panchal and Jangid 2008 proposed VFPS for liquid storage tank under near fault ground motion; Panchal and Jangid 2012 investigated seismic response of liquid storage tank by VCFPS.

In spite of the above studies, there have not been attempt to investigate the behavior of elevated liquid storage tanks isolated by VCFPS. In this paper, the seismic response of liquid storage slender and broad steel tanks isolated with VCFPS is investigated under near-fault ground motions. The specific objectives of the present study may be summarized as: (1) to study the dynamic behavior of elevated liquid storage steel tanks isolated with VCFPS under near-fault ground motions, (2) to compare the seismic response of elevated liquid storage tanks isolated with VCFP and FPS in order to measure the effectiveness of VCFPS.(3) to compare the seismic response of Non-Isolated elevated liquid storage tanks and isolated with VCFP and FPS in order to measure the effectiveness of isolated model at top with non-isolated model.

II. DESCRIPTION OF VCFPS

The general behavior of VCFPS is quite identical to FPS which was proposed by Zayas (Zayas et al. 1987, Al-Hussaini et al. 1994). The main alteration between the VCFPS and FPS is the radius of curvature. In case of VCFPS it can be elongated with increase of the isolator displacement. Therefore, the fundamental period of the base-isolated structure can be moved more away from the predominant periods of near-fault ground motions, so hence the problem of resonance condition can be avoided so this way earthquakes can be prevented.

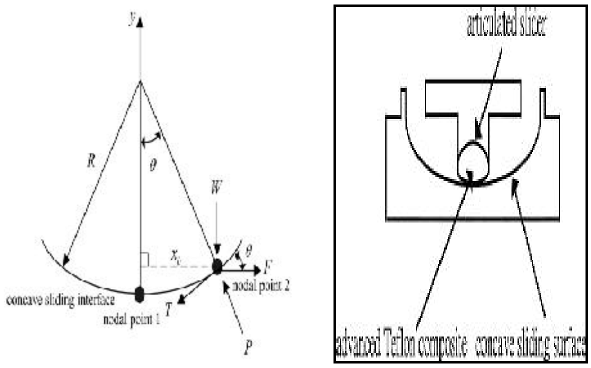
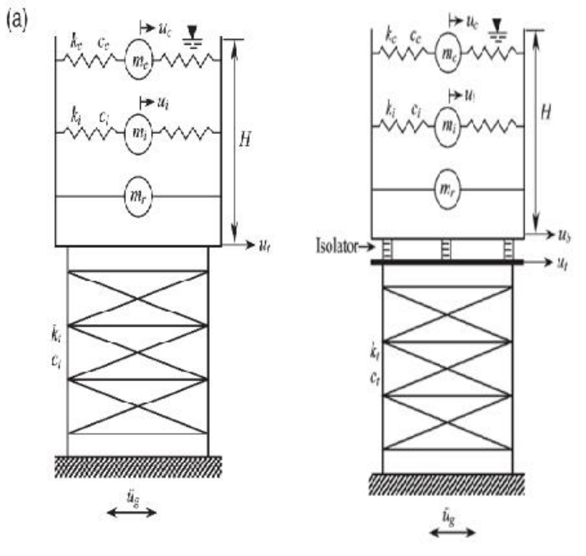


Fig. 1 (a) geometric formulation of VCFPS [5] (b) Schematic details of the VCFPS [9]

III MODEL OF THE ISOLATED LIQUID STORAGE TANK ISOLATED AT TOP OF TOWER

Figure 2 depicts the model of elevated liquid storage tank which is mounted on a tower structure that is fixed to the ground. The supporting system of the tank i.e tower structure is considered as columnar type. Here constant liquid mass which is lumped as convective, impulsive lastly rigid masses can be designated as m_c, m_i, and m_r respectively also convective and impulsive masses are linked to tank wall by consistent corresponding spring with stiffness k_c and k_i respectively. c_c and c_i are known as damping constant of convective and impulsive masses respectively. Tank mainly consist of three-of-freedom subjected to one directional excitation u_c u_i and u_s,are total displacements of x_c , xi , drift of tower,respectively.The above mentioned elevated tank is isolated by VCFPS in which the isolation bearings are placed immediately above top of tower and below the cyclindrical liquid tank as shown in Figure 2 (referred as isolation model-II).



(a) (b)

The fundamental frequency of impulsive mass, ω_i and convective mass, ω_c are given by the following expressions (Haroun,1983):

$$\omega_i = \frac{P}{H}\sqrt{\frac{E}{\rho_s}}$$

$$\omega_c = \sqrt{1.84\,\frac{g}{R}\,\tanh(1.84S)}$$

Where E and ρ_s are the modulus of elasticity and density of tank wall, respectively is the acceleration due to gravity; P is a dimensionless parameter obtained from charts given by Haroun (1983);$S = H/R$ is the aspect ratio of the tank; H is liquid height; and R is radius of the tank. The equivalent stiffness of the convective mass is $k_c (= m_c\omega_c^2)$ and that of the impulsive mass is k_i $(= m_i\omega_i^2)$. Similarly, the equivalent damping of the convective mass is C_c $(=2\zeta_c m_c\omega_c)$ and that of the impulsive mass is C_i $(=2\zeta_i m_i\omega_i)$, where ζ_c and ζ_i are damping ratio of convective and impulsive masses.

IV. GOVERNING EQUATION OF MOTION

Here equations of motion of elevated liquid storage tank isolated at top subjected to one directional earthquake excitation of earthquake ground motion can be depicted as below

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}+\{F\}=-[M]\{r\}\ddot{x}_g$$

The vector of displacements for non-isolated tank can be expressed as $\{x\} = \{xc, xi, xt\}^T$; $x_c = u_c - u_t$ is, $x_i = u_i - u_t$; $x_s = u_t - u_g$. The equations are solved in the incremental form using Newmark's step-by-step method assuming linear variation of acceleration over small time interval. The matrices having $[m]$, $[c]$, $[k]$ $\{r\}$ vectors for isolated tank at top (isolated Model-II) can be expressed as below as

$$[m] = \begin{bmatrix} m_c & 0 & m_c & m_c \\ 0 & m_i & m_i & m_i \\ m_c & m_i & M & M \\ m_c & m_i & M & M+2m_b \end{bmatrix}$$

V. NUMERICAL STUDY

Here in present study, earthquake response of elevated slender and broad steel tank isolated by VCFPS is examined when subjected to unilateral component of six near-fault ground motions.The behavior of VCFPS isolated at the top of tower is investigated (i.e isolated model –II). The formation of VCFPS isolator is mainly to provide two main parameters which is fundamental period of sliding surface and second one is friction coefficient (μ). Referring to previous papers fundamental period of sliding surface for VCFPS is taken as 2.5 sec and friction coefficient for VCFPS is taken as 0.05 in case of near fault ground motions.

Tank parameters such as damping ratio for convective, impulsive mass, aspect ratio, co-efficient of friction, fundamental period of sliding surface is taken from paper of Jangid and shrimali in 2002

For comparative study slender and broad tanks, are considered. The tank parameters such as damping Ratio of convective mass ξ_c for water is taken as 0.005 and impulsive mass ξ_i for both slender and broad tank is taken 0.02.The modulus of elasticity and mass density of tank are 200 GPA and 7900 kg/m^3.The properties of the slender and broad tanks are taken from paper of Shrimali and Jangid (2002a) which are as follows (i) aspect ratio, S for slender and broad tank is taken as 1.85 and 0.6 respectively, (ii) the height H of water filled in the slender and broad tanks are 11.3m and 14.6 m (iii) the natural frequencies of convective mass, ω_c and impulsive mass ω_i for the broad and slender tank are 0.123, 3.994 Hz and0.273,5.963Hz,respectively; (iv) the ratio of tank wall thickness to its radius t_h/R_t is taken as 0.004 for slender and broad tank respectively.

Figure 3 shows time history of non-isolated and isolated by vcfps and fps at top of tower **slender** steel tank under unilateral component of January 17, 1994 Northridge, California recorded at Sylmar. The peak values obtained of isolator displacement, impulsive displacement, convective displacement and base shear of non-isolated ,vcfps and fps are 0, 52.12 & 50 ; 0.97,0.17 and 0.31cm ; 73.16,124 & 148 ; 1.40 (w) ,0.18(w) and 0.37(w).

Time variation of non-isolated and elevated liquid storage tank isolated by vcfps and fps **slender** steel tank under unilateral component of October 15, 1979 Imperial Valley, California (El Centro Array #5) is shown in Fig 4 .The peak values obtained of isolator displacement, impulsive displacement, convective displacement and base shear of non-isolated ,vcfps and fps are 0, 37.7 & 30.5 ; 0.36,0.14 & 0.195 cm ; 151.04,204 & 206;1.37 (w) ,0.17(w) & 0.24(w).

Near-fault ground motions (Normal Component)	Recording Station	Duration (sec)	PGD (m)	PGV (m/sec)	PGA (*g*)
October 15, 1979 Imperial Valley, California	El Centro Array # 5	39.420	0.765	0.98	0.37
October 15, 1979 Imperial Valley, California	El Centro Array # 7	36.900	0.491	1.13	0.46
October 15, 1979 Imperial Valley, California	Newhall	60.000	0.381	1.19	0.72
June 28, 1992 Landers, California	Lucerne Valley	49.284	2.300	1.36	0.71
January 17, 1994 Northridge, California	Rinaldi	14.950	0.391	1.75	0.89
January 17, 1994 Northridge, California	Sylmar	60.000	0.311	1.22	0.73

I: - Some characteristics of Normal Component of Near-fault Ground Motions used in study.

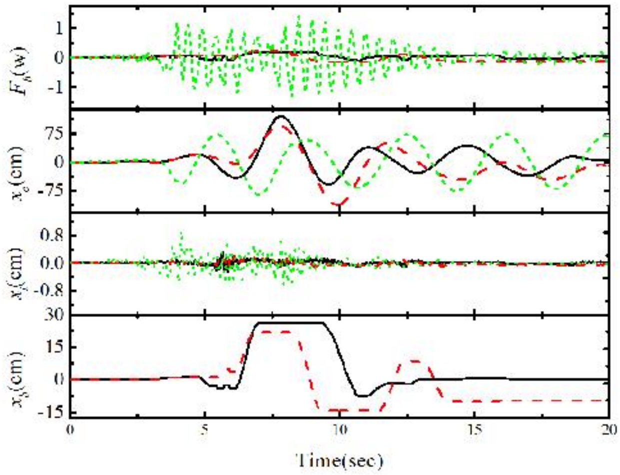


Fig 3 Time variartion of slender tank Northridge valley,1994 earthquake recorded at sylmar

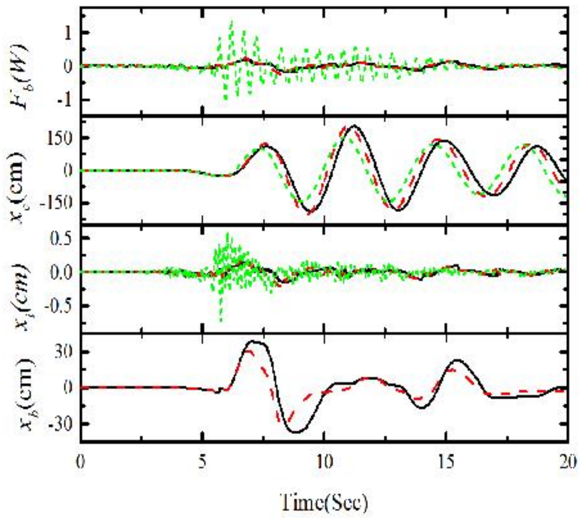


Fig 4 Time variartion of slender tank imperial valley earthquake recorded at el centro Array # 5

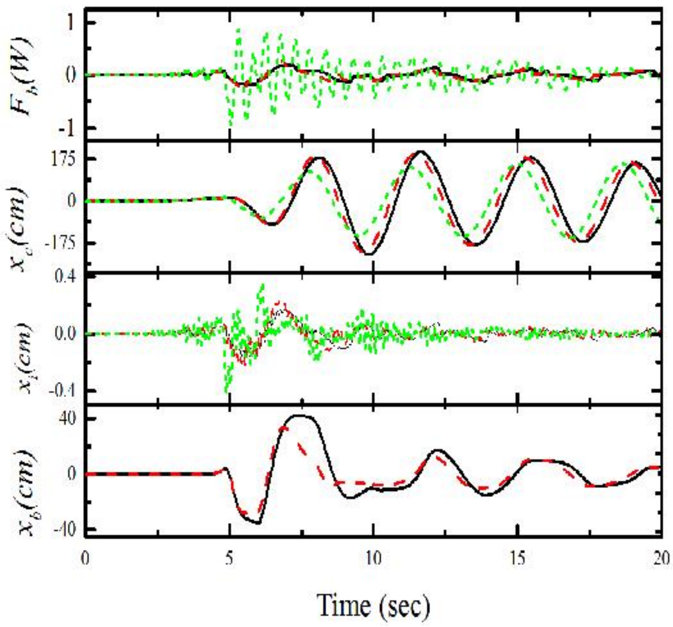


Fig 5 Time variartion of slender tank northridge valley earthquake 1994 recorded at el centro Array # 7

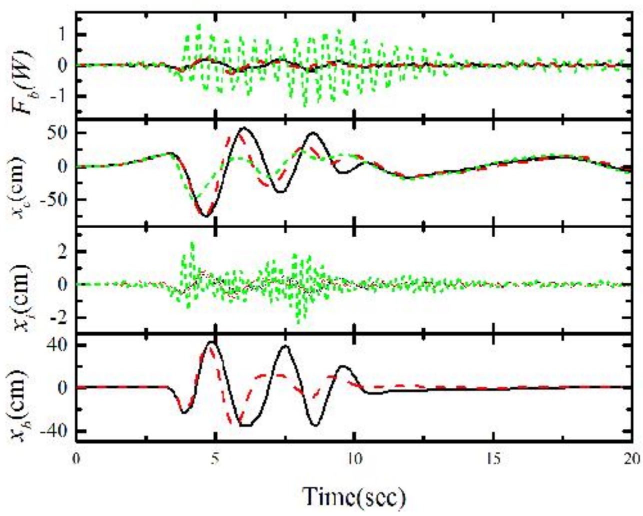


Fig 6 Time variartion of broad tank northridge valley 1994,earthquake recorded at sylmar

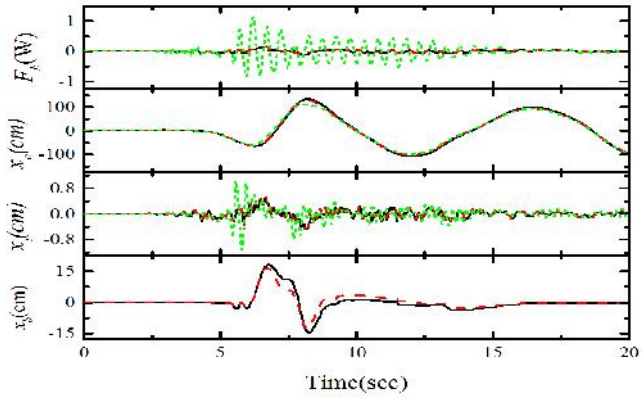


Fig 7 Time variartion of broad tank imperial valley 1979, earthquake recorded at el centro Array # 5

Near fault ground motions	Tank condition (slender)	$F_b(W)$	x_c (cm)	x_i (cm)	x_b (cm)
Northridge.1994 (Sylmar)	**Non-isolated**	1.40	73.16	0.97	-
	Isolated (FPS)	0.37	148	0.31	50
	Isolated (VCFPS)	0.18	124	0.17	52
Imperial valley,1979 (El Centro Array#5)	**Non-isolated**	1.37	151.04	0.36	-
	Isolated (FPS)	0.24	204	0.19	30.5
	Isolated (VCFPS)	0.17	202	0.14	37.7
Imperial valley,1979 (El Centro Array#7)	**Non-isolated**	0.87	154.81	0.36	-
	Isolated (FPS)	0.27	204	0.20	30.5
	Isolated (VCFPS)	0.18	202	0.14	37.5

Figure 5 illustrates time history of non-isolated and isolated by vcfps and fps elevated liquid storage **slender** steel tank under unilateral component of October 15, 1979 Imperial Valley, California recorded at El Centro Array #7 .The peak values obtained of isolator displacement, impulsive displacement, convective displacement and base shear of non-isolated, vcfps and fps are 0, 14.90 & 13.74; 0.36, 0.14 & 0.195cm; 154.81,204 & 202; 0.87 (w), 0.18(w) & 0.27(w).

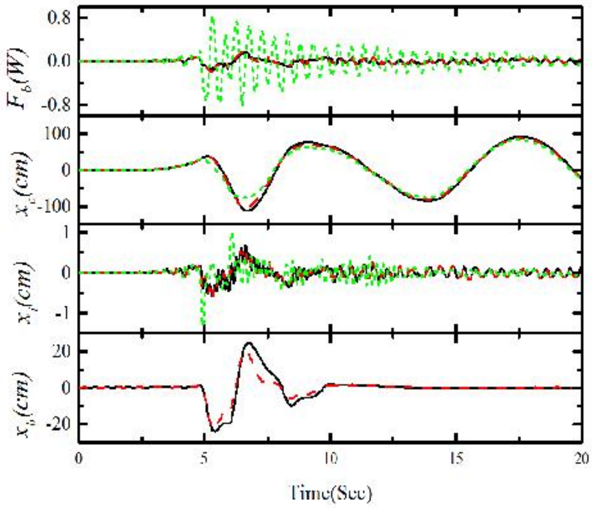


Fig 8 Time variartion of broad tank, imperial valley earthquake1979, recorded at el centro Array # 7

Time history of non-isolated and isolated at top by vcfps and fps **broad** steel tank under Imperial Valley, January 17, 1994 Northridge, California Sylmar is shown in Fig **6**. The peak values obtained of isolator displacement, impulsive displacement, convective displacement and base shear of non-isolated ,vcfps and fps are 0, 43.1 and 39.2 ; 2.61,0.62 and 0.56cm ; 26.92,56.3 and 52.1 ; 1.40 (w) ,0.19(w) and 0.25(w).

Figure 7 shows time variation of elevated liquid storage **broad steel** tank, non-isolated and isolated by vcfps and fps under Imperial Valley, October 15, 1979, California El Centro Array #5.

Figure 8 depicts time history of non-isolated and isolated by vcfps and fps **broad steel** tank under unilateral October 15, 1979 Imperial Valley, California El Centro Array #7.

II:- Peak Response of non-isolated and elevated isolated at top liquid slender Tank under Near-fault ground motions

Note: - In above Figures 3 to 8, Green color stands for Non-isolated, black stands for VCFPS and Red color line for FPS

Near fault ground motions	Tank condition (Broad)	$F_b(W)$	x_c (cm)	x_i (cm)	x_b (cm)
Northridge. (Sylmar,1994)	Non-isolated	1.40	26.92	2.61	-
	Isolated (FPS)	0.302	52.1	0.564	39.2
	Isolated (VCFPS)	0.179	56.3	0.62	43.1
Imperial valley (El Centro Array#5,1979)	Non-isolated	1.13	123.62	1.046	-
	Isolated (FPS)	0.156	130	0.564	16.5
	Isolated (VCFPS)	0.14	134	0.51	18.2
Imperial valley (El Centro Array#7,1979)	Non-isolated	0.82	105.14	1.00	-
	Isolated (FPS)	0.179	109	0.642	20
	Isolated (VCFPS)	0.159	113	0.688	24.8

III: - Peak Response of non-isolated and elevated isolated at top liquid Broad Tank under Near-fault ground motions

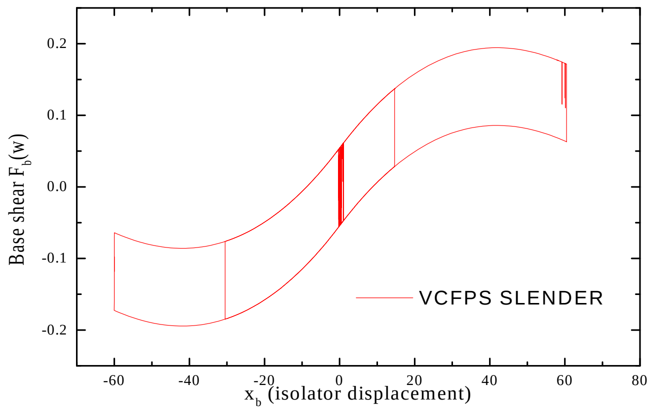


Fig 9:- hysteresis loop of slender tank isolated by vcfps under unilateral component of Northridge valley, 1994, Sylmar.

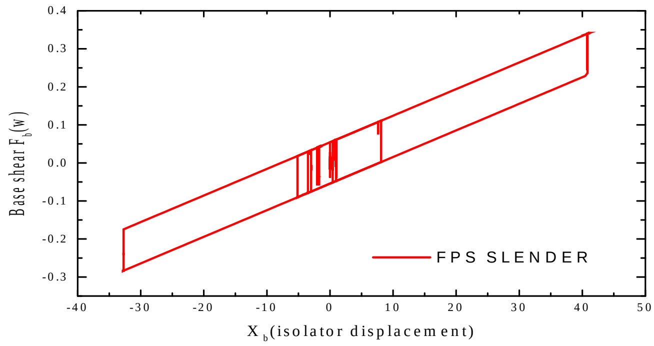


Fig 10:- hysteresis loop of slender tank isolated by FPS under unilateral component of Northridge valley, 1994, Sylmar

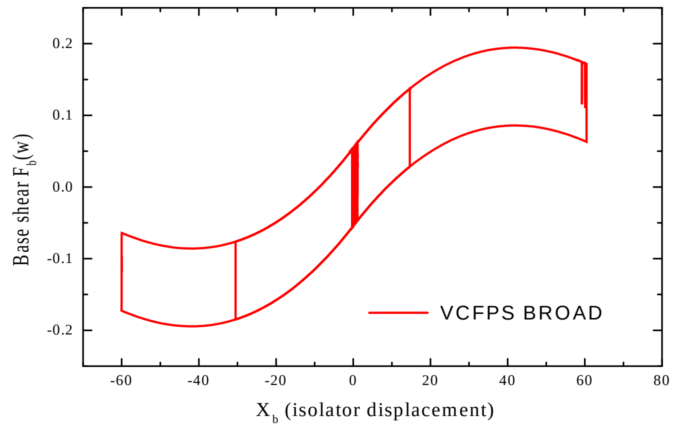


Fig 11:- hysteresis loop of Broad tank isolated by VCFPS under unilateral component of Northridge valley, 1994, Sylmar

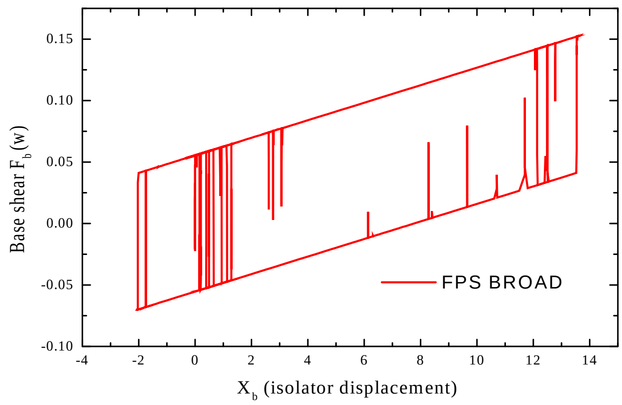


Fig 11:- hysteresis loop of Broad tank isolated by FPS under unilateral component of Northridge valley, 1994, Sylmar

VI. CONCLUSIONS

The earthquake response of elevated steel slender and broad tanks isolated by VCFPS at top of tower is examined when subjected to unilateral component of near fault ground motions. Also to see the change of response quantities such as base shear, convective displacement, impulsive displacement, isolator displacement when subjected uni-lateral components of selected ground motions are used as input also earthquake response of VCFP isolated liquid storage tank is compared with same of FPS elevated isolated storage tank and also Non-Isolated tank to know its effectiveness during an earthquake

The seismic response of elevated liquid storage slender and broad steel tanks isolated with the VCFPS is investigated under unilateral component of near-fault ground motions. The uni-lateral components of selected ground motions are utilized as input to study the variation of the base shear, convective displacement, impulsive displacement, isolator displacement. The seismic response of VCFP isolated liquid storage tank is compared with same of FPS elevated isolated storage tank to know its effectiveness during an earthquake. From the numerical and parametrical results of the present study, the following conclusions may be drawn.

(1) In elevated slender steel tanks, the performance of VCFP is found to be more effective in reducing the convective displacement, impulsive displacement and base shear as

compared to FPS and Non-isolated. The isolator displacement of the VCFPS is more that of the FPS.

(2) In broad steel tanks, the performance of VCFPS is found to be more effective in reducing the impulsive displacement, convective and base shear when compared to FPS and Non-isolated tank. The isolator displacement of the VCFPS is more that of the FPS.

(3)From above results we can say VCFPS is quite effective in controlling response quantities such as convective, impulsive and base shear.

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