Improving Resistance of Structure to Earthquake using Damper

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Abstract— This paper describes the results of an extensive study on the seismic behavior of a structure with damper and without damper under different earthquake acceleration frequency like Earthquake Altadena, Earthquake Lucerne and Earthquake New Hall. It is observed through nonlinear time history analysis that maximum displacement, maximum base shear and maximum acceleration can be effectively reduced by providing the damper in building frame from base support to fifth- floor and base support to ninth-floor.

Key words: Earthquake, Damper, Structures, Energy absorber

I. INTRODUCTION

Earthquakes are natural hazards and structural damage due to that depends on many parameters, including intensity, duration and frequency content of ground motion, soil condition and quality of construction. Design of building should be such as to ensure that the building has adequate strength, high ductility, and will remain as one unit, even while subjected to very large deformation. Sociologic factors are also important, such as density of population, time of day of the earthquake occurrence. However we can do much to reduce risks and thereby reduce disasters provided, we should design and build or strengthen the buildings so as to minimize the losses based on the knowledge of the earthquake performance of different building types during an earthquake. The seismic performance of a building can be improved by energy absorbing device, which may be active and passive in nature. Active control techniques have not found much appreciation due to its cost and large instrumentation set up. Whereas passive control systems such as base isolation, dampers, bracing systems are found to be easy to install and cost effective as compare to active control. Use of damper is now becoming cost effective solution to improve seismic performance of existing buildings as well as new buildings.

Dampers are classified as given below:

A. According to working

- Passive Damper
- Active Damper
- Semi-Active Damper

B. According to type of the materials

- Metallic Yield Damper
- Viscoelastic Damper
- Viscous Fluid Damper

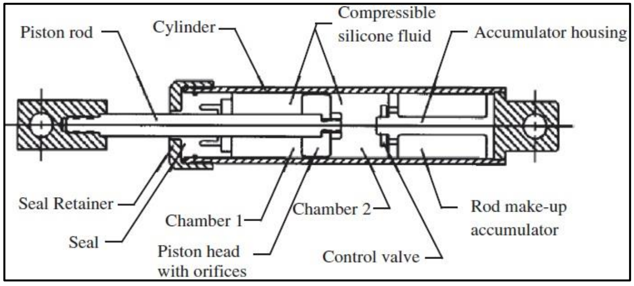

Fig. 1: Schematic diagram of fluid viscous damper

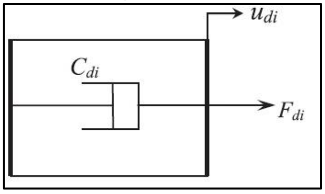

Fig. 2: Mathematical model of fluid viscous damper

The force in a viscous damper, Fdi is proportional to the relative velocity between the ends of a damper.

$$Fdi=Cdi|\dot{u}di|^{\alpha}sgn(\dot{u}di)$$

Where,

F_{di} is damper force,

Cdi is damper coefficient of the ith damper,

$\dot{u}$di is relative velocity between the two ends of a damper which is to be considered corresponding to the position of dampers,

α is the damper exponent ranging from 0.2 to 1 for seismic applications,

sgn(·) is signum function.

In this paper nonlinear time history analysis of nine story 2D frame with damper and without damper for various earthquakes loading at different location is done. For nonlinear time history analysis of 9 storey 2D frame software SAP2000 v 15 is used. Seismic performance of a building can be improved by the use of damper. When dampers are applied to the structure the seismic forces such as absolute acceleration, absolute displacement and base shear are reduced.

II. LITERATURE SURVEY

By using linear elastic and also nonlinear degrading stiffness idealization J. R. Sladek and R. E. Klingner [1] had designed and modeled a realistic prototype high rise building in year 1983. In linear elastic range the structure was idealized as a vertical cantilever beam with a fixed base and the flexural stiffness of the core wall was assumed to decrease from base to the tip of the structure and the nonlinear structure was modeled using the nonlinear analysis program DRAIN 2D. A damping coefficient of 5% of critical was used for the first and second vibrational modes. They designed tuned mass damper using a mass ratio of 0.65% corresponding to an effective damper mass ratio of 0.026. Then they computed the response of idealized prototype building to strong ground motion with tuned mass damper and without tuned mass damper. The purpose of the author was to investigate whether tuned mass damper or similar device could be used to reduce the response of the structure to earthquake ground motion. Therefore they found out that using tuned mass damper of mass ratio of 0.65% or effective mass ratio of 0.26 made no contribution towards reducing the maximum lateral forces at the base of the building. In addition vibration absorbers are also not recommended for reducing the maximum seismic response of tall buildings.

Application of viscoelastic damper to building structure for the enhancement of seismic performance was studied by Ri-Hui Zhang and T. T. Soong [2] in the year 1992. Once the optimal location indices were found, the optimal location of the first damper was determined as the story with maximum index value, the controllability index was given by

$$\rho(x) = \max \sqrt{\sum_{i=1}^{n} \left\{ \frac{\Delta[\varphi_i(x)]}{\Delta x} Y_i(t) \right\}^2}$$

Therefore, the optimal location of a controller is given by x where ρ is maximum. The next best position is where ρ has the second maximum value, and so on. Adding one viscoelastic damper to that story means an increase in stiffness and equivalent viscous damping. Therefore the response was recalculated to find the best location of next damper accounting for the increased stiffness and damping coefficient due to the addition of first viscoelastic damper. This procedure is known as sequential procedure for viscoelastic damper placement that was developed for optimally placing viscoelastic damper to structure. The optimality of location found out by this procedure is also supported by experimental results. The author also pointed out that since added viscoelastic damper change both damping and stiffness of the original structure, therefore the optimal damper location found for one set of damper may be different from those of another set of damper with changed dimension. They also presented a simple design procedure by which the dimension and number of viscoelastic damper can be determined.

In a paper the authors Manuel Aguirre and Roberto Sanchez [3] had investigated, the energy dissipating characteristics of U-shaped mild steel strips of 1.3cm x 3.8cm cross section, called as U-element by subjecting them to rolling bending motion during operation in the year 1992. The U-element was tested using a rig, which consist of basically hydraulic ram at the bottom, confiner structure, center member joined to the load cell at the top. The value of Applied Force P was given by

$$\mathrm{P} = \frac{\mathrm{M_p}}{\mathrm{R}} \qquad (01)$$

But

$$\mathrm{M_p} = \frac{\sigma \mathrm{be}^2}{4} \qquad (02)$$

Therefore

$$\mathrm{P} = \frac{\sigma \mathrm{be}^2}{4\mathrm{R}} \qquad (03)$$

$\mathrm{M_p}$ = Bending moment generated at each of the two plastic hinges

σ = Bending stress generated at each of the two plastic hinges

b = width of steel strip
e = thickness of steel strip

The typical procedure for carrying out a test was, a controlled sinusoidal displacement of given amplitude was applied to a test specimen through confiner structure keeping the center member stationary this cyclic motion continued until a predetermined cycles was completed or one of the two test specimen was ruptured. Cycle of such motion was applied to the U-element, obtaining information whereby viscous effect as well as fatigue life was determined. The temperature rise was also recorded at the end of each test which was measured by using a digital thermometer. A force displacement model of U-element was worked out to facilitate analysis of structure to be equipped with these elements. A prototype of structural seismic damper consisting of multiplicity of U-element was constructed and tested and the illustration was presented regarding possible installation of such damper in the structures.

Application of the viscoelastic damper to high rise buildings for improving their seismic resistance and the features of energy absorbing capacities of viscoelastic dampers and its effect on the structure during earthquake had been investigated by the C. S. Tsai, And H. H. Lee [4] in the year 1992. The fractional derivative of viscoelastic model (Bagley and Torvik 1986) was given by

$$\tau(t) = G_0\gamma(t) + G_1 D^{\alpha}[\gamma(t)] \qquad (1)$$

Where τ(t)= shear stress, γ(t)= shear strain, G_0 and G_1 = constitutive model parameters

The formulation in equation (01) was not accurately reflecting the behavior of the damper when it was subjected to wind-like or earthquake like loadings at different temperature levels. Therefore, in this paper the authors had proposed the following formula for describing the material behavior of the viscoelastic damper subjected to arbitrary loadings and temperatures is given as

$$G_0 = G_1 = A_0\left\{1 + \mu e^{-\beta[\int \tau d\gamma + \theta(T - T_0)]}\right\} \qquad (2)$$

Where α, A_0, β, μ and θ = unknown coefficients to be determined from the experimental data, T = ambient temperature, and T_o = reference temperature at which the unknown coefficients are obtained. An advanced analytical model and finite element formulation for the viscoelastic damper to account for the effect of temperature and earthquake like and wind like loading were developed. The proposed method could be implemented easily in finite element program. They studied a 10 story building equipped with viscoelastic damper subjected to earthquake ground motion. Analytical and experimental results have shown that the capacities of energy absorption of the viscoelastic damper decrease with the increase of the ambient temperature and not only displacement but also stresses of that structure were significantly reduced by the addition of viscoelastic damper during earthquakes.

In a paper the authors K. C. Chang, T. T. Soong, S.-T. Oh, and M. L. Lai [5] was concerned with the seismic behavior of viscoelastically damped structure under mild and strong earthquake ground motion. A shaking table test was conducted on a 2/5 scale five story steel model with three added type of viscoelastic damper distinguished by dimension and viscoelastic material under a variety of ambient temperature and recorded ground motion. Simple analytical methods were proposed to predict the equivalent damping ratios and seismic response of viscoelastically damped structure under various damper type, damper placement cases, and ambient temperature and earthquake intensities. The numerical results had shown that structural damping and structural response with added damper can be easily and accurately estimated by the proposed analytical method. The method can be applied to determine the optimum number of damper, damper sizes and damper location for a given design damping ratio, ambient temperature and earthquake. The author have shown both analytically and experimentally that viscoelastic damper were effective against both the mild and strong earthquake ground motion.

A structure La Gardenia housing complex consist of 7 towers of eighteen story's with two level of basement have been adopted for a total of 66 friction dampers to safeguard the structure and its content from damage. In a paper the authors Ramesh chandra, moti masand, s k nandi, c p tripathi, rashmi pall and avtar pall [6] had described that the earthquake resistance and damage control potential of the structure has dramatically increased by including pall friction damper in steel bracing. As per the author Pall friction damper were simple and foolproof in construction and inexpensive in cost. The friction damper was designed not to slip during seismic load and windstorms. During a major earthquake friction damper slip at a predetermined optimum load before yielding occurs in other structural members and dissipates a major portion of seismic energy. Hence the total dependence on ductility is avoided and the structural elements generally remain elastic without damage. Three dimensional nonlinear time history analysis was carried out using the computer program ETABS and the results have shown superior performance of friction damped frames as compared to conventional construction. The author concluded that the use of Pall friction damper have shown to provide a practical and economical solution for seismic control of the structure.

Dampers position and optimizing their position at the height of the structure was studied by V. Sadeghi Balkanlou, M. Reza Bagerzadeh Karimi, B. Bagheri Azar and Alaeddin Behravesh [7] in the year 2013. They investigated about viscous damper systems and the effects on seismic behavior of multistory structures and determine effects of damper system position on structure height using uniform distribution and SSSA methods. For uniform distribution of dampers in height the formula used to calculate effective damping of viscous linear devices was

$$\beta_{eff} = \beta + \frac{T.\ \sum_j C_j\,.\ \varphi_{rj}^2.\ \cos^2\theta_j}{4\pi\sum_i\left[\frac{W_i}{g}\right].\ \varphi_i^2}$$

Where θ_j stands for angle of slope for jth device with horizon, φ_{rj} for relative horizontal displacement between two ends of jth device in the first mode, W_i available weight of ith floor and φ_i for displacement of ith floor at first mode. In this paper three 4, 8 and 12 storey steel structure were selected and the structure were designed using computer aided software ETABS. Viscous damper was modeled using SAP2000 software and time history analysis was also done using software SAP2000. Three earthquake records were used in time history analysis. Damper system significantly affects dynamic features of the structures. As the damping ratio of the damper system is higher, the seismic response will be lower. Using both the methods uniform distribution method and SSSA method to place damper at a height, with fixed damping coefficient of all damper higher effective damping ratio was obtained. In SSSA method with less number of damper higher effective damping ratios was created in structure. Generally SSSA method leads to better result than uniform distribution method. Even though SSSA method offer better results than uniform distribution method it requires high computational operation than uniform distribution method.

The authors Ras A., Boukhari B, Boumechra N. and Hamdaoui K. [8] had made clear approach of seismic dissipation by considering the following time dependent conservation of energy relationship

$$E(t) = E_k(t) + E_s(t) + E_h(t) + E_d(t) \qquad (01)$$

Where E is the absolute energy input from the earthquake motion, E_k is the absolute kinetic energy, E_s is the elastic (recoverable) strain energy, E_h is the irrecoverable energy dissipated by the structural system through inelastic or other forms of action (viscous and hysteretic) E_d is the energy dissipated by the supplemental damping system and t represents time. The model can be described by relation

$$P(t) + \lambda\,\frac{dP(t)}{dt} = C_d\,.\frac{du_d}{dt}$$

$$u_d(t) = u_0.\sin(\omega t) \qquad (02)$$

P is the damper output force, λ is the relaxation time, C_d is the damping constant at zero frequency, and u is the displacement of the piston head with respect to the damper housing. The equation of motion of the structure subjected to a ground vibration connected with fluid viscous damper becomes

$$[M].\ddot{U} + [(C)].\dot{U}. + [(K)].U + F_d(t) = -[M].\ddot{x}_g \quad (03)$$

Where M = Structure mass, K = Structure equivalent stiffness, C =Damping coefficient of the structure, $F_d\ (t)$ = FVD force vector,U, $\dot{U}$, $\ddot{U}$ are Displacement, velocity and acceleration vectors of the structure. Considering a MDOF system the total effective damping ratio of the system defined as

$$\xi_{eff} = \xi_0 + \xi_d \qquad (04)$$

Where ξ_0 is the inherent damping ratio of the MDOF without dampers, and ξ_d is the damping ratio of the FVD

$$\xi_d = \frac{\sum W_j}{2\pi W_k} \qquad (05)$$

$\sum W_j$ is the sum of the energy dissipated by the jth damper of the system in one cycle and W_k is the elastic strain energy of the frame

The effective damping ξ_{eff} of a structure with linear FVD is given by

$$\xi_{eff} = \xi_0 + \frac{T.\sum_j C_j.\varphi_{rj}^2.\cos^2\theta_j}{4\pi^2\sum_i M_i.\varphi_i^2} \qquad (06)$$

Where θ_j stands for angle of slope for jth device with horizon, φ_{rj} for relative horizontal displacement between two ends of jth device in the first mode and φ_i for displacement of ith floor at first mode. The benefits of energy dissipaters were clearly demonstrated by the comparison data and improving performance of the structure during an earthquake has been proven. The passive control system absorbs vibrations automatically and systematically. These devices are generally inexpensive and effective reinforcement of buildings subjected to dynamic excitations.

The conclusions showed the formidable potential of the FVD to improve the dissipative capacities of the structure without increasing its rigidity. It is contributing significantly to reduce the quantity of steel necessary for its general stability.

III. COMPUTATIONAL MODEL

Modelling of building frames is done by using SAP2000 software**.** SAP is structure analysis programming software. With the help of SAP2000 we will analyse the tall building structure for lateral load without damper and again we will analyse the tall building for lateral load providing passive type dampers at different levels. The nine storey reinforced concrete building modeled is composed of columns, beams and slabs. The columns and beams are modeled as frame elements while the slabs are modeled as shell element. It also does linear as well as nonlinear analysis.

Frame building with the following three case types are considered for analysis:

Case	No of Bays	Height of Floor	Types of Structure
Case 1	2	27 meter (G+8)	Without damper
Case 2	2	27 meter (G+8)	Damper Up to 5 storeys
Case 3	2	27 meter(G+8)	Damper Up to 9 storeys

Table 1: Type of Models

Following material properties and geometry have been considerd

Live load: 3 kN/m^2
Wall thickness: 300 mm
Storey height: 3 m for all storey
Floors: G.F. + 8 upper floors
Size of beams: 250 mm x 350 mm (assumed)
Size of column: 350 mm x 350 mm (assumed)
Thickness of floor slabs: 125 mm (assumed)

Steps for modelling and analysis of the frame:

- Selection of building geometry, 2 bays and 9 story of 2D frame.
- Define the material property of frame.
- Define the section property of frame beam and column.
- Assign the joint pattern as fixed support.
- Define the dampers properties.
- Define the load pattern dead load and live load.
- Define the accelerogram file for earthquake load in SAP2000.
- Define the analysis case.
- Run analysis programme.
- A comparison in analysis results as absolute displacements, absolute acceleration, and base shear has been carried out as a result in this thesis.

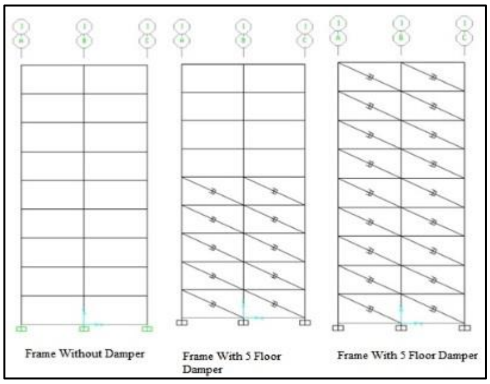

Fig. 3: 2 bays, 9 storey frames before analysis

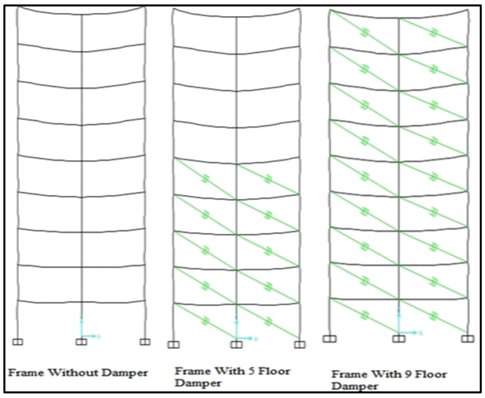

Fig. 4: 2 bays, 9 story frames after analysis

IV. RESULTS AND DISCUSSION

As mentioned in the objective of the study, the time history analysis of building frames with and without damper considering different positions of damper is done. The results obtained from the analysis are represented by tables and graphs. It has been observed that there is significant variation in results based on the load case.

A. Base Shear

The maximum values of base reaction of 9 floor frame when damper is provided up to 5th floor and 9th floor from base for EQ Altadena, EQ Lucerne, EQ New Hall load are given in table 2. It can be observed from the table 3 that maximum base shear decrease effectively from 11.93% to 16.64% for different earthquake load case when dampers are provided up to 5th floor, compared to normal frame and from 17.69 % to 24.80% for different earthquake load case when dampers are provided up to 9th floor, compared to normal frame.

Load cases	Base Shear Without Damper	Base Shear With 5 Floor Damper	Base Shear With 9 floor Damper
EQ Altadena	32210	26850	24220
EQ Lucerne	11660	9950	9097
EQ New Hall	37190	32750	30610

Table 2: Base Shear (kN)

Load case	% reduction of Base Shear With 5 Floor Damper	% 0f Base Shear With 9 floor Damper
EQ Altadena	16.64	24.80
EQ Lucerne	14.66	21.98
EQ NewHall	11.93	17.69

Table 3: Percentage reduction of Base shear compare to normal frame

B. Absolute Displacement

The maximum values of absolute displacement of 9 floor frame when damper is provided up to 5th floor and 9th floor from base for EQ Altadena, EQ Lucerne, EQ New Hall, are given in table 4. It can be observed from the table 5 that absolute displacement reduces effectively from 57.49% to 77.42% for different earthquake load case when dampers are provided up to 5th floor, compared to normal frame and from 87.04% to 93.08% for different earthquake load case when dampers are provided up to 9th floor, compared to normal frame.

Load cases	Abs Displacement Without Damper	Abs Displacement with 5 Floor Damper	Abs Displacement with 9 floor Damper
EQ Altadena	28.56	12.14	3.7
EQ Lucerne	73.4	16.57	7.9
EQ New Hall	31.1	9.5	2.15

Table 4: Absolute displacement (mm)

Load case	% reduction of Abs Displacement with 5 Floor Damper	% reduction of Abs Displacement with 9 floor Damper
EQ Altadena	57.49	87.04
EQ Lucerne	77.42	89.23
EQ New Hall	69.45	93.08

Table 5: Percentage reduction of Absolute Displacement compare to normal frame

C. Absolute Acceleration

The maximum values of Absolute Acceleration of 9 floor frame when damper is provided up to 5th floor and 9th floor from base for EQ Altadena, EQ Lucerne and EQ New Hall, are given in Table 6. It can be observed from the table 7 that absolute acceleration reduces effectively from 2.155% to 61.51% for different earthquake load case when dampers are provided up to 5th floor, compared to normal frame and from 5.89% to 78.24% for different earthquake load case when dampers are provided up to 9th floor compared to normal frame.

Load cases	Abs Acceleration Without Damper	Abs Acceleration with 5 Floor Damper	Abs Acceleration with 9 floor Damper
EQ Altadena	3404	1310	740.5
EQ Lucerne	11260	10440	6700
EQ New Hall	1578	1544	1485

Table 6: Absolute Acceleration (mm/sec^2)

Load case	% reduction of Abs Acceleration with 5 Floor Damper	% 0f Abs Acceleration with 9 floor Damper
EQ Altadena	61.51	78.24
EQ Lucerne	7.28	40.49
EQ New Hall	2.15	5.89

Table 7: Percentage reduction of Absolute Acceleration compare to normal frame

V. CONCLUSION

Based on the analysis results following conclusions are drawn:

1) Dampers help in reducing the vibration with its material properties. Providing dampers helps in reducing the damage caused by the earthquake.
2) By providing energy dissipating device seismic performance of building can be improved, which absorb the input energy during earthquake hazards.
3) It is found that the frame is safer when damper is provided up to ninth floor than damper provided up to fifth floor.
4) The maximum response and base shear reduces when damper is applied to the frame.
5) Base Shear reduction makes the structure cost effective.
6) Due to absolute displacement reduction the structure does not require more ductility to resist earthquake forces.

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