SEISMIC EVALUATION AND RETROFIT OF A MOMENT FRAME BUILDING WITH VISCOUS DAMPERS

Rupa Purasinghe
Professor of Civil Engineering, California State University at Los Angeles, California.
(email: rpurasi@calstatela.edu)

Gen Hasegawa
Civil Engineering Graduate Student, California State University at Los Angeles, California.

Abstract

This study investigates the seismic performance level of an existing multistory steel building based on FEMA 356 criteria. The building consists of several pre-Northridge moment resisting frames and gravity frames. The structure's seismic performance level was determined based on story drift criteria. Linear Dynamic Procedure (LDP) with seven Maximum Credible Earthquake (MCE) time history records suitable for this site was used. The results demonstrate that this building is seismically deficient. The building is successfully retrofitted with diagonally positioned fluid viscous dampers on several moment frames. The study included numerical simulation with SAP 2000 where acceptable dampers were selected based on their force and stroke to match commercially available dampers.

Keywords: seismic performance levels, fluid viscous dampers, pre-Northridge moment frames

1. Introduction

The paper documents results of a case study of a pre-Northridge steel moment resisting multi-story building in Los Angeles for seismic vulnerability. Performance level evaluations using FEMA 356 (Federal Emergency Management Agency) guidelines (2000.) were performed.

The building used for basis of this study is a steel moment frame building with pre-Northridge moment connections, per seismic guidelines at the time it was built in 1961. Plan view of the building with locations of the moment frames (Figure 1-1), and the three dimensional view (Figure 1-2) are shown. The building is 208x111 ft with 26-ft bays in the longitudinal (x) direction and 27.7-ft bays in the transverse (y) direction. The first and second floors are 18 ft high and the others are 13.5 ft high. Floors are concrete formed steel deck with a total thickness of 6.5 inches and light weight concrete 110 pcf.

Total weight of the building is 22175 kips. Fundamental periods are 2.64 seconds in the longitudinal direction and 2.84 seconds in the transverse direction. The foundations are pinned supports which make the first story a soft and weak story. Loadings:

Superimposed dead load: 37 psf on all floors.

Weight of exterior cladding: 135 plf along perimeter beams.

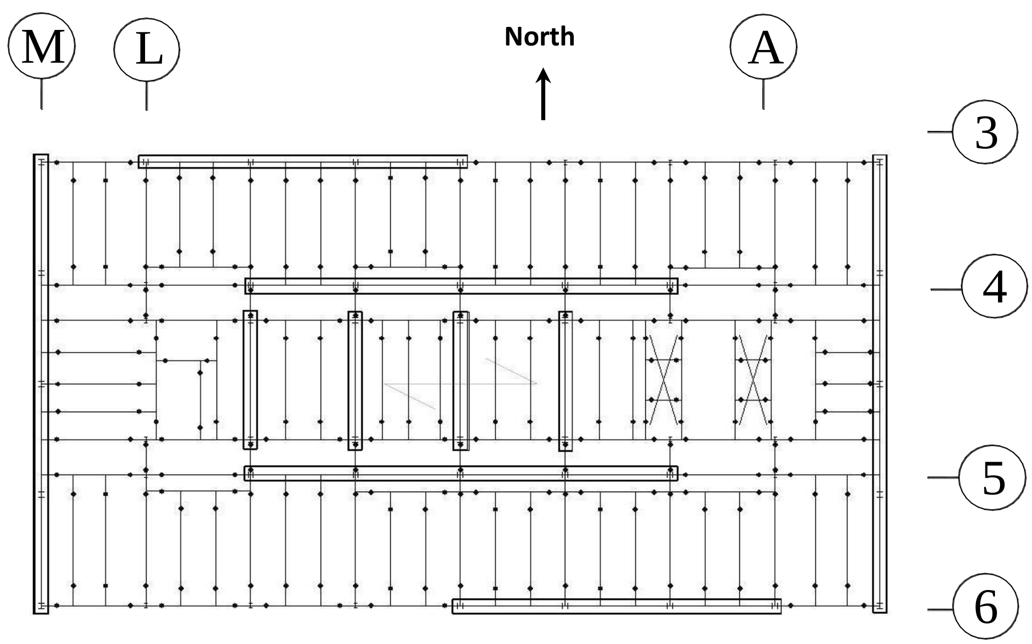

Figure 1-1 Typical Building Plan with locations of moment frames highlighted

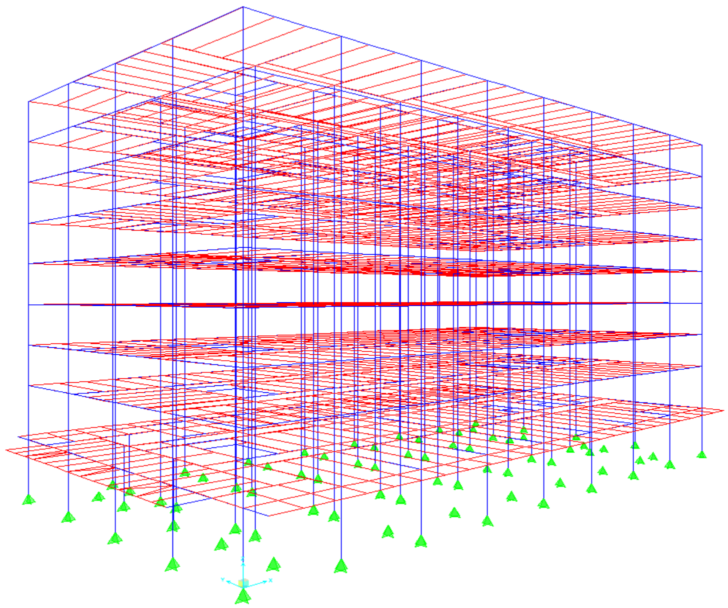

Figure 1-2 Three dimension view of the building

2.0 Methods of Analysis

2.1 Seismic Linear Time History Analysis (LDP)

Time-history analysis is used with SAP 2000 (2011) to obtain the results in the LDP calculations. The design displacement in LDP is established through dynamic analysis using ground motion time histories. Since the calculated responses are sensitive to the characteristics of each ground motion, FEMA recommends the analysis to be conducted with more than one ground motion record. Per Section 1.6.2.2 of FEMA 356, time history analysis shall be performed with 07 sets of ground motion time histories. The average values of the results from the 07 records are then used to determine the design acceptability of the building.

2.2 Retrofit Using Passive Energy Dissipative Devices

Fluid viscous dampers, which are velocity-depended devices, are selected as the passive energy dissipative devices for the building to achieve the target structural performance level. Time-history analyses with seven sets of ground motion time histories are used to obtain the results. The damping in the structural frame shall be set as 0.05 per Section 9.3.5.1.2 of FEMA 356. The average values of the results from the 07 records are then used to determine the design acceptability of the building per Section 3.3.2.2.4 of FEMA 356. Per Section 9.3.1.1 of FEMA 356, all energy dissipative devices shall be capable of sustaining 130% of the maximum displacement.

3.0 COMPUTER SIMULATION MODELS

3.1 Seismic Linear Time History Analysis (Linear Dynamic Procedure)

The dynamic analysis using the time history method in FEMA 356, Section 3.3.2.2.4, which is one of the two available linear dynamic methods, was selected, and the analysis is performed in SAP2000 with seven different time history functions of the following:

1) Northridge Century City North (NCCN)
2) Loma Prieta Gilroy Array 06 (LPGA)
3) Morgan Hill Anderson Dam Downstream (MHAD)
4) Chi Chi Taiwan TCU 087 (CCTT)
5) Denali TAPS Pump Station 9 (DTPS)
6) Loma Prieta Corralitos (LPC)
7) Turkey 1992 Erzincan (T92E)

These functions are scaled to site specific Maximum Credible Earthquake (MCE) for a structure in Los Angeles area based on above earthquake records, and each function has data in both normal and parallel directions. Since there is no much interaction between the longitudinal and transverse directions in the building, only one record is applied in one direction at a time.

The objective is to determine if the structure is acceptable based on the collapse prevention performance level for a MCE earthquake. For simplicity in this study drift was used as primary acceptance criteria for the LDP. The performance levels of 0.01, 0.02 and 0.04 are used as Immediate Occupancy (IO), Life Safe (LS) and Collapse Prevention (CP), respectively as recommended in FEMA 274 (1997), Section 5.4.2.3. The acceptance criteria of story drift ratio are set at 0.04 or 4% as collapse prevention criteria are used since the MCE is used.

3.2 Retrofit Using Passive Energy Dissipative Devices

A SAP linear model was used to incorporate dampers. Diagonal braces with a viscous damper were selected to be placed in each bay of the frames as shown in Figure 2-1.

$$F = c\,V^{n}$$

Where

F = damping force   c = damping coefficient
V = damper velocity   n = damping exponent

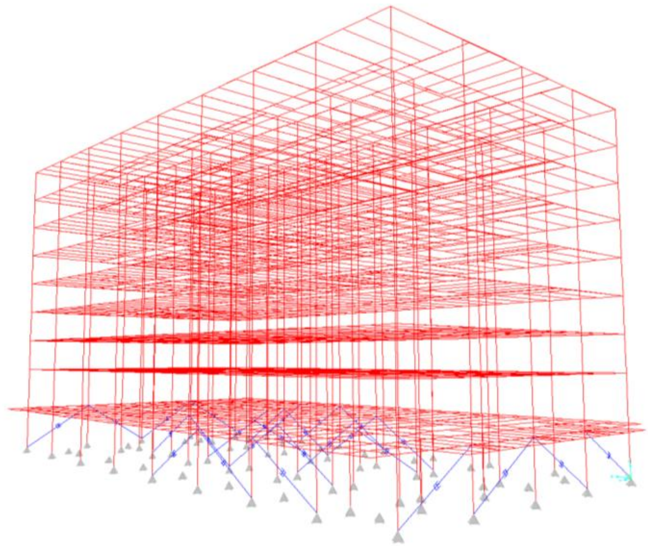

Figure 2-1 Analysis Model with Fluid Viscous Dampers

4.0) ANALYSIS RESULTS

4.1 Story Drifts / Displacements

For the initial study, with building with 5% damping the majority of story drift ratios are less than 4%. However at Story 1 level, the average story drift ratios exceeded 4% (see Table 4.1). As a result this structure is not acceptable beyond the Collapse Prevention (CP) level with a MCE earthquake records.

Table 4.1

AVERAGE STORY DRIFT RATIO				
	Without DAMPERS		**With DAMPERS**	
LEVEL	**X-Dir.**	**Y-Dir.**	**X-Dir.**	**Y-Dir.**
Penthouse	1.320%	1.454%	1.192%	1.286%
Level 8	3.405%	3.633%	2.929%	3.038%
Level 7	2.739%	2.769%	2.140%	2.229%
Level 6	2.724%	2.720%	2.123%	2.231%

Level 5	2.173%	2.213%	1.660%	1.736%
Level 4	2.285%	2.282%	1.711%	1.745%
Level 3	2.366%	2.372%	1.721%	1.751%
Level 2	2.991%	3.024%	1.753%	1.844%
Level 1	6.117%	5.569%	2.579%	2.626%

Originally dampers were placed only in frames at the exterior face of the structure, and it was enough to control the story drift ratios to be less than 4%, however force in braces and stroke of dampers exceeded allowable values of typical available viscous dampers. Therefore, dampers were added in the interior frames as well, making total number of dampers to be 26. Fourteen dampers were placed at the frames in X-direction and 12 placed in that of Y-direction.

The viscous damper consists of several variables that would affect structural response, and Table 4.2 shows how different combinations of damping coefficient, *c*, and exponent, *n*, affect story drift as well as damping force and stroke.

Table 4.2

COMPARISON OF c-n COMBINATIONS					
C (k-s/in)	70	100	60	70	70
n	0.80	0.80	0.80	1.00	0.60
Base Shear (kip)	6577	6945	6681	7226	6684
Drift Ratio					
Penthouse	1.223%	1.371%	1.163%	1.394%	1.093%

Level 8	2.864%	3.230%	2.734%	3.321%	2.551%
Level 7	1.854%	2.067%	1.810%	2.124%	1.813%
Level 6	1.945%	2.166%	1.865%	2.161%	1.730%
Level 5	1.533%	1.690%	1.470%	1.680%	1.407%
Level 4	1.446%	1.582%	1.395%	1.578%	1.382%
Level 3	1.450%	1.540%	1.452%	1.591%	1.466%
Level 2	1.531%	1.454%	1.574%	1.440%	1.674%
Level 1	1.961%	1.734%	2.135%	1.728%	2.608%
Damper Force (kip)	680.6	853.7	609.4	913.7	435.0
Damper Stroke (in)	3.883	3.47	4.246	3.4777	5.154

5.0) Conclusions

The structure without dampers did not satisfy Collapse Prevention acceptance level under MCE earthquake. The structure is successfully retrofitted with Fluid Viscous Dampers to bring it to acceptance level. The structure requires a total of 26 commercially available viscous dampers with allowable force of 900 kips and damper stroke of ±6 inches.

Acknowledgement

This work was partially supported by the Earthquake Engineering Research Center Program of the National Science Foundation (through Multidisciplinary Center for Earthquake Engineering Research) under NSF Award Number EEC-9701471. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation. Help from K. Gebhart, S.E., and Kingsley Ozeabe and several others are also greatly appreciated.

References

FEMA 356, 2000, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, 2000, Washington, D.C.

FEMA 274, 1997, NEHRP *Commentary for the Seismic Rehabilitation of Buildings*, prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, 1997, Washington, D.C.

"CSI Analysis Reference Manual for SAP2000, ETABS, and SAFE," Computers and Structures, Inc., Berkeley, California, 2011.