Parametric Study of Elevated Water Tank with Metallic and Friction Damper

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Abstract – *Present research attempts to find the response of RC elevated water tank with metallic dampers. Analytical investigation of metallic damper and friction damper in reducing seismic response of an Elevated Water Tank is done using different time history. Seismic response parameters such as base shear, base moment, time period, top staging displacement and sloshing displacements are evaluated and compared.*

Key Words: Time history, Seismic response, Elevated water tank, Metallic damper, Friction damper

1. INTRODUCTION

Many structures such as bridges buildings etc. damaged in previous earthquakes. Important structures such as water tanks hospitals etc. should remain functional even after an earthquake. Failure of water tanks makes evacuation and rehabilitation during earthquakes worse. All structures irrespective of its importance should be designed for lateral forces induced during ground motions. Performance of elevated water tanks during Bhuj earthquake was studied by Durgesh C Rai [11].

Generally, water tanks are designed for deadloads, live loads, and forces due to wind and earthquakes. Selection of type of water tank is a crucial step in design of water tanks. Intze type tanks are very economical as it reduces the size of bottom ring beam.

1.1 SEISMIC CONTROL DEVICES

Conventional seismic design method, overall safety, and safety of structures against earthquake, are designed and constructed to have sufficient strength. The traditional design methodology is quite expensive. The use of passive control devices results in reduction of seismic design forces on the building [14]. This method uses an external source of energy to resist lateral forces due to earthquake. Vibrations induced by wind or earthquake forces can be diminished without increasing the strength of the structure by addition of structural control devices.

Generally seismic control devices are classified into active, passive, and semi-active. Active control devices require an external source of energy for activation. Passive control devices do not require any external energy and only require earthquake forces to act. Semi active devices require some external energy to activate. These are modification of passive control devices. Since passive control devices do not require external source to operate it can be a viable solution for seismic retrofit as well as rehabilitation of structures. Passive control devices convert lateral forces induced by earthquake into other forms of energy such as heat energy [4]. Supplemental energy dissipation system and seismic isolation system comes under passive energy dissipation devices. Devices such as dampers comes under supplemental control system whereas base isolation and multi-story isolations come under seismic isolation system. Optimization of dampers can result in economic design and is done in various literatures. Optimal design of metallic and friction dampers is proposed by Moreschi et al [9]. On installation of isolation devices time period of the structure increases and whereas there is a decrease in time period on application of dampers.

1.2 X - PLATE METALLIC DAMPER (XPD)

Generally metallic dampers are made of steel, aluminum, copper, lead, and shape memory alloys. Mild steel is the most commonly used material as a metallic damper. Steel material can be simplified as a bilinear or trilinear elastoplastic model. Hence these dampers are also called elastoplastic dampers. These dampers are also called hysteretic dampers. These dampers are also yielding dampers as dissipation of energy occurs by yielding of metals.

XPD is a type of metallic damper which consists of a series of X shaped plates arranged parallelly. These can be connected diagonally or on top of chevron bracing etc. This type of dampers was introduced by Kelly et.al [15]. XPD's made of steel undergoes many cycles until it reaches the yield limit [1]. These dampers showed good response reduction in piping systems [10]. The properties of an XPD can be derived using beam theory which is done after a series of tests. Initially XPD is assumed to be made of two triangular plates and properties such as stiffness and yield strength is found out. Fig 1 shows a typical diagram of an XPD with holding devices.

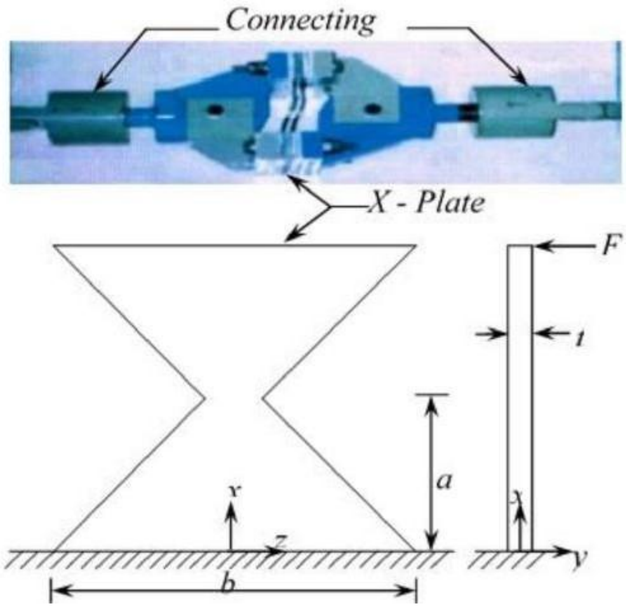

Fig -1: XPD with holding devices [12]

$$F_y = \frac{\sigma_y b\, t^2 n}{6a}$$
$$K_d = \frac{Eb\, t^3 n}{12a^3}$$

Fy and Kd denotes the yield strength and stiffness of the damper. σy, E and n represents the yield stress modulus of elasticity and number of plates of the damper. The height, width and thickness of the damper is represented by a, b and t respectively XPD can be modelled as a link element which is available in SAP2000.

1.3 FRICTION DAMPER

These dissipates energy through solid friction between two sliding bodies [3]. A typical friction damper contains a series of steel plates which are clamped together. When subjected to ground motions these plates slip and dissipates energy through heat. These dampers can be connected diagonally, with chevron bracings cross bracings and so on. Pall friction damper is one of the best friction dampers available. Friction dampers are not designed for wind and minor earthquakes. They require heavy lateral forces to operate [3]. During earthquakes they slip at a load known as slip load. These dampers also have very good hysteretic behavior. Like metallic dampers they also undergo large cycle of loading. One of the dis advantage of friction dampers is that it is not reliable in a long run. Also, these can undergo permanent deformation if restoring force is not provided. Nonlinear analysis is required to understand the behavior of friction damper system.

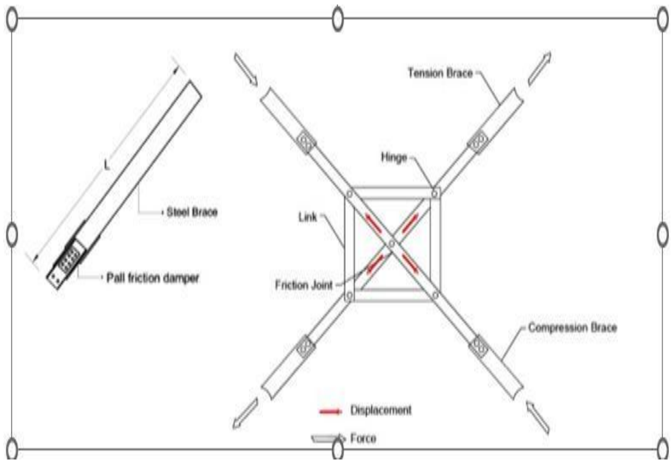

Fig -2: Friction damper [3]

1.4 MODELLING OF ELEVATED WATER TANK

Numerous structural analysis software's are available to model engineering structures. Eulerian approach, Lagrangian approach and added mass approach are some of the methods adopted to model fluid structure interaction using finite element software. Provisions to use Westerguard's added mass approach and Alegreane's water mass approach to model fluid structure interaction are available in SAP2000. Water tanks are modelled as a typical spring mass model. Initially water tank was modelled as one mass model. But this method is not reliable for tanks of larger capacity. Hence more suitable method of spring mass model called two mass idealization (Housner et.al) was introduced. IITK GSDMA guidelines IS 1893 -2014 part 2 also follows two mass model of water tank. The liquid in the upper part of water tank is called convective mass and undergoes sloshing effect. The water mass attached to the walls of the container is called impulsive mass. Generally, these idealizations are used for cylindrical and rectangular water tanks. For elevated water tanks of different shape of container, the spring mass parameters are obtained by assuming an equivalent circular container of same diameter.

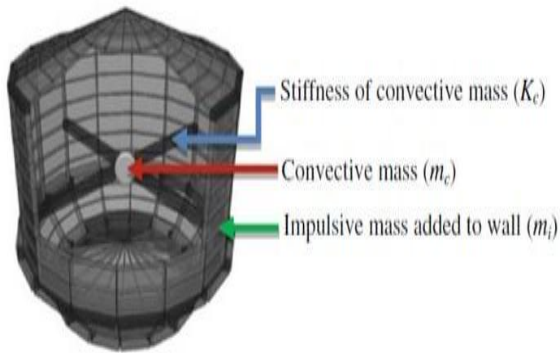

Fig -3: Fluid structure interaction [14]

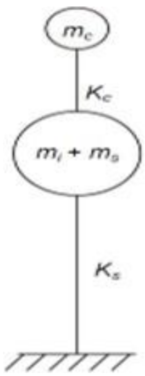

Fig -4: Two mass idealization of elevated water tank [5]

IITK GSDMA guidelines and IS 1893-2014 part 2 suggests equations for spring mass model of water tanks. The spring mass parameters can also be obtained from graphs provided in codal provisions.
Westerguard's added mass approach is used for the analysis. In this approach impulsive mass is added to the walls of the container.
The equation for finding the impulsive mass is given by

$m_{\alpha i} = A_i$ [$m_{\alpha i} = A_i$ [$7/8\ \rho\sqrt{(h(h-y_i))}$]]

h = height of water level
y_i = height to center of each panel from tank bottom
A_i = Area of each panel.
Initially the container walls are divided into various panels and the impulsive mass calculated from the equations are added to these panels.

2. PROBLEM DISCRIPTION

A reinforced concrete elevated intze tank with a capacity of 1000m3 and 20m staging height is adopted. Columns and beams are modelled as frame element whereas container is modelled as area section with thin shells. M30 grade concrete and Fe 415 grade steel is used to model water tank. Density of concrete is taken as 25kN/m3. Stiffness of XPD and friction damper is taken as 956812.5kN/m and 321654kN/m respectively and yield strength of XPD is taken as 190.35kN and slip load of friction damper is assumed as 190.35kN.

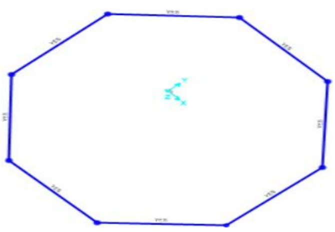

Fig -5: Staging configuration for EWT

Table -1: Data for EWT of 1000m^3 capacity

Thickness of top dome	0.1m
Rise of top dome	2m
Size of top ring beam	0.3*0.25m
Diameter of tank	12m
Height of cylindrical tank	8.15m
Thickness of cylindrical wall	0.3m
Size of middle ring beam	0.5*1.2m
Rise of conical dome	2.25m
Thickness of conical wall	0.5m
Rise of bottom dome	1.4m
Thickness of bottom dome	0.25m
Size of bottom circular girder	0.6*1.2m
Diameter of column	0.7m
Size of bracing	0.5*0.5m

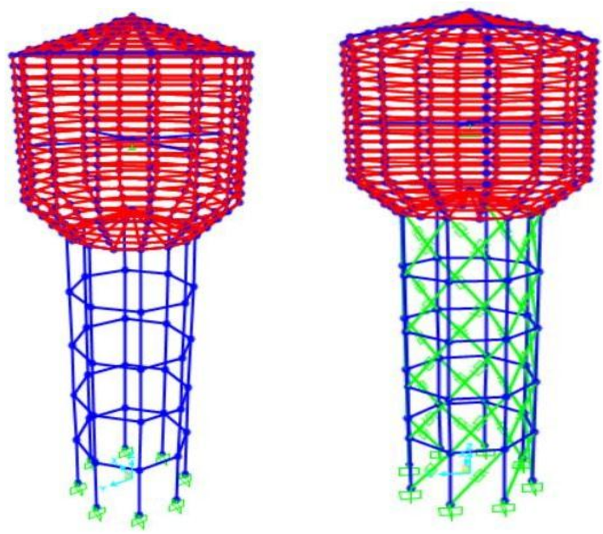

Fig -6: Elevated water tank without and with damper

Table -2: Time History data

Time History	Station
Kobe	Nisi-Akashi
Imperial Valley	Delta
Imperial Valley	Elcentro

3.RESULTS

The results obtained from the analysis of intze tank are provided with suitable tables and charts.

Table -3: Time Period(s) for 1000m^3 capacity intze tank

Fluid Level	Without Damper	XPD	Friction Damper
Empty	1.07	0.537	0.635
Half	1.67	0.82	0.99
Full	2.08	1.07	1.26

Table -4: Base Shear(kN) for 1000m^3 capacity intze tank

Fluid Level	Time History	Without Damper	XPD	Friction Damper
Empty	Kobe	1911	3580	3854
	Imperial Valley-Delta	1307	2466	2516
	Imperial Valley-Elcentro	2615	3767	3490
Half	Kobe	2700	4211	4507
	Imperial Valley-Delta	2770	3061	2665
	Imperial Valley-Elcentro	2770	4220	3751
Full	Kobe	4007	4726	6548
	Imperial Valley-Delta	3801	3580	3920
	Imperial Valley-Delta	4530	4473	5118

Table -5: Base Moment(kNm) for 1000m^3 capacity intze tank

Fluid Level	Time History	Without Damper	XPD	Friction Damper
Empty	Kobe	40627	135287	97981
	Imperial Valley-Delta	30348	96517	67705
	Imperial Valley-Elcentro	65166	15445	93186
Half	Kobe	60765	178527	126724
	Imperial Valley-Delta	61959	124984	102539
	Imperial Valley-Elcentro	61959	165173	111713
Full	Kobe	80751	181094	157186
	Imperial Valley-Delta	88164	134889	124468
	Imperial Valley-Delta	108793	171794	167968

Table -6: Top staging displacement(mm) for 1000m^3 capacity intze tank

Fluid Level	Time History	Without Damper	XPD	Friction Damper
Empty	Kobe	135	117	114
	Imperial Valley-Delta	154	109	119
	Imperial Valley-Elcentro	154	120	110
Half	Kobe	149	121	117
	Imperial Valley-Delta	167	120	121
	Imperial Valley-Elcentro	167	126	128
Full	Kobe	224	132	152
	Imperial Valley-Delta	240	140	150
	Imperial Valley-Delta	223	138	145

Table -7: Sloshing displacement(mm) for 1000m^3 capacity intze tank

Fluid Level	Time History	Without Damper	XPD	Friction Damper
Half	Kobe	150	123	122
	Imperial Valley-Delta	170	125	119
	Imperial Valley-Elcentro	170	133	145
Full	Kobe	236	147	163
	Imperial Valley-Delta	249	170	150
	Imperial Valley-Delta	238	150	186

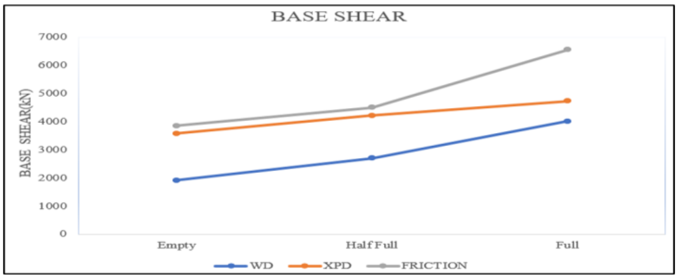

Chart -1: Variation of base shear(kN) for Kobe earthquake

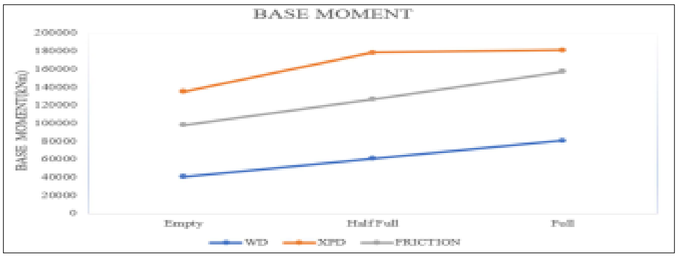

Chart -2: Variation of base moment(kNm) for Kobe earthquake

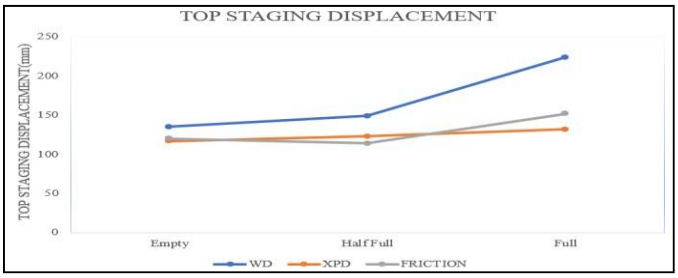

Chart -3: Variation of top staging displacement(mm) for Kobe earthquake

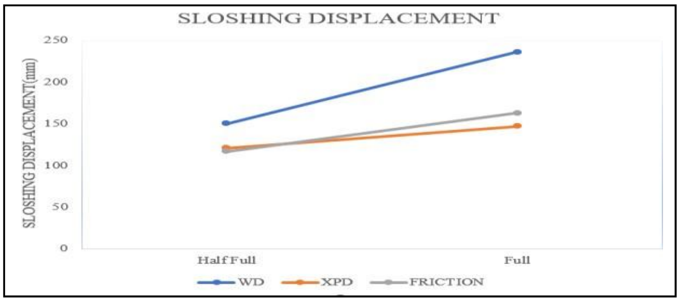

Chart -3: Variation of Sloshing displacement(mm) for Kobeearthquake

4.CONCLUSION

- X plate metallic damper is good in reducing sloshing and top staging displacement of EWT.
- Both friction and metallic dampers shows good reduction in sloshing displacement and top staging displacement.
- Maximum reduction of 40% and 37% in top staging displacement and sloshing displacement was observed with metallic damper
- Metallic damper showed higher reduction in top staging displacement.
- Reduction in base shear base moment and acceleration is slightly less for EWT with friction dampers

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