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MODELING, TESTING AND STUDY OF VIBRATION CONTROL DUE TO EARTHQUAKE EFFECT USING TUNED DAMPERS

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Abstract- This paper is focused on the implementation of various tuned dampers for mitigation of structural response for vibration control due to earthquake effect. Although there are various conventional methods for earthquake resistant building, like using ductile detailing provided by IS 13920-1993, there are certain limitation for the same as the past earthquake depict the failure of these structure. Hence, there is a need for modern techniques for earthquake resistant building which includes the dampers and base isolation techniques. The main focus is on passive dampers which are tuned mass damper, tuned liquid damper with and without baffle wall and tuned liquid column damper. A model is designed as a three storey building acting as conventional building. Four different types of damper arrangement are later provided on this model, functioning as TMD, TLD without and baffle wall and TLCD. These models are tested on a servo shake table to find out the displacement and acceleration of each for natural frequencies of conventional building and natural frequencies of individual dampers. Later the dampers with least displacement are tested for Koyna earthquake. Finally, comparing all the results obtained i.e., among TMD, TLD without and with baffle wall and TLCD model having maximum vibration control due to earthquake effect is found out.
Keywords – Dampers, passive dampers, natural frequency, TMD, TLD, TLCD.

1. INTRODUCTION

Earthquake refers to a sudden violent shaking and vibration of the earth surface resulting from underground movement along a fault plane or from volcanic activity. Although there are various conventional methods for earthquake resistant building, like using ductile detailing provided by IS 13920-1993, there are certain limitation for the same as the past earthquake depict the failure of these structure. Also, these techniques can't be used for multistoried and high rise buildings. Hence, there is a need for modern techniques for earthquake resistant buildings. The modern techniques used for earthquake-resistant structures are mainly classified into two types:

1. Dampers
2. Base Isolation

Dampers are Mechanical system which dissipate earthquake energy into specialized devices which deforms or yield during earthquake. Dampers are mainly classified into response control systems and in accordance to their operation principles as

1. Passive control systems
2. Active control systems
3. Hybrid control systems

Passive control systems operate without utilization of any external energy source. Active control systems require external power supply and operate based on sensors which are attached within the structures. Hybrid systems are combination of both passive and active control systems which require external power supply and they operate based on sensors attached to within the structures.

The following types of Passive Control Dampers are

1. Tuned Mass Dampers
2. Tuned Liquid Dampers
3. Tuned Liquid Column Dampers

Tuned mass damper (TMD) is a viscous spring-mass unit, when attached to a vibrating main structure, provides a frequency dependent hysteresis that increases the damping in the structure [1]. Tuned liquid damper (TLD) is a type of tuned mass damper (TMD) where the mass is replaced by liquid (generally water) [2]. Whereas tuned liquid column damper (TLCD) is a modification of TLD that rely on the motion of the liquid column in a U-shaped tube to counteract the action of external forces acting on the structure [3]. The efficiency of TMD for controlling structural response is sensitive to its parameters i.e. mass, frequency, and damping ratio. TMD acts as a secondary vibrating system when connected to primary vibrating system [4]. Similarly, by tuning (matching) frequency of TLD and TLCD to frequency close to natural frequency of

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structure, vibration of structure makes relative movement of damper with respect to the structure [5-6].

2. PROPOSED WORK

2.1 Total of five types of models are considered for this paper viz.,

1. Conventional building model
2. Tuned mass damper
3. Tuned liquid damper
4. TLD with baffle wall.
5. Tuned liquid column damper

2.1.1 Conventional building model -

Figure 1. Conventional Buildibng Model

The conventional building model is designed as
a three storeyed building. The material used for construction of model is Aluminium as it is light and flexible material. The model is made up of four aluminium strips acting as columns and four aluminium plates acting as slab. The size of column is 25mm X 1200mm X 3mm – 4Nos. Thus, height of each storey is 400mm. The size is choosen to make the model flexible enough. The size of plate is 150mm X 300 mm X 10mm – 4 Nos. The bolts used to connect the column with plate are of 6mm ø. Each plate to column connection has total 8 bolts. Thus a total of 32 bolts are used. Holes of 10mm ø are provided at the bottom plate to connect bolts with the shake table. A total of 5 holes of 8mm ø are provided at the top plate for various arrangement of Dampers.

2.1.2 Tuned mass damper -

Figure 2. Tuned Mass Damper

The frame used for testing of tuned mass damper is same of conventional building. A damper arrangement is made at the top plate funtioning as
TMD. A pendulum type TMD is used which is more suitable for the model. The material used as weight for TMD is iron bob. The weight of the bob is 1 kg.The weight is selected considering all the dampers weigh approximately 1 kg to be able to compare all dampers effectively [7-8].

2.1.3 Tuned Liquid Damper -

Figure 3. Tuned Liquid Damper

The frame used for testing of tuned liquid damper is same of conventional building. A damper arrangement is made at the top plate funtioning as TLD.A tank is provided at the top which works as TLD damper. Glass material is used for making the tank containing water. Glass being transparent material makes it easy to see through for taking water levels. Marking is done at the outer side of tank for measurement of water. The dimensions of tank are 12” X 6” X 9”. The base width is kept 12” X 6” matching the dimension of upper plate, while the height is considered with suitability of model and storey height. The thickness of entire glass material for tank used is 4mm making it lighter in weight of approximately 1 kg. Proper water tightness of the water tank is ensured. The tank is well fitted on top the upper plate with help of slightly extended columns of model [9-10].

2.1.4 TLD with Baffle Wall-

Figure 4. TLD with Baffle Wall

The frame used for testing of tuned liquid damper with baffle wall is same of conventional building. A damper arrangement is made at the top plate funtioning as TLD with baffle wall. The water tank used in this testing is same as that of TLD with some modifications in it. The tank is provided with a notch arrangement at the mid portion. Thus a baffle wall can be slided into this notch. A single baffle wall is used made up of thin plastic to ensure less weight. The dimensions of the baffle wall is 6” X 12” which fits into the tank. Proper water tightness is ensured between the gap of notch and baffle wall to avoid entry of water across both partitions in the water tank created.

2.1.5 Tuned Liquid Column Damper –

Figure 5. Tuned Liquid Column Damper

The frame used for testing of tuned liquid column damper is same of conventional building. A damper arrangement is made at the top plate funtioning as TLCD. The material used for column for TLCD is of PVC.Plastic material is chosen to make the arrangement light in weight. The weight of the entire damper arrangement is up to 1kg when filled with water. Three pipes are used to for a U – tube like column. This arrangement is fixed to the top of upper plate by using hooks. Proper water tightness within the joints is ensured. The lengths of vertical pipes are 9” each and that of horizontal pipe is 12”. The horizontal height is chosen as the width of base plate is 12” and vertical height is chosen considering the practicality of the model. The diameter of pipe is 3” throughout the length. The central portion of horizontal pipe has an orifice fitted inside it. The diameter of the orifice is 3” and has a central hole of 1”. The orifice is provided to restrict the sloshing effect of water inside the U – tube column making it more effective [11-13].

2.2 Configuration of Shake Table –

Figure 6. Servo Shake Table

The shake table used for executing this project is a Servo shake table. It is used for random vibration and earthquake simulation. The servo shake table used is made my Millennium. The shake table has a maximum payload of 30 kg. The dimension of the shake table is 500mm X 500mm. Above this, there are two plates to attach or fix the model. The diameter of the circular plate is 400mmø. The upper plate had 8 holes of 10mmø equally spaced at an diameter of 300mmø, while at outer diameter of 350mmø, there were 16 holes of 10mmø equally spaced. The shake table has a frequency of 0-12Hz and an amplitude/stroke of 0-1500mm. It has an input power of 230 Volts AC.

The two software used for experimental purpose are,

1. Test lab shake table software
2. Kampana software

Test lab shake table software is to give displacement, frequency, amplitude and cycles of vibration to the model. It can also provide time history of past earthquake data to the model. Kampana software is used to find out the displacement, velocity and acceleration in the X, Y and Z direction.

For the connection purpose, rigid connection is adopted to ensure sufficient stiffness. Bolting of model is best suited for model flexibility. So it is decided to provide flat headed bolts of varying diameter and length for connections. For each connection of column with single plate, a total number of 8 bolts are used. The diameter of each hole is 6mm. Hence, the total number of bolt connection used is 32. Some extra connection holes are provided at the top plate so it can be utilised for attachment of different damper configuration. Also for connection the model with shake table, bolts are used. The bolts fit correctly into the holes provided at the bottom plate and the holes at the plate of shake table. The diameter of bottom holes is 10mm. Model is connected with accelerometer on each storey Accelerometer is placed in horizontal direction which shows displacement on each floor in X, Y and Z direction.

Accelerometer

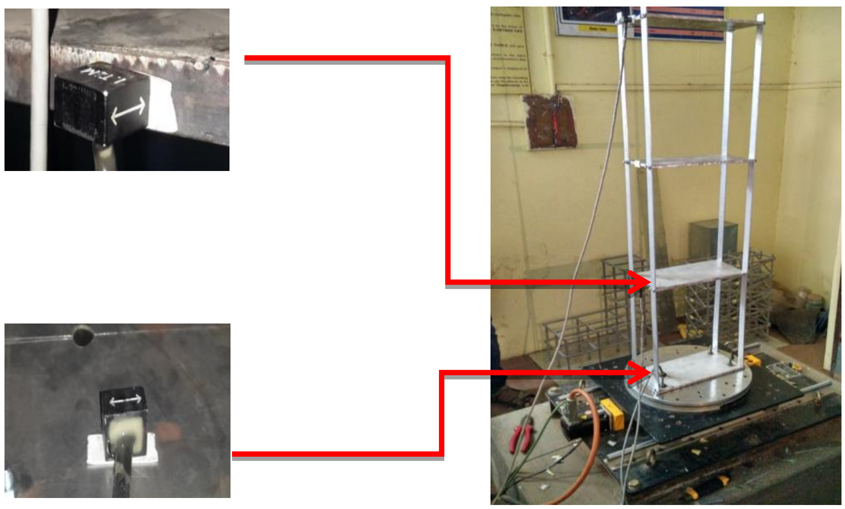

Figure 9. Connection of model with shake table with accelerometers

3. EXPERIMENT AND RESULT

Results and analysis is divided into three parts.

1. Part I consists of comparison between the displacement and acceleration of conventional building model and model with damper at natural frequency of conventional model.
2. Part II consists of comparison between the displacement and acceleration of conventional building model and model with dampers at natural frequency of individual damper model.
3. Part III consists of comparison between the displacement and acceleration of conventional building model and model with dampers for Koyna earthquake.

In Part I, the conventional building model and models with dampers are considered and the readings are taken for displacement and acceleration at each floor i.e. Ground, first, second and third floor. Dampers considered for testing are TMD, TLD, TLD with baffle wall, TLCD. For TMD, the readings are taken at height of weight at 8" and 12".from top position. These heights are selected considering floor height of 15". For TLD, the readings are taken at water levels of 3", 4.5" and 6" which are 1/3rd, 1/2 and 2/3rd of tank capacity. The levels are decided to obtain readings at various heights. A free board of 3" is kept at the top as the sloshing effect of water may cause damage to the cap arrangement provided at top to avoid spillage of water when operated. For TLD with baffle wall, readings are taken at water level of 4.5" which is half capacity of the tank beacause amongst the reaings obtained from TLD, half filled tank is more effective.For TLCD, the readings are taken at 3", 6" and 9" which is 1/3rd, 2/3rd and full height of the column to obtain different results at various heights.

By giving forced frequencies to the shake table, the natural frequency of conventional building model is found out to be 2.3 Hz.

Table -1 Testing for natural Frequency of conventional building i.e., 2.3 Hz.

Sr. No.	Structure	Level (Inch)	Displacement (mm)				Acceleration (mm/sec^2)			
			G	1	2	3	G	1	2	3
1	Conventional building	-	8.01	60.7	102.9	122.8	0.11	0.82	1.30	1.26

2	Tuned Mass Damper	8	7.60	32.87	30.45	46.95	64.74	0.11	0.48	0.65
		12	7.60	21.59	30.45	36.11	0.10	0.28	0.39	0.47
3	Tuned Liquid Damper	3	7.68	5.92	3.19	6.41	0.08	0.07	0.03	0.09
		4.5	7.09	6.54	3.13	6.18	0.08	0.07	0.03	0.09
		6	7.50	5.81	3.98	5.92	0.09	0.08	0.03	0.07
4	TLD with Baffle Wall	4.5	7.35	7.12	4.56	1.87	0.09	0.1	0.06	0.02
5	Tuned Liquid Column Damper	3	6.48	7.75	2.72	7.61	0.09	0.09	0.04	0.1
		6	7.20	8.46	4.10	7.91	0.09	0.1	0.05	0.1
		9	7.65	10.1	5.06	7.85	0.08	0.09	0.04	0.1

Table -1 shows the displacement and acceleration of individual damper with different levels of height for natural frequency of conventional building i.e. 2.3 Hz.

Table -2 Percentage Comparison with Conventional Building

Sr. No.	Structure	Level (Inch)	Displacement %	Acceleration %
1	Conventional Building	-	100%	100%
2	Tuned Mass Damper	8	49.748%	61.024%
		12	24.825%	32.20%
3	Tuned Liquid Damper	3	0.793%	0.434%
		4.5	1.103%	1.128%
		6	1.379%	1.736%
4	TLD with Baffle Wall	4.5	4.77%	6.163%
5	Tuned Liquid Column Damper	3	0.985%	0.607%
		6	0.614%	0.95%
		9	0.117%	0.86%

Table-2 shows percentage comparison conventional building and model with dampers to find out the least displacement and acceleration

By doing percentage comparison with natural frequency of conventional building i.e., frequency of 2.3 Hz, it is found that TMD with 8”, TLD with 3”, TLD with baffle wall at 4.5”, TLCD at 9” is least.

In Part II, by giving forced frequencies to the shake table for each damper arrangement, the natural frequency of various model with dampers at different levels were found out. The models were then tested for their respective natural frequencies at different levels to find out the displacement and acceleration.

Table -3 Testing for various dampers at their individual natural frequencies

Sr. No.	Structure	Natural Frequency (Hz)	Level (Inch)	Displacement (mm)				Acceleration (mm/sec^2)			
				G	1	2	3	G	1	2	3
1	Conventional building	2.3	-	8.01	60.7	102.9	122.8	0.105	0.819	1.30	1.26
2	Tuned Mass Damper	2.6	8	11.58	39.77	106.0	117.4	0.101	0.27	0.48	0.842
		2.6	12	10.9	25.5	55.5	82.07	0.105	0.418	1.05	1.42
3	Tuned Liquid Damper	1.7	3	6.53	14.81	27.27	31.76	0.054	0.130	0.23	0.281
		1.9	4.5	4.19	5.07	15.45	17.84	0.056	0.087	0.13	0.237
		1.9	6	5.40	6.79	12.74	22.48	0.059	0.086	0.13	0.237
4	TLD with Baffle Wall	2.3	4.5	3.49	8.24	12.32	26.81	0.013	0.047	0.07	0.100
5	Tuned Liquid Column Damper	1.8	3	4.93	32.43	42.54	61.60	0.055	0.425	0.65	0.874
		1.9	6	5.59	10.00	13.45	29.28	0.058	0.144	0.23	0.415
		1.9	9	3.43	4.31	11.84	18.20	0.059	0.068	0.18	0.247

Table-3 shows the displacement and acceleration of individual dampers with different levels for their own natural frequency. While comparing the various dampers with their respective natural frequencies, the displacement and acceleration of TMD at 12”, TLD at 4.5”, TLD with baffle wall at 4.5” and TLCD at 9” were least.

In Part III, these dampers are tested for Koyna earthquake. The 1967 Koyna Earthquake is recorded at 1 A gallery of koyna dam at latitude 17 23 51N and longitude 74 45 0E. This earthquake time history is digitalized and corrected for the time interval of 0.02 seconds and 536 points. The time history plot of 10th Dec. 1967 Koyna earthquake is shown in Figure. 12.74 Km away from Koyna and 7 Km away from Koyna HPP Stage I and II. The earthquake has PGA 0.48g, peak velocity 19.6 cm/sec and peak displacement 1.33 cm.

Table -4 Test for Koyna Earthquake

Sr. No.	Structure	Level (Inch)	Displacement (mm)				Acceleration (mm/sec^2)			
			G	1	2	3	G	1	2	3
1	Conventional building	-	5.995	11.17	12.448	19.081	0.461	0.481	0.44	0.385
2	Tuned Mass Damper	12	6.151	10.16	11.191	13.927	0.255	0.152	0.20	0.306
3	Tuned Liquid Damper	4.5	6.334	11.94	7.713	11.575	0.116	0.135	0.13	0.066
4	TLD with Baffle Wall	4.5	6.983	12.18	6.609	10.449	0.129	0.140	0.15	0.063
5	Tuned Liquid Column Damper	9	7.879	9.242	9.39	10.66	0.114	0.180	0.25	0.122

Table-4 shows displacement and acceleration of best dampers when tested for koyana earthquake

Later the percentage wise comparison is done with conventional building for Koyna earthquake to find out best of best damper as shown in following table,

Table -5 Percentage Comparison with Conventional Building for Koyna Earthquake

Sr. No.	Structure	Level (Inch)	Displacement %	Acceleration %
1	Conventional Building	-	100%	100%
2	Tuned Mass Damper	12	59.42%	65.78%
3	Tuned Liquid Damper	4.5	40.05%	67.10%
4	TLD with Baffle Wall	4.5	26.486%	86.84%
5	Tuned Liquid Column Damper	9	21.25%	10.52%

Table-5 shows percentage comparison of displacement and acceleration between conventional building model and model with dampers when tested for koyana earthquake

4. CONCLUSION

The present study focused on the implementation of a tuned mass damper, tuned liquid damper and tuned liquid column damper for mitigation of structural response for vibration control using dampers.

The natural frequency of conventional building was found out to be 2.3 Hz. The various dampers were tested for frequency of 2.3 Hz. From the results, the conventional building showed a storey deflection of 114.79mm while the least storey deflection was of TLCD at 9” with just 0.2mm. The comparison among individual damper with different arrangement showed that TMD with 12”, TLD with 4.5”, TLD with baffle wall at 4.5”, TLCD at 9” were shows the least response. While the TLCD with 9” showed least reduction in displacement and acceleration of about 0.117% and 0.86% respectively to that of conventional building model. Thus testing for natural frequency of conventional building model, TLCD with 9” was effective for vibration control.

Later, natural frequencies of individual dampers with different levels as mentioned above were found. These were then tested to find out their displacement and acceleration at their own natural frequencies. From the results the displacement and acceleration of individual damper models, TMD at 12”, TLD at 4.5”, TLD with baffle wall at 4.5” and TLCD at 9” have least response among the various levels. While ,TLCD with 9” was the most effective with storey deflection of 14.77 mm when compared to that of conventional building storey deflection of 114.79 mm. The test also concludes that the damper arrangement also effectively reduced the natural frequency of a building.

After testing for natural frequency of individual damper, the best dampers i.e, TMD at 12”, TLD at 4.5”, TLD with baffle wall at 4.5” and TLCD at 9” were tested for Koyna earthquake. In this test, the conventional building model showed a maximum displacement of 19.081 mm while TLCD at 9” showed the least displacement of 10.66 mm among all dampers. From the results it is concluded that for Koyna earthquake, TLCD with 9” have a response of displacement and acceleration to about 21.25% and 10.52% respectively when compared to conventional building.

Thus analyzing the results obtained from various observations, it is concluded that the natural frequency of various models changes with change in the damper levels. The natural frequency of all buildings with damper is less than that of conventional building which helps in vibration control. The displacement and acceleration of model also changes with change in damper levels. Finally, it is concluded that tuned liquid column damper with full water level proved to be best of best damper for the excitation force considered in this paper.

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