OPTIMAL HYBRID OUTRIGGER LOCATIONS FOR TALL STRUCTURES

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Abstract
With the global population on the rise, tall buildings with diverse lateral resisting systems are becoming increasingly prevalent. However, as these structures reach greater heights, the risk of structural failure escalates. To address this challenge, outriggers have emerged as a crucial technique for bolstering stiffness and seismic resilience. Despite their widespread adoption, hybrid outrigger structures, which combine conventional outriggers (CO) and virtual outriggers (VO) at different levels, are notably absent from current practice.
This study aims to explore the response of hybrid outrigger systems, focusing on gaining crucial insights into their performance. Specifically, the study seeks to evaluate the seismic response of hybrid outrigger systems. In this approach, the G+20 storey RC structure with and without cores is compared with the RC structure equipped with a hybrid outrigger system installed at different floors (locations) of the building. The first three modes are taken into consideration and the outriggers are positioned where a certain mode shape of the building is larger. The time history analysis is done using five different earthquake ground motions. Key responses such as base shear, Storey displacement and storey drift are obtained and analysed. The findings illuminate the significant impact of the positioning of the hybrid outrigger within the system on structural stability.

Keywords:
High rise building, conventional outrigger, virtual outrigger, Modal Frequency/shape, Time History Analysis.

I. Introduction
Tall Building has always been a vision of dreams and technical advancement leading to the progress of the world. Tall building development has been rapidly increasing worldwide introducing new challenges that need to be met through engineering judgment. Selection of the proper structural system for a tall building subjected to horizontal load is a very difficult task. The major factor that affects the design of tall structures is its sensitivity to the horizontal load. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls but when the building increases in height, the stiffness of the structure becomes more important and introduction of outrigger between the core of building and external columns is often used to provide sufficient lateral stiffness to the structure to each other as possible.
The principle of using an outrigger system to enhance the structural lateral stiffness and overall stability is that the core-tube and the external columns are connected by rigid horizontal cantilevers. The outrigger and belt truss system are one of the lateral loads resisting system in which the external columns are tied to the central core wall with very stiff outriggers and belt truss at one or more levels. The belt truss tied the peripheral column of building while the outriggers engage them with main or central shear wall. Outrigger systems enhance the stiffness of high-rise buildings by the introduction of stiff outriggers at different locations. Outrigger systems represent a very efficient structural system because the outrigger can reduce top deflection, overall deflection, and lateral drift can be reduced.

II. Literature
Nitthu John (2023) The concept of hybrid outrigger system which has a conventional and a virtual outrigger at different levels has been proposed.

Pratiksha Patil (2022) defined that an outrigger system is a type of lateral load resisting system that is used in high-rise buildings to improve their overturning stiffness and strength. It is located within the interior of the building and consists of a core structure connected to the perimeter columns of the building by means of structural members called outriggers.
Kiran Kamath (2015) investigates, a multi-outrigger structure's seismic performance using a three-dimensional model in ETABS. The findings underscore the efficacy of multi-outrigger configurations in enhancing structural resilience against seismic loads, particularly in minimizing lateral displacement and core wall bending moments, pivotal for seismic design considerations.
Aakash Gupta (2021) employed pushover analysis to explore the behavior of high-rise RCC buildings employing core and outrigger-belt systems, aiming to identify optimal outrigger-belt positions. The study suggests optimal outrigger-belt positions between 30%-50% of building height, showcasing improved fundamental vibration periods, capacity curves, storey shear, and performance points over standard frames.
Alaa Habrah (2022) This study delves into the pivotal role of outrigger positions and numbers in core-outrigger lateral systems for tall buildings, focusing on top displacement reduction and cost efficiency. Outrigger positioning: The second outrigger's location becomes less critical if the first outrigger is placed in the upper half of the building.
Han-Soo Kim (2017) The method combined integer and real number nonlinear programming, incorporating piecewise quadratic interpolation to create continuous constraint functions based on finite element analysis. The results reveal that outrigger numbers increase beyond two, the distances between outriggers stabilize. The study indicates that while additional outriggers decrease total volume, their performance remains nearly constant. For multiple outriggers, the lower outrigger requires a larger area than the upper, especially in dual outrigger configurations.
Honggang Lei (2021) This study pioneer's novel approaches in Performance-Based Seismic Design (PBSD) to streamline tall building evaluations.
Hamid Beiraghi (2016) In a core-wall structure with buckling restrained braces (BRB) outrigger, locations of the plastic hinges are influenced by the outrigger action.
Takehiko Asai (2013) in this smart outrigger damping systems have been proposed as a novel energy dissipation system to protect high-rise buildings from severe earthquakes and strong winds, where devices such as magnetorheological (MR) dampers are installed vertically between the outrigger and perimeter columns to achieve large and adaptable energy dissipation.
Dhanaraj M. Patila (2016) investigated the the seismic behaviour of outrigger braced buildings to find out the optimum location of outrigger in high rise 2-D steel buildings.
Ruofan Jia (2023) This paper presents research on the seismic response control of core wall structures through the installation of innovative damped outriggers known as tuned viscous mass damper (TVMD) outriggers.
FeiFei Sun (2021) Using the passive control performance curve and the idea of mapping, a single step seismic optimal design method for damped outrigger structure with buckling-restrained brace (BRB) was proposed in this paper.
The objective of the present study is to evaluate the effect of position of virtual and core outriggers at different floors of the building. The modal analysis is carried out and outriggers are positioned where larger modal displacement is observed. The time history analysis is done using five different earthquake ground motions.

III. Objective

To find the Optimal position of hybrid outrigger system in a structure

IV. Specification of building

The section describes the methodology used to achieve objectives of the study. The present study is to evaluate the comparative analysis of conventional structure with and without core and hybrid outrigger

structural system. All building parameters are presented below. The dead load, super dead load and live load on floor slab are 1.5 kN/m^2, 1.5 kN/$m^2$and 3.5 kN/m^2. Modeling and analysis are carries out using commercial software ETABs 2016. Time
history analysis is carried out and time history data is obtained from Earthquake Engineering Research Institute (EERI).

Table 1: Parameters of the structure

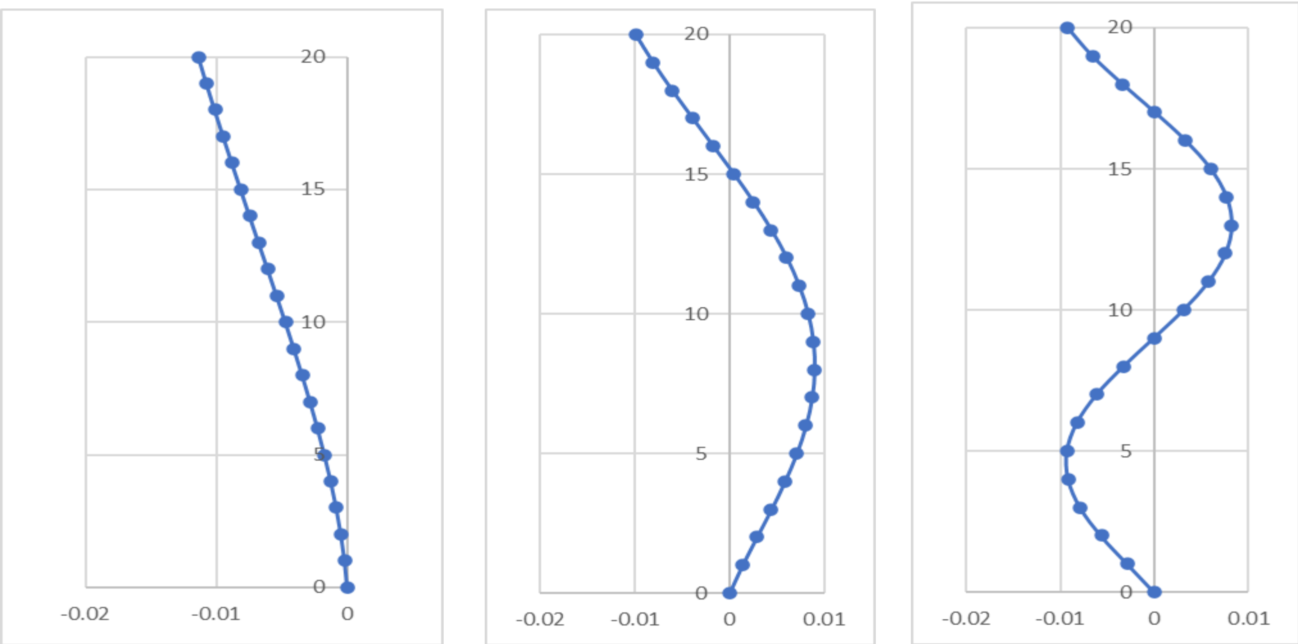
Sr. No.	Member	Values
1	Type of Structure	R.C.C. Frame Structure
2	Concrete Grade	M40
3	Steel Grade	FE 500
4	Plan Dimension	36 m X 36 m
5	No of storey	G+20
6	Floor to Floor Height	4 m
7	Beam	450 mm x 600 mm
8	Column	600 mm x 600 mm
9	Slab Thickness	200 mm
10	Outrigger Type – Shear Wall	150 mm
11	Shear Wall	150 mm

Table 2: Ground motion Characteristics

Sr. No.	Earthquake	Magnitude
i.	North East India (1986)	4.5
ii.	India-Bangladesh Border (1988)	5.8
iii.	India-Burma Border (1988)	7.2
iv.	Uttarkashi (1991)	7
v.	Chamoli (1999)	6.6

V. Position of outrigger

After modelling modal analysis of conventional structure with core is done for G+20. From analysis the first 3 mode shapes are considered and outrigger are positioned where larger modal displacement is observed. **Figure 4.13** shows the first three mode shape of G+20 building with core.



1st mode shape 2nd mode shape 3rd mode shape

Figure 2: Mode shapes of G+20 storey building

From the modal analysis of all storeys we get the floors where larger modal displacement is observed for. Outriggers are placed on these floors

For G+20

- 1st mode - 20
- 2nd mode - 8, 20
- 3rd mode - 5,13, 20

The relative position of hybrid outrigger system is studied on G+20 storey models, Total 8 models are made i.e. for G+20 storey Frame, FWC, 20 FC 1, 20 FC 2, 20 FC3, 20 FC 4, 20 FC 5 and 20 F 6.

Table 3: Relative outrigger position of 10, 20 and 30 storey models

No of storey	Mode shape		Abbreviation	CO	VO
20			Frame	-	-
			FWC	-	-
	1st	20	20 FC 1	20	-
			20 FC 2	-	20
	2nd	20,8	20 FC 3	20	8
			20 FC 4	8	20
	3rd	20,13,5	20 FC 5	20,5	13
			20 FC 6	13	20,5

VI. Modeling of Outrigger structure

Modelling of all structures are carried out by using ETABS 2016. The symmetrical building is of storey height 4 m. The structure plan dimensions are 36 m x 36 m is same for all buildings. For modelling **Table 1.** building parameters are used.

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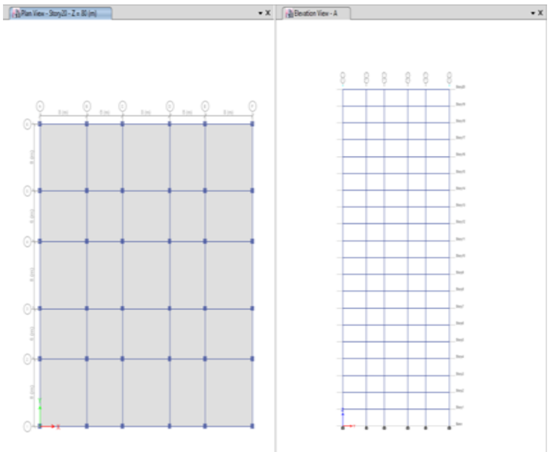
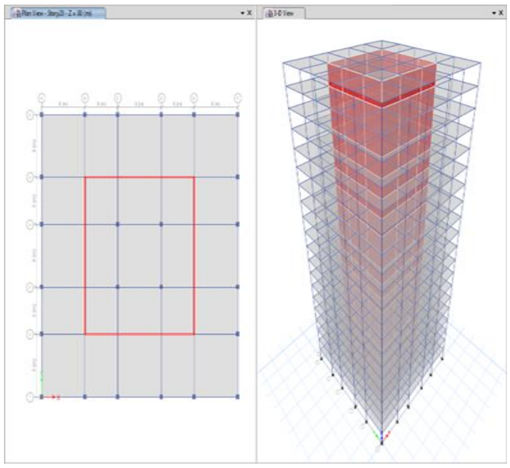
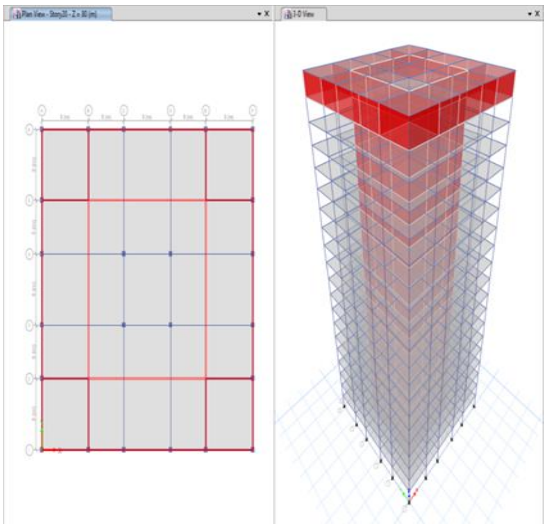


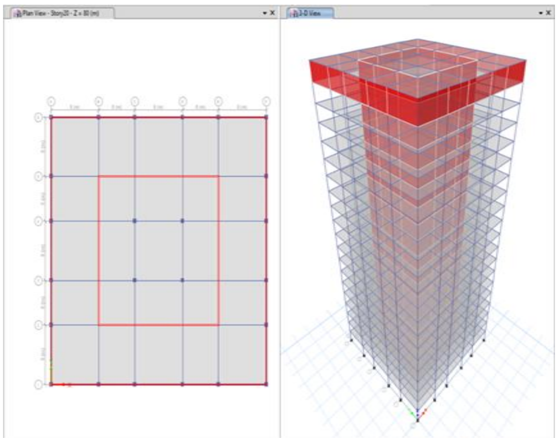
(a)Frame



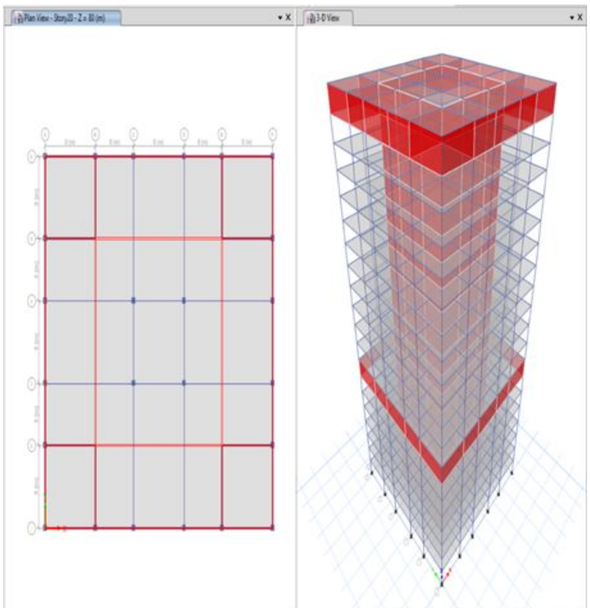
(b) FWC

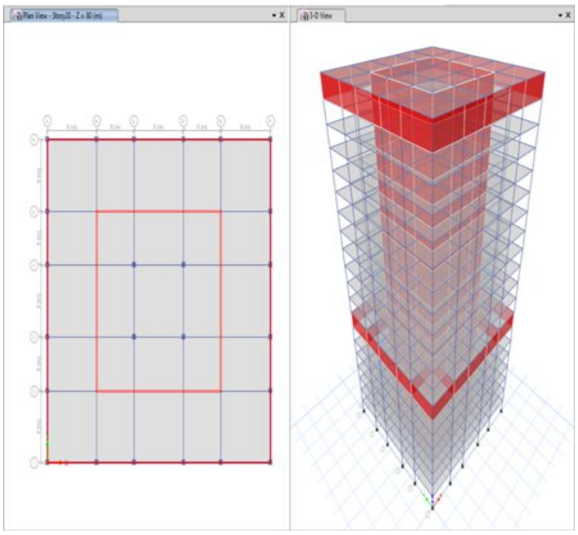


(c) 20 FC 1

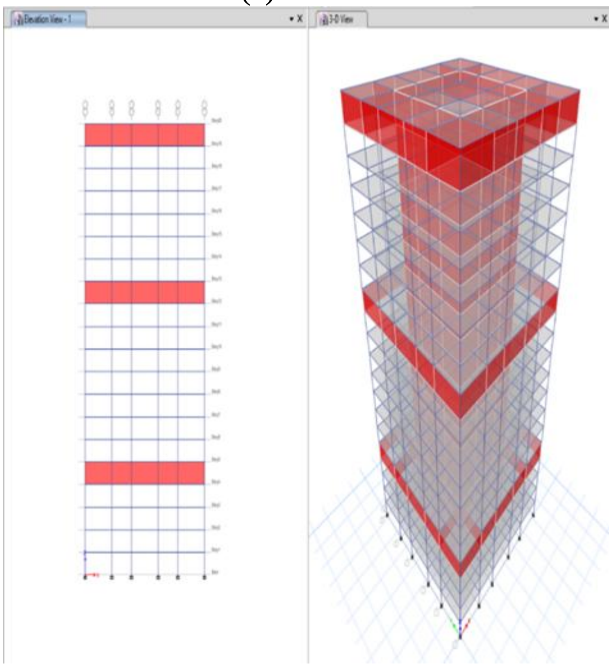


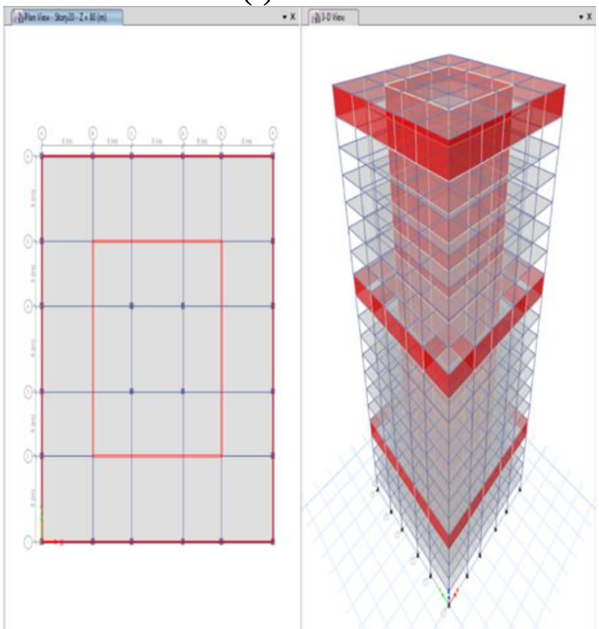
(d) 20 FC 2





(e) 20 FC 3 (f) 20 FC 4





(g) 20 FC 5 (h) 20 FC 6

Figure 3: Hybrid outrigger models of G+20 storey building

VII. Results and Discussion

a) Time Period

Table. 4 and Fig. 4 show time period of conventional structure with and without core and hybrid outrigger structures. Following Fig. 6 to Fig. 10 shows Story displacement and Fig. 11 to Fig. 154 shows storey drift reduced when compared with building without hybrid outrigger system. Table 5. and Table 6. Shows maximum Storey displacement and maximum storey drift.

FRAME	3.349
FWC	1.515
20 FC 1	1.429
20 FC 2	1.483
20 FC 3	1.349
20 FC 4	1.299
20 FC 5	1.252
20 FC 6	1.259

Table 4: Time period

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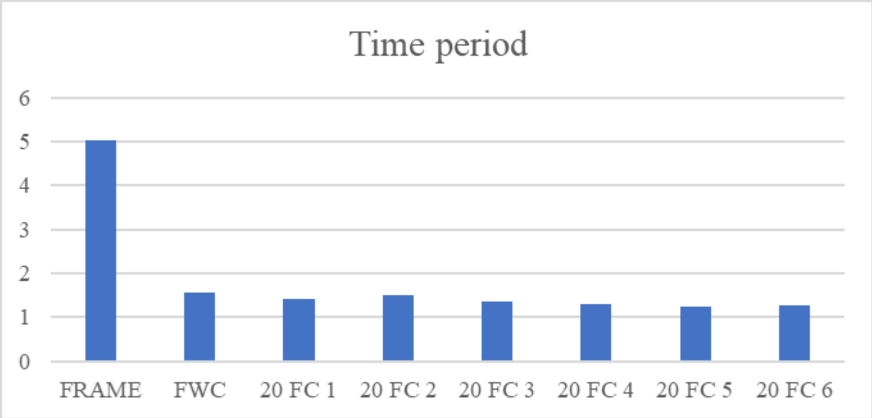
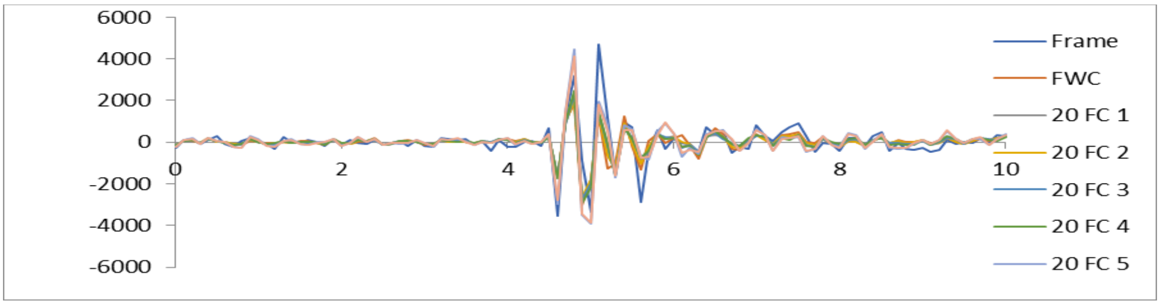


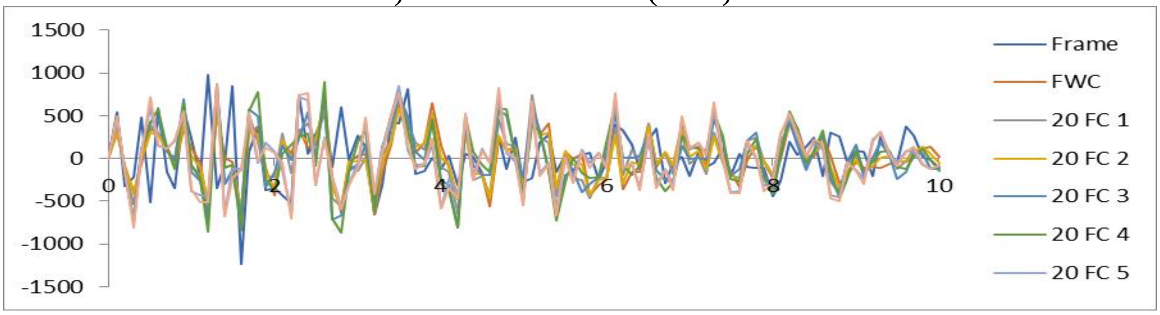
Figure 4: Fundamental time period for G+20

b) Acceleration-Time Graph

From **Figure 5** of acceleration-time graphs of Frame, FWC, 20 FC 1, 20 FC 2, 20 FC3, 20 FC 4, 20 FC 5 and 20 FC 6 it is observed that during earthquake acceleration of frame structure without core is more than that of other structures. Building with hybrid outrigger structure experiences less acceleration because of the presence of core and outriggers which provides enhanced lateral stiffness and resistance to lateral loads.



a) North East India (1986)



b) India-Bangladesh Border (1988)

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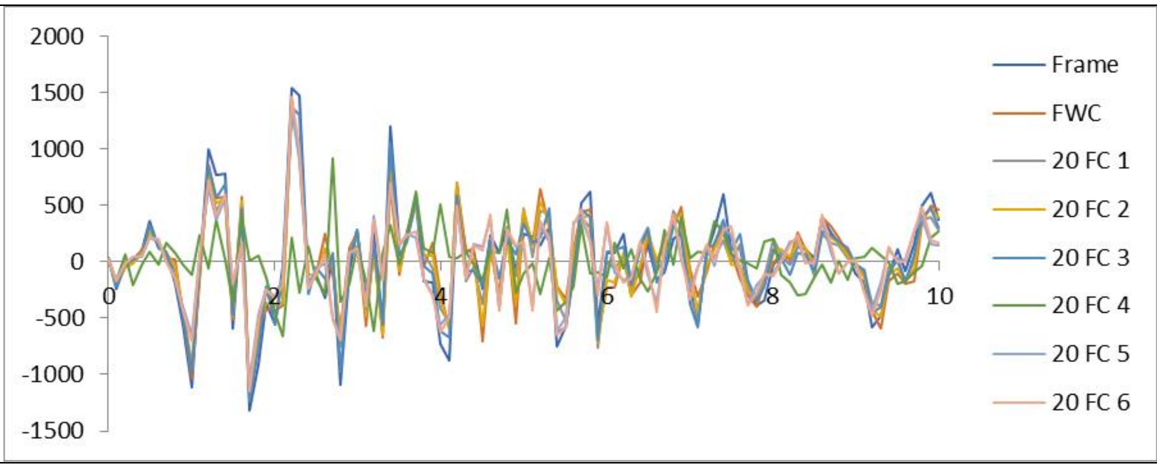
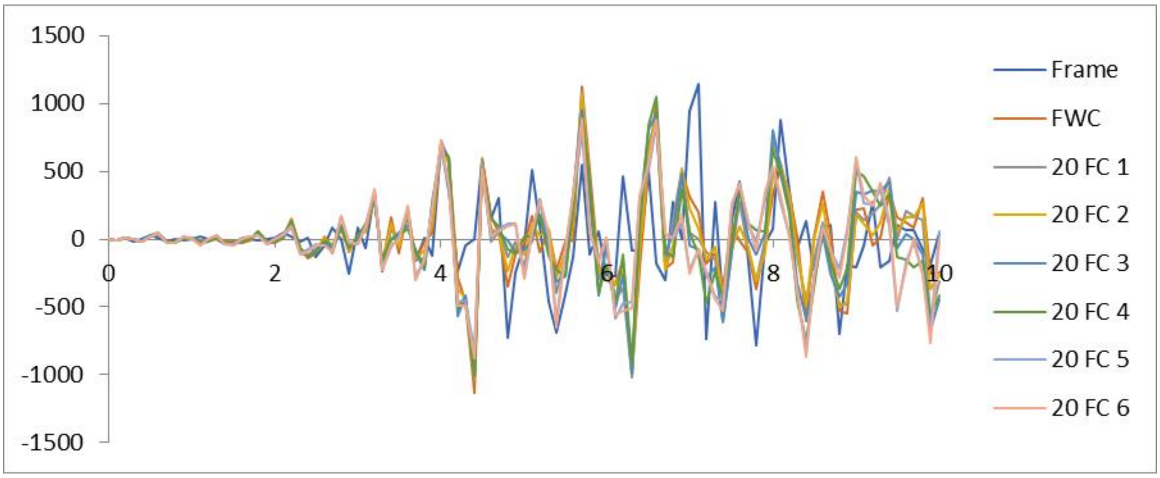
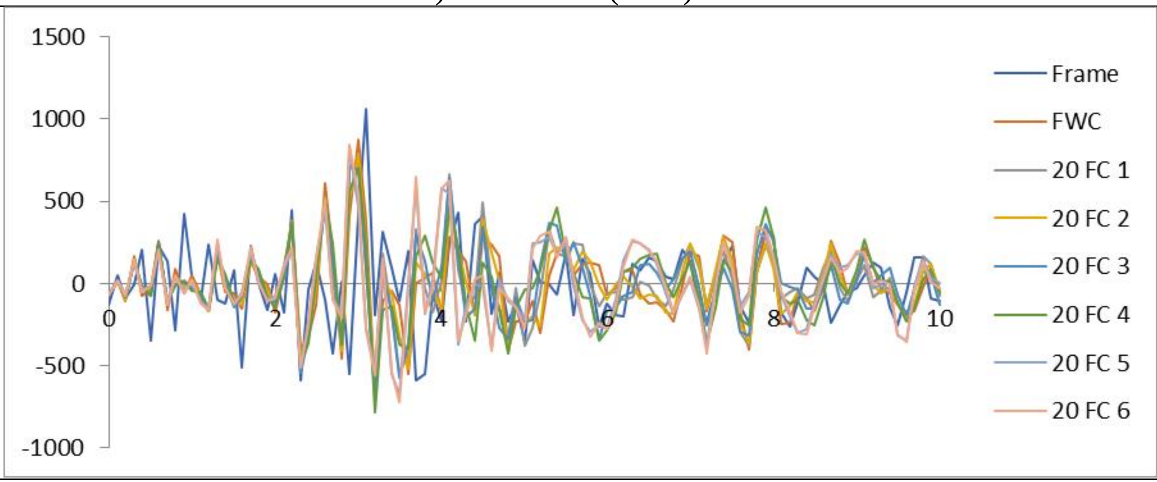


c) India-Burma Border (1988)



d) Uttarkashi (1991)



e) Chamoli (1999)

Figure 5: Acceleration-Time Graph (G+20)

c) Storry Displacement

From **Table 5** it is observe that 20 FC 5 (CO at 20th and 5th floor and VO at 13th floor) is preferred when displacement is critical factor in 20 FC 5 it is observed that displacement is reduced up to 62% compared with other hybrid outrigger combinations. Placing outriggers at the top and at intermediate levels allows for a more distributed stiffness along the height of the building. This configuration can help to distribute lateral loads more effectively, reducing displacement there can be a more direct load path for transferring lateral forces to the foundation, potentially reducing torsional effects and overall displacement.

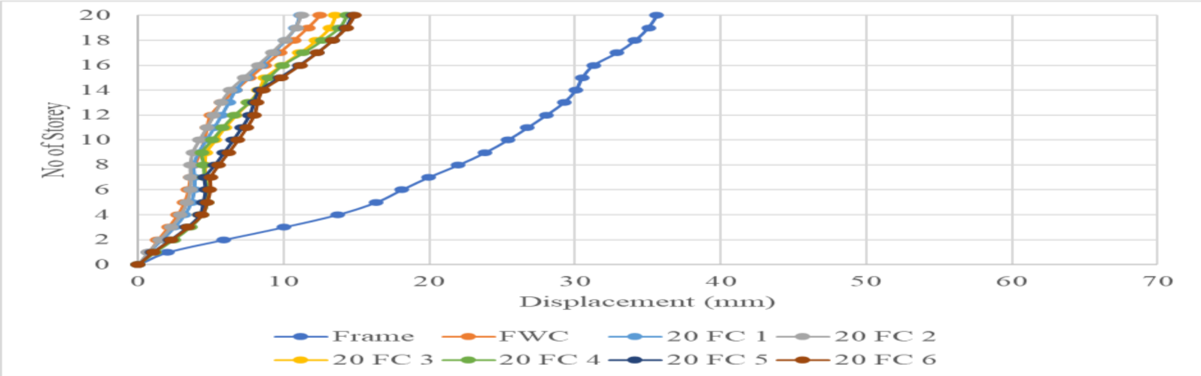


Figure 6: Storey displacement for North east India (1986)

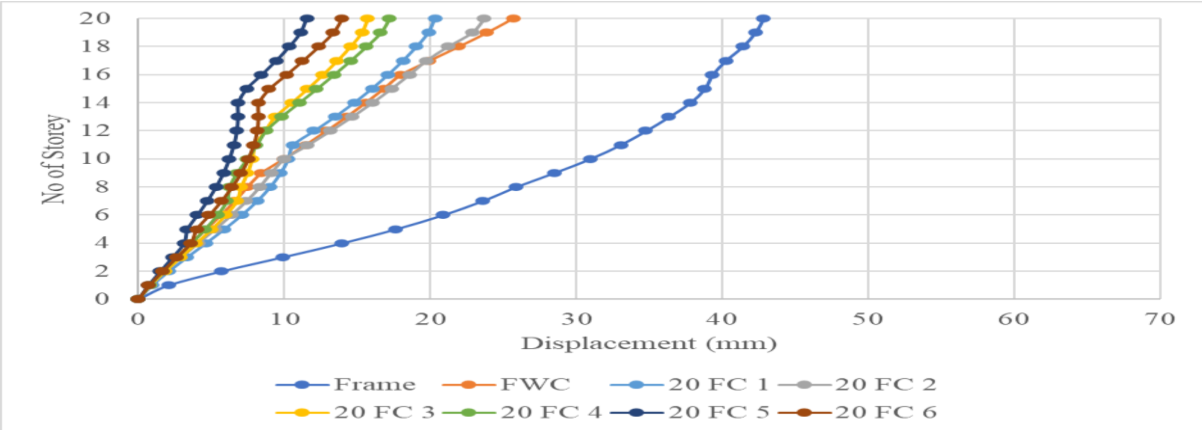


Figure 7: Storey displacement for India-Bangladesh Border (1988)

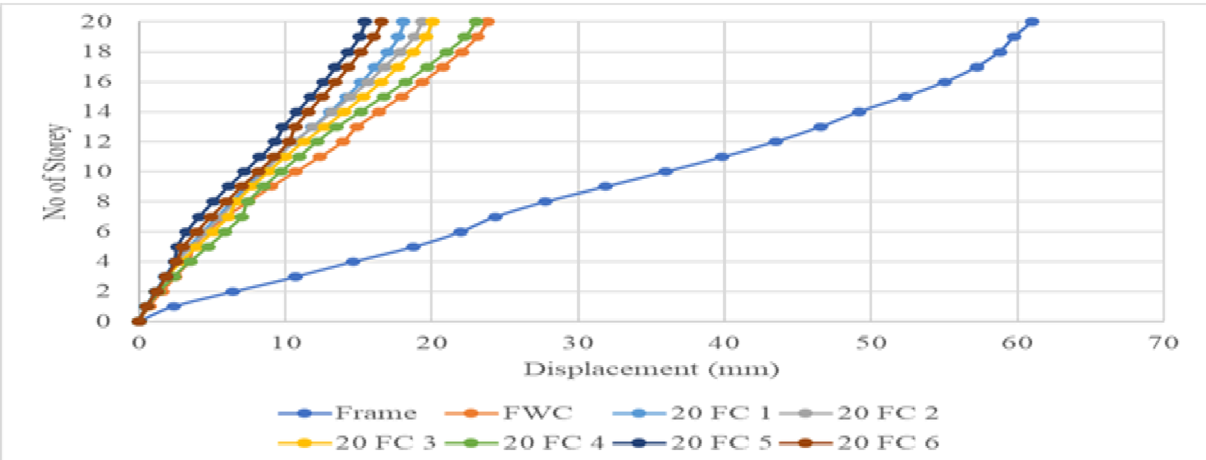


Figure 8: Storey displacement for India-Burma Border (1988)

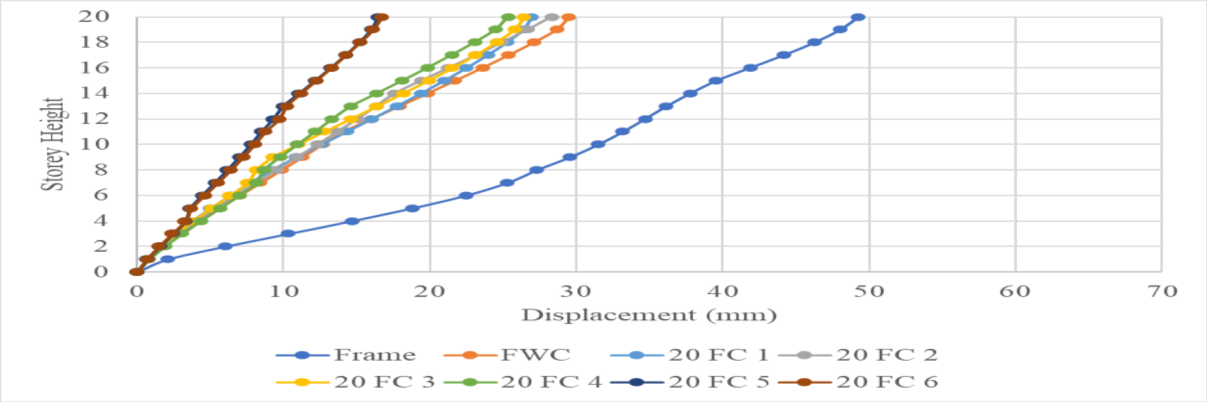


Figure 9: Storey displacement for Uttarkashi (1991)

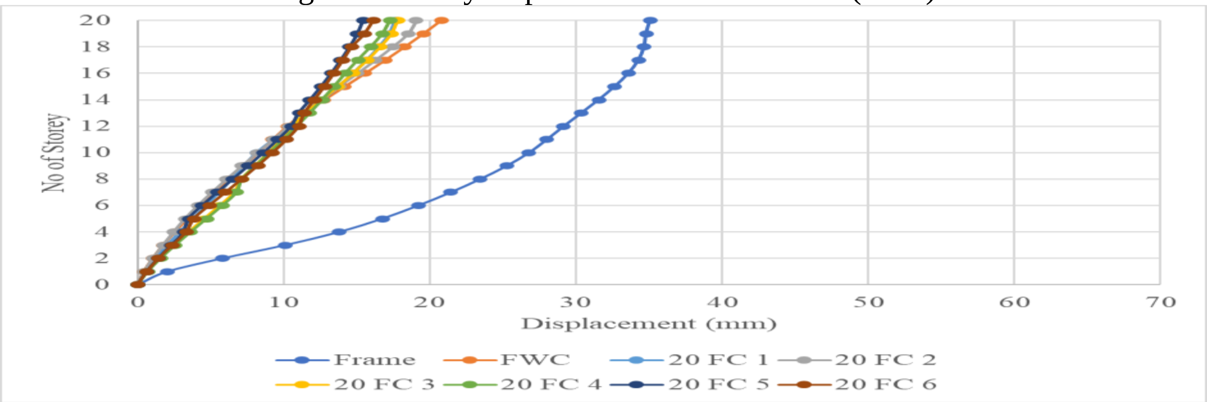


Figure 10: Storey displacement for Chamoli (1999

Table 5: Maximum displacement for G+20 building

Earthquake	Frame	FWC	20 FC 1	20 FC 2	20 FC 3	20 FC 4	20 FC 5	20 FC 6
NE India (1986)	35.642	12.52	**11.14**	11.25	13.54	14.35	14.75	14.89
India-Bangladesh Border (1988)	42.819	25.682	20.32	23.72	15.73	17.20	**11.54**	13.95
India-Burma Border (1988)	61.0029	23.8073	18.07	19.316	20.044	22.997	16.572	**15.436**
Uttarkashi (1991)	49.290	29.512	26.97	28.34	26.44	25.36	**16.47**	16.724
Chamoli (1999)	35.0768	20.76	17.60	19.07	17.77	17.277	**15.42**	16.138

d) Storey Drift

From **Table 6** it is observe that 20 FC 5 (CO at 20th and 5th floor and VO at 13th floor) is preferred when storey drift is critical factor in 20 FC 5 it is observed that storey drift is reduced up to 66% compared with other hybrid outrigger combinations. Placing outriggers at both top and an intermediate level distributes the stiffness along the height of the building. This helps to distribute lateral loads more evenly, reducing drift. The stiffness provided by the conventional outrigger at the 20th and 5th floor helps to resist lateral forces, thereby reducing the overall drift of the building.

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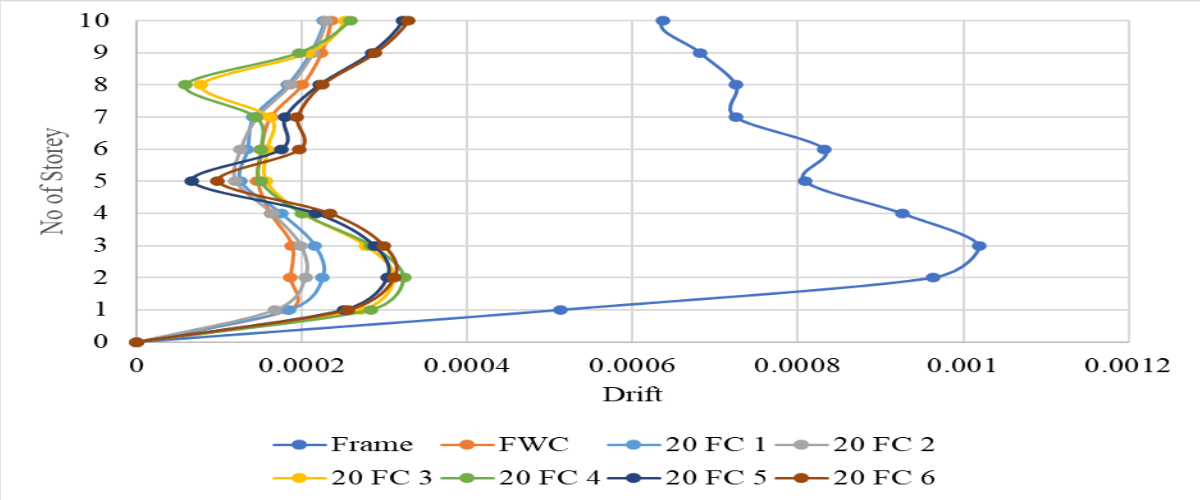

Figure 11: Storey drift for North east India (1986)

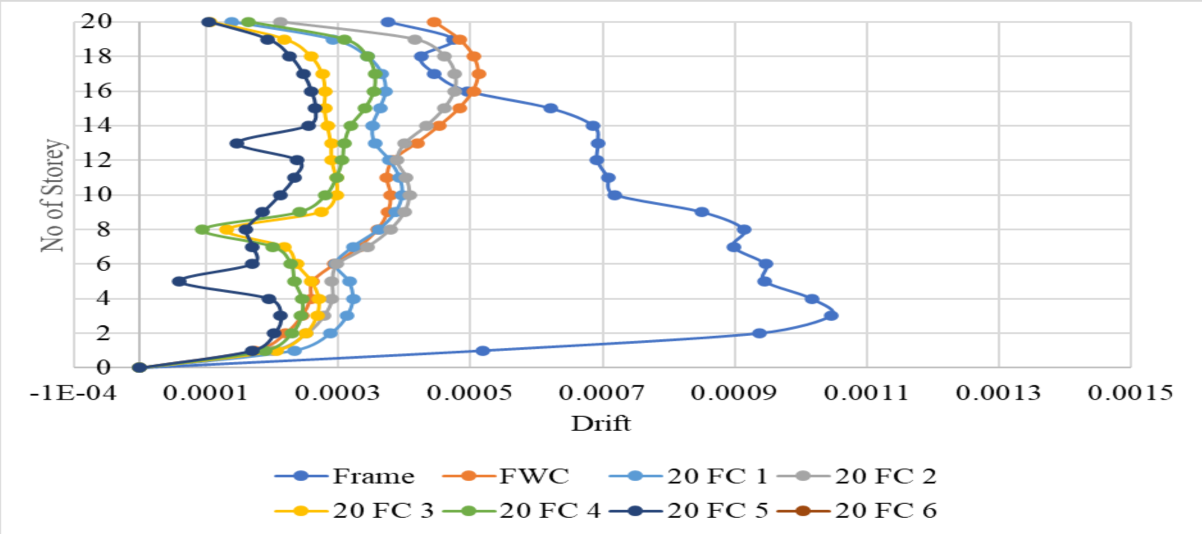

Figure 12: Storey drift for India-Bangladesh Border (1988)

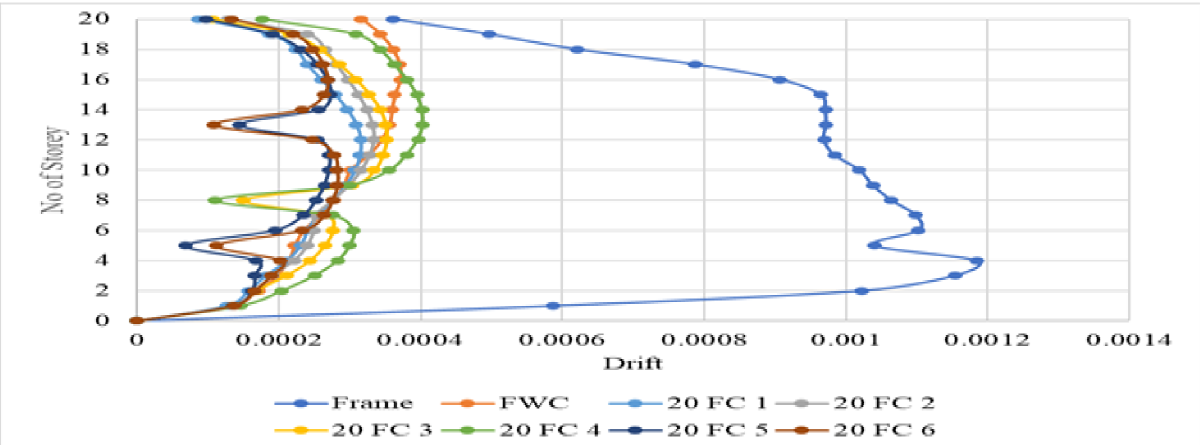

Figure 13: Storey drift for India-Burma Border (1988

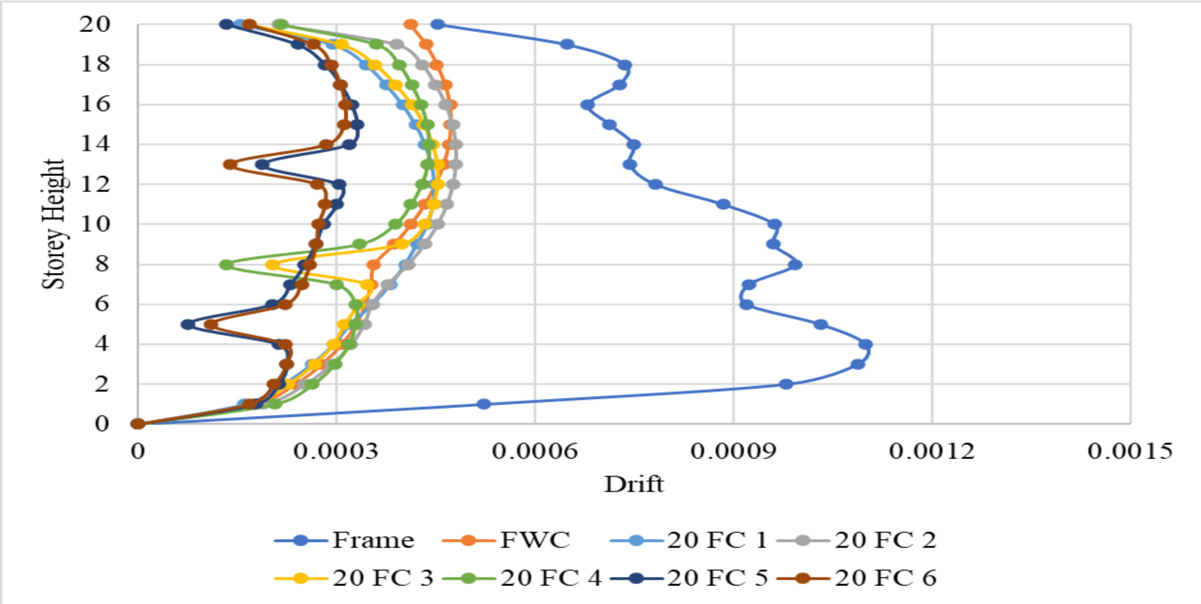

Figure 14: Storey drift for G+20 Uttarkashi (1991)

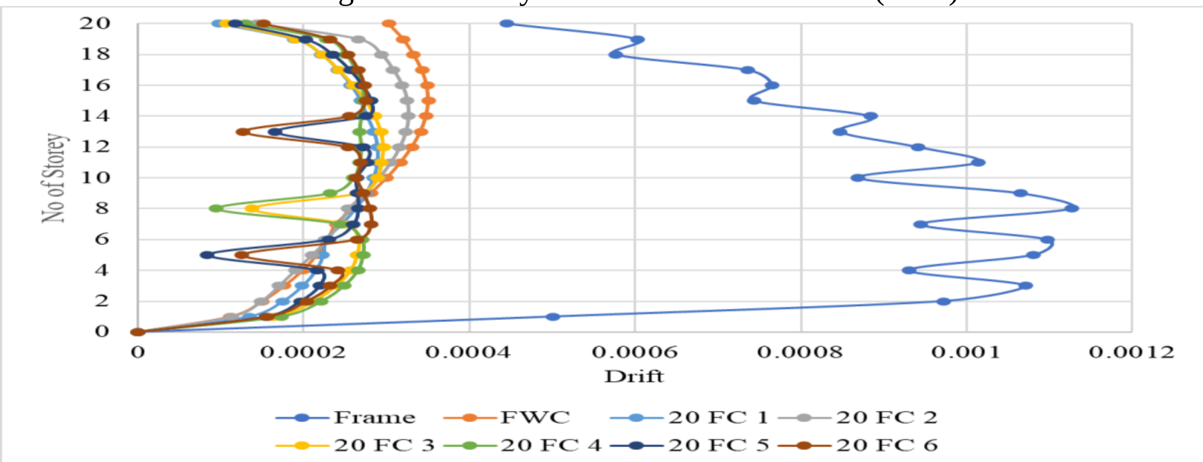

Figure 15: Storey drift for Chamoli (1999)

Table 6: Maximum storey drift for G+20 building

Earthquake	Frame	FWC	20 FC 1	20 FC 2	20 FC 3	20 FC 4	20 FC 5	20 FC 6
NE India (1986)	0.0010 1922	0.0002 57	**0.0002 398**	0.0002 421	0.0003 296	0.0003 637	0.0003 504	0.0003 355
India-Bangladesh Border (1988)	0.0010 45795	0.0005 125	0.0003 869	0.0004 763	0.0002 97	0.0003 551	**0.0002 591**	0.0002 898
India-Burma Border (1988)	0.0011 84303	0.0003 708	0.0003 15	0.0003 34	0.0003 51	0.0004 03	0.0002 73	**0.0002 68**
Uttarkashi (1991)	0.0010 99616	0.0004 7286	0.0004 479	0.0004 80	0.0004 5256	0.0004 3981	0.0003 307	**0.0003 12**
Chamoli (1999)	0.0011 2598	0.0003 50425	0.0002 88362	0.0003 25886	0.0002 95945	0.0002 81	**0.0002 7138**	0.0002 80543

VIII. Conclusions

This study aims to explore the comparative analysis of conventional structure with and without core and hybrid outrigger structure to enhance seismic resilience in structures. The modal analysis is done and first three modes are taken then outriggers are placed where large modal displacement is observed, where CO and VO are installed alternately in a building. Through time-history analyses, it evaluates key structural responses like acceleration time graph for all ground motions, storey displacement, storey drift and base shear. Additionally, the study investigates the optimal position of hybrid outriggers system in a building.

Hybrid outrigger system has a remarkable effect on reducing the storey displacement and storey drift of building.

Following conclusions are drawn:

- According to analysis of conventional structure with and without core, displacement and drift values are minimum and base shear is maximum in case of structure with core.
- Time period increases with increase in height of structure. As the height of structure increases displacement, drift and Base shear increases for all three structural systems.
- For G+20 storey, optimum position of outrigger at 20 FC 5 i.e. Core Outrigger at 20th and 5th floor and virtual outrigger at 13th floor. Displacement reduces up to 62%.
- From this project it is found that if we try to control 3rd mode shape it reduces effective displacement, 20 FC 5 is best hybrid configuration in best for building means first CO then VO and again CO.

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