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EFFECTIVENESS OF LOCATION OF VISCOUS DAMPERS IN RC FRAME STRUCTURE AGAINST SEISMIC LOADING

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Abstract

Earthquakes are one the world's deadliest natural hazards. Large earthquakes often strike without warning in areas of high population density, which can lead to catastrophic events. The National Earthquake Information Centre (NEIC) records an average of 20,000 earthquakes every year (about 50 a day) around the world. There are, however, millions of earthquakes estimated to occur every year that are too weak to be recorded. Most of the structures being RC frames which will have larger impact due to seismic loading. There are fundamentally two ways to improve the seismic performance of these structures. One method is to improve the deformation capacity of the beams and columns of these structures which is not always possible in practical situations. Another method is to add dampers or base isolators to increase the seismic performance of the structures. Adding dampers to the structures, in order to reduce the seismic responses, not only found to be effective but also economical in some of the constructions. Therefore, in this paper the efficiency of viscous damper on 3D-RC frame is evaluated based on placement of the dampers at different locations. FE analysis is carried out to study the dynamic behaviour of the structure.

Keywords: Base Shear, Equivalent Static Analysis, Fundamental Time Period, Modal Analysis, Response Spectrum Analysis, Storey Displacement, Storey Drift.

1. INTRODUCTION

Damping plays vital role in plan of Earthquake Resistant Structures, which lessens the reaction of the structure when they are exposed to horizontal loads. There are a wide range of sorts of dampers being used. The primary devices utilized for protection of structures during seismic events include active, passive and semi active damping systems [1]. Their primary objective is to efficiently dissipate vibration energy. This can be achieved through two main approaches. The first method involves direct conversion of kinetic energy into heat, such as through metal yielding, deformation of viscoelastic solids and fluids, or utilization of friction slides. The second method focuses on redistributing energy across two or more vibration modes of the building, typically accomplished by incorporating a supplementary oscillator that absorbs primary structure vibrations. Passive systems like tuned liquid dampers, tuned mass dampers and base isolation represent this approach.

2. STATEMENT OF THE PROBLEM

The structural response to dynamic loads, which induces stresses and deflections, is inherently dynamic and time-varying. Tall buildings, particularly in regions prone to high seismic activity and strong winds, require meticulous design considerations. Several laboratory testing campaigns aimed at verifying their behavior during both wind storms and earthquake [2] Traditionally, the approach has been to stiffen buildings to mitigate dynamic responses. However, this inadvertently amplifies seismic base shear forces. Introducing supplementary damping to the structure offers a solution by reducing the building's flexural stiffness, thus minimizing seismic base shear while simultaneously managing wind-induced responses. Research and implication have been done configuring viscous dampers in high-rise buildings by time history analysis [3].

3. VISCOUS DAMPER

Originally, fluid viscous dampers found their application in the military and aerospace sectors. Their adaptation for use in structural engineering emerged in the late 1980s and early 1990s, as documented by [4], [5] & [6]. These dampers typically operate within a fluid medium, such as gas, air, water or oil where the resistance exerted by the fluid against the moving body effectively dissipates energy [7]

3.1 Preliminary Design

Selecting locations for the manufactured dampers. Some locations are not a problem to the owners or architects because they are hidden from public view or do not block access. Selecting the number and the location of the manufactured viscous damper is not easy and finding one optimal solution is not always possible. Therefore, the first trial design often differs from the final design in both regards.

Once the location and numeral quantity of the dampers are selected for the first trial design, the focus turns to the size of the dampers [6]. The next step in developing the first trial design is to construct the natural damping matrix for the structure. The natural damping matrix can be written as,

$$Cnd = \alpha M + \beta K$$

Where, Cnd is natural damping matrix, M is the mass matrix, K is the stiffness matrix and α, β are constants. It is then desirable to perform a response spectra analysis of the structure without the dampers to determine how much the response needs to be reduced for the response variables of interest.

4. EXISTING RESEARCH

The research conducted in this paper examines RC bare frame buildings and bare frames outfitted with various damper configurations. The dynamic analysis employed in this study is response spectrum analysis. It's noted that the effectiveness of response reduction isn't solely dependent on the damping capacity of the damper, but also on their placement and optimal quantity. While achieving a single optimal solution may prove challenging, there's value in making efforts towards finding one. The limit state of viscous dampers has a significant effect on the response of the building [8]. Additionally, solutions that offer economical construction are commendable in this regard.

5. DEFINITION OF THE BUILDING MODELS

A square building with square columns is under consideration. Dampers of equal capacity are installed in the modeled buildings, with variations in their placement.

Model Details:

G+9 model with each storey height 3m is considered. Each model has 5 bays in X-direction and 5 bays in Y-direction of 4m wide. Table 1 contains details of the model used in the analysis.

Table 1: Details of the model

Type of structure	Special moment resisting RC frame
Grade of concrete	M 25 (fck=25 N/mm^2)
Grade of reinforcement	Fe 500 (fy=500 N/mm^2)
Number of stories	G+9
Each floor height	3m
Height of the building	30m
Column size	600X600mm
Beam size	300X450mm
Density of concrete	25 kN/m^3
Live Load on Floor	2.5 kN/m^2
Live load on Roof	2.5 kN/m^2
Floor finish	1.0 kN/m^2
Importance factor	1
Zone	V
Response reduction factor ‘R’	5

5.1 Damper details

The dampers used in modelling are from Taylor Devices, India [9]. The properties of the dampers are given in Table 2.

Table 2: Damper details

Damper notation	Mass (kg)	Coefficient (kN.s/m)	Exponent	Stiffness kN/m
AL3.0	44	300	0.3	25000

In Table 3, the models considered in this paper are tabulated. Elevations and 3D views of all the models are shown from Figures 1 to 12 respectively.

Table 3: Nomenclature of the building model.

Sl. No.	Details	Nomenclature
1	RC bare frame	BF
2	RC bare frame, dampers at Intermediate Bay, only in ground storey	BDIG
3	RC bare frame, dampers at corner, only in ground storey	BDCG
4	RC bare frame, dampers at Intermediate Bay, in all storeys	BDIA
5	RC bare frame, dampers at corner, in all storeys	BDCA
6	RC bare frame, dampers at exactly middle, in bottom half storeys.	BDMBH
7	RC bare frame, dampers at exactly middle, in top half storeys.	BDMTH
8	RC bare frame, dampers at Intermediate Bay, in bottom half storeys.	BDIBH
9	RC bare frame, dampers at corner, in bottom half storeys.	BDCBH
10	RC bare frame, dampers at intermediate, in top half storeys.	BDITH
11	RC bare frame, dampers at corner, in top half storeys.	BDCTH
12	RC bare frame, dampers at exactly middle, in all storeys.	BMA

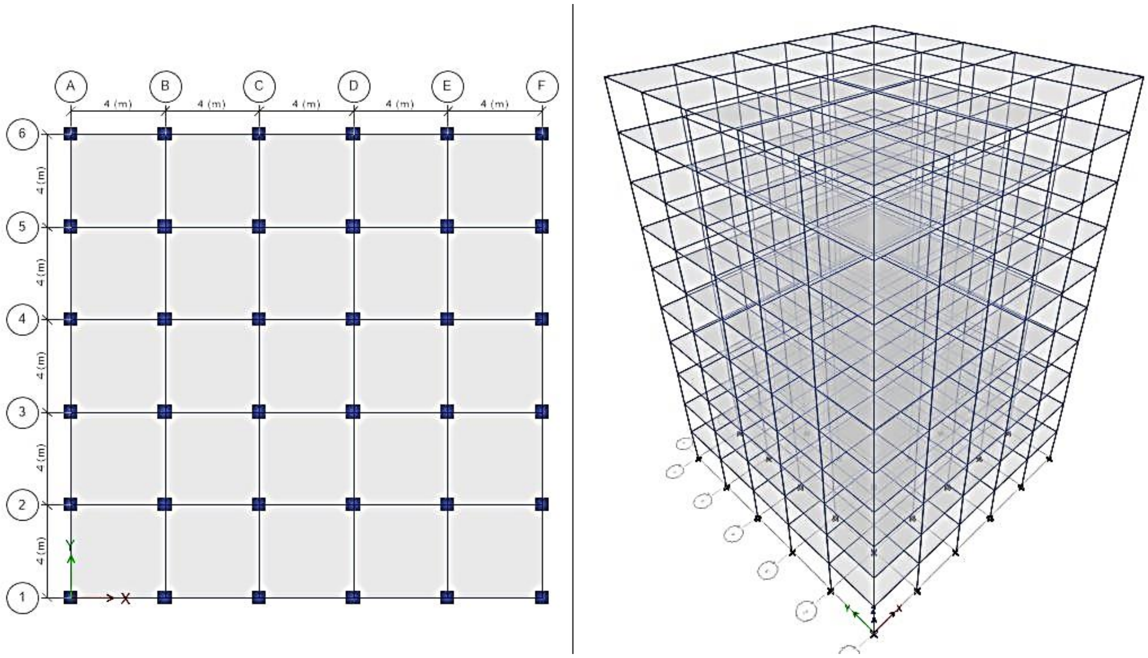

Fig.1: RC bare frame (BF)

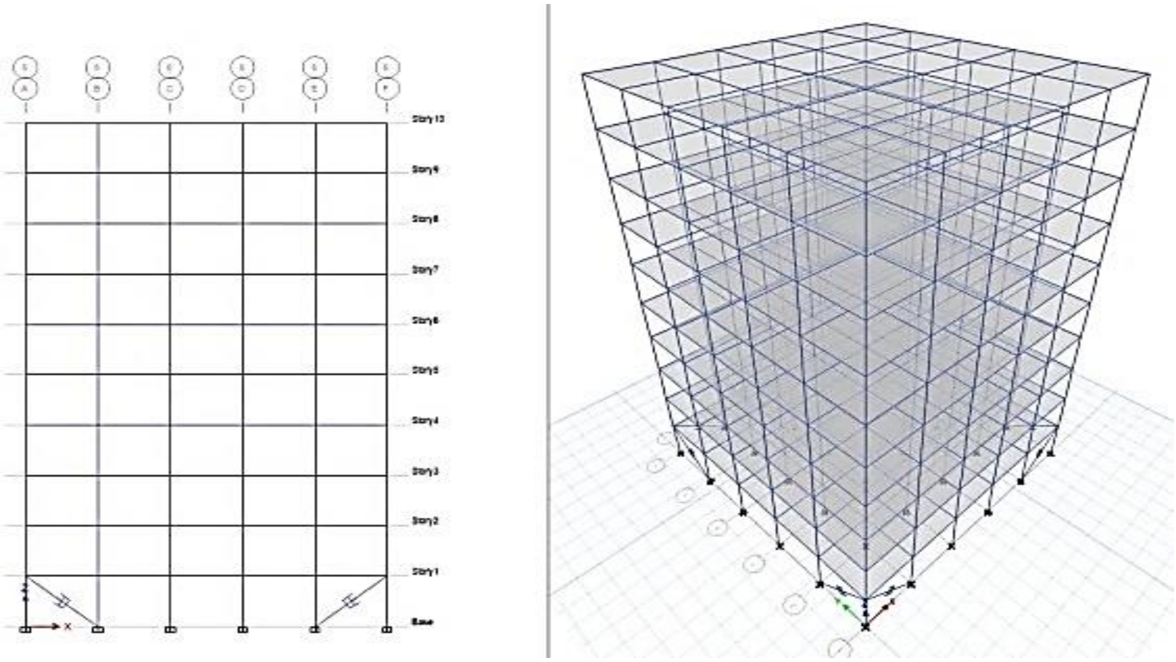

Fig .2: RC bare frame, dampers at corner, only in ground storey (BDCG)

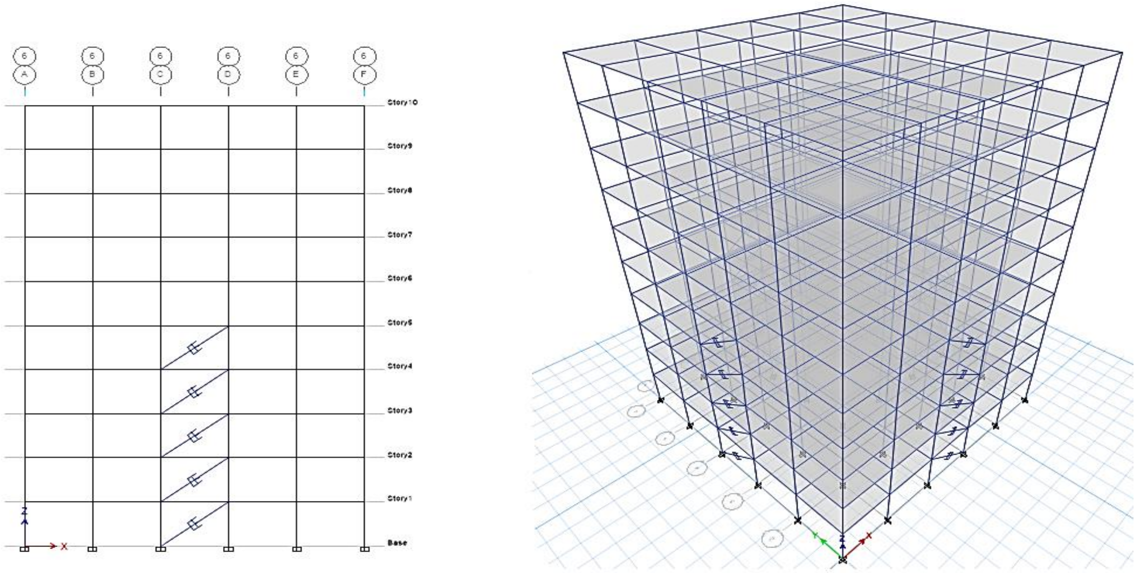

Fig .3: RC bare frame, dampers at exactly middle, in bottom half storeys (BDMBH)

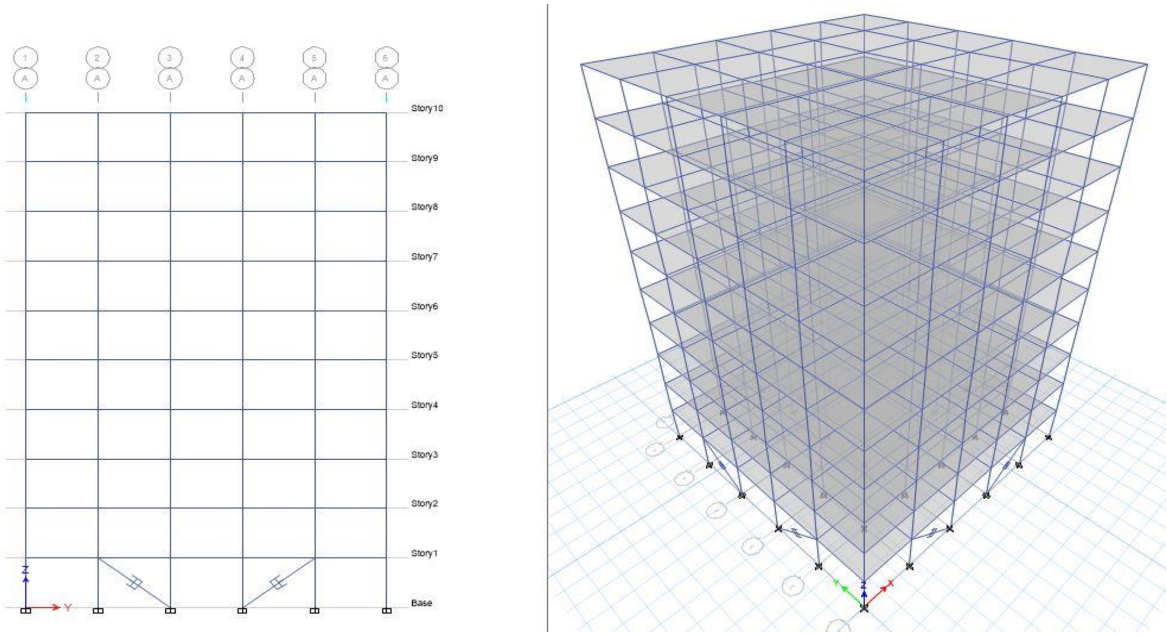

Fig .4: RC bare frame, dampers at Intermediate Bay, only in ground storey (BDIG)

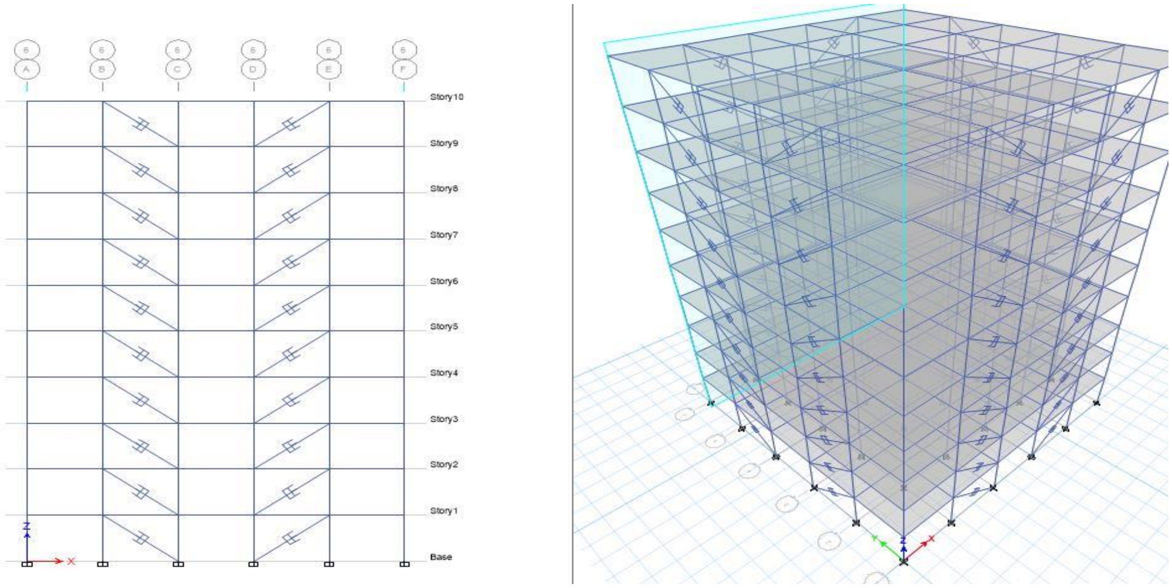

Fig .5: RC bare frame, dampers at Intermediate Bay, in all storeys (BDIA)

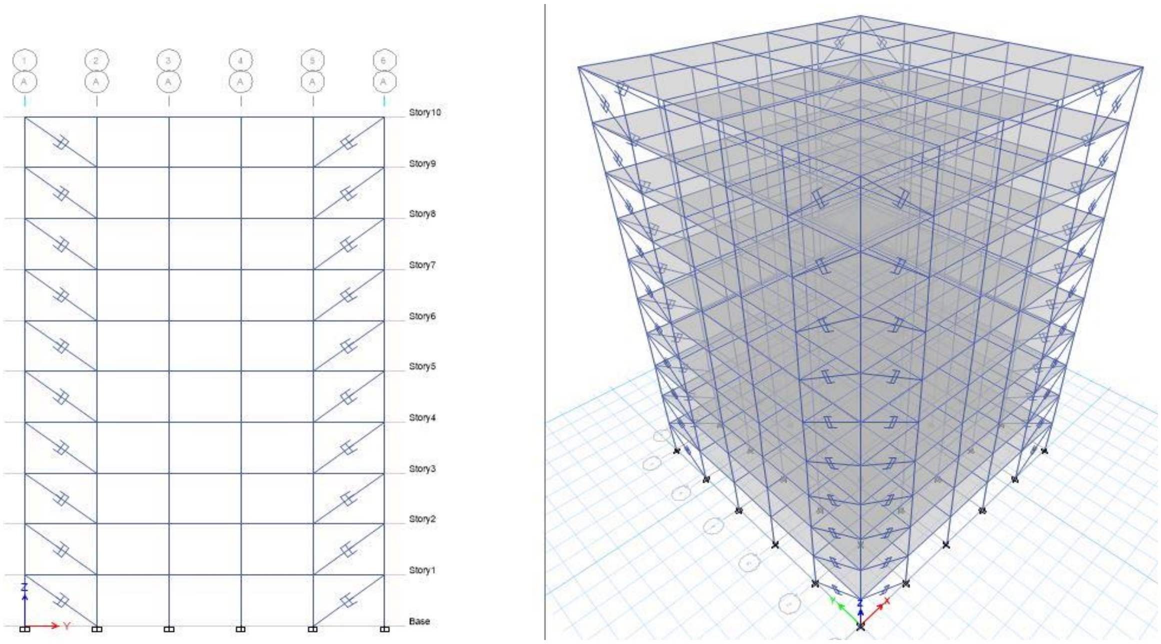

Fig.6: RC bare frame, dampers at corner, in all storeys (BDCA)

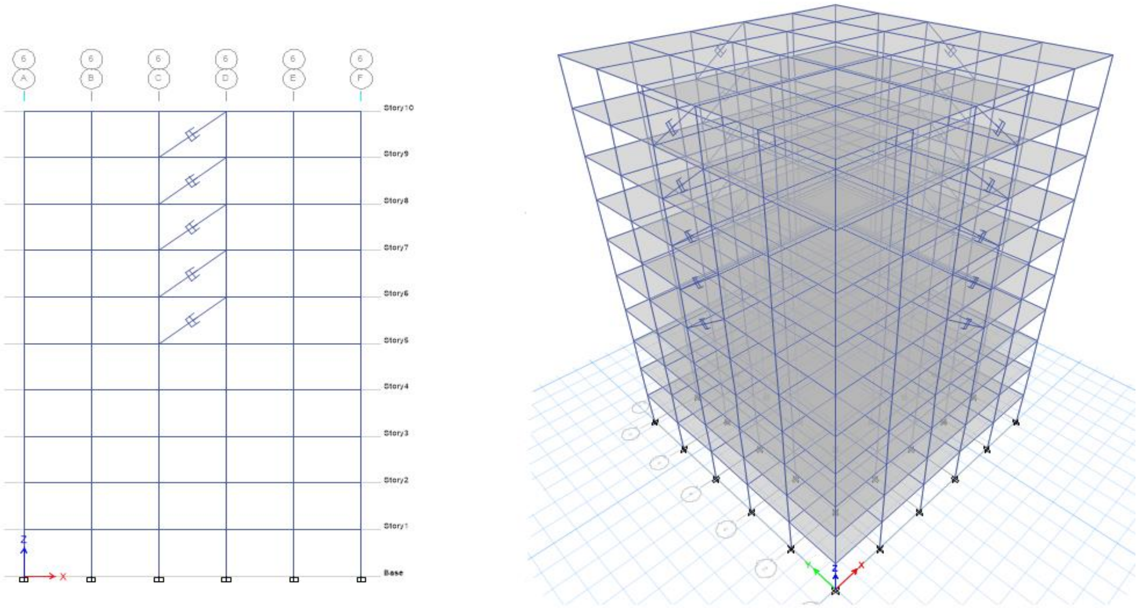

Fig. 7: RC bare frame, dampers at exactly middle, in top half storeys (BDMTH)

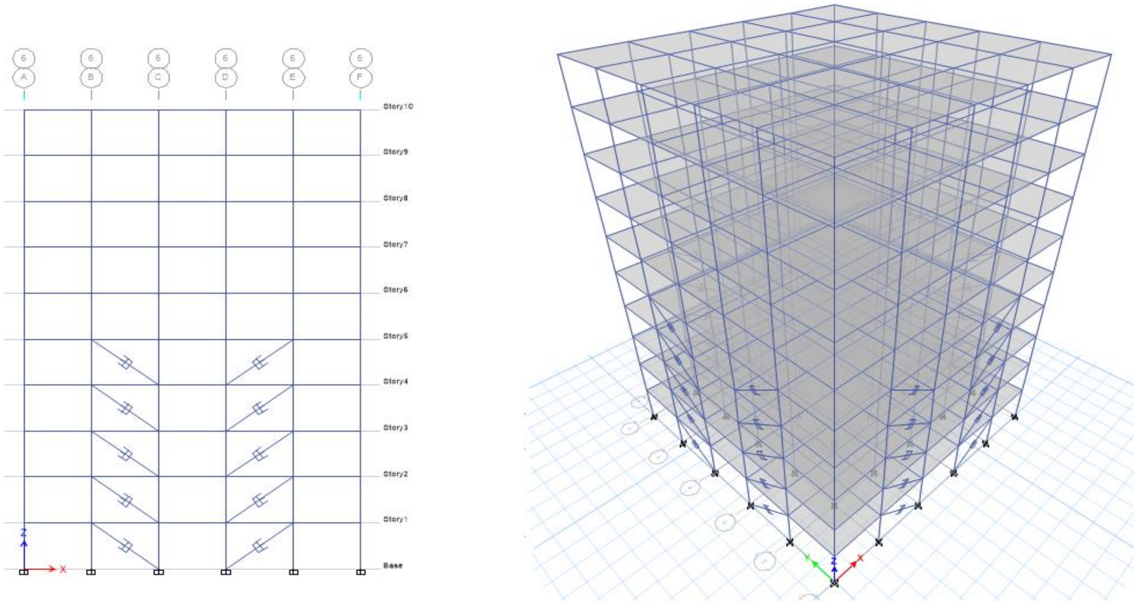

Fig. 8: RC bare frame, dampers at Intermediate Bay, in bottom half storeys (BDIBH)

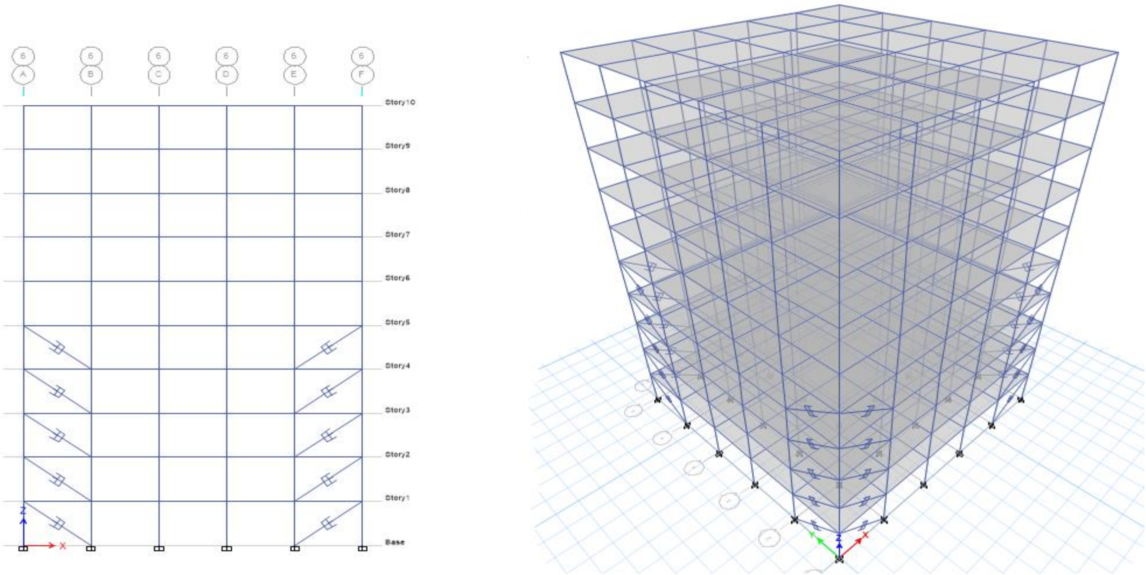

Fig. 9: RC bare frame, dampers at corner, in bottom half storeys (BDCBH)

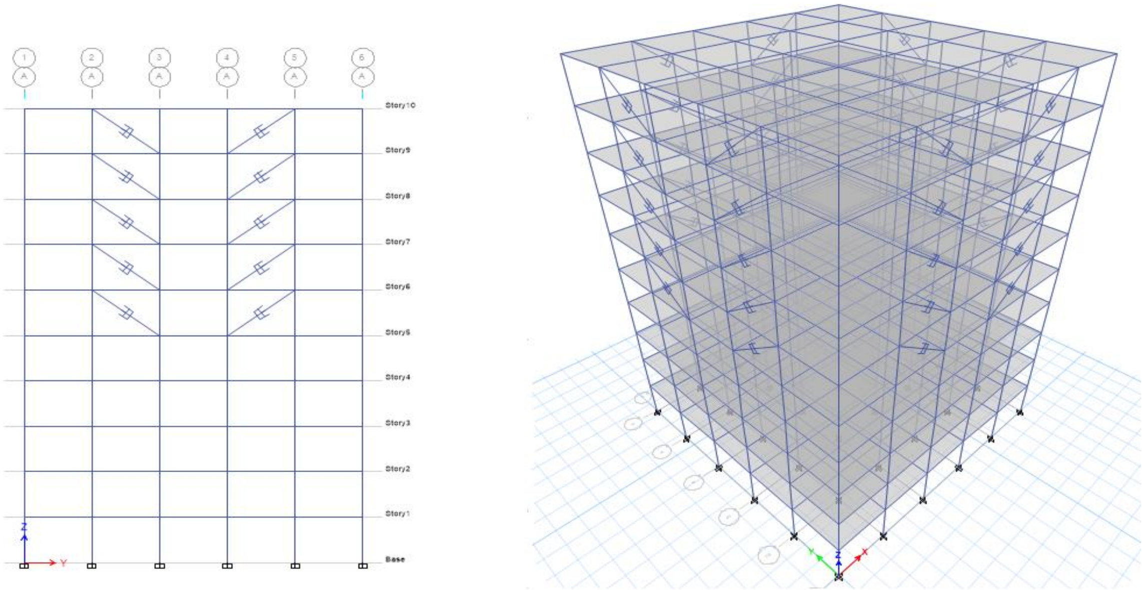

Fig.10: RC bare frame, dampers at intermediate, in top half storeys (BDITH)

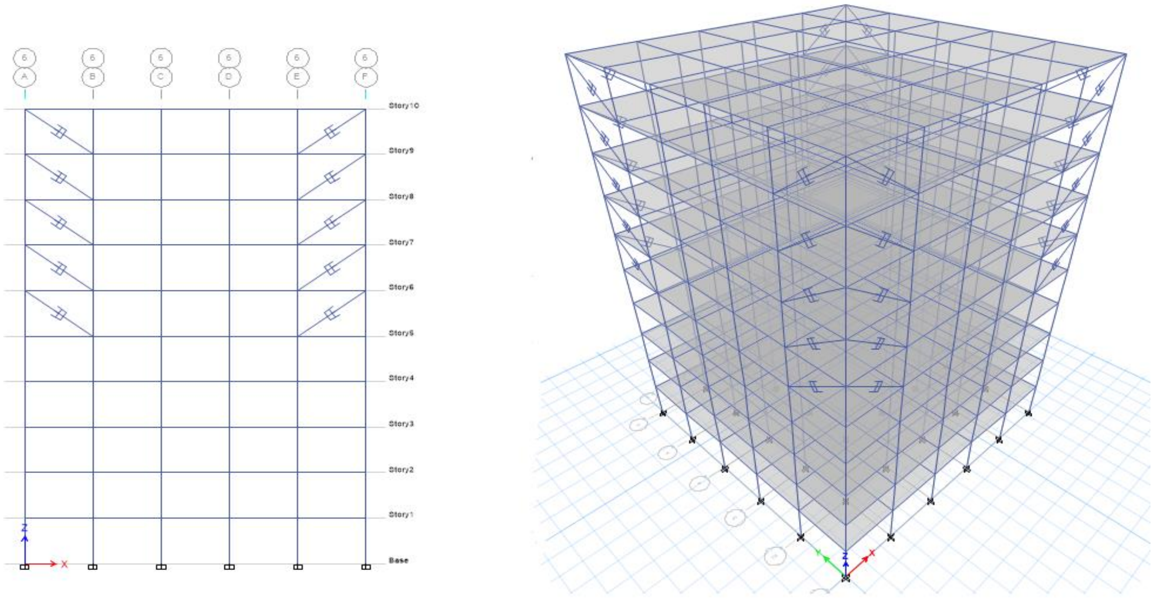

Fig.11: RC bare frame, dampers at corner, in top half storeys (BDCTH)

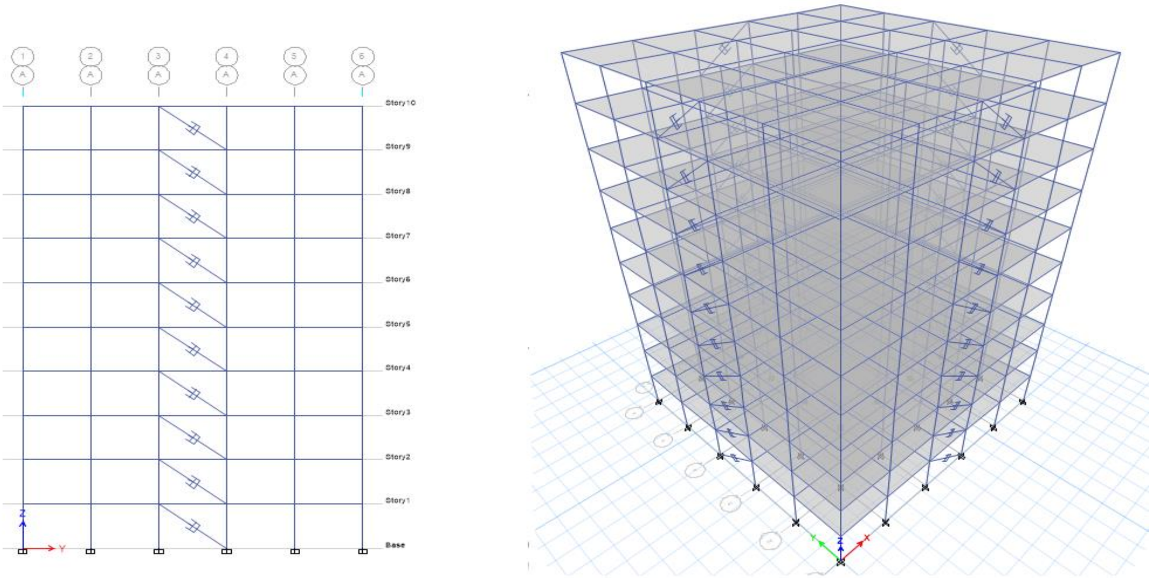

Fig. 12: RC bare frame, dampers at exactly middle, in all storeys (BMA)

6. FEM ANALYSIS

The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements. Some of the prevalent packages are STAAD-PRO, GT-STRUDEL, NASTRAN, NISA, ANSYS and ETABS. In the present work ETABS is used. The analyses carried out are,

- Modal analysis.
- Equivalent static analysis.
- Response spectrum analysis.

There are certain advantages in using the response spectrum method analysis for prediction of member forces and displacements in structural systems. The method contains the calculation of only the maximum values of the displacements and member forces in each mode of vibration by a smooth design spectrum that are the average of several past earthquake motions.

7. RESULTS AND DISCUSSION

FE analyses are carried out on models of different configurations of G+9 storeys including modal and response spectrum analysis. The results are compared between the structures without dampers and with dampers. They are categorized in the following ways.

- Fundamental time period
- Base shear
- Displacements
- Acceleration
- Storey drift

i. Comparison of fundamental time period without and with damper at different location

The fundamental time period for all models is shown in Figure 13.

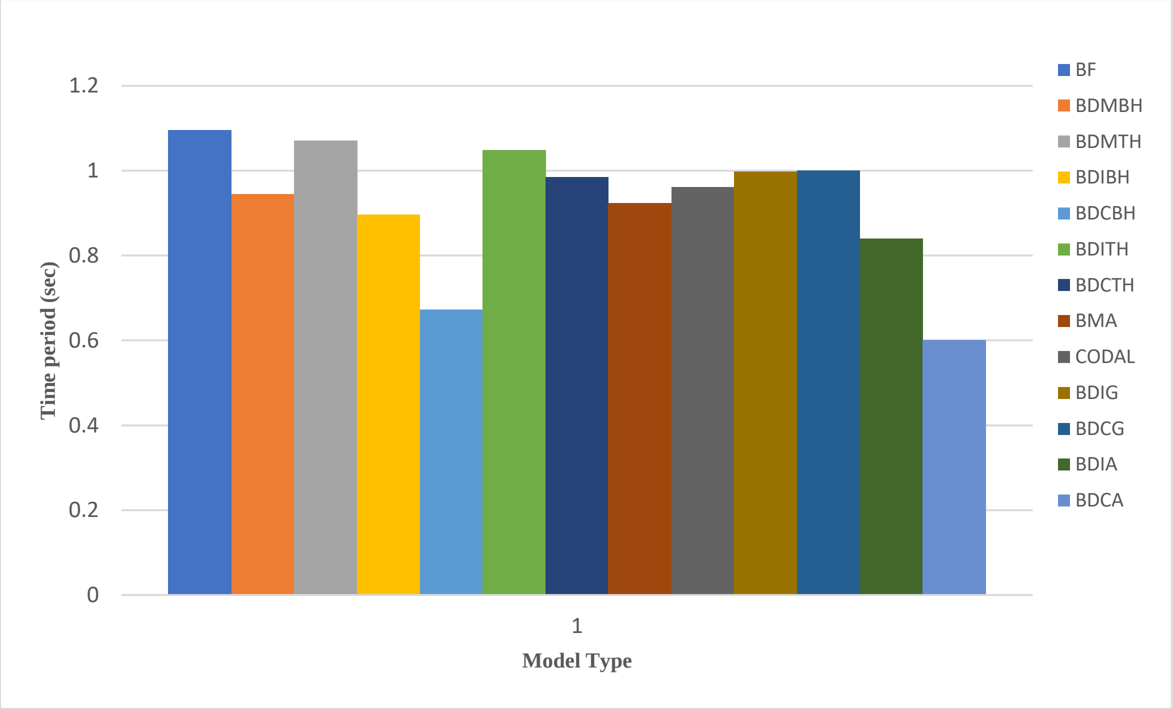

Fig.13: Fundamental time period

The fundamental time period of the bare frame structure decreases upon the addition of dampers. Regardless of their location, dampers installed at ground level (BDIG and BDCG) exhibit similar reductions in the time period, while those installed on all floors (BDIA and BDCA) display significant differences in reduction. Structures with corner-mounted dampers demonstrate greater reductions in time period.

However, the time period obtained from modal analysis doesn't precisely match with the time period derived from codal formulae [10]. Hence, there is a need for provisions to be made in the code to improve accuracy and ensure better results

ii. Comparison of base shear without and with damper at different location

The base reaction for all models is shown in Figure 14.

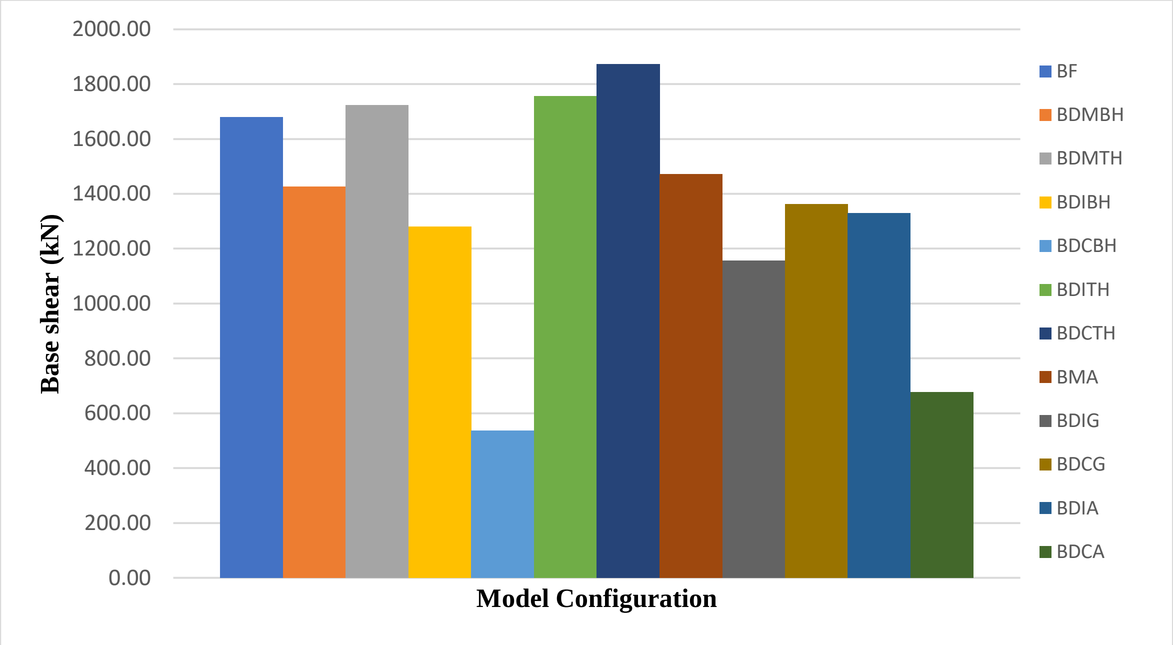

Fig.14: Base shear

The base shear of the bare frame structure is significantly reduced when dampers are strategically placed at the corners and in the bottom half of the structure (BDCBH) compared to when they are placed exclusively at the corners throughout the entire height (BDCA). However, dampers positioned at ground level (BDIG) prove to be more effective in reducing base shear compared to those positioned at the ground and distributed across the height (BDCG).

The base shear of three models (BDMTH, BDITH, and BDCTH), where dampers are positioned in the top half of the structure, proves to be ineffective in reducing the value, primarily due to the significant mass concentrated at the top.

iii. Comparison of storey displacement without and with damper at different location

The storey displacements over storey height is shown in Figure 15.

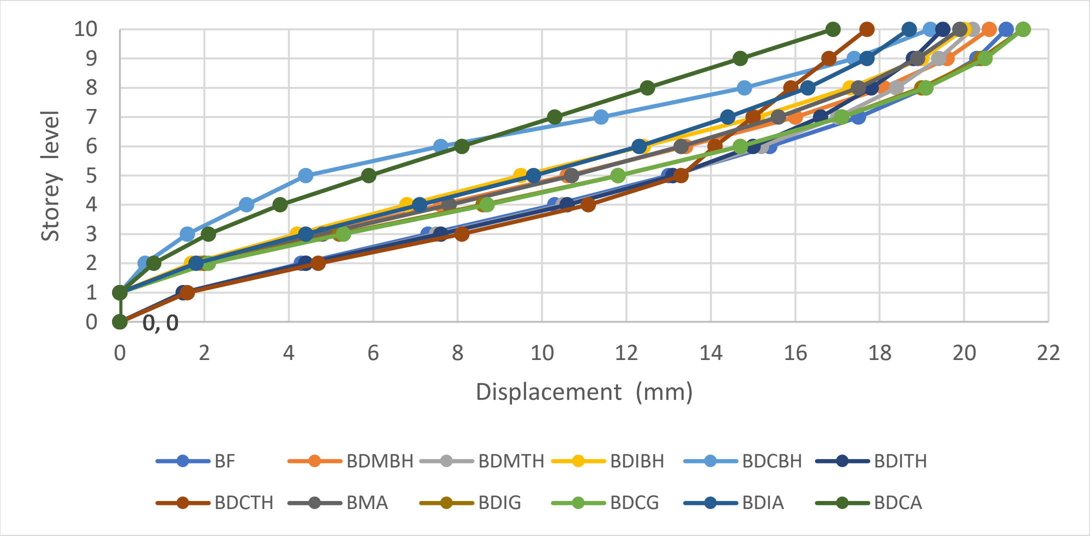

Fig.15: Displacement curves of G+9 storey building

It has been observed that in the case of a bare frame structure, there is approximately a 19.5% reduction in displacement response when dampers are installed at all floors in the corners. The displacement response of BDIG aligns with that of BDCG, while BDITH corresponds to BDCTH.

Hence the position has no influence in the response reduction when dampers installed at the ground level.

iv. Comparison of maximum acceleration without and with damper at different location

The maximum acceleration for all models is shown in Figure 16.

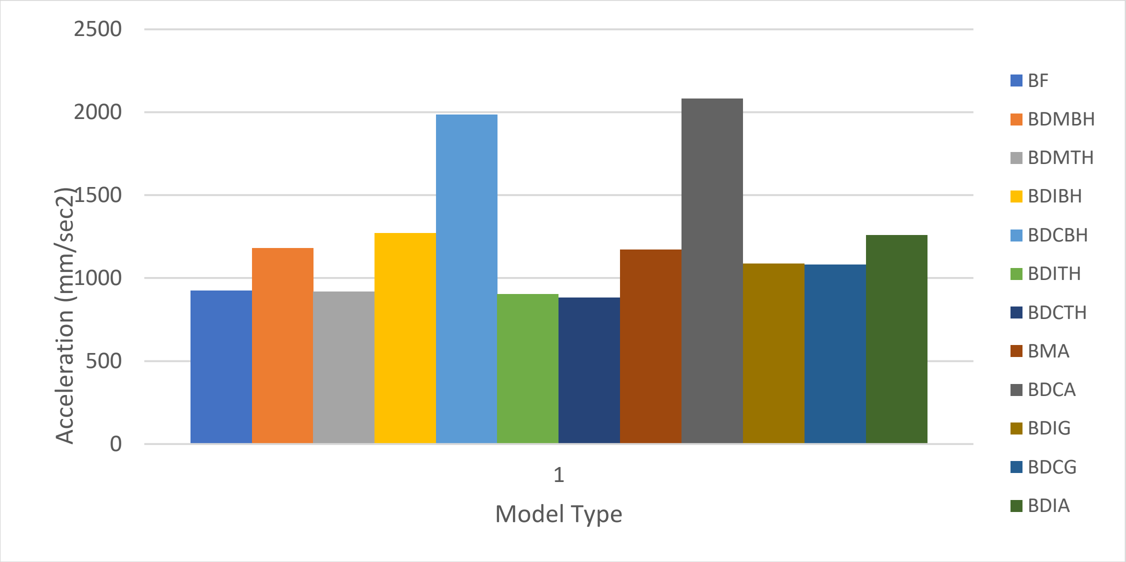

Fig.16: Acceleration

Due to the Maxwell modeling of dampers, the stiffness of the structure is heightened, consequently elevating the structure's frequency. With this increase in frequency, the fundamental time period decreases, resulting in an acceleration increase.

Even within the models under consideration, it is noted that the acceleration of structures equipped with dampers surpasses that of structures without dampers. BDCBH and BDCA structures exhibit higher stiffness compared to other configurations, thus demonstrating higher acceleration values.

v. Comparison of storey drifts without and with damper at different location

The storey drifts over storey height are shown in Figure 17.

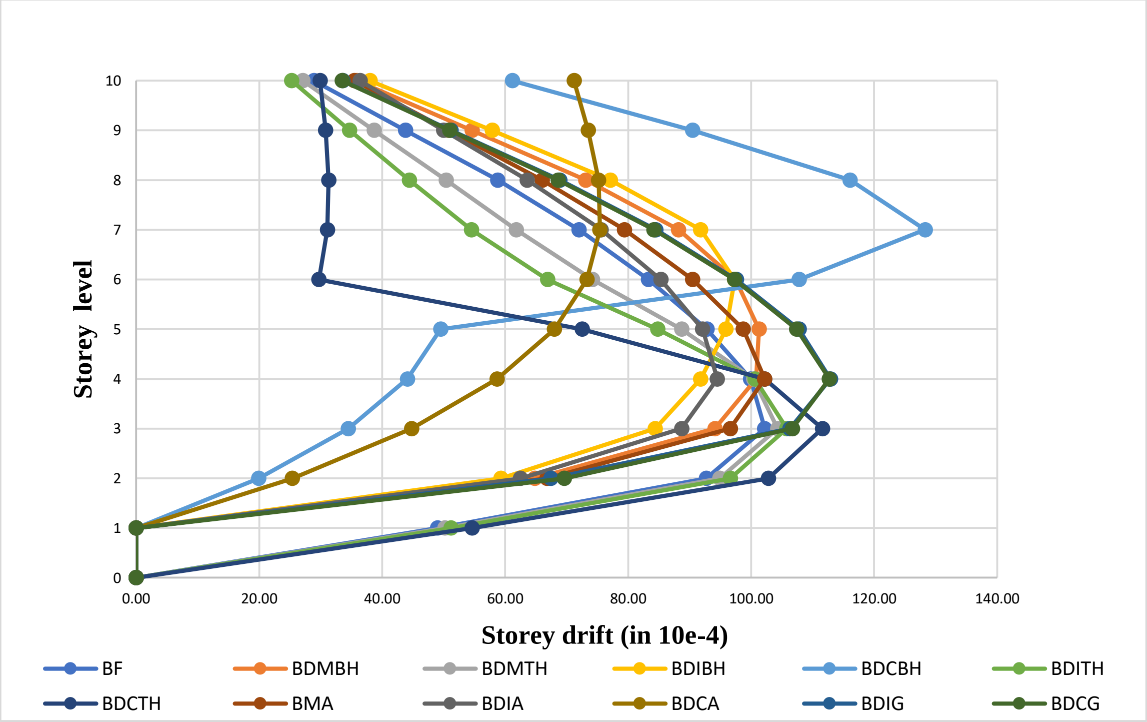

Fig.17: Drift curves of G+9 storey building

The reduction in storey drift is noticeable primarily in the lower heights of BDIG and BDCG, while significant reduction in drift is observed in BDIA and BDCA configurations. However, once the dampers are removed, as in the BDCBH and BDCTH setups, the drift increases.

In the G+9 model, the drift is quite similar to the other two sets of models, and the storey drift of all configurations remains within the safe permissible limit, as stipulated by IS 1893-2002, which is 0.004h.

8. CONCLUSION

- Viscous dampers are the most effective type of dampers for high rise buildings. The following conclusions can be made based on the analysis carried out.
- Upon the integration of dampers into the structure, an intriguing observation emerged: the time period of the structure showed a discernible reduction. This phenomenon underscores the transformative influence of dampers, as they effectively dissipate energy and mitigate vibrations, consequently accelerating the rate at which the structure stabilizes itself. This unexpected but welcome outcome underscores the dynamic interplay between structural components and damping mechanisms, ultimately contributing to a more agile and resilient built environment.
- With the strategic deployment of dampers, a notable shift in the distribution of forces has been observed, resulting in a tangible reduction in base shear. This phenomenon arises from the collaborative action of dampers, which actively take a portion of the applied force, thereby lessening the burden on the structure. This shared responsibility not only mitigates the overall force exerted on the structure but also underscores the interdependent relationship between dampers and structural elements, enhancing the stability and flexibility to dynamic loads.
- The introduction of dampers has accompanied in a visible reduction in displacement, marking a significant advancement in structural performance. This notable decrease in displacement underscores the effectiveness of dampers in dissipating energy and curbing excessive motion within the structure. By moderating the amplitude of oscillations, dampers play a pivotal role in enhancing the structural integrity and occupant comfort, thereby contributing to a safer and more stable built environment. This appreciable reduction in displacement highlights the influence of damping technologies on structural dynamics, paving the way for more robust structures.
- In optimizing the performance of dampers, it's not merely their capacity or quantity that holds influence, but rather their strategic placement within the structure. The efficiency of dampers depends greatly on their precise location, as this determines their ability to dissipate energy effectively. This underscores the importance of meticulous planning and analysis in determining the optimal placement of dampers, ultimately concluding in a collaborative combination that strengthens the structure against dynamic forces. Hence, while the capacity and quantity of dampers are essential considerations, it is their premeditated positioning that truly unlocks their potential in emphasizing structural performance.

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