Application of passive and semi-active control on base isolated liquid storage tanks

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1. Introduction

Numerical studies have been performed to study performance of liquid storage tanks controlled by passive base isolation system and semi-active control system based on idea of pseudo-negative stiffness damper. Dynamic response of the tank and liquid such as tank base shear, displacement of the isolation system and height of sloshing in each system have been calculated and compared.

2. Background

Dynamic models of rigid liquid tanks containing liquids have been already presented by Housner **[1],** Haroun and veletsos by which the tank is modeled as some discretized lumped masses. Here the model proposed by Housner has been used. Three different base isolation systems described in **Fig 1** have been studied for this case to discover the merits of each case; Base isolation system with a linear behavior **(case 1)**, bilinear base isolation with a hysteretic behavior **(case 2)** and hybrid linear base isolation system with semi active control **(case 3)**.

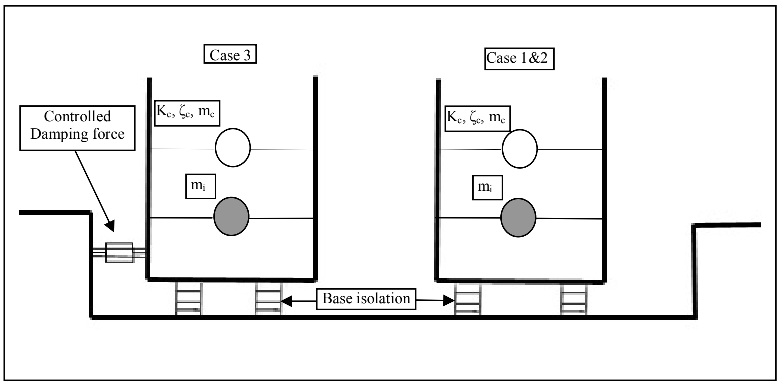

Fig 1) Dynamic model of the studied systems

3. Semi active control by pseudo-negative stiffness algorithm

The idea of controlling the structures by applying active forces – active control- was studied for the first step of the research. But there are difficult problems such as cost and reliability of systems during hazardous conditions that guided researches toward the new idea of semi-active control of the structures which doesn't have the mentioned problems. The pseudo-negative stiffness is one of the algorithms designed for semi-active control of structures. This algorithm describes the applied force by a variable damper to the structure as a function of its velocity (V) and displacement (U) as Equation 1[2]:

$$\begin{cases} F_d = -kfac * K * U + cfac * C * V & if\ F_d * V > 0 \\ F_d = 0 & if\ F_d * V < 0 \end{cases}$$

Eq. 1

Where F_d is the load produced by the variable damper, K and C are the damping coefficient and stiffness of the base and U and V are relative displacement and velocity of the damper respectively

4. Numerical studies

Because of different hydrodynamic behavior of the liquid tank, two aspect ratios equal to 1.67(H=5m & R=3m and T_c=2.42s) as slender tank and 0.6(H=2.84 & R=4.73 and T_c=3.65s) as broad tank have been studied where T_c is the natural period of convective mass in Housner model, R the radius of the tank and H height of the liquid in the tank. Each system was designed through a parametric study. In case of the linear and hysteretic base isolation systems the dynamic parameters have been selected such that the structure has minimum base shear under Elcentro-1940 ground motion, N-S

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component considering displacement of the bearings and sloshing of the liquid (Optimum). In slender tank the base-isolation period for linear case T_b=2 sec. and damping ratio ζ=0.25 percent. In case of the base isolation system with hysteretic behavior a period of 2 sec and damping ratio of 0.1 and yield strength of 5 percent of total weight of the structure and liquid was chosen. Equation presented by Wen **[3]** was used to model a hysteretic, smooth behavior of the bearing by the hysteretic component described by Equation 2. In case of the semi- active control by pseudo-negative stiffness *kfac* and *cfac* factors are dealt with as parameters. Since the value of damping force applied by the variable damper is limited because of limitations in the device a saturation force as much as 10 percent of weight of the structure is considered as the limit of the F_d. It is clear that dynamic parameters for the broad tank will change to have an optimum response in each case.

$$\begin{cases} \dot{Z} = -\beta|\dot{U}|Z^n - \tau\dot{U}|\dot{Z}| + A\dot{U} & \text{for } n \text{ odd} \\ \dot{Z} = -\beta|\dot{U}|Z^{n-1}|Z| - \tau\dot{U}Z^n + A\dot{U} & \text{for } n \text{ even} \end{cases}$$

Eq. 2

5. Discussions on Results

Considering N-S component of Elcentro-1940 earthquake as the applied ground motion, the force produced by variable damper in semi active controlled case is as shown in **Figure 2**. based on **Figure 3** and **Table 1**, ratio of base shear to weight (F_s/W) in slender tank is 0.1, 0.11 and 0.07 in cases 1,2 and 3 respectively which shows a reduction of about 30% in case 3 comparing other cases. Displacement of the structure (Disp.) also was 8, 8 and 6cm in cases 1, 2 and 3 respectively. Here again reduction of displacement can be observed in case 3. Maximum height of sloshing has also reduced from 64 cm in cases 1&2 (similar) to 41cm in case 3 (**Fig4**). From **Table 1**, in broad tanks also the same trend of reduction of base shear, displacement and sloshing response to the excitation can be observed, although this trend is not as sharp as the ones in slender case.

	Slender Tank			Broad tank		
	F_s/W	Disp(cm)	Sloshing	Fs/W	Disp(cm)	Sloshing
Case 1	0.1	8	64	0.06	6	17
Case 2	0.11	8	64	0.09	6	19
Case 3	0.07	6	41	0.05	5	14

Table 1

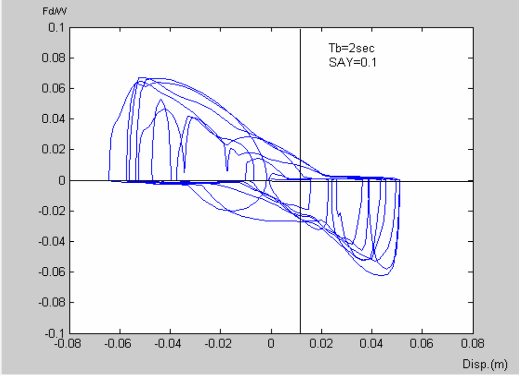

Fig2) force produced by controlled damper

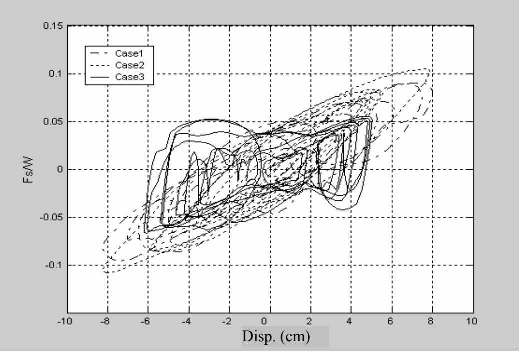

Fig3) Comparison of base shear in three cases, slender tank

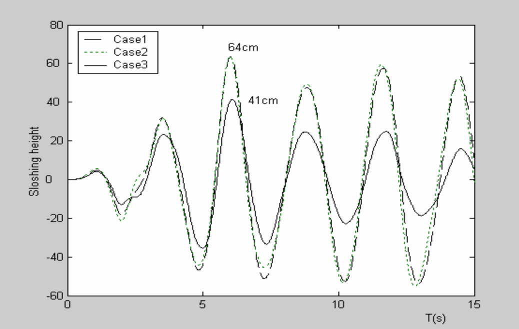

Fig4) Sloshing height in slender tank in three cases

6. Conclusions

Merits of pseudo- negative stiffness system in control of liquid storage tanks have been studied. Results show that this control system has a good capability in reduction of dynamic response of liquid tanks and sloshing of contained liquid comparing with passive linear and bilinear base isolation.

7. References

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