COMPARISON OF SEISMIC PERFORMANCE OF OUTRIGGER AND BELT TRUSS SYSTEM IN A RCC BUILDING WITH VERTICAL IRREGULARITY

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Abstract

Height of the building is one of the important factor which restricts its upward movement. Today, tall buildings are inevitable in urban cities. So, the structure requires an efficient system which can actively participate in the event of wind and earthquake. One such type of system is outrigger-belt truss system. The main objective of this research is to compare models with outrigger, belt truss and outrigger with belt truss in which their position remains constant in all the models. A 30-storey structure with vertical irregularity is subjected to seismic analysis as per IS 1893 (Part-1): 2002 using finite element software ETABS and compares the parameters such as base shear, lateral displacement and storey drift. Seismic analysis using equivalent static and response spectrum method has been performed. This paper aims in concluding the efficient lateral load resisting system.

Key Words: *Outrigger,Belt truss, Tall building, Vertical Irregularity , Lateral displacement, Base shear, Storey drift, ETABS*

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1. INTRODUCTION

The growthof tall building is rapidly rising in India andworldwide. In large cities where the population is growing togetherwith a need of accommodation, tall buildings are inevitable. As the height of building increases, it is very difficult to control the parameters such as storeydrift and lateral displacement. Then there must be systems that withstand the lateral loads acting on the tall structure. One such type of system is outrigger and belt truss system.

1.1. Outrigger System

Outrigger system is a type of lateral load resisting system which consists of core and outriggers. This is one of the most efficient systems used for high rise construction to resist forces caused by wind and earthquakes. Outriggers will bedeep and stiff. They connect core to exterior columns which aid in keeping the columns in their position at the same

time limits the sway. While comparing the system with freely standing core without outriggers, this system helps in reducing the movement of the core. The incorporation of outrigger reduces the lateral drift at top. The connection of outrigger beams to the core and external columns are relatively more complicated and performance of such type of system primarily depends on adequate stiffness and strength of the outrigger beams. Therefore overall rigidity is of vital importance in tall buildings in order to control lateral deflection and inter-storey drift.

1.2 Belt Truss System

The belt truss will tie together all the external columns located at theperiphery of the structure. The outriggers connect these belt trusses to the central core of thestructure thus inhibiting the periphery columns from experiencing rotation and help the entire structure to act as a single unit. A 3D view of outrigger and belt truss system is shown in below fig 1

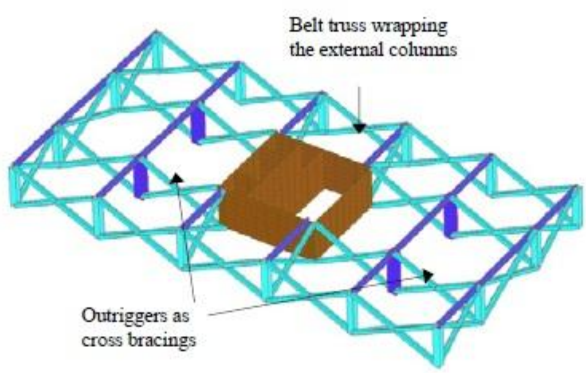


Fig -1: 3D view of outrigger and belt truss[15]

1.3 Structural Behaviour of Outrigger

The buildings will tend to rotate due to torsion under a lateral load. However, with the addition of outrigger to the structure, the outrigger will resist the rotation of the core and hence displacement will be minimized when compared to the freely standing structure. When the core is subjected to forces, the stiffness against overturning of the core is achieved by developing a tension-compression couple in perimeter columns gaining a restoring moment and it acts on the core at the outrigger level. The outrigger arm is hinged to the exterior columns which improves the performance of the system and will improve the moment-resisting capacity of the core. Since the connections are hinged, there will be no bending moment in the column, which in turn will increase the axial capacity of the columns. The structural behaviour of outrigger and its force transfer is shown in fig 2 and 3.

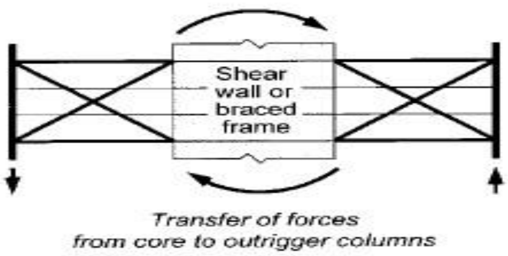


Fig -2:Force transfer in conventional outrigger system[13]

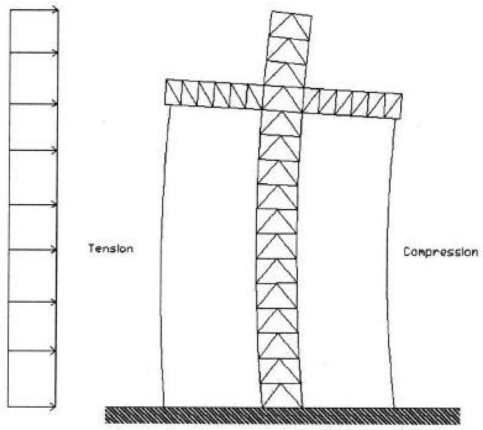


Fig-3:Structural behavior under loading condition[14]

2. LITERATURE REVIEW

Karthiket.al [1], done a study on optimizing the position of outrigger system for tall vertical irregular structures and concludes that optimum position of outrigger is at mid height of the structure.Mistry and Dhyani[2] conducted a study on optimum outrigger location in outrigger structural system for high rise building and suggested that the 1st outrigger location was determined to be at mid height, 2nd outrigger to be at at 1/4th height, 3rd outrigger location to be at 3/4th height of the structure. Nanduri et.al [3] studied on optimum position of outrigger system with belt truss for high-rise reinforced concrete buildings under earthquake loadings and found that the optimum location of the outrigger to be approximately at 0.5 times its height. Kogilgeri and Shanthapriya[4] done a study on the static and dynamic behaviour of outrigger system on high rise steel structure by varying outrigger depth.Karthiket al [5] carried out a research to determine the the optimum position of outrigger system and belt truss for tall vertical irregular structures subjected to lateral loads and showed that the optimum position of outrigger is at mid height of the structure. Sathyanarayananet al [6] checked the feasibility studies on the use of outrigger system for RC core frames by providing outriggers for single bay frame at single level and two levels. KiananandSiahaan [7] studied the use of outrigger and belt truss system for high-rise concrete buildings subjected to earthquake load. Herath [8] examined the optimum location of outrigger beams in high rise buildings under earthquake loads and concluded that the optimum outrigger height for the building from the base to be 0.44-0.48 times the total height for both earthquake and wind loads.

3. ANALYTICAL PROGRAM

Theanalytical program consists of a RCC outrigger with belt truss structure, 30 story (90 m height), and analysis was carried out in accordance with IS 1893 (Part I):2002. The structure modelled is a hypothetical building. Although the structure modelled was a hypothetical structure, the plan, the section properties and other parameters chosen resembles a real building. The building designed was subjected to gravity load as well as earthquake load and the structure was analysed using ETABS v15. Equivalent static analysis and response spectrum analysis has been carried out for the models.

3.1 Model

The model is vertical irregular shaped with unsymmetrical plan with base dimensions 35x35m shown in fig 4. In all models slab spans were assumed to be 5m, arranged in seven bays in each direction for storeys 1-10, five bays for storeys 11-20, three bays for storeys 21-30. The plan has a 5x5 central core opening provided in the middle of building, surrounded by columns, with a thickness of 250 mm and the thickness is constant throughout building height. The columns and beams were representedby frame type element, slabs by membrane and the shear walls by shell type components. The slab in the model was taken as a 2 way slab. The columns, beam sections, slab sections, shear wall thickness, outrigger and belt truss properties were kept constant throughout building height. The outrigger and belt truss system were provided at storeys 15 and 29. This optimum location for the outrigger and belt truss were obtained from literature reviewed[1].

Table -1:Model data

Structure	SMRF
Number of stories	G+29
Type	Vertical irregular
Column to Column spacing	
In X-direction	5m
In Y-direction	5m

Bay size (Nos)	Storey	1-10	7	7
		11-20	5	5
		21-30	3	3
Storey height			3m	
Support condition			Fixed	
Slab thickness			150mm	
Infill wall thickness			200mm	
Outrigger diameter(solid steel pipe)			300mm	
Shear wall thickness			250mm	
Column size			750 x 750mm	
Beam size			300 x 450mm	
Grade of concrete			M30	
Grade of steel			Fe500	
Grade of outrigger and belt truss			Fe345	
Live Load				
Regular Floors			3 kN/m^2	
Terrace Floor			2 kN/m^2	
Superimposed Dead Load				
Regular Floors			1 kN/m^2	
Terrace Floor			2 kN/m^2	

Earth Quake Load (IS 1893(Part 1): 2002) :
Zone IV – 0.24
Importance factor – 1
Type of soil – Medium Soil (II)
Reduction Factor – 5
Mass Source Definition
Dead Load - 1
Floor Finish- 1
Live Load- 0.25

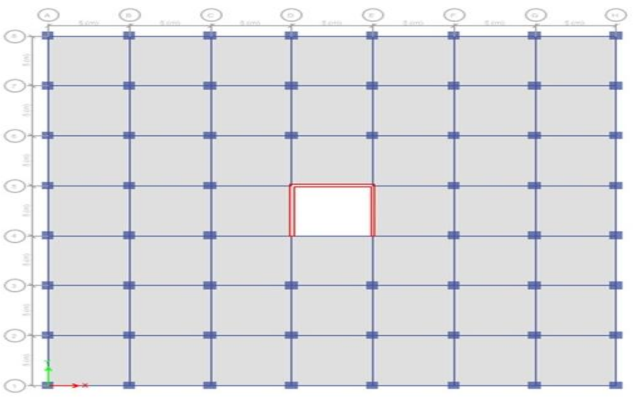
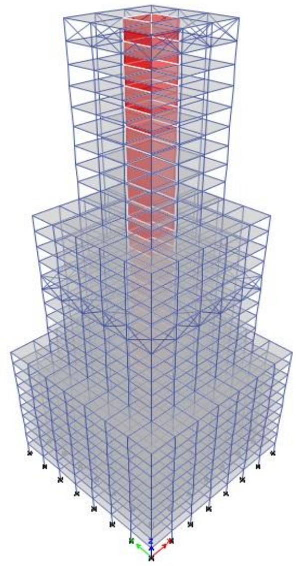
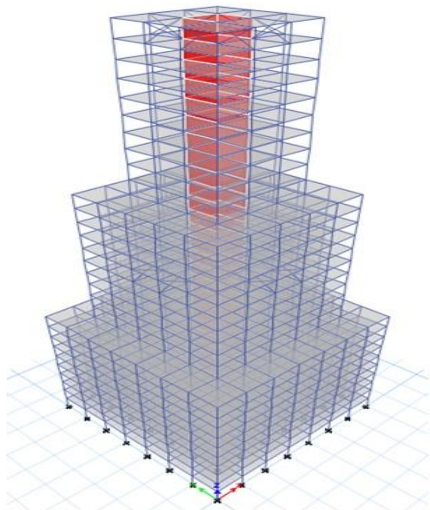


Fig -4:Plan of the structure

3.2 Modelling Arrangements

MODEL 1: Outrigger with Belt Truss (OB)
MODEL 2: Outrigger only (O)
MODEL 3: Belt Truss only (B)





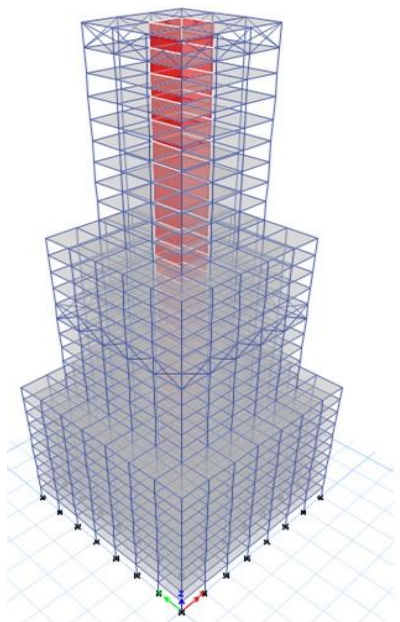


Fig-5: 3D view of model 1 **Fig-6**: 3D view of model 2**Fig-7**: 3D view of model 3

4. RESULTS AND DISCUSSIONS

4.1BaseShear

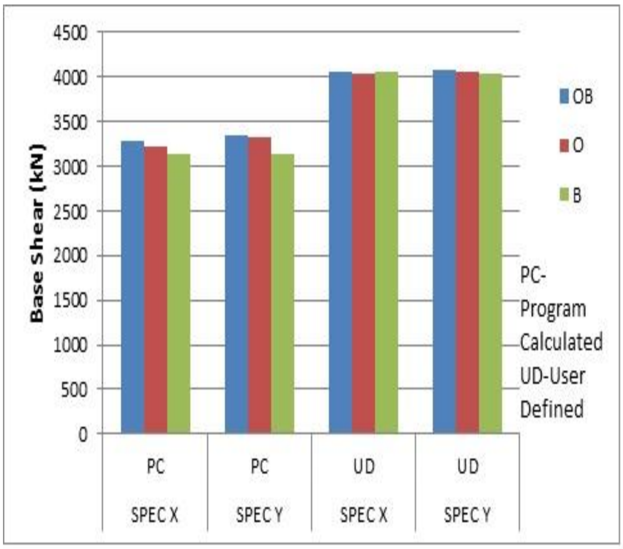


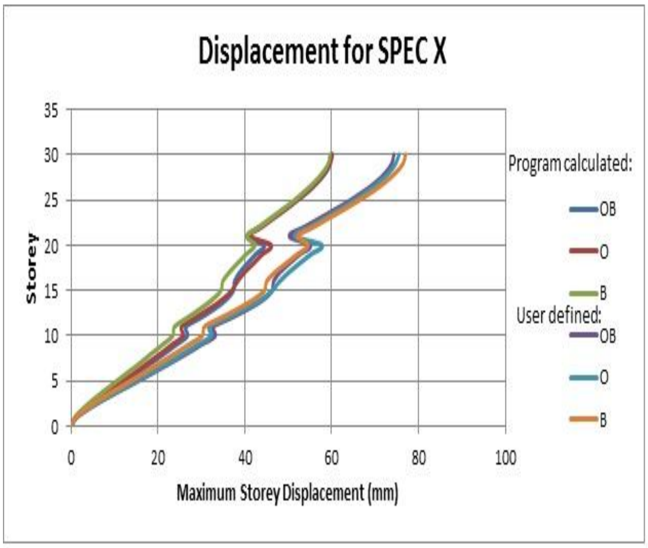
Chart -1:Base Shear for three models subjected to earthquake loads in X and Y direction (PC and UD)

Table -2: Base shear

Models	Base Shear (kN)			
	Program Calculated		User Defined	
	SPEC X	SPEC Y	SPEC X	SPEC Y
1	3286.969	3347.469	4064.801	4084.526
2	3221.615	3324.836	4039.409	4050.255
3	3139.214	3141.939	4050.599	4035.518

- There is an increase in base shear value when user defined time period is used compared to program calculated time period.
- For both program calculated and user defined time periods, the base shear is more in Y-direction.
- The maximum base shear for program calculated and user defined time period is 3286.96 kN and 4064.8 kN respectively (X-direction) for model 1.
- The maximum base shear for program calculated and user defined time period is 3347.47 kN and 4084.52 kN respectively (Y-direction) for model 1.
- The minimum base shear for program calculated and user defined time period is 3139.21 kN and 4050.59 kN respectively (X-direction) for model 3.
- The minimum base shear for program calculated and user defined time period is 3141.94 kN and 4035.51 kN (Y-direction) for model 3.

4.2 Lateral Displacement



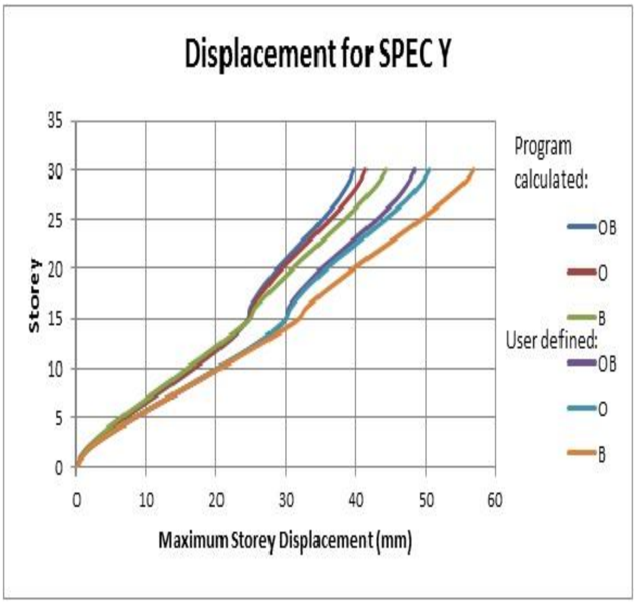


Chart-2:Comparison of storey displacement for different models along X and Y direction

- There is an increase in displacement range when user defined time period was insertedcompared to program calculated time period.
- For both program calculated and user defined time periods, the displacement is morein X-direction.
- The maximum displacement for program calculated and user defined time period is60.2 mm and 77 mm for model 1 and 3 respectively (X-direction).
- The maximum displacement for program calculated and user defined time period is44.3 mm and 56.8 mm respectively for model 3 (Y-direction).
- The minimum displacement for program calculated and user defined time period is59.6 mm and 74.3 mm for model 3 and 1 respectively (X-direction).
- The minimum displacement for program calculated and user defined time period is39.7 mm and 48.4 mm respectively for model 1 (Y-direction)

4.3 Storey Drift

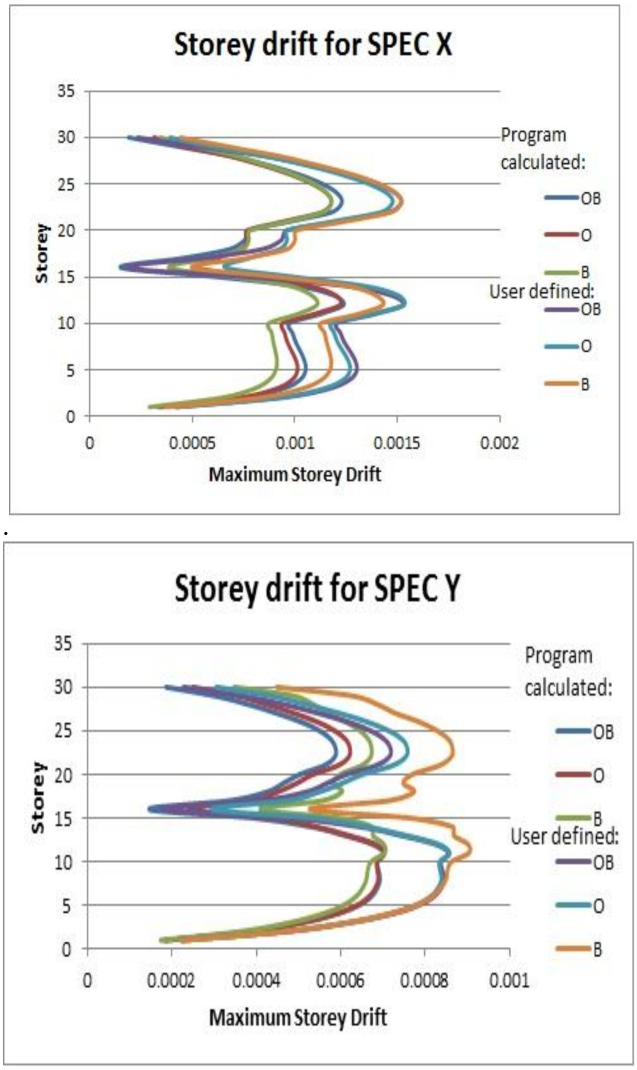


Chart-3:Comparison of storey drift for different models along X and Y direction

4.4 Lateral Loads

- There is an increase in drift range when user defined time period was inserted compared to program calculated time period.
- For both program calculated and user defined time periods, the drift is more in Xdirection except belt truss in Y-direction.
- The maximum drift for program calculated and user defined time period is 0.000344 and 0.000444 respectively for model 3 (X-direction).
- The maximum drift for program calculated and user defined time period is 0.000348 and 0.000448 respectively for model 3 (Y-direction).
- The minimum drift for program calculated and user defined time period is 0.000189 and 0.000233 respectively for model 1 (X-direction).
- The minimum drift for program calculated and user defined time period is 0.000186and 0.000227 respectively for model 1 (Y-direction).

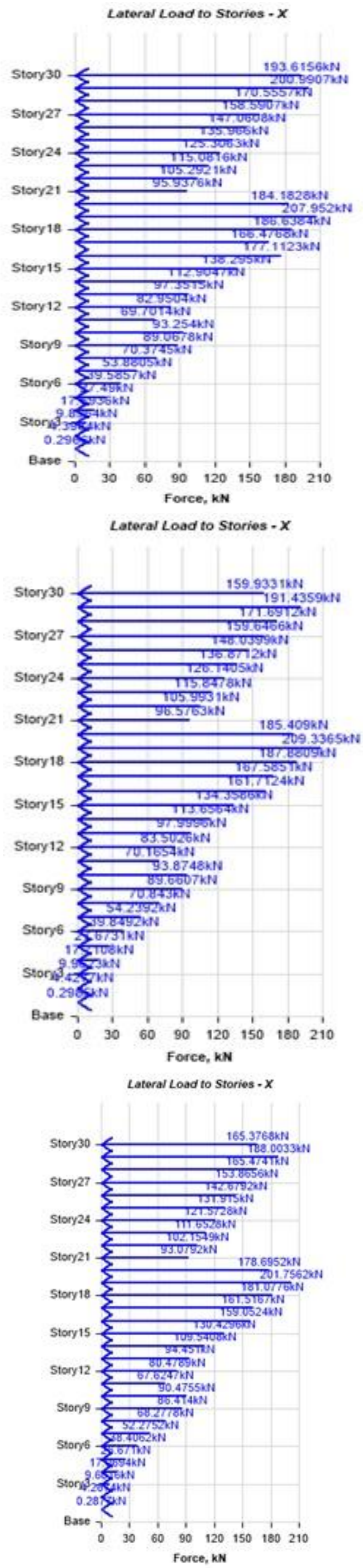


Chart -4: Lateral loads for three models in X-direction for program calculated time period

Chart -5: Lateral loads for three models in Y-direction for program calculated time period

Chart -6: Lateral loads for three models in X-direction for user defined time period

Chart -7: Lateral loads for three models in Y-direction for user defined time period

5. COMPARATIVE STUDY

A comparative study has been carried out for the three models on the basis of percentage increase with respect to maximum storey displacement, maximum storey drift and base shear and is shown in table 3

Table -3:Comparative Study of Models

	Percentage Increase (%)											
	X						Y					
	Program Calculated			User Defined			Program Calculated			User Defined		
	OB	O	B	OB	O	B	OB	O	B	OB	O	B
Maximum Storey Displacement (mm)	0.8	1	least	least	1.6	3.6	least	4.1	10.4	least	4.1	14.8
Maximum Storey Drift	least	39.4	45	least	40.4	47.5	least	25.6	46.6	least	25.6	49
Base Shear (kN)	4.5	2.6	least	0.6	least	0.3	6	5.5	least	1.2	0.4	least
Lateral Loads (kN)	21.1	least	3.4	20.3	least	6.8	21.11	least	1.5	20.3	least	6.8

6. CONCLUSIONS

- For uniformity in comparison and arriving at the conclusions, results of only program calculated time period is taken into consideration.
- With respect to base shear and lateral loads, building with only belt truss performs better than the building with only outrigger and building with both outrigger and belt truss system.
- The base shear is increasing by 2.6 % to 5.5 % for building with outrigger and 4.5 % to 6 % for building with outrigger with belt truss.
- With respect to lateral displacement, building with both outrigger and belt truss and belt truss system performs better than the building with only outrigger system.
- The displacement is increasing by 1 % to 4.1 % for building with outrigger.
- With respect to storey drift, building with both outrigger and belt truss system performs better than the building with only outrigger and building with belt truss system.
- The storey drift is increasing by 25.6 % to 39.4 % for building with outrigger and 45 % to 46.6 % for building with belt truss.
- Based on the above conclusions, it can be predicted that building with outrigger and belt truss performs better compared to the other two models.
- However, since building with outrigger and belt truss may be uneconomical and also reduces the working space, building with only belt truss can be chosen as the lateral load resisting element in buildings with vertical irregularity.

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