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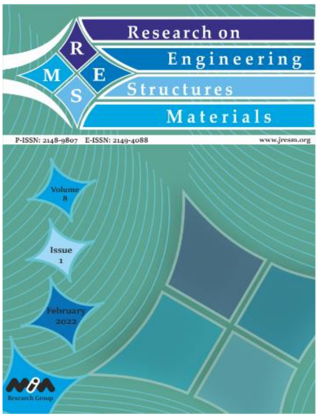

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Research Article

A study on high-rise RC structure with fluid viscous damper using python

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Abstract

Dampers are being used in the buildings as one of the control mechanisms to bring down the vibration due to lateral loads like earthquakes. Different types of dampers such as viscous damper, friction damper, tuned mass damper, hybrid damper, etc have gained importance in the recent past in mitigating the undesirable effects of earthquakes. The behavior of damper installed buildings during earthquakes depends on the arrangement as well as the number of dampers also. In this study, fluid viscous damper (FVD) is provided in a G+19 storey high rise RC building to reduce the vibration due to earthquake effects. IS 1893:2016 code based methods are adopted to determine the seismic responses such as lateral displacement, drift, base shear and energy dissipation of the building with and without damper using ETABS software version 2018. The main focus of this investigation is to obtain a maximum benefit of using FVD considering the different arrangement and number of dampers in the building using PYTHON on the basis of drift and energy dissipation criteria. Out of 28 building models, models 4, 27 and 28 experienced drift more than the permissible limit (0.004) as specified in IS 1893:2016. The energy dissipation capacity of the buildings with dampers varies between 1306 and 2091 kN-m for the different models under study. The program suggests the positions 2, 22, 14, 17, 5, 11 with 80 numbers of dampers for the building and recommends the position 2 for the maximum benefit in terms of drift, energy dissipation and cost.

1. Introduction

Earthquake is one of the major disasters which affect civil engineering structures. Seismic action causes deterioration to the structure. To improve the response of the building due to seismic action, earthquake resistant systems can be incorporated in the building. Damper is one of the most effective earthquake resistant systems which is generally used in the buildings. It is a passive control system which dissipates the seismic energy into a specialized device which yields during earthquakes. Dampers absorb seismic energy developed at the time of earthquakes and dissipate it which damps the motion of the structure. Different varieties of dampers are available now in the market viz. pall friction damper, fluid viscous damper, tuned mass damper, metallic damper, etc. Fluid Viscous Damper (FVD) is effective and easy to install among the varieties of dampers.

Many research studies have been carried out to investigate the seismic behavior of buildings with different types of dampers and design of dampers. New design formulae for commonly used installation schemes of viscous damper by considering vertical deformation were proposed and implemented for reinforced concrete and steel structures to reduce the storey displacements and inter-storey drifts [1-6]. Dilip et al [7], Luca et al

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[8] and Reza and Mahmood [9] studied the effectiveness of linear and non-linear FVD experimentally and numerically and found that the non-linear FVD performs better in seismic vibration control. Different optimization techniques were adopted by the researchers for the optimum design of FVD to improve the efficiency. Dario and Giuseppe [10] put forward six different formulations of stochastic linearization technique and examined it. The proposed method offered improved accuracy over the force-based Gaussian stochastic linearization technique. Shanshan et al [11] proposed an optimization design procedure using an automatic tool. Cheng et al [12] presented optimal viscous damper design under non stationary random seismic excitation. Giuseppe et al [13] focused on the damping-repair cost relationship for the optimum design. Sina et al [14] proposed an effective method for the design of semi active fluid viscous damper. The designed semi active fluid viscous damper was effective in the reduction of vibration characteristics. Many studies investigated the distribution of dampers in the building for the optimal usage for vibration control and found that a large number of dampers may not always leads to the best benefit in terms of drift reduction for all stories [15-18].

2. Research Significance

Researchers have adopted different approaches for the evaluation and design of buildings under seismic loading with FVD. Optimization of dampers to be used in the buildings has opened the area for research for scientists and engineers to evaluate the maximum and efficient utilization of dampers. The previous studies provide the guidance on the seismic evaluation of buildings with FVD for seismic protection using different analytical, experimental and numerical approaches. The authors suggested that further investigation on FVD installed buildings' performance based on energy dissipation capacity and cost is required for the maximum benefit. This study focuses on the effects of the number and placement of dampers in a tall RC framed structure subjected to earthquake ground motion.

3. Methodology

For the study a G+19 storied building regular in plan is considered. The structure is modelled using ETABS software version 2018 and analysed using response spectrum (RS) and time history (TH) method of analysis. The response spectrum method of analysis is one of the dynamic methods to predict the seismic behavior of structures which involves the determination of only peak values of structural responses in each mode of vibration in the linear range. Time history method of analysis is the powerful method for the determination of seismic response of structures under actual earthquakes which calculates the response of structures at every instant of time in the linear and non-linear range. From both the methods, the drift value is found to be more than the limiting value, 0.004 as given in IS 1893 Part 1. Therefore the building is not safe under seismic condition in terms of lateral displacement and drift. In order to enhance the responses of the structure, a nonlinear type fluid viscous damper is designed and installed in the structure at different positions. The seismic responses of the structure with and without FVD are compared as per IS 1893:2016 Codal provisions. Totally 28 models are investigated and the model with maximum benefit is found using PYTHON.

4. Modeling of RC Building and Seismic Analysis

A G+19 storey reinforced concrete framed building is used for the study. The building plan consists of six bays of 4 m length each in the x direction and four bays of 4 m length each in the y direction. Table 1 shows the details of the building under study.

Table 1. Details of building

Beam Size	300 mm x 450 mm
Column Size	750 mm x 750 mm
Slab Thickness	150 mm
Masonry Wall Thickness	230 mm
Storey Height	3 m
Grade of Concrete	M 25
Grade of Steel	Fe 415

Modeling and analysis of the building is done using ETABS software. The beams and columns are modeled as frame elements and the slab is modeled as a shell element. All the structural elements are rigidly jointed. The walls are not modeled and their loads are assigned on the beams. The unit weight of concrete is taken as 25 kN/m^3 and the Poisson's ratio is considered as 0.2. The plan and 3-D view of building are shown in Figures 1 and 2, respectively. Though 2 D model is simple and adequate to study the seismic response of structures, 3D model is preferred in the current study to achieve the global behavior of the structure under earthquake loading.

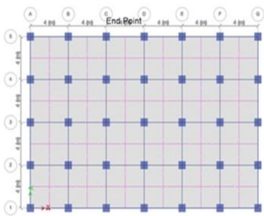


Fig. 1 Plan of RC building

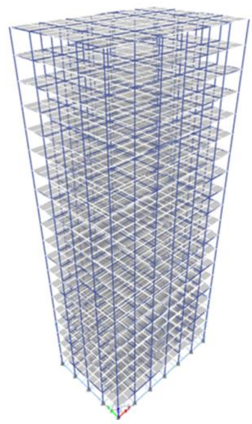


Fig. 2 3-D View of RC building

Table 2. Seismic parameters considered

Seismic Zone	III
Response Reduction Factor	5
Importance Factor	1.2
Soil Type	Medium Soil
Boundary Condition at Base	Fully Fixed
Response Spectrum Method	As per the specification of IS 1893:2016
Time History Method	El Centro 1940 strong motion

Live load of 3 kN/m^2 is considered on all floors except roof and 1.5 kN/m^2 is considered on roof [19] as per IS 875 Part 1. The building is assumed to be situated in Chennai, Tamil Nadu, india which falls on the seismic zone III with a seismic zone factor (Z) of 0.16. The seismic parameters are taken from IS 1893 Part 1[20]. Table 2 presents the seismic parameters used as inputs for the analysis.

The importance factor is taken as 1.2 as the building is a residential building with more than 200 occupants. The response reduction factor R is considered as 5 because the building is a special moment resisting framed structure. Soil type is considered as medium. When a structure is subjected to ground motion, the responses will be influenced by the soil and foundation characteristics. In this study, it is assumed that the building is resting on a stable ground and the structure is a rigid frame, therefore the bottom is considered as fully fixed which provides three degrees of restraint, vertical, horizontal, and rotational.

Response Spectrum (RS) analysis as per IS 1893:2016 specifications and Time History (TH) analysis using NS component of the El Centro 1940 earthquake data (Figure 3) are carried out on the building to get the dynamic responses. Due to the unavailability of local earthquake records and also to reduce the computational effort, a single earthquake record is considered in this study.

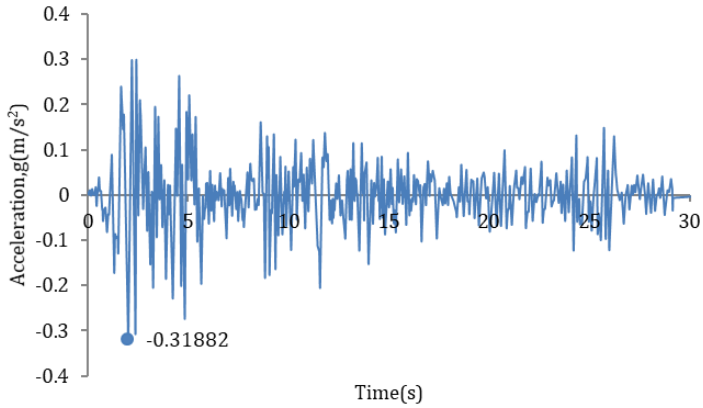
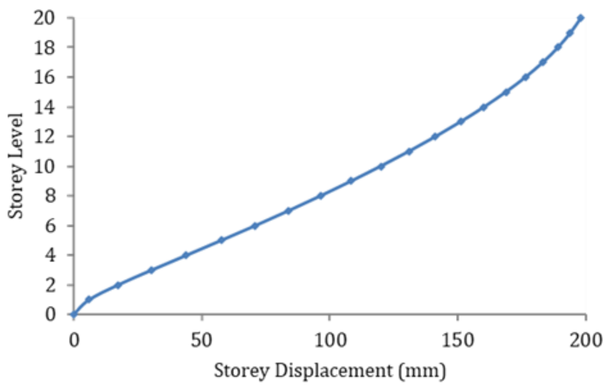
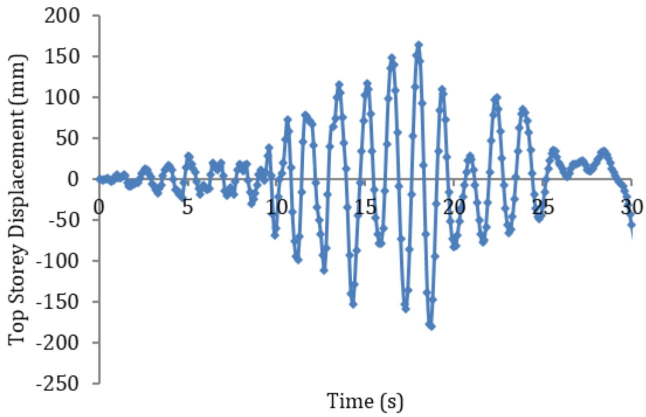


Fig. 3 El-Centro earthquake data



(a) Maximum displacement from RS



(b) Maximum displacement from TH

Fig. 4 Maximum displacements

From the modal analysis the fundamental time period of the building is observed as 1.539 s. The maximum displacement is 198.17 mm in response spectrum method and 189.37 mm in time history method. Here the displacement is almost reached 83 % and 79 % of maximum allowable displacement which is 240 mm. The displacement plot corresponding to RS and TH is presented in Figure 4(a) and (b), respectively. From Table 3 it is observed that the maximum value of drift from the RS and TH analyses is 0.0045 and 0.0042, respectively which is more than the drift limit (0.004) as specified in the seismic code IS1893:2016. It is required that the building needs to be strengthened with a suitable vibration control device to bring down the drift level.

Table 3. Responses of the RC Building

Load Case	Displacement (mm)	Drift	Shear (kN)
RSx	178.24	0.0043	15018.95
RSy	198.17	0.0045	14967.10
THx	180.26	0.0041	14135.88
THy	189.37	0.0042	14087.89

5. Design of Fluid Viscous Damper for the RC Building Under Study

In this investigation, Fluid Viscous Damper (FVD) is selected and installed (Figure 5) to control the vibration of the building under study. FVD is one of the passive energy dissipating devices which improves the performance of the structure by reducing the dynamic responses. Fluid viscous damper dissipates large amount of energy formed at the time of earthquake. The damping coefficient (C) of the damper can be calculated using Eq (1) which is given by Jenn et al. (2008).

$$\xi = \frac{T^{2-\alpha} \sum_j \eta_j C_j \lambda_j |(f_h)_j (\phi_h)_{rj} - (f_v)_j (\phi_v)_{rj}|^{1+\alpha}}{(2\pi)^{3-\alpha} A^{1-\alpha} \sum_j m_j (\phi_h)_i)^2} \tag{1}$$

Where ξ represents the damping ratio, fundamental time period of the structure is represented by T, α denotes damping exponent, η_j corresponds to the number of identical dampers with similar damping coefficient in each of the storey, C_j is the damping coefficient for damper j, $(f_h)_j$ and $(f_v)_j$ represents the horizontal magnification factor and vertical magnification factor, respectively, relative horizontal displacement and vertical displacement between ends of the jth damper in the first mode of vibration are represented by $(\phi_h)_{rj}$ and $(\phi_v)_{rj}$, respectively. A is the top floor displacement of the structure in the damping ratio expected for the building, m_i represents the mass of i^{th} floor level, $(\phi_h)_i$ is the horizontal displacement of the i^{th} floor level in the first mode, λ_j is a variable which can be calculated using Eq. 2 and gamma function is represented by Γ in Eq (2).

$$\lambda_j = 2^{2+\alpha} \frac{\Gamma^2(1+\frac{\alpha}{2})}{\Gamma(2+\alpha)} \tag{2}$$

In order to improve the energy dissipation capacity fluid viscous damper is connected to supporting bars having stiffness K. Stiffness can be calculated using Eq (3).

$$K = 5C\omega \tag{3}$$

The properties of fluid viscous damper designed are as follows. The designed damper has a damping coefficient of 62.69 kN/(mm/s)$^{0.5}$, damping exponent is considered to be 0.5 and supporting bar stiffness is 1683.22 kN/mm.

6. Building with Fluid Viscous Damper in Different Positions

FVD is installed with the calculated properties in the RC building in seven different positions and Figure 5 shows the typical 3-D view of the RC building with damper. In each position, four different ways are adopted; 1. Damper is installed in all floors, 2. Damper is installed in alternate floors, 3. Damper is installed in two alternate floors and 4. Damper is installed in four alternate floors as shown in Figures from 6(a) to (g).

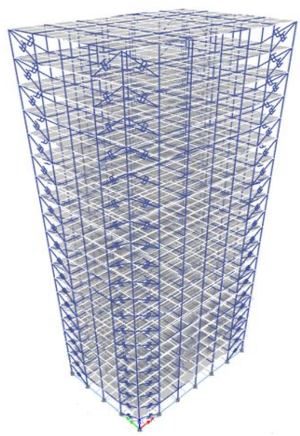


Fig. 5 3-D view of RC building with damper-Typical

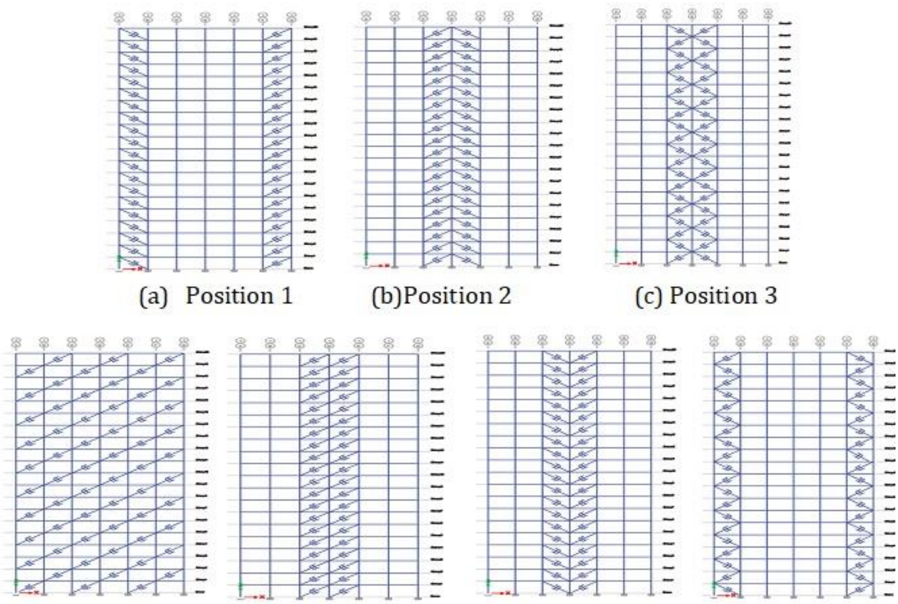
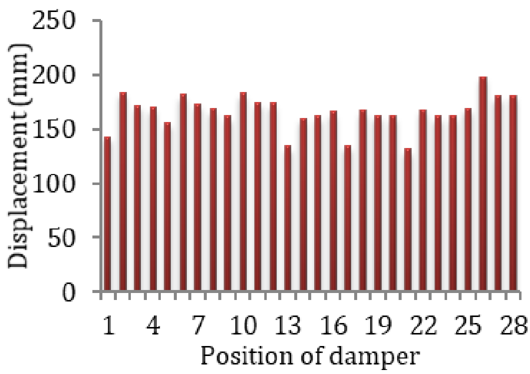


Fig. 6 Different positions of dampers in the RC building

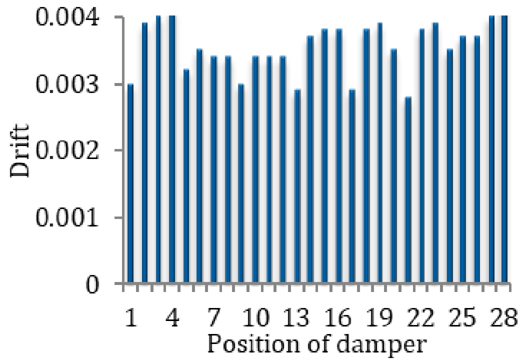
7. Results and Discussion

7.1 Response of G+19 Storey Building with Damper

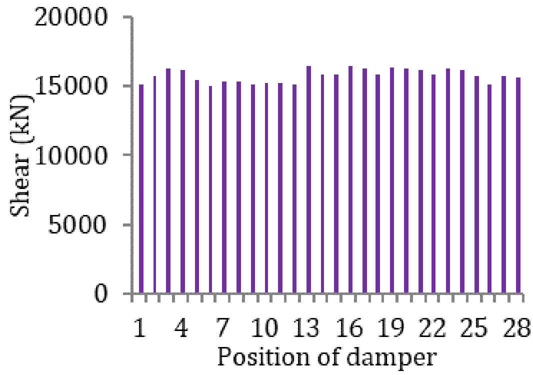
The designed FVD is installed in the building in different positions and analysed using RS method and TH method. The dynamic responses such as the lateral displacement, the drift, the shear and the energy dissipation of the building with damper are shown in Figures from 7 (a) to 7 (d). The dampers number and placement influences significantly the building's response. From the results it is observed that after the installation of damper in different positions there are some changes in the behavior of the building. A large number of dampers may not always leads to the best benefit in terms of drift reduction for all stories [21-22].



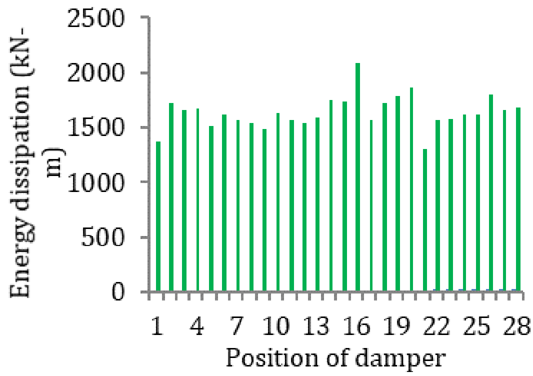
(a) Displacement versus position of damper



(b) Drift versus position of damper



(c) Shear versus position of damper



(d) Energy dissipation versus position of damper

Fig. 7 The dynamic responses of the building with damper

Except 4th, 27th and 28th positions, the building models are within the drift limit and showing good energy dissipation capacity. Therefore, models other than 4, 27 and 28 may be recommended for the building under study. The base shear increase in the building models after the addition of dampers is not significant and this implies that the mass increase due to dampers does not have much influence on the building's shear response [23].

7.2 Algorithm Developed for Maximum Usage of Dampers Using PYTHON

Python programming is widely used and accepted in the research thrust areas in all engineering disciplines. Here, this programme aims to minimize the cost of dampers by identifying the most optimal number of dampers and its position to be installed according to the drift and energy dissipated by the building. The dataset described is loaded data(m,n). The attributes are nDamp, Displacement, Shear, Position, EnergyDis and Drift. The data values are initially labelled as either class 0 or Class 1 depending on the Drift value. For the data with Drift >0.004, the class label is assigned as 0, otherwise it is assigned as 1. The attributes are organized in descending order according to the EnergyDis. For each of the rows in the dataset, the values are sorted in ascending order as per the number of dampers required.

Algorithm:

Step1: The dataset described is loaded data(m,n) where m specifies the number of rows, n specifies the number of columns. The attributes are nDamp, Displacement, Shear, Position, EnergyDis, Drift

Step2: For i=1:m

```
      {
 For j=1:n
      {
   If Drift>0.004 set
  'Class' =   { 0
              { 1  Otherwise
      }
      }
```

Step3: For i=1:m

```
      {
          For J=1 to n
      {
Sortvalues('Drift') as Ascending
Sortvalues('EnergyDis') as Descending
Sortvalues('nDamp') as Ascending
      }
      }
```

Step4: Outputs the following;

- The optimal number of dampers for a minimum drift (Table 4)
- Cost effective number of damper for a maximum energy
- Predicts the feasible number of required dampers along with position (Table 5)

Table 4. Data organized as per drift in non- decreasing order

Position	Displacement (mm)	Drift	Shear (kN)	Energy Dissipation (kN-m)	No. of Dampers	Class
21	131.26	0.0028	16171.00	1306.02	160	1
13	133.68	0.0029	16414.00	1594.83	200	1
17	134.95	0.0029	16289.00	1564.42	160	1
9	161.86	0.0030	15059.04	1488.87	160	1
1	142.35	0.0030	15089.12	1365.27	160	1
5	156.06	0.0032	15359.45	1511.36	160	1
10	182.83	0.0034	15176.97	1633.51	80	1
11	174.23	0.0034	15198.50	1566.10	80	1
7	173.12	0.0034	15334.86	1565.09	80	1
12	173.59	0.0034	15053.96	1547.00	96	1
8	168.60	0.0034	15329.46	1537.56	96	1
20	161.65	0.0035	16261.42	1863.21	96	1
24	161.52	0.0035	16172.97	1619.82	96	1
6	181.36	0.0035	15009.62	1614.78	80	1
26	197.79	0.0037	15146.67	1795.59	80	1
14	159.96	0.0037	15862.52	1747.27	100	1
25	168.68	0.0037	15680.92	1621.99	160	1
16	165.53	0.0038	16399.52	2091.10	120	1
15	161.60	0.0038	15788.30	1737.53	104	1
18	166.97	0.0038	15866.21	1725.89	80	1
22	167.80	0.0038	15782.60	1565.75	80	1
19	162.35	0.0039	16327.73	1787.96	80	1
2	183.21	0.0039	15747.62	1722.29	80	1
23	161.98	0.0039	16246.59	1581.35	80	1
3	171.49	0.0040	16209.72	1661.59	80	1

Table 5. Prediction for feasible usage of dampers

Position	No. of Dampers	
	Actual	Predicted
2	80	80
22	80	80
14	104	80
17	80	80
5	80	80
11	96	80

8. Conclusion

This paper focuses on the design of nonlinear fluid viscous damper for the RC framed building under study and the optimal damper number and its position in the building. Code based static and dynamic analysis are carried out on the buildings with and without fluid viscous damper. The responses such as top displacement, drift, base shear and energy dissipation capacity are obtained and compared. The results showed that in most of the cases damper placement reduced the dynamic responses of the building.

- The top displacement of the building without damper is around 82 % of the maximum value of 240 mm whereas in the case of buildings with dampers it varies between 55 and 82 % of the maximum value.
- The drift value of the building without damper is more than the maximum allowable value (0.004). The drift reduction in the buildings with dampers is significant in most of the cases and this majorly depends on the number of dampers and their position in the building.
- The variation in base shear of the building with and without dampers is not much significant.
- The energy dissipation capacity of the buildings with dampers is improved and varies between 1306 and 2091 kN-m.
- Optimization work is carried out using algorithm using PYTHON with drift and energy dissipation of the building as the governing factors. The programme suggests the positions 2, 22, 14, 17, 5, 11 with 80 numbers of dampers for the building and recommends the position 2 for the maximum benefit in terms of drift, energy dissipation and cost.
- The analysis results clearly show the influence of dampers, their numbers and position in the building.
- This study bears fruitful results and these details would be beneficial to the engineers and fabricators to utilize the maximum benefit of dampers by knowing the required number of dampers and their optimum placing in the buildings.

The present study can be extended for the seismic evaluation of structures with different types of dampers and hybrid dampers.

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