Factors Affecting the Optimal Location and Orientation of Dampers in an R.C.C. Building

Ashish Kumar[1], Raunak Joshi[2], Abhishek Arge[3]

[1]*Dept. of Civil Engineering, MIT School of Engineering, Pune*
[2]*Dept. of Civil Engineering, MIT School of Engineering, Pune*
[3]*Dept. of Civil Engineering, MIT School of Engineering, Pune*

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Abstract – Seismic Dampers have been used for years as means to protect structures from adverse effects of earthquakes. However, dampers cannot be placed in buildings in a random fashion. The efficacy of dampers depends on their location and orientation. The objective of this experiment is to determine how any alteration in the aforementioned factors affects the efficacy of these dampers. In this project, 2D models were formulated and simulations were run to determine the factors affecting the optimal location and position of dampers. The simulations were run on the ETABS software. The Response Spectrum Analysis method was incorporated using the IS 1893-2016. The results of this experimentation will help placing the dampers in a building in an economic way. Dampers were found to be most effective when placed in the lower storeys of a building. Also, placing dampers closer to the centroidal axis increases their efficacy. When placing dampers side to side, it is recommended to place them in opposite orientations. Orientation inversion is also recommended in consecutive storeys. However, when it comes to giving priority to lower storey or closeness to centroidal axis, the latter was found to be the governing factor. Above results will help placing dampers in the most efficient way, when the number of dampers is restricted.

***Key Words*:** Dampers, Location, Orientation, ETABS, Response Spectrum.

1. INTRODUCTION

The use of various energy absorption devices such as friction dampers, viscoelastic dampers, viscous fluid dampers, and metallic dampers in earthquake-resistant design and retrofitting of structures has garnered a lot of attention in recent years. The usage of these devices is recommended as they boost a structure's energy dissipation capacity against moderate and intense earthquakes. This method offers an alternative to traditional earthquake-resistant construction, with the potential to considerably reduce seismic risk without jeopardizing the safety, reliability, or economic viability of the structures.

Fluid viscous dampers were used for energy dissipation in the simulations run as a part of experimentation for this paper. FVDs or Fluid Viscous Dampers were chosen in particular because of their easy availability in the market. According to Adithya G. S & H. Narendra, the introduction of dampers in a RC structure considerably reduces displacements and forces on each storey. The experimentation conducted by Prakriti Chandrakar and Dr. P. S. Bokare suggests that Response Spectrum analysis and Time History method can be used to determine the effect of dampers on response of a structure. It also suggests that Response Spectrum analysis yields a greater value of storey displacement than Time History method on any given storey. Thus, Response Spectrum Analysis was used in this experimentation. This helps to determine the peak values of responses in any given condition. In the paper presented by SS Sanghai and PY Pawade, it can be inferred that when the number of dampers placed in a structure is increased, the response of the structure considerably reduces. Also, when a given number of dampers are placed at various locations in a structure, the response of the building changes.

So, the scope of this paper is to determine how and where the dampers need to be placed in order to optimize the damping effect. The results of this experimentation will help in determining the most economic arrangement of dampers in a structure when the number of dampers are fixed.

2. METHODOLOGY

The objective of this paper is to optimize the location and orientation of dampers. In order to achieve the objectives, following questions must be answered-

- What is the most suitable vertical position for a damper?
- What is the most suitable horizontal position for a damper?
- What is the most suitable orientation for dampers used in pairs?

- What is the governing factor when it comes to deciding the damper position – storey level or distance from the centroidal axis?
- Does inversion of direction of damper sets on consecutive stories have any effect on the damping?
- What sort of distribution of dampers is the most efficient way to damp a structure?

For curating the answers to above questions, simulations for various cases were run. The cases are described in the upcoming sections.

3. TEST FRAME DESCRIPTION

The simulations were carried out on a 4 bay, 10 storey frame with storey height of 3m for each storey and a bay width of 3m for each bay. The dampers used in the simulation had the following properties, as listed in Table 1. The seismic data for the simulation is listed in Table 2. The response spectrum was in accordance with IS 1893:2016.

Table 1: Damper Properties

Property of Damper	Value
Link Type	Damper - Exponential
Weight	500 kN
Mass	98 kg
Directional Properties	Fixed in U1 direction

Table 2: Seismic Data

Seismic Property	Value
Zone	V
Zone Factor (Z)	0.36
Importance Factor (I)	1
Soil Type	II (Medium)
Response Reduction Factor (R)	5
Constant Damping Ratio	0.05
Scale Factor	0.98

The section properties of the R.C.C. elements are given in Table 3.

Table 3: Section Properties

Section Properties	Value
Beam Dimensions	230mm X 230mm
Column Dimensions	230mm X 230mm
Concrete Grade	M30
Steel Grade	Fe250

4. TEST CASES

Case Study 1: Determining the optimal storey to place a damper. (Vertical Position)

In this study, a 1 bay 10 storey frame, as shown in figure 1, was used to observe the maximum displacement in each storey. Multiple simulations were run by placing the damper at each storey one at a time. The results were checked for the damper location which yielded the least maximum displacement as compared to all other storeys.

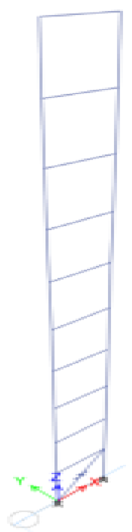

Figure 1: Case Study 1 Model

Case Study 2: Determining the optimal distance of damper from the centroidal axis. (Horizontal Location)

In this case, a 4 bay 10 storey frame was used to determine the effect of variation in damper position in terms of distance from the centroidal axis, on the frame response. In the first simulation, two dampers were placed on extreme ends of the base. In the second simulation, two dampers were placed closer to the centroidal axis on the base as shown in figure 2 and 3.

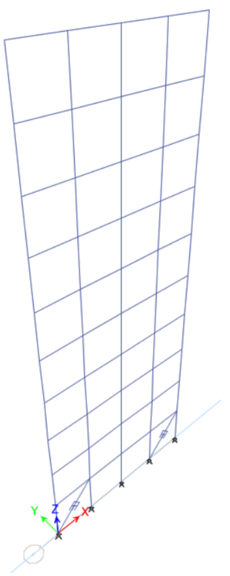

Figure 2: Case Study 2 - Model A

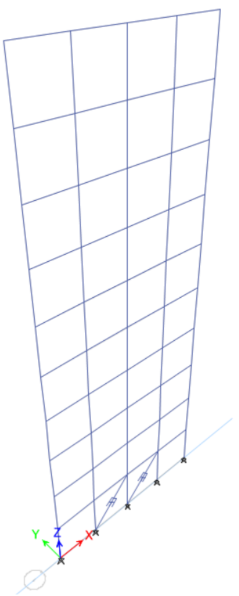

Figure 3: Case Study 2 - Model B

Case study 3: Orientation inversion when dampers are placed side to side.

In this case a 4 bay 10 storey frame was used to determine the optimal orientation of dampers when placed side to side on the same storey. In both the simulations the dampers were placed on the base storey in the second and third bay. In the first simulation, both the dampers were placed in a similar orientation, i.e. facing the same direction; whereas in the second simulation, both the dampers were placed in an opposite orientation with respect to each other, i.e. in opposite directions as shown in figure 4 and 5.

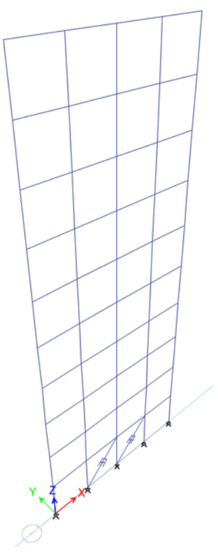

Figure 4: Case Study 3 - Model A

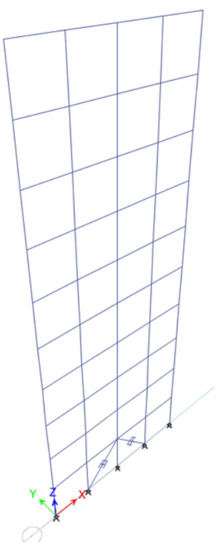

Figure 5: Case Study 3 - Model B

Case study 4: Governing factor in the selection of damper location - vertical location or horizontal location.

In this case a 4 bay 10 storey frame was used. This case was used to study the combined effect of 4 dampers when vertical location is considered the governing factor and when horizontal location is considered the governing factor. In the first simulation, all the four dampers are placed on the base storey, making vertical location the governing factor. In the second simulation, two dampers were placed on the base story on bay 2 and 3, and the other two dampers were placed in a similar fashion on storey number 1, making horizontal location, i.e. distance from the centroidal axis the governing factor as shown in figure 6 and 7.

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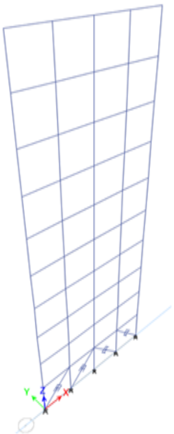

Figure 6: Case Study 4 - Model A

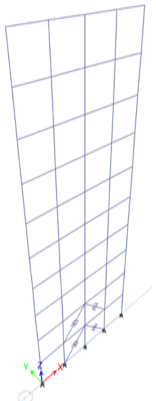

Figure 7: Case Study 4 - Model B

Case study 5: Orientation inversion when dampers are placed in the same bay on adjacent storeys.

In this case a 4 bay 10 storey frame was used to determine the effect of change in orientation of dampers. 4 dampers were used in pairs for each simulation. In the first simulation, both pairs of dampers were placed in different orientation on adjacent storeys. In the second simulation, both pairs of dampers were placed in the same orientation at adjacent storeys, as shown in figures 8 and 9.

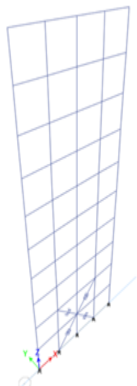

Figure 8: Case Study 5 - Model A

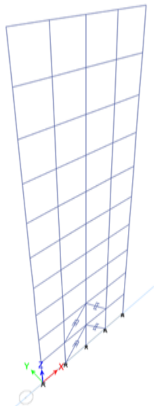

Figure 9: Case Study 5 - Model B

Case study 6: Distribution of Dampers

In this case, multiple combinations of dampers were tested. 4 dampers were tested together in each simulation. In the first combination (the 3+1 system), two simulations were run. In the first simulation, one damper was placed in the bottom storey whereas three dampers were placed at the second and third storeys as shown in figure 10 (model 6A). In the second simulation, one damper was placed at the third storey and the other three dampers were placed at the bottom and first storeys as shown in figure 11 (model 6B).

In the second combination (the 2020 system), two simulations were run. In the first simulation, a pair of dampers was placed at the bottom storey and the other pair was placed at the second storey (model 6C) as shown in figure 12. In the second simulation, a pair of dampers was placed at the first storey and the other was placed at the third storey (model 6D) as shown in figure 13.

In the third combination (the even distribution system), one damper was placed at every storey for all the three simulations as shown in figures 14, 15 and 16. Model 6E, 6F and 6G demonstrate the different arrangements of dampers used in the three different simulations.

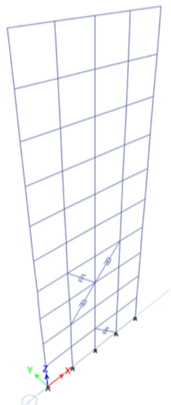

Figure 10: Case Study 6 - Model A

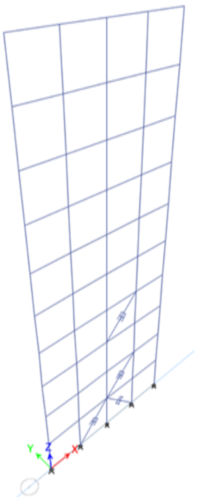

Figure 11: Case Study 6 - Model B

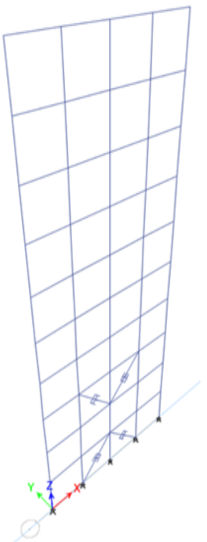

Figure 12: Case Study 6 - Model C

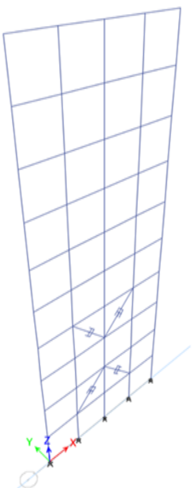

Figure 13: Case Study 6 - Model D

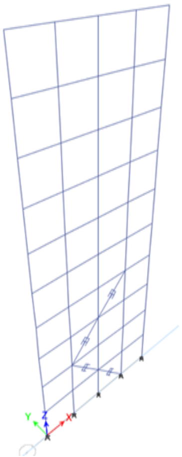

Figure 14: Case Study 6 - Model E

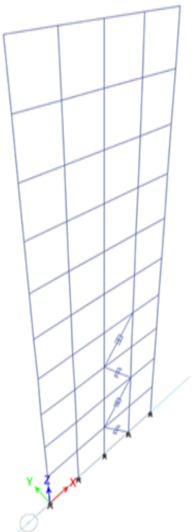

Figure 15: Case Study 6 - Model F

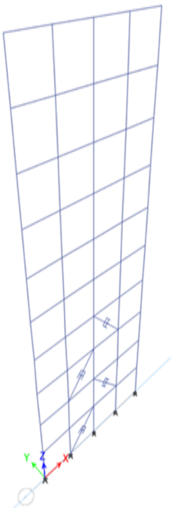

Figure 16: Case Study 6 - Model G

5. RESULTS

The results in the form of storey displacements for each case study were recorded. The results are as follows -

Results from Case Study 1 -

Table 4: Maximum Storey Displacement readings from simulations performed in Case Study 1.

1	TABLE: Story Response												
2	Story	Elevation	No Damper	Damper-1	Damper-2	Damper-3	Damper-4	Damper-5	Damper-6	Damper-7	Damper-8	Damper-9	Damper-10
3		m	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
4	Story10	30	499.09	321.866	380.072	416.25	427.86	437.108	447.495	459.477	472.815	487.543	502.443
5	Story9	27	482.775	306.254	363.791	400.301	412.319	421.873	432.395	444.385	458.025	474.911	491.529
6	Story8	24	459.422	283.61	340.361	377.473	390.188	400.334	411.306	424.06	441.503	464.285	465.933
7	Story7	21	428.863	253.986	309.735	347.641	361.331	372.444	384.843	403.189	431.393	433.647	431.711
8	Story6	18	391.691	218.242	272.699	311.482	326.471	339.657	359.55	393.636	397.18	393.479	391.6
9	Story5	15	348.703	177.448	230.306	270.046	287.484	309.962	350.63	356.069	352.513	348.093	346.643
10	Story4	12	300.796	132.799	183.889	225.566	253.698	301.82	309.964	307.183	302.958	298.751	297.675
11	Story3	9	248.857	85.744	136.036	188.591	246.574	258.484	257.202	253.723	249.915	246.233	245.436
12	Story2	6	193.078	38.764	98.48	182.835	200.552	201.701	199.572	196.589	193.52	190.551	189.966
13	Story1	3	127.706	1.311	94.603	128.93	133.7	133.585	131.995	129.934	127.864	125.851	125.468
14	Base	0	0	0	0	0	0	0	0	0	0	0	0

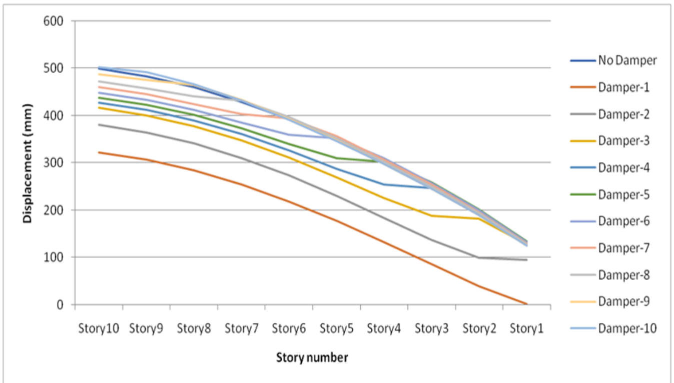

Figure 17: Graph of Maximum Storey Displacement in Case Study 1

Results from Case Study 2 -

Table 5: Maximum Storey Displacement readings from simulations performed in Case Study 2.

	CASE 2	
Storey	Model A	Model B
Storey 10	256.404	255.657
Storey 9	248.66	247.936
Storey 8	234.291	233.587
Storey 7	213.279	212.599
Storey 6	186.257	185.609
Storey 5	154.002	153.393
Storey 4	117.401	116.843
Storey 3	77.527	77.03
Storey 2	36.104	35.687
Storey 1	0.881	0.639
Base	0	0

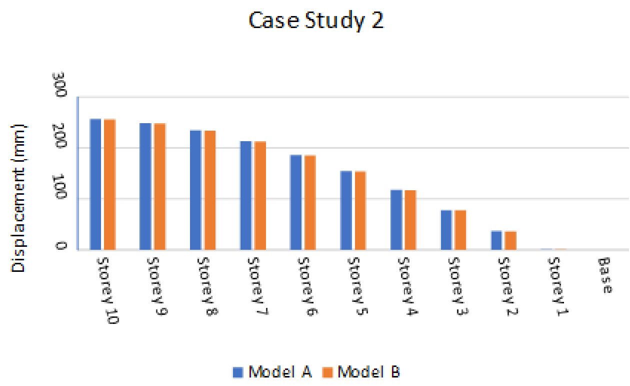

Figure 18: Graph of Maximum Storey Displacement in Case Study 2

Results from Case Study 3 -

Table 6: Graph of Maximum Storey Displacement in Case Study 3

	CASE 3	
Storey	Model A	Model B
Storey 10	255.657	255.358
Storey 9	247.936	247.641
Storey 8	233.587	233.298
Storey 7	212.599	212.317
Storey 6	185.609	185.333
Storey 5	153.393	153.125
Storey 4	116.843	116.584
Storey 3	77.03	76.783
Storey 2	35.687	35.457
Storey 1	0.639	0.336
Base	0	0

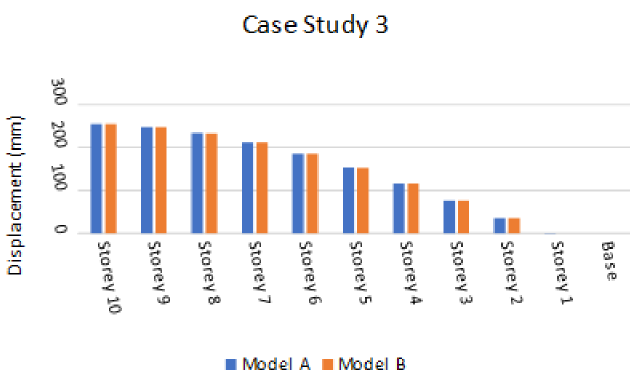

Figure 19: Graph of Maximum Storey Displacement in Case Study 3

Results from Case Study 4 -

Table 7: Graph of Maximum Storey Displacement in Case Study 4

	CASE 4	
Storey	Model A	Model B
Storey 10	255.232	202.465
Storey 9	247.517	194.994
Storey 8	233.177	180.963
Storey 7	212.199	160.399
Storey 6	185.219	134.048
Storey 5	153.014	102.906
Storey 4	116.476	68.204
Storey 3	76.679	31.762
Storey 2	35.357	0.823
Storey 1	0.228	0.24
Base	0	0

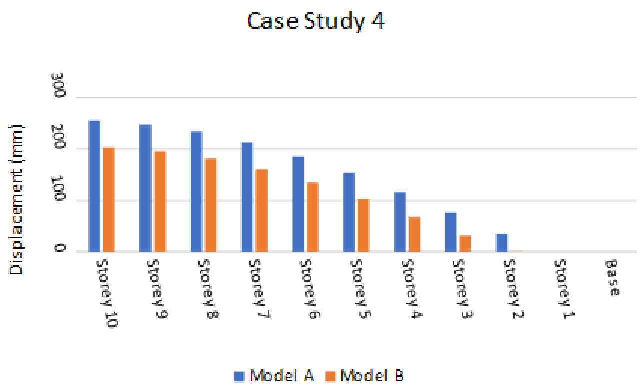

Figure 20: Graph of Maximum Storey Displacement in Case Study 4

Results from Case Study 5 -

Table 8: Graph of Maximum Storey Displacement in Case Study 5

	CASE 5	
Storey	Model A	Model B
Storey 10	202.182	202.465
Storey 9	194.712	194.994
Storey 8	180.68	180.963
Storey 7	160.12	160.399
Storey 6	133.779	134.048
Storey 5	102.653	102.906
Storey 4	67.976	68.204
Storey 3	31.564	31.762
Storey 2	0.587	0.823
Storey 1	0.07	0.24
Base	0	0

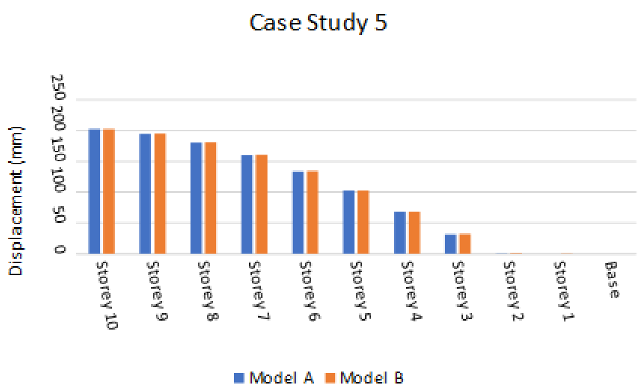

Figure 21: Graph of Maximum Storey Displacement in Case Study 5

Results from Case Study 6 -

Results of the 3+1 arrangement:

Table 9: Graph of Maximum Storey Displacement in Case Study 6 - 3+1 arrangement

	CASE 6	
Storey	Model A	Model B
Storey 10	155.455	153.36
Storey 9	148.002	145.99
Storey 8	133.772	131.924
Storey 7	113.078	111.4
Storey 6	87.043	85.475
Storey 5	57.461	55.901
Storey 4	31.124	29.584
Storey 3	29.665	25.674
Storey 2	28.307	2.284
Storey 1	0.671	0.043
Base	0	0

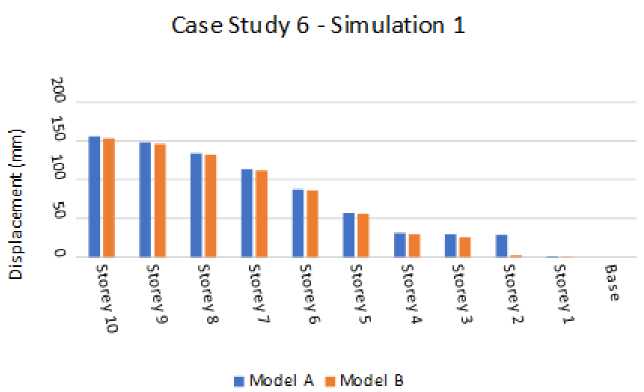

Figure 22: Graph of Maximum Storey Displacement in Case Study 6 - 3+1 arrangement

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Results of the 2020 arrangement:

Table 10: Graph of Maximum Storey Displacement in Case Study 6 - 2020 arrangement

	CASE 6	
Storey	Model C	Model D
Storey 10	190.696	261.514
Storey 9	183.197	255.278
Storey 8	169.009	243.361
Storey 7	148.221	225.67
Storey 6	121.65	202.672
Storey 5	90.435	175.439
Storey 4	56.379	150.553
Storey 3	27.097	148.927
Storey 2	26.141	121.728
Storey 1	0.326	120.383
Base	0	0

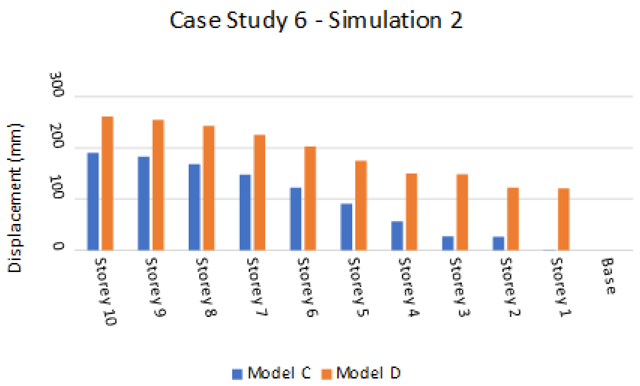

Figure 23: Graph of Maximum Storey Displacement in Case Study 6 - 2020 arrangement

Results of the even distribution arrangement:

Table 11: Graph of Maximum Storey Displacement in Case Study 6 - Even Distribution arrangement

	CASE 6		
Storey	Model E	Model F	Model G
Storey 10	120.157	134.568	120.97
Storey 9	113.12	127.335	113.923
Storey 8	99.631	113.488	100.422
Storey 7	80.08	93.354	80.846
Storey 6	55.705	68.092	56.424
Storey 5	28.408	39.512	29.047
Storey 4	4.414	13.627	4.695
Storey 3	2.365	8.562	2.498
Storey 2	1.279	4.42	1.709
Storey 1	0.089	1.324	0.393
Base	0	0	0

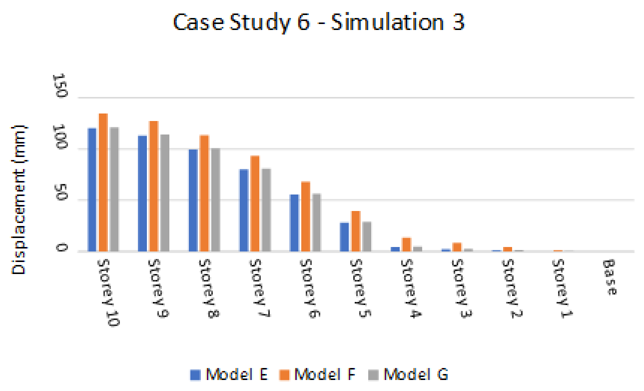

Figure 24: Graph of Maximum Storey Displacement in Case Study 6 - Even Distribution arrangement

Results comparing best cases from all three arrangements:

Table 12: Graph of Maximum Storey Displacement in Case Study 6 - Comparing best cases from all three arrangements

	CASE 6		
Storey	Model B	Model E	Model G
Storey 10	153.36	120.157	120.97
Storey 9	145.99	113.12	113.923
Storey 8	131.924	99.631	100.422
Storey 7	111.4	80.08	80.846
Storey 6	85.475	55.705	56.424
Storey 5	55.901	28.408	29.047
Storey 4	29.584	4.414	4.695
Storey 3	25.674	2.365	2.498
Storey 2	2.284	1.279	1.709
Storey 1	0.043	0.089	0.393
Base	0	0	0

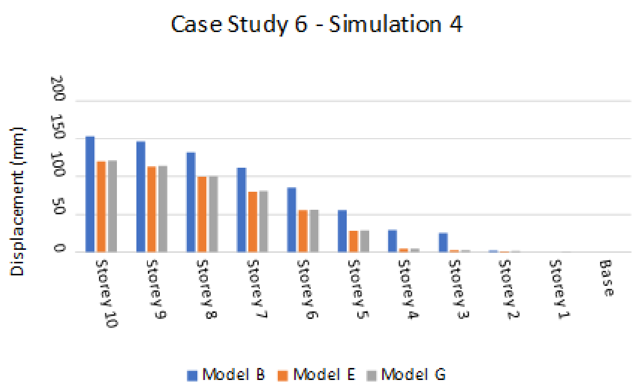

Figure 25: Graph of Maximum Storey Displacement in Case Study 6 - Comparing best cases from all three arrangements

6. DISCUSSIONS

Case Study 1: Determining the optimal storey to place a damper. (Vertical Position)

From this case, we can infer that, as the number of storeys increases, the maximum displacement at each floor increases as shown in Table 4 and Figure 17. Thus, we can conclude that when the damper is placed near to the base, the damping efficiency of the frame increases.

Case Study 2: Determining the optimal distance of damper from the centroidal axis. (Horizontal Location).

In this case, the values of maximum displacement as shown in Table 5 and Figure 18 suggest that when the dampers are placed closer to the centroidal axis, the efficiency of the frame increases as compared to the dampers placed away from the centroidal axis. Thus, we can conclude that dampers are to be placed closer to the centroidal axis.

Case study 3: Orientation inversion when dampers are placed side to side.

In this case, the values of maximum displacement were higher when the dampers were placed in the same direction as compared to the dampers which were placed in opposite directions as shown in Table 6 and Figure 19. Thus we can conclude that, when dampers are placed consecutively on the same storey, they are to be placed in opposite directions so as to form a triangular shape.

Case study 4: Governing factor in the selection of damper location - vertical location or horizontal location.

This case was carried out to study whether dampers perform more efficiently when the dampers are arranged on multiple storeys (closer to the centroidal axis) or when all the dampers are placed at the base. The test results suggest that when the dampers are arranged on multiple storeys (closer to the centroidal axis), the maximum displacement on each storey is lesser as compared to when all the dampers are placed at the base as shown in Table 7 and Figure 20. Thus we can conclude that the governing factor for damper arrangement is closeness to the centroidal axis.

Case study 5: Orientation inversion when dampers are placed in the same bay on adjacent storeys.

In this case, it is observed that when two pairs of dampers that face in the opposite direction, the value of maximum displacement is lesser as compared to the two pairs of dampers which face in the same direction as shown in Table 8 and Figure 21. Thus, we can conclude that when two pairs of dampers are placed consecutively on floors, they should face the opposite direction (inverted formation).

Case study 6: Distribution of Dampers

In the first combination (the 3+1 system), it is observed that when three dampers are placed at the bottom storeys and one at the mid-storey (model 6B, Figure 11), the frame is more efficient against seismic loads as shown in Table 9 and Figure 22

In the second combination (the 2020 system), we observe that when a pair of dampers is placed at the bottom storey and the other pair at the second storey (model 6C, Figure 12), the efficiency of the frame increases as shown in Table 10 and Figure 23.

In the third combination (the even distribution system), we can note that model 6F as shown in Figure 15 has high values of maximum displacement, followed by model 6G (Figure 16), followed by model 6E (Figure 14) as shown in Table 11 and Figure 24. Thus we can conclude that, when two dampers behave as a single unit (model 6E), the resistance of the frame against seismic loads is the greatest among all other miscellaneous cases adopted.

Furthermore, upon comparison of best arrangements of all three types, it was found that an even distribution yields better results as shown in Table 12 and Figure 25.

7. CONCLUSIONS

- Dampers prove to be more efficient when placed on lower stories.
- Dampers placed closer to the centroidal axis prove to be more effective.
- Dampers placed in opposite directions to each other prove to be more efficient.

- The governing factor in deciding the position of a damper is its closeness to the centroidal axis.
- It's found that inverting the direction of dampers on alternate stories yields better results.
- An even distribution of dampers is recommended.

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