

COMPARISON OF TIME HISTORY ANALYSIS RESULTS OF A STEEL BUILDING WITH DAMPERS AND WITHOUT DAMPERS

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ABSTRACT

Energy induced by strong earthquakes affects the structure. The seismic performance as well as response of the structure will be substantially improved if this energy is dissipated in a manner independent of structural components. Analysis of 15storey steel building which will be used as commercial building, with concrete shear wall core and typical floor area 4334.4 m² was performed. The structure is modeled using the finite element program ETABS and is analysed using non-linear dynamic analysis ie. time history analysis.

The building is situated in Earthquake zone III, the design of which is conforming to recent IS codes. Use of passive dampers for improvement of seismic performance and enhancing design of new structure has increased in recent years. The main objective of the study is to assess the improvement in seismic performance achieved through use of the passive devices, and the suitability of various dampers for the seismic response of frames fitted with dissipative devices.

Passive dampers are installed in existing lay out. They are either viscous dampers or friction dampers or combination of the two. It is shown that modifications made to the original code-based design using passive damper system satisfies the design objective of Life Safety performance expected to be achieved under design earthquake.

Key words: *Passive dampers ,Seismic performance, Time history analysis,*

I INTRODUCTION

Design of civil engineering structures is generally based on relevant building codes. Under normal conditions, loads on these structures produce elastic structural behavior. During a strong seismic event, a structure may actually be subjected to forces beyond its elastic limit. In this case it is not possible to predict the performance of designed structure. Also the existing building can become seismically deficient since seismic design code requirements are constantly upgraded due to advancement in engineering knowledge.

Performance based seismic engineering (PBSE), where inelastic structural analysis is combined with seismic hazard assessment to calculate expected seismic performance of a structure, has become increasingly feasible because of availability of modern computing techniques. The static non linear pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The expectation is that the pu-

shover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components and modify design accordingly. The non-linear static procedure (NSP) or pushover analysis, as described in FEMA-273 [3] and its successor FEMA-356 [4] is now used by the structural engineering profession as a standard tool for estimating seismic demands for buildings.

Strong earthquakes induce high amount of energy to the affected structures. The seismic performance and response of the structure will be substantially improved if this energy can be controlled and dissipated in a manner independent of the structural components. This can be achieved by using supplementary passive control devices for the structures or base isolation techniques. The present study reports effect of use of passive dampers in the seismic performance of a vulnerable steel structure. The passive damper systems which are used are friction dampers, viscous dampers or their combinations.

II SEISMIC PERFORMANCE ASSESSMENT OF BUILDINGS

The seismic performance of buildings is measured by the state of damage under a certain level of seismic hazard. The state of damage is quantified by the drift of the roof and the displacement of the structural elements. A building performance level is a combination of the performance levels of the structure and the nonstructural components. A performance level describes a limiting damage condition which may be considered satisfactory for a given building with specific ground motion. The performance levels as per FEMA [3, 4], ATC 40 [2] are: Immediate occupancy IO: damage is relatively limited; the structure retains a significant portion of its original stiffness and most if not all of its strength.

Life safety level LS: substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur. Collapse prevention CP: at this level the building has experienced extreme damage, if laterally deformed beyond this point; the structure can experience instability and collapse. ATC-40 and FEMA-273 documents define force-deformation criteria for hinges used in pushover analysis As shown in Figure 1, five points labeled A, B, C, D, and E are used to define the force deflection behavior of the hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge.

III BUILDING DESCRIPTION AND MOTIVATION FOR ANALYSIS

Building analyzed is a fifteen storey, 59.5 meter high commercial building made up of steel structure with plan dimension as 43.0 meter x 100.8 meter located in Mumbai with a gross area of 43,344 square meter. The columns are placed on grid of 8.4 meter in X direction and 8.6 meter in Y direction.

The lateral system of the building consists of four C shaped shear walls along with moment resisting frames arrangement as shown in a typical floor plan (refer Figure 2) The building was designed per IS 1893 [5] with an intended performance objective of Life Safety under design seismic event. However, due to the following reasons a concern was felt regarding whether the building would meet Life Safety performance level intended by the code. A more recent 2003 International Building Code (IBC) [6] limits the maximum height of a concrete shear wall building to 160 feet, where as the building analyzed has shear wall height as 202 feet. Also the plan

dimension in X direction is large which may need supplementary passive dampers. Thus passive dampers are placed in braces connected diagonally in X and Y direction as shown in Figure 3.

This necessitates use of Push over analysis to verify performance of building.

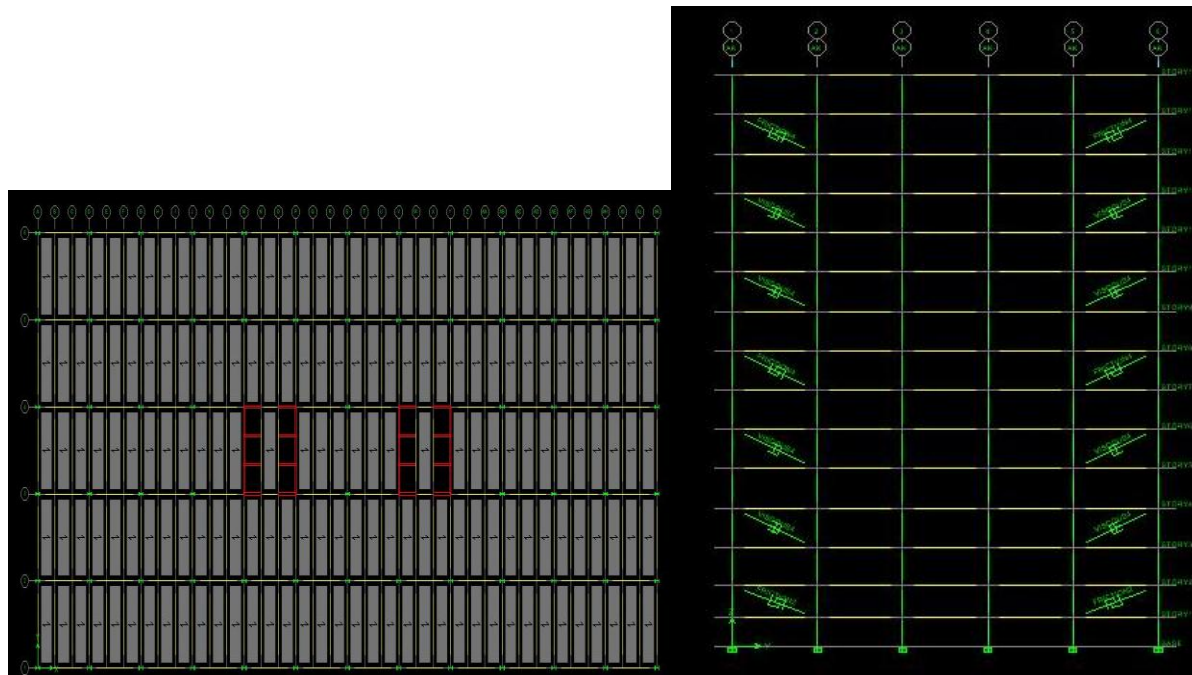


Figure 1: Typical floor plan **Figure 2: Typical Y direction frame with dampers**

IV MODELING AND ANALYSIS

4 separate Time History analysis for X and Y directions were performed as: Building without dampers, Building with viscous dampers, Building with friction dampers and with combination of dampers.

Software ETABS version 9 were used for non linear dynamic time history analysis.

Given that all shear walls in the building are slender with wall height-to-length ratio well above 3 and therefore seismic response of the shear walls is expected to be dominated by flexure, as well as because modeling nonlinear behavior in ETABS is limited to frame elements, the shear walls were modeled as equivalent frame elements. In order to provide connectivity between walls, the equivalent frames were connected at the floor level with rigid links on the side of the wall without any opening.

Single diagonal tension –compression brace with pall friction damper with slip load of 250 KN is used and Single diagonal tension –compression brace with viscous damper with damping force of 700 KN is used. For combined FD (friction damper) and VD(viscous damper) FD are used on 2nd ,8th and 14th storey while VD are used on 4th ,6th ,10th and 12th storey.

Also Shear walls are modeled as equivalent frame elements as against shell elements. To compare whether the equivalent frame model of shear wall building is good representation of building with shear wall as shell element, their time period is verified . The Table 1 below shows the values for first three modes for two models, which are in fair agreement with each other.

Table 1 Comparison of linear and pushover analysis models

Mode Number	Period in sec.	Period in sec.
	Building with shear wall as shell element	Building with shear wall as equivalent frame element
Mode 1	3.15	3.46
Mode 2	3.02	3.33
Mode 3	2.45	2.69

V TIME HISTORY ANALYSIS

Time History analysis: The above building without dampers and with dampers is subjected then to nonlinear dynamic time history analysis for four earthquake time history :Bhuj, Kobe, Northridge and Maxico. The storey drift and maximum diaphragm displacements are then verified for performance of the building.

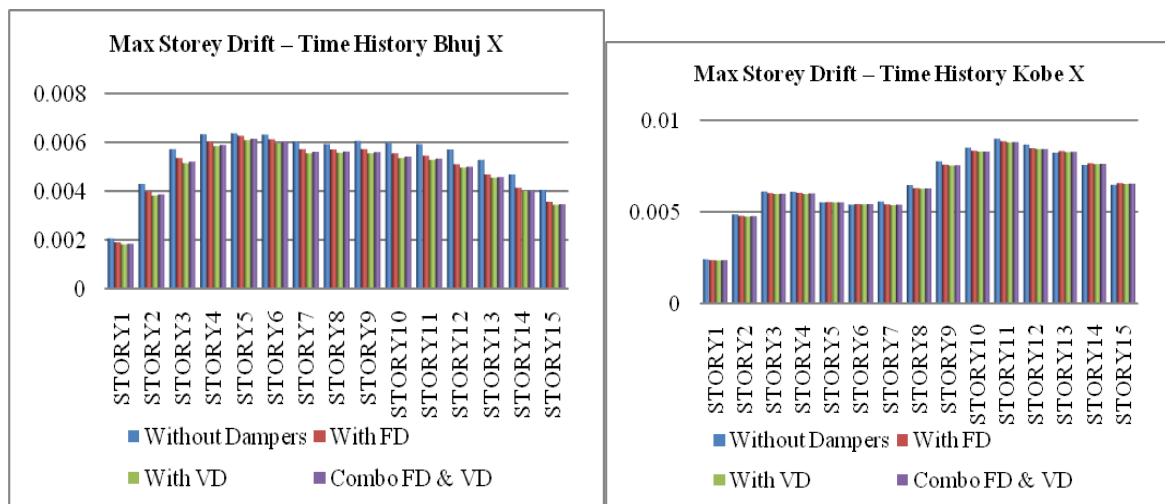
VI ANALYSIS RESULTS

Time history analysis shows that the response of the building such as the story drift and diaphragm displacement are reduced when various passive damping devices are installed in the building. This indicates that structure needs either strengthening or supplementary damping devices. Passive dampers namely Pall friction damper and viscous dampers are used either individually or in combination.

Storey	Max Storey Drift				Max Storey Drift			
	Drift - X				Drift -X			
	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.002065	0.001899	0.001816	0.001835	0.00240	0.002368	0.002345	0.002358
2	0.004292	0.003981	0.003817	0.003861	0.00485	0.004786	0.00474	0.004763
3	0.005712	0.005349	0.005148	0.005204	0.00611	0.006026	0.005969	0.005994
4	0.006329	0.00602	0.00584	0.005893	0.00610	0.006034	0.005981	0.005997

5	0.006367	0.006266	0.006086	0.006146	0.00551	0.005527	0.005514	0.005521
6	0.006316	0.006123	0.005952	0.006016	0.00539	0.005422	0.005413	0.00542
7	0.006017	0.005724	0.005544	0.005608	0.00556	0.005409	0.00536	0.005392
8	0.005923	0.005707	0.005576	0.005626	0.00646	0.006289	0.006259	0.006275
9	0.006062	0.005713	0.005546	0.005601	0.00775	0.007568	0.007522	0.007537
10	0.005974	0.005545	0.005355	0.005414	0.00850	0.008341	0.008287	0.008298
11	0.005922	0.005444	0.005285	0.005332	0.00898	0.008855	0.0088	0.008808
12	0.005707	0.005098	0.004964	0.004994	0.00868	0.00848	0.008427	0.008435
13	0.005282	0.00468	0.004543	0.004568	0.00823	0.008316	0.008256	0.008277
14	0.004681	0.004127	0.003995	0.004017	0.00756	0.007657	0.007604	0.007626
15	0.004051	0.003561	0.003443	0.003462	0.00648	0.006565	0.006521	0.00654

Table 2: Time history results for Bhuj and Kobe



Storey	Max Storey Drift				Max Storey Drift			
	Drift - X				Drift -X			
	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.16219	0.161098	0.155831	0.158613	0.000406	0.000421	0.000421	0.000421
2	0.314108	0.312042	0.302877	0.307514	0.000869	0.000899	0.0009	0.0009
3	0.372358	0.370007	0.361645	0.36587	0.001191	0.001231	0.001234	0.001233
4	0.347283	0.345644	0.339667	0.34237	0.001374	0.001419	0.001422	0.001421

5	0.28906	0.288264	0.284919	0.28600	0.00144	0.001487	0.001491	0.00149
6	0.291515	0.289234	0.279239	0.28469	0.001434	0.001492	0.001495	0.001494
7	0.303300	0.300882	0.290335	0.296983	0.001381	0.001463	0.001465	0.001464
8	0.368444	0.365429	0.354377	0.361098	0.001299	0.001414	0.001415	0.001415
9	0.400873	0.397824	0.386086	0.392345	0.001198	0.001349	0.001349	0.001349
10	0.390418	0.387928	0.377971	0.382246	0.001089	0.001269	0.001268	0.001268
11	0.403734	0.401811	0.392501	0.395713	0.001009	0.001211	0.001209	0.001209
12	0.452789	0.449469	0.436726	0.44265	0.000892	0.001088	0.001087	0.001087
13	0.469175	0.464629	0.446767	0.455492	0.000771	0.000957	0.000955	0.000955
14	0.454651	0.450021	0.43078	0.440393	0.00066	0.000823	0.000821	0.000821
15	0.399934	0.39583	0.378333	0.387106	0.000567	0.000705	0.000704	0.000704

Table 3: Time history results for North ridge and Maxico

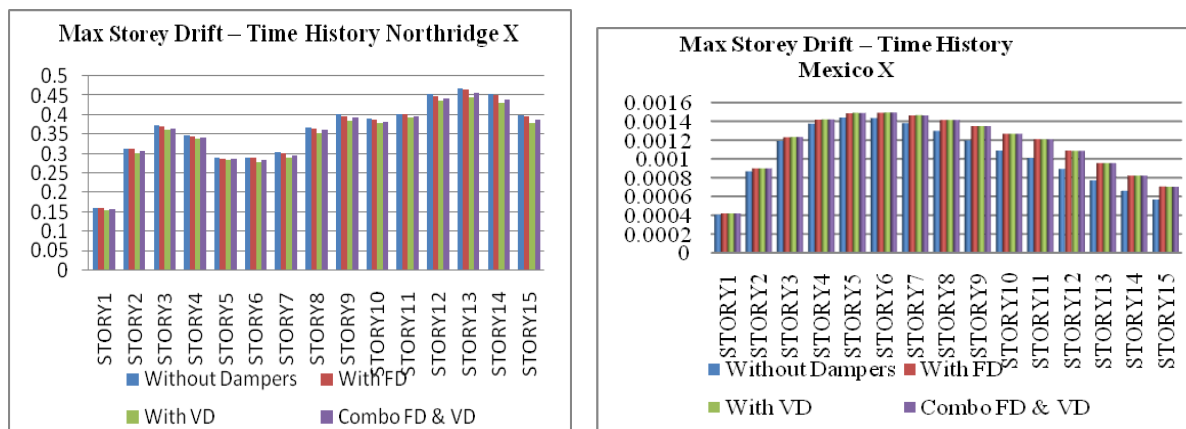


Table 4: Time history results (Max Diaphragm Displacement) for Bhuj and Kobe

Max Diaphragm Displacement – Time History Bhuj X					Max Diaphragm Displacement – Time History Kobe X			
Storey	UX				UX			
	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.0059	0.0057	0.0054	0.0055	0.0072	0.0071	0.007	0.0071
2	0.0196	0.0188	0.018	0.0182	0.0232	0.0229	0.0227	0.0228
3	0.0416	0.0402	0.0386	0.039	0.0476	0.047	0.0466	0.0468
4	0.0668	0.0648	0.0624	0.0631	0.0727	0.0717	0.0711	0.0714
5	0.0924	0.0898	0.0867	0.0876	0.0935	0.0924	0.0915	0.0918

6	0.1175	0.1142	0.1108	0.1118	0.1076	0.1065	0.1056	0.1059
7	0.1411	0.1376	0.1335	0.1348	0.1142	0.1133	0.1124	0.1126
8	0.1629	0.1585	0.1538	0.1554	0.1183	0.1161	0.1152	0.1154
9	0.1822	0.1765	0.1714	0.1731	0.1221	0.1201	0.1194	0.1195
10	0.1988	0.1916	0.1861	0.188	0.1271	0.1267	0.1262	0.1263
11	0.2126	0.2057	0.2003	0.2023	0.1327	0.1323	0.1319	0.1321
12	0.2304	0.221	0.2158	0.2178	0.1384	0.1362	0.1357	0.1359
13	0.2467	0.2364	0.2312	0.2331	0.1689	0.1679	0.1671	0.1674
14	0.2619	0.2503	0.2449	0.2469	0.1999	0.1993	0.1983	0.1986
15	0.2749	0.2621	0.2565	0.2586	0.2264	0.2262	0.225	0.2255

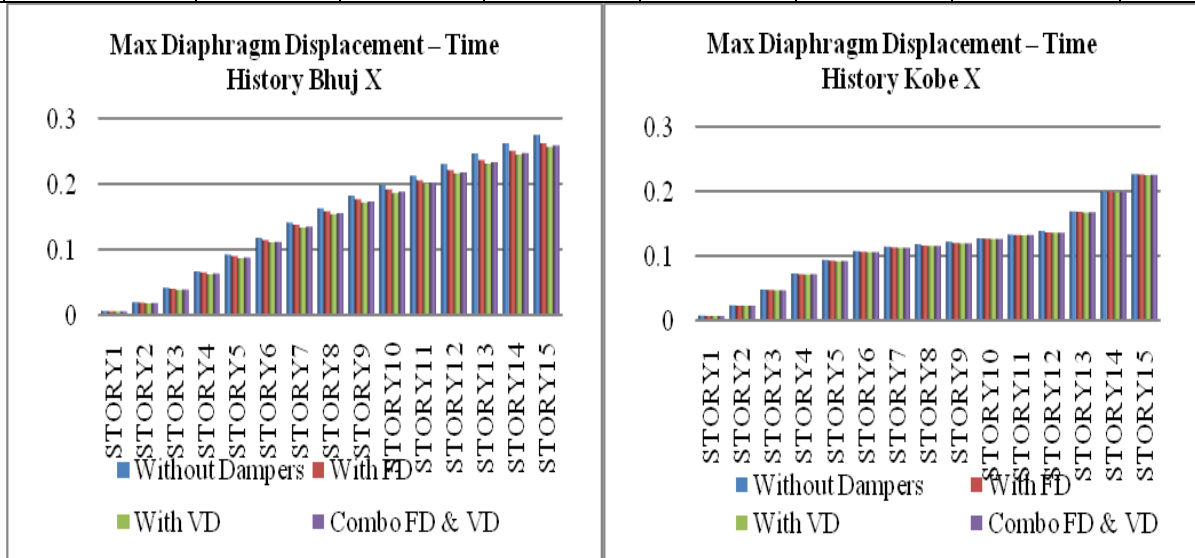


Table 5: Time history results (Max Diaphragm Displacement for North ridge and Mexico)

Max Diaphragm Displacement – Time History Northridge X					Max Diaphragm Displacement – Time History Mexico X			
	UX				UX			
Storey	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.0046	0.0045	0.0043	0.0044	0.0011	0.0012	0.0012	0.0012
2	0.0146	0.0144	0.0134	0.0139	0.0038	0.0039	0.0039	0.0039
3	0.0289	0.0284	0.0267	0.0276	0.0083	0.0085	0.0086	0.0085
4	0.0420	0.0413	0.0390	0.0402	0.0136	0.014	0.0141	0.0141
5	0.0510	0.0503	0.0479	0.0491	0.0191	0.0198	0.0199	0.0199
6	0.0552	0.0546	0.0525	0.0534	0.0247	0.0257	0.0258	0.0258
7	0.0605	0.0603	0.0597	0.0599	0.03	0.0315	0.0316	0.0316

8	0.0673	0.0671	0.0664	0.0666	0.035	0.0371	0.0372	0.0372
9	0.0702	0.0700	0.0691	0.0695	0.0396	0.0423	0.0425	0.0424
10	0.0707	0.0704	0.0695	0.0700	0.0438	0.0472	0.0473	0.0473
11	0.0700	0.0698	0.0691	0.0696	0.0476	0.0517	0.0519	0.0519
12	0.0773	0.0772	0.0770	0.0771	0.051	0.0559	0.056	0.056
13	0.0956	0.0954	0.0949	0.0950	0.0539	0.0596	0.0597	0.0597
14	0.1133	0.1129	0.1118	0.1122	0.0563	0.0627	0.0628	0.0628
15	0.1286	0.1281	0.1263	0.1271	0.0584	0.0654	0.0655	0.0655

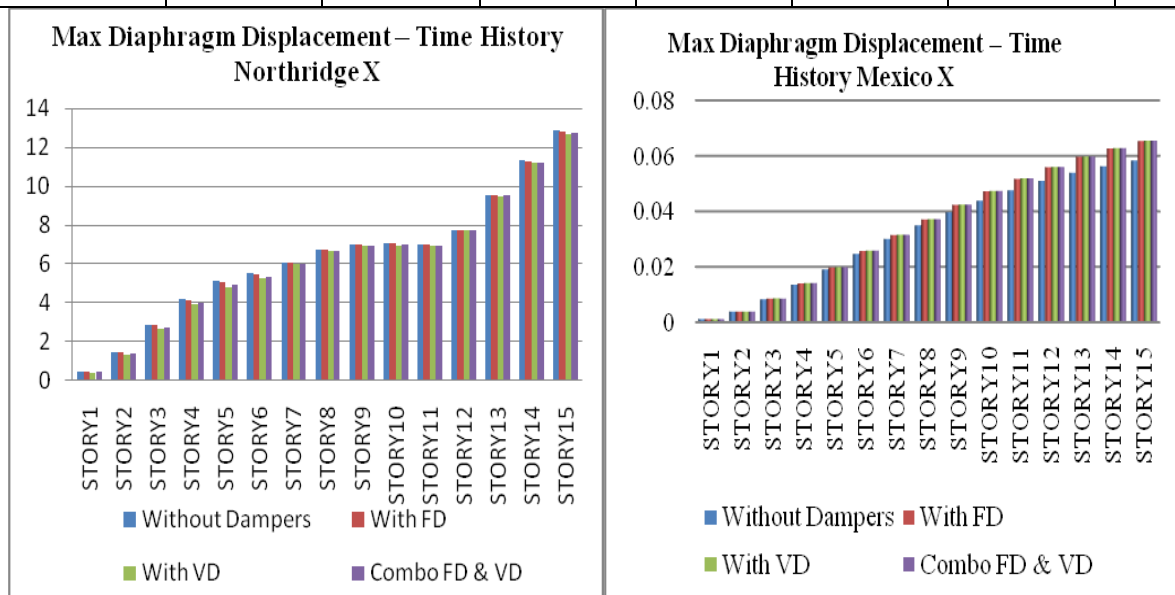


Table 5: Time history results for Bhuj and Kobe

Max Story Drift – Time History Bhuj Y					Max Story Drift – Time History Kobe Y			
	UY				UY			
Storey	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.001615	0.001556	0.001493	0.001511	0.005334	0.004669	0.004563	0.004608
2	0.002623	0.00242	0.002377	0.002391	0.008122	0.007125	0.007007	0.007073
3	0.00335	0.00302	0.002969	0.00299	0.009418	0.008321	0.008187	0.00826
4	0.003781	0.003335	0.003268	0.003295	0.009558	0.008477	0.00829	0.00836
5	0.003852	0.003431	0.003365	0.003394	0.008868	0.008278	0.007885	0.008046
6	0.003635	0.003364	0.00329	0.003318	0.007886	0.007392	0.007065	0.007215
7	0.003694	0.003701	0.003621	0.003651	0.006349	0.005946	0.005704	0.005843
8	0.003977	0.003917	0.003833	0.003866	0.006099	0.005837	0.005681	0.005773

9	0.004139	0.004094	0.004005	0.004039	0.009139	0.008419	0.008121	0.008253
10	0.004915	0.004266	0.004236	0.00425	0.0116	0.010748	0.010206	0.010466
11	0.00585	0.005134	0.005091	0.005112	0.01424	0.013275	0.012596	0.012903
12	0.006323	0.005608	0.005558	0.005579	0.016102	0.014631	0.014227	0.014334
13	0.006563	0.005855	0.005802	0.005822	0.017879	0.015752	0.015509	0.01563
14	0.006587	0.005888	0.005835	0.005854	0.018511	0.016152	0.015901	0.016028
15	0.006436	0.005748	0.005696	0.005715	0.018057	0.015739	0.015494	0.015618

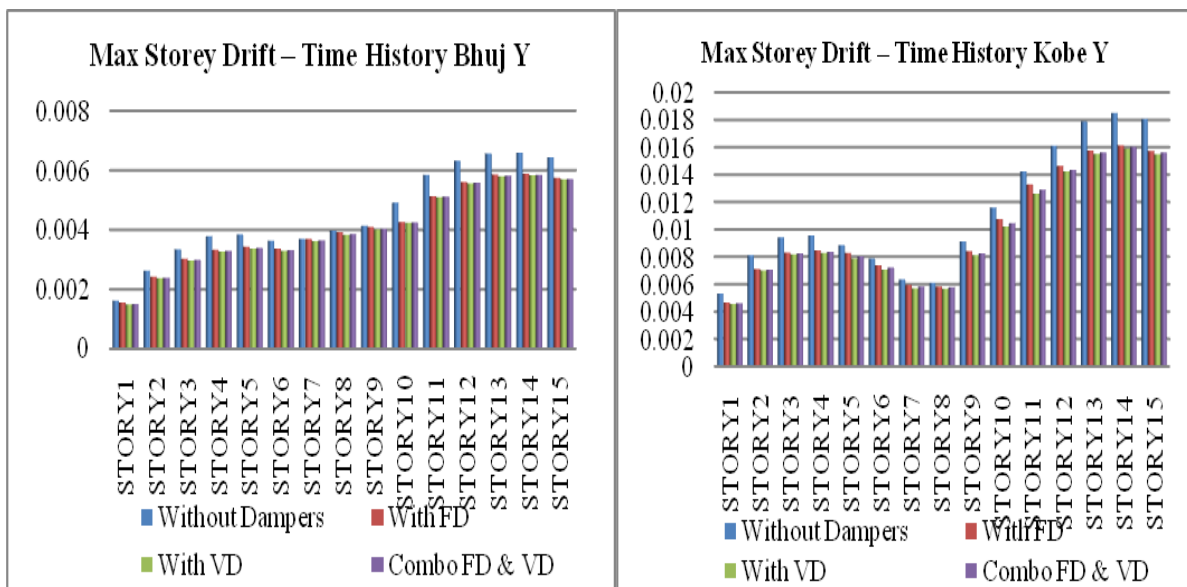


Table 6: Time history results for Northridge and Mexico

Max Story Drift – Time History Northridge Y					Max Story Drift – Time History Mexico Y			
	UY				UY			
Storey	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.002253	0.002213	0.002077	0.002165	0.0014	0.0014	0.0014	0.0014
2	0.003173	0.003110	0.002939	0.003048	0.0045	0.0046	0.0043	0.0044
3	0.003294	0.003234	0.003071	0.003165	0.01	0.01	0.0095	0.0097
4	0.002808	0.002774	0.002647	0.002711	0.0171	0.0172	0.0164	0.0167
5	0.002449	0.002436	0.002365	0.002398	0.0256	0.0256	0.0245	0.025
6	0.003481	0.003444	0.003288	0.003385	0.0351	0.0352	0.0336	0.0342
7	0.004134	0.004079	0.003864	0.004000	0.0454	0.0454	0.0434	0.0442
8	0.004525	0.004427	0.004130	0.004298	0.0563	0.0563	0.0538	0.0548

9	0.004604	0.004518	0.004182	0.004381	0.0677	0.0675	0.0647	0.0658
10	0.004102	0.004046	0.003802	0.003946	0.0793	0.0791	0.0758	0.0771
11	0.003382	0.003373	0.003339	0.003351	0.0916	0.0913	0.0876	0.0891
12	0.004826	0.004772	0.004644	0.004719	0.1042	0.1036	0.0993	0.101
13	0.005905	0.005834	0.005627	0.005755	0.1167	0.1158	0.111	0.1129
14	0.006404	0.006325	0.006079	0.006233	0.1291	0.1278	0.1228	0.1248
15	0.006274	0.006198	0.005957	0.006108	0.1413	0.1397	0.1344	0.1365

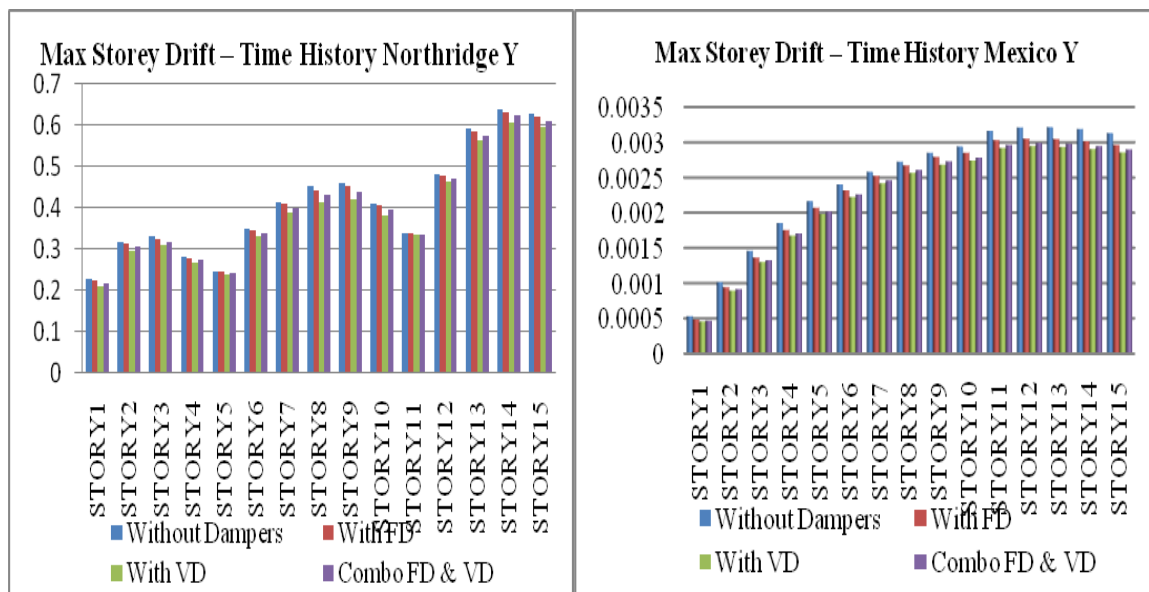


Table 7: Time history results (Max Diaphragm Displacement) for Bhuj and Kobe

Max Story Drift – Time History Bhuj Y					Max Story Drift – Time History Kobe Y			
	UY				UY			
Storey	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.0048	0.0047	0.0044	0.0045	0.0158	0.014	0.0137	0.0138
2	0.0134	0.0125	0.0122	0.0123	0.0425	0.0375	0.0368	0.0372
3	0.0268	0.0245	0.0241	0.0242	0.0799	0.0707	0.0696	0.0702
4	0.0423	0.0382	0.0375	0.0377	0.1185	0.1052	0.1035	0.1045
5	0.0581	0.0517	0.0507	0.0511	0.1527	0.1356	0.1335	0.1346
6	0.0728	0.0641	0.0628	0.0633	0.1795	0.1598	0.1558	0.1576
7	0.0855	0.0753	0.0739	0.0745	0.1961	0.1808	0.1723	0.1757
8	0.0954	0.0836	0.0822	0.0828	0.2076	0.1947	0.1848	0.1895

9	0.102	0.0897	0.0885	0.089	0.2091	0.1971	0.1878	0.1924
10	0.1057	0.102	0.1006	0.1012	0.1977	0.188	0.1801	0.1841
11	0.1196	0.1156	0.114	0.1146	0.173	0.1666	0.1611	0.1641
12	0.1335	0.1289	0.1272	0.1279	0.1597	0.1545	0.1517	0.153
13	0.1471	0.1421	0.1401	0.1409	0.2245	0.2137	0.2076	0.2103
14	0.1606	0.1548	0.1528	0.1536	0.2915	0.2769	0.2676	0.2716
15	0.1743	0.1703	0.1675	0.1686	0.3574	0.3385	0.3261	0.3314

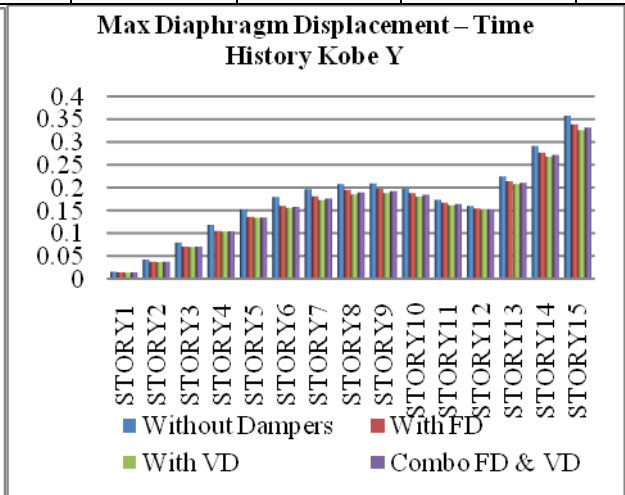
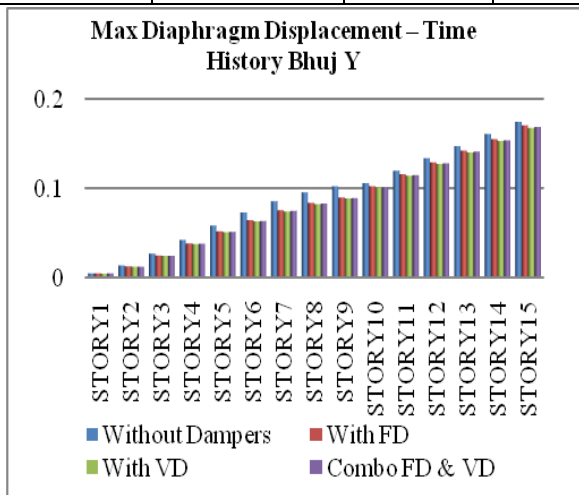
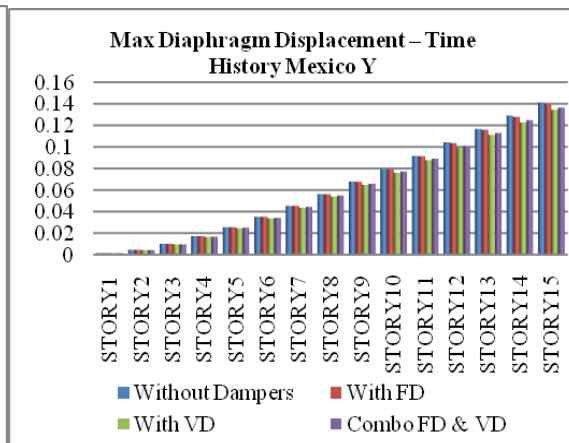
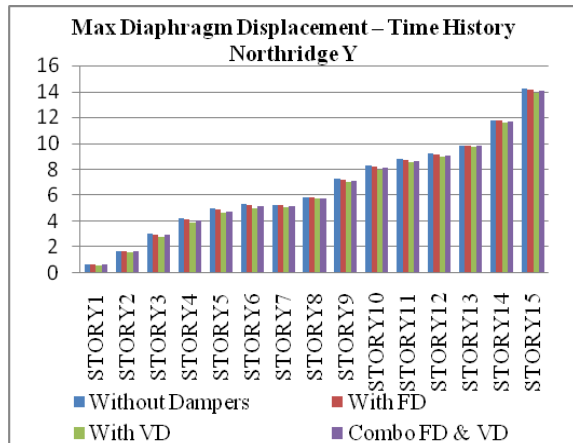


Table 8: Time history results (Max Diaphragm Displacement) for Northridge and Mexico

Max Story Drift – Time History Northridge Y					Max Story Drift – Time History Mexico Y			
	UY				UY			
Storey	Without Dampers	With FD	With VD	Combo FD & VD	Without Dampers	With FD	With VD	Combo FD & VD
1	0.00676	0.0066	0.0062	0.0065	0.0014	0.0014	0.0014	0.0014
2	0.01723	0.01691	0.0159	0.0165	0.0045	0.0046	0.0043	0.0044
3	0.03041	0.02978	0.0282	0.0292	0.01	0.01	0.0095	0.0097
4	0.04192	0.04115	0.0391	0.0403	0.0171	0.0172	0.0164	0.0167
5	0.04963	0.04888	0.0465	0.0477	0.0256	0.0256	0.0245	0.025
6	0.05304	0.05245	0.0502	0.0513	0.0351	0.0352	0.0336	0.0342
7	0.05291	0.05263	0.0510	0.0518	0.0454	0.0454	0.0434	0.0442
8	0.05865	0.05843	0.0573	0.0578	0.0563	0.0563	0.0538	0.0548
9	0.07271	0.07221	0.0700	0.0712	0.0677	0.0675	0.0647	0.0658
10	0.08261	0.08197	0.0792	0.0808	0.0793	0.0791	0.0758	0.0771
11	0.08781	0.08719	0.0853	0.0864	0.0916	0.0913	0.0876	0.0891

12	0.09201	0.09145	0.0896	0.0905	0.1042	0.1036	0.0993	0.101
13	0.09845	0.09834	0.0977	0.0979	0.1167	0.1158	0.111	0.1129
14	0.11794	0.11764	0.1162	0.1169	0.1291	0.1278	0.1228	0.1248
15	0.14203	0.14142	0.1387	0.1402	0.1413	0.1397	0.1344	0.1365



The building with FD, VD dampers and combination of the two are analysed for non-linear dynamic analysis , time history analysis for four earthquake time history data: Bhuj, Kobe, Northridge and Maxico, which is presented here in Table 2,3, 4,5and 6..

It is seen from above tables that for Bhuj time history data storey drift reduces to 12 % by use of FD and up to 15 % by use of VD. Reduction in storey drift is also observed for Northridge , where as for Kobe and Maxico time history there is increase in storey drift as well as storey shear. Thus application of supplementary damping devices are satisfying criterion of life safety.

Overall use of supplementary damping devices enhance seismic performance of structure.

VII CONCLUSION

Pushover analysis is a useful tool of Performance Based Seismic Engineering to study non- linear behavior of a structure. Pushover analysis was performed on a Fifteen story steel building with concrete shear wall lateral system. By modifying shear wall model as equivalent frame element the analysis simplifies and also size of the problem reduces considerably.

Utilizing the results from this analysis, modifications were made to the original code-based design by adding supplementary damping devices so that the design objective of Life Safety performance is expected to be achieved under design earthquake.

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