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# Optimum Shape and Position of Outrigger System for High Rise Building under Earthquake Loading

**Ritu Khandelwal, Raghvendra Singh**

***Abstract:*** ***The advancement of high rise building has been increasing on a large scale. In tall structures shear wall often resisted the lateral load induced by wind and earthquake but as the building height increases the stiffness of the structure reduces. To provide sufficient lateral stiffness of the structure implementation of outrigger system between the shear walls and peripheral columns is often used. The aim of this study is to identify the optimum shape of outrigger belt truss in tall buildings under earthquake load condition. A thirty storey with single belt truss, forty five storeys with two belt trusses and sixty storey with three belt trusses structure was investigated with three different shape outrigger belt truss that is X, V and N. The optimum location by providing single belt truss at 10th story, 15th story and at top story in thirty story building is considered in the analysis. From the analysis a comparative study are made with and without variation of shape of outrigger with belt truss with parameters likes storey displacement and storey drift under earthquake loading and get a optimum position of outrigger belt truss for thirty storey building with single belt trusses placing at different locations.***

***Keywords: Outrigger System, Earthquake load, Optimum shape and position of belt truss, Storey Drift, Lateral Displacement.***

## I. INTRODUCTION

When height of the building tremendously increases, the structure becoming more slender and this lead to possible sway and risk during the occurrence of lateral load and vertical load. The structure system such as moment resisting frames and braced core are not able to provide lateral stiffness against lateral load. The building should have lateral load resisting system other than shear walls for avoiding the effect of lateral loads, when only shear wall used in structure it is suitable upto 20 stories high. The outrigger structural system is one of such prominent, popular and efficient for the lateral loads resisting system. Outriggers are rigid horizontal structure that is truss or beam which connect the external column of the building with central core to improve building strength and overturning stiffness. In outrigger structural system the belt truss ties all the external columns on the periphery of the structure and the outrigger connect these belt trusses to the central core of the structure thus restraining the exterior columns from rotation. When the lateral forces acting on a building, the outrigger resist the rotation of the core and thus reduce the lateral displacement and base moment.

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* Correspondence Author
**Ritu Khandelwal***, Student Computer Aided Structural Designing and Drafting, Department of Civil Engineering, Ujjain Engineering College, Ujjain, M.P., India, Email: ritukhandelwal767@gmail.com
**Dr. Raghvendra Singh** Professor, Department of Civil Engineering, Ujjain Engineering College, Ujjain, M.P., India, Email: raghvendr@gmail.com



To increase stiffness action against wind and seismic load outriggers are provided by the shear core with exterior frames in tall structure.

Types of outrigger structure area as follows:
Conventional outrigger structure
Virtual outrigger structure

### A. Conventional outrigger Concept:

In this concept of conventional outrigger in tall buildings, the outriggers are directly connected to braced frames or shear wall at the core of the building. The location of column at the outer edges is not necessary. Conventional outrigger as shown in Fig.1

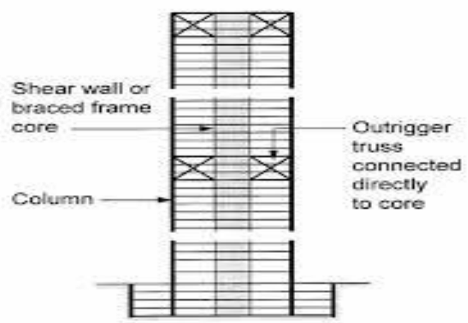


**Fig.1: Conventional Outrigger beam/truss Connected directly to Core**

### B. Virtual outrigger Concept:

In this concept the outriggers connecting core and and the peripherical column directly with the belt truss with a combination of stiff and strong diaphragms. The moment occurred in the core is converted in to horizontal couple in top and bottom of the floors of basement. Belt truss as virtual outrigger as shown in Fig. 2.

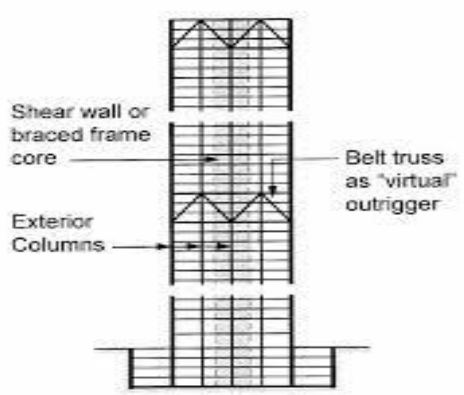


**Fig. 2: Belt Truss as Virtual Outrigger**

### C. Factors Affecting the Outrigger Structures

1. Geometry of tall building.
2. Floor to floor height of the tall building.
3. Location of belt truss system.
4. The stiffness of outrigger truss system.
5. Stiffness of central core system.

## II. OBJECTIVES OF STUDY

The objectives of present study are as follows :

- Analysis of high rise building without use of outriggers under earthquake loading.
- Analysis with the use of outriggers under earthquake loading.
- Analysis with the change of locations of outriggers in the building.
- Analysis with the change of shape of outriggers (X,V and N-Type) in the building.

## III. METHEDOLOGY

In the present study a three dimensional 30, 45 & 60-story RCC vertically regular building having symmetry along X and Y direction and square in shape is considered. RCC building having concrete shear wall as central core modeled in form of shell-thin with thickness of 400mm and concrete slab in form of membrane with thickness of 180mm. For the belt truss using ISA 200 X 200 X 12 steel section for X, V & N type bracing in belt truss. The structure having fixed support and all joints designed as perfectly rigid. The floor height is assumed to be 3m.Structure model having different size of beams and columns and other parameters used for the analysis are given in table no. 1 & 2. All the dimensions of the building used as per code IS 456-2000.

**Table 1: Parameters of the Structures**

| Sl. No. | Particulars | Model Data |
|---|---|---|
| 1. | Size of plan | 35mX35m |
| 2. | No. of Stories | 30 story, 45 story & 60 Story building |
| 3. | Type of Bracing | X, V & N Type Bracing |
| 4. | Size of Column | 900 mmX 900 mm & 1000 mm X 1000mm |
| 5. | Size of Beam | 450mm X 550mm |
| 6. | Belt Truss | ISA 200X200X12 |
| 7. | Size of Slab | 180 mm M-30 |
| 8. | Shear Wall | 400 mm M-40 |

**Table 2: Some of the parameters used for the analysis of building**

| Sl.No. | Particulars | Model Data |
|---|---|---|
| 1. | Analysis Type | Response Spectrum |
| 2. | Software Selection | ETABs |
| 3. | Data Analysis | Max. Displacement Value, Story Drift Rotation Value |
| 4. | Load Pattern | Live Load, Dead Load, $EQ_x$&$EQ_y$ |
| 5. | Zone Factor | IV Zone (Z=0.24) |
| 6. | Importance of Structure | 1 |
| 7. | Soil Type | II (Medium) |
| 8. | Type of Structure | RC Moment Resisting Building |

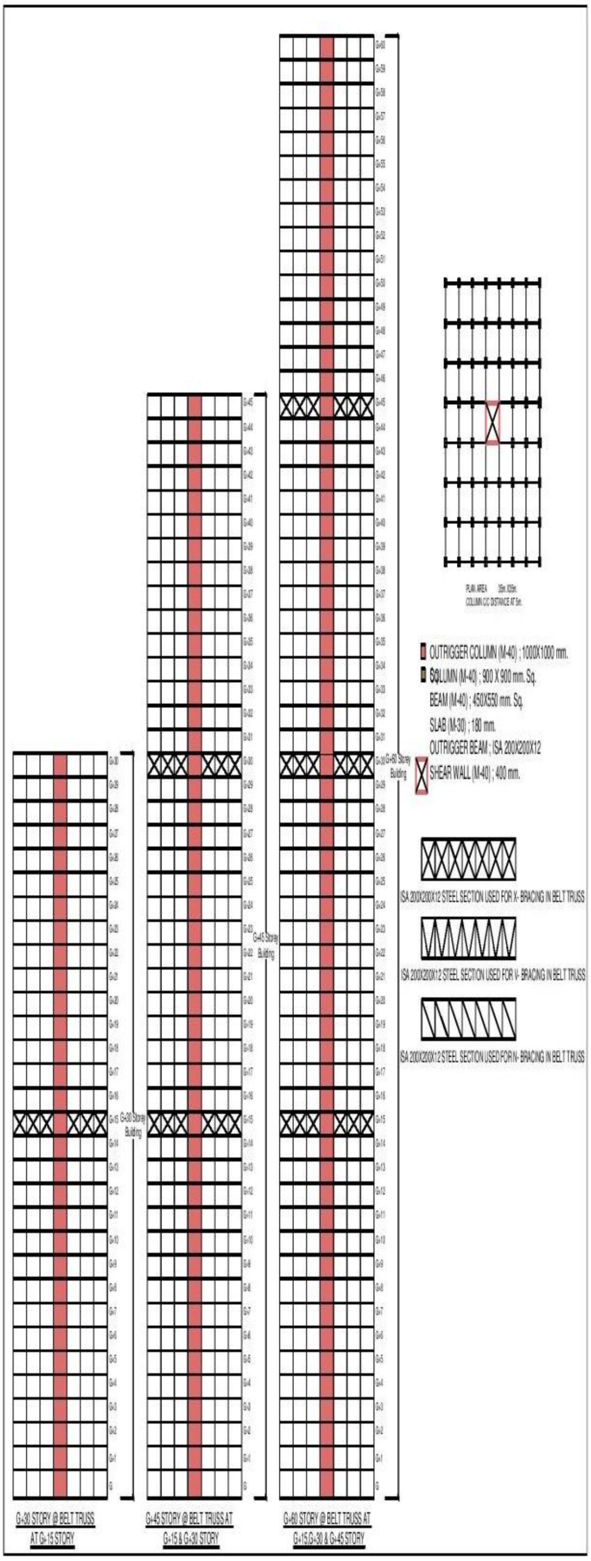


**Fig.3: Building view and storyplan with their details**

### D. Load Combination:

The design load and its combination areconsidered in the analysis as per provisions in IS code clause no. 6.3.1.2 of IS 1893 (Part I) : 2016, and limit state design of reinforced concrete structure, the following load combination is taken for the analysis of high rise building under earthquake loading is represented below:

1.5 (DL+LL)

1.2 (DL+LL +EL_X)

1.2 (DL+ LL –EL_X)

1.2 (DL+ LL +EL_Y)

1.2 (DL+ LL –EL_Y)

1.5 (DL+EL_X)

1.5 (DL–EL_X)

1.5 (DL+EL_Y)

1.5 (DL–EL_Y)

0.9 DL+1.5EL_X

0.9 DL–1.5EL_X

0.9 DL+1.5EL_Y

0.9 DL–1.5EL_Y

(DL denotes dead load plus floor finish load and EL_X/ EL_Y denotes earthquake load in X-direction and Y-direction respectively).

## IV. RESULTS

The results extracted from the analysis of high rise building with different shape outrigger with belt truss and without outrigger and belt positions using computer software ETABS (ver. 4.0) under earthquake loading. The descriptions of various prepared software models which includes story height, belt type, shape of outrigger and provision of belt truss at different levels considered for the analysis are listed below:

Model 1 (M1) considered analysis for a model with thirty story building without belt truss under earthquake loading

Model 2 (M2) considered analysis for a model with thirty story building with single belt truss under earthquake loading

Model 3 (M3) considered analysis for a model with forty five story building with double belt truss under earthquake loading

Model 4 (M4) considered analysis for a model with sixty story building with triple belt truss under earthquake loading

Provisions of belt truss at different levels in the building are included in the models (M1 to M4) as types from T1 to T5:

Type 1 (T1) : Belt truss at 10th story

Type 2 (T2) : Belt truss at 15th story

Type 3 (T3) : Belt truss at 30th story

Type 4 (T4) : Belt truss at 15th story and 30th story height

Type 5 (T5) : Belt truss at 15th story, 30th story and 45th story height

The shapes of outrigger are taken in the analysis as mentioned in C1 to C2:

Case 1 (C1) : X, V & N - Shape outrigger belt

Case 2 (C2) : X- Shape outrigger belt

The position and shapes of the belts considered in the analysis of high rise building under case 1 as represented by Figure 4.

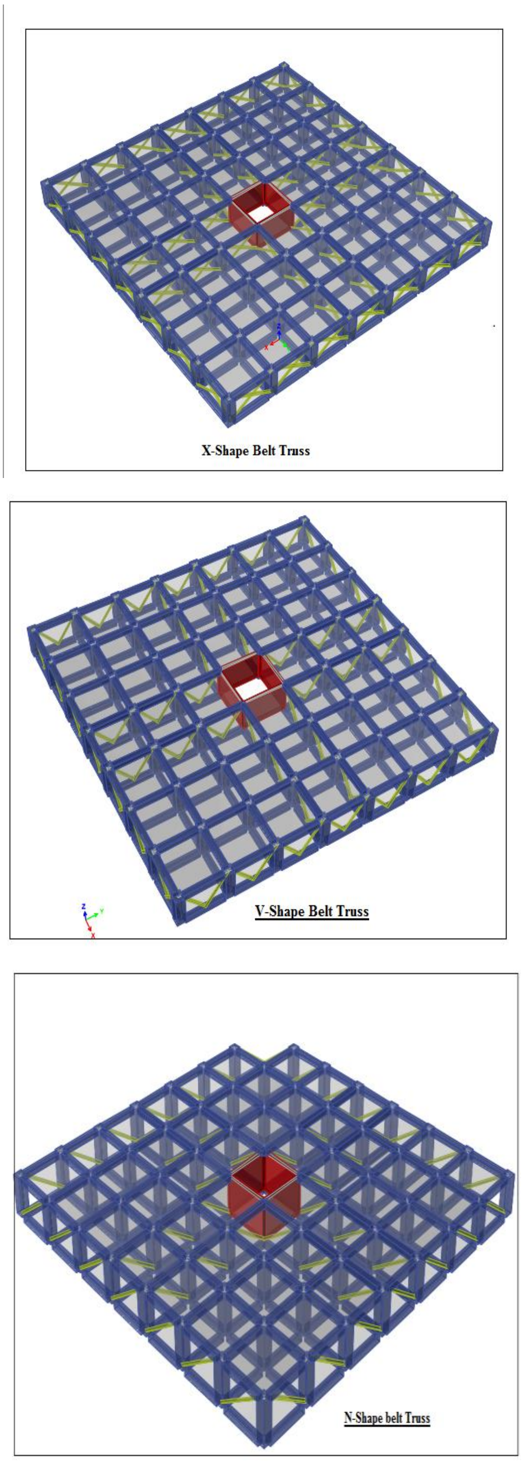


**Fig.4: Case1(X,V & N-Shape outrigger belt)**

The fig.5 represent the sectional view 30 story building without belt truss structure in which shear wall is placed at the centre of the building

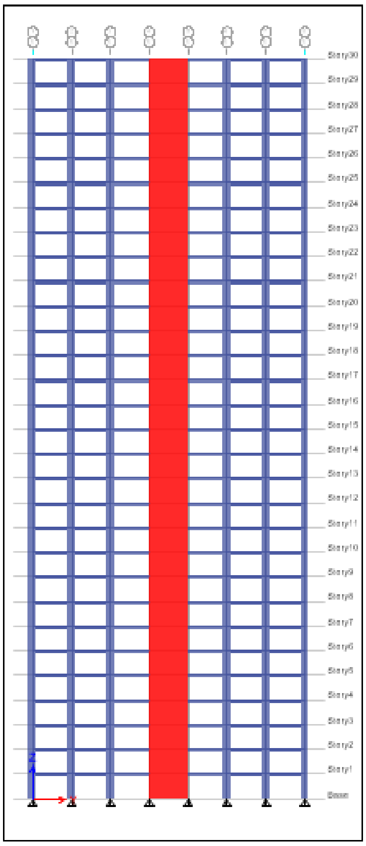

**Fig. 5: M1**

**(30 Story without belt truss)**

The fig.6 represent the sectional view of 30 story building with single belt truss in which belt truss provided at 15$^{th}$ story.

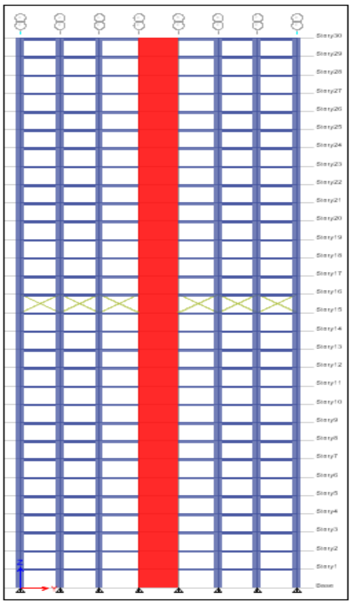

**Fig.6: M2T2**

**(30 Story with Single Belt Truss)**

The fig.7 represent the sectional view of 45 story building with double belt truss in which belt truss provided at 15$^{th}$ and 30$^{th}$ story.

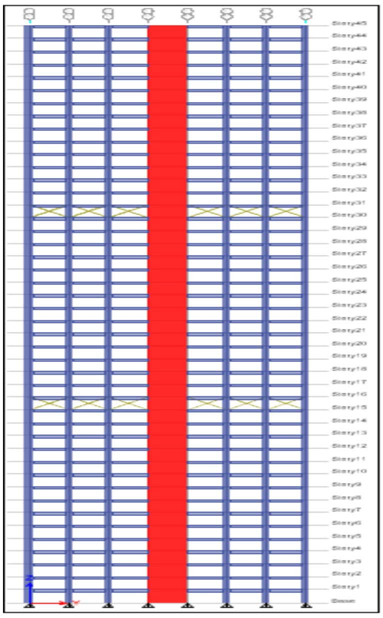

**Fig. 7: M3T4**

**(45 Story with Double Belt Truss)**

The fig.8 represent the sectional view of 60 story building with three belt truss in which belt truss provided at 15$^{th}$ 30$^{th}$ and 45$^{th}$ story.

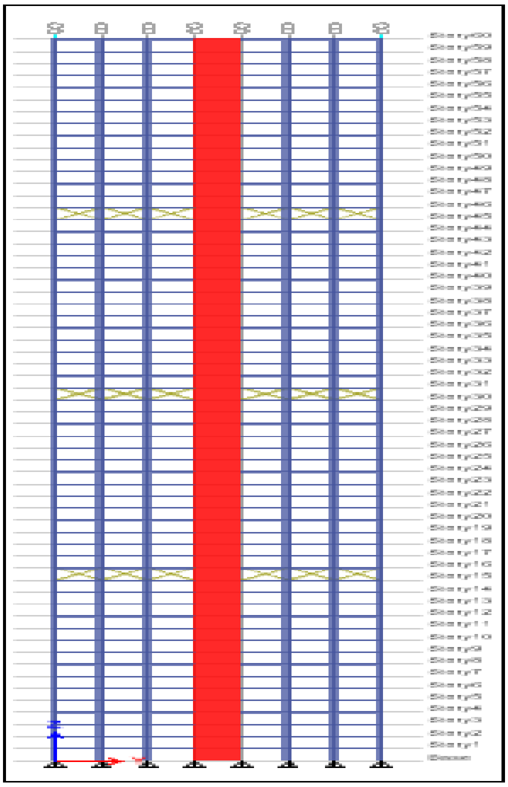

**Fig. 8: M4 T5**

**(60 Story with Triple Belt Truss)**

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**E. Results of displacement and story drift for different shape of outrigger with belt truss**

As shown in Fig 6,A 30 story model with single outrigger belt truss provided at 15th story of different shape X,V and N-type, after analysis obtain values are compared with displacement and story drift ratio as presented in table 3.

**Table 3: Maximum Displacement & Story drift for M1M2T3C1**

| Model Arrangement | Displacement at top Story (mm) | Ma. Story Drift Ratio | Variation of Displacement | Variation of Story Drift Ratio |
|---|---|---|---|---|
| Without outrigger belt | 88.56 | 0.001335 | 0% | 0% |
| X-shape outrigger belt | 75.68 | 0.001100 | 14.54% | 17.60% |
| V-shape outrigger belt | 76.05 | 0.001109 | 14.12% | 16.92% |
| N-shape outrigger belt | 76.95 | 0.001111 | 13.10% | 16.77% |

***M1M2T3C1:** 30-story model without outrigger with belt truss and single outrigger with belt truss system placed at the middle of the structure. 15th story X-shape, V-shape and N-shape

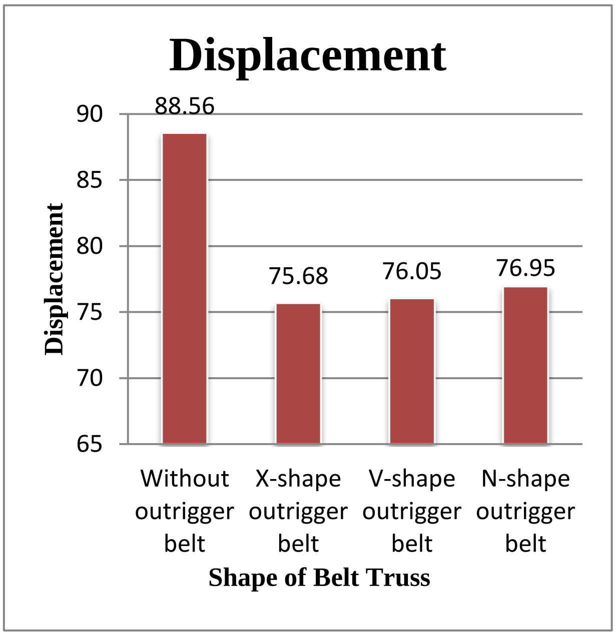



**Fig 9: Graph of displacement for table 3**

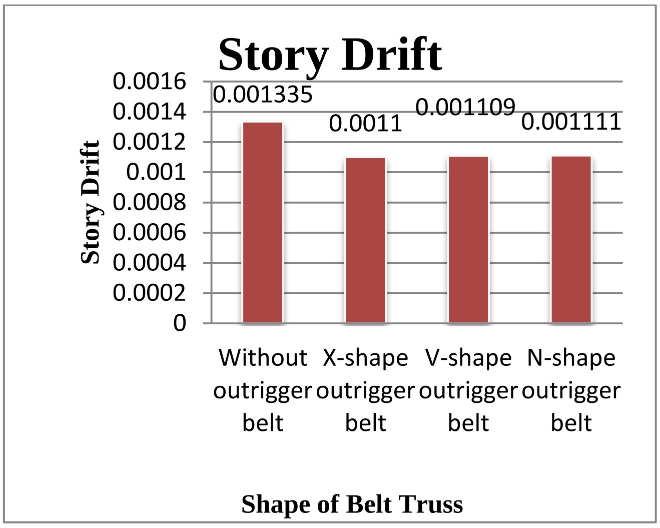



**Fig 10: Graph of Story Drift for table 3**

**F. Double outrigger belt truss system (45-story)**

As shown in Fig 7,A 45 story model with double outrigger belt truss provided at 15th and 30th story of different shape X,V and N-type, after analysis obtain values are compared with displacement and story drift ratio as presented in table 4.

**Table 4: Maximum Displacement & Story drift for M1M3T4C1**

| Model Arrangement | Displacement at top Story (mm) | Max. Story Drift Ratio | Variation of Displacement | Variation of Story Drift Ratio |
|---|---|---|---|---|
| Without outrigger belt | 201.35 | 0.002185 | 0% | 0% |
| X-shape outrigger belt | 165.80 | 0.001593 | 17.65% | 27.09% |
| V-shape outrigger belt | 170.23 | 0.001610 | 15.45% | 26.31% |
| N-shape outrigger belt | 172.97 | 0.001657 | 14.09% | 24.16% |

***M1M3T4C1:** 45-story model without outrigger with belt truss and double outrigger belt truss system placed at 15th story & other at 30th story of the structure X-shape, V-shape and N-shape.

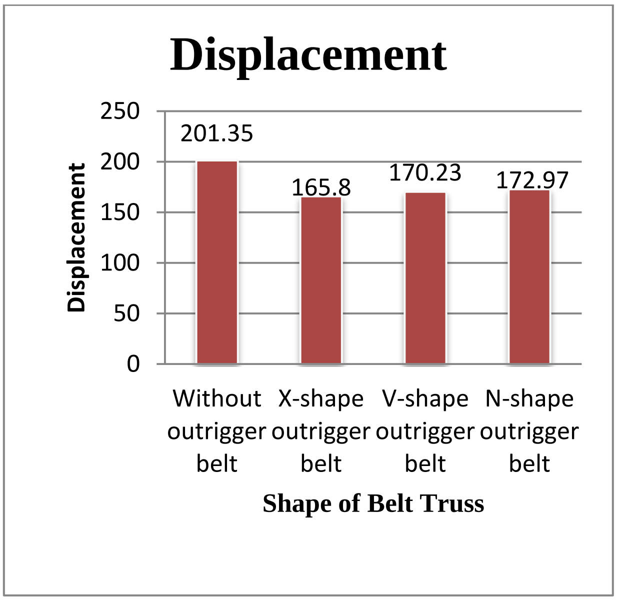



**Fig 11:Graph of displacement for table4**

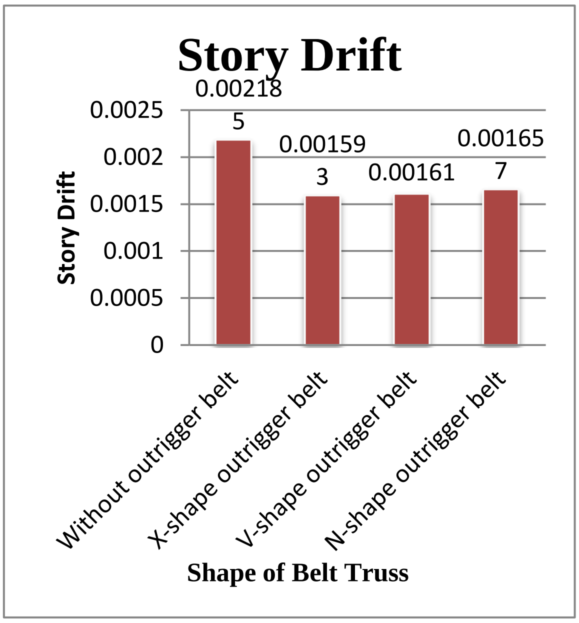



**Fig 12 : Graph of Story Drift for table 4**

As shown in Fig 8, a 60 story model with triple outrigger belt truss provided at 15th ,30th and 45th story of different shape X,V and N-type, after analysis obtain values are compared with displacement and story drift ratio as presented in table 5.

**Table 5: Maximum Displacement & Story drift for M1M2T5C1**

| Model Arrangement | Displacement at top Story (mm) | Max. Story Drift Ratio | Variation of Displacement | Variation of Story Drift Ratio |
|---|---|---|---|---|
| Without outrigger belt | 370.58 | 0.003187 | 0% | 0% |
| X-shape outrigger belt | 295.05 | 0.002113 | 20.38% | 33.69% |
| V-shape outrigger belt | 298.33 | 0.002122 | 19.49% | 33.41% |
| N-shape outrigger belt | 297.48 | 0.002153 | 19.72% | 32.44% |

*M1M4T5C1: 60-story model without outrigger with belt truss and triple outrigger belt truss system one by one belt at the 15th story, 30th& other at 45th story of the structure X-shape, V-shape and N-shape.

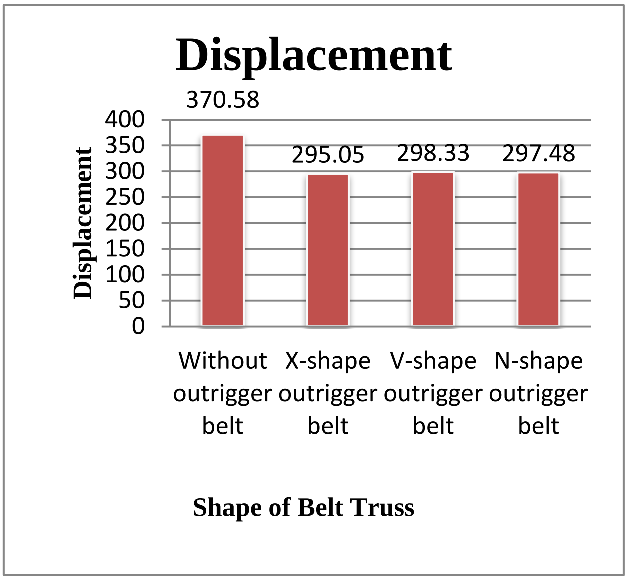
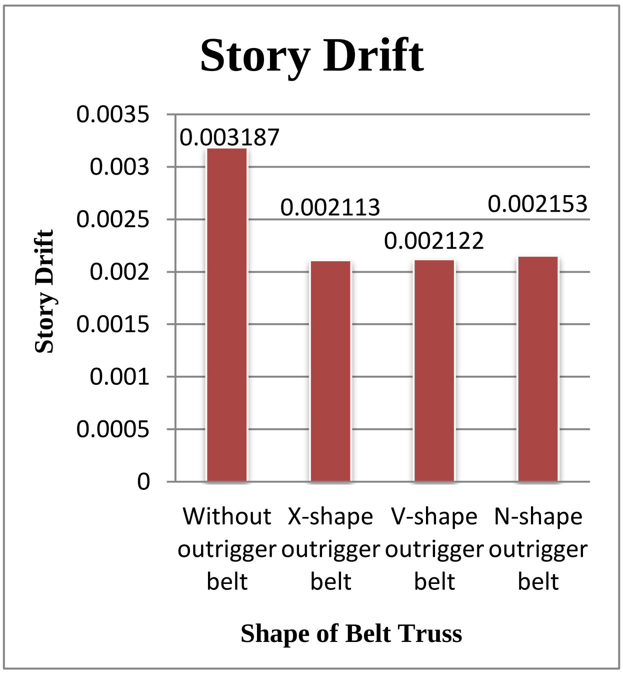


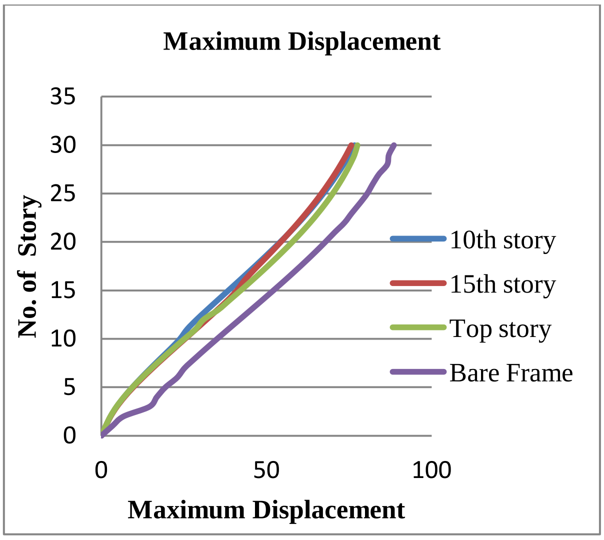

**Fig 13: Graph of displacement for table 5**




The maximum displacement with optimum position of the outrigger obtained from the analysis of high rise building under earthquake loading is presented in Table 6 respectively. The graphical representation of these results is also presented in Figure 15 respectively.

**Table 6: Maximum Displacement for M1M4T1T2T3C12***

| Story | Outrigger Position | | | Bare Frame |
|---|---|---|---|---|
| | 10th Story | 15th Story | Top Story | |
| 30 | 76.71 | 75.68 | 77.56 | 88.56 |
| 25 | 67.25 | 66.61 | 70.06 | 80.48 |
| 24 | 64.92 | 64.39 | 67.95 | 78.24 |
| 23 | 62.44 | 62.04 | 65.67 | 75.84 |
| 22 | 59.81 | 59.56 | 63.21 | 73.60 |
| 21 | 57.05 | 56.98 | 60.59 | 70.62 |
| 20 | 54.16 | 54.30 | 57.82 | 67.79 |
| 15 | 38.47 | 41.01 | 42.19 | 52.06 |
| 14 | 35.23 | 38.25 | 38.82 | 48.69 |
| 13 | 32.01 | 35.11 | 35.41 | 45.28 |
| 12 | 28.85 | 31.89 | 30.97 | 41.85 |
| 11 | 25.99 | 28.62 | 28.53 | 38.42 |
| 10 | 23.80 | 25.32 | 25.12 | 35.02 |
| 5 | 9.37 | 9.64 | 9.40 | 19.36 |
| 0 | 0 | 0 | 0 | 0 |

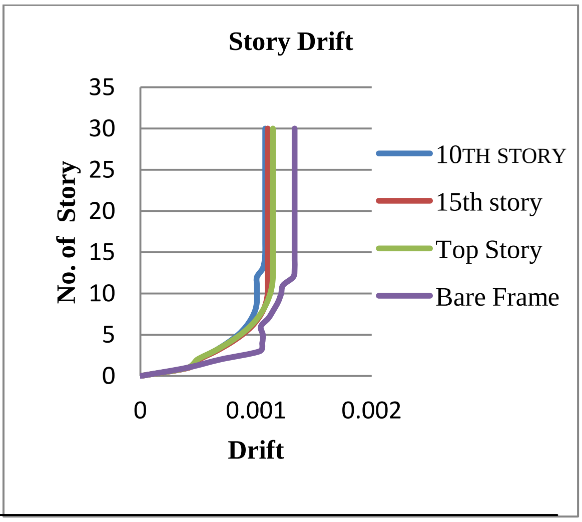



**Graph1: Maximum displacement and story**

The maximum story drift with optimum position of the outrigger obtained from the analysis of high rise building under earthquake loading is presented in Table 7 respectively. The graphical representation of these results is also presented in Figure 16 respectively.

**Table 7: Maximum Story Drift for M1M4T1T2T3C12***

| Story | Outrigger Position | | | Bare Frame |
|---|---|---|---|---|
| | 0.33 | 0.50 | 1 | |
| 30 | 0.0011 | 0.00108 | 0.001146 | 0.001335 |
| 25 | 0.0011 | 0.00108 | 0.001146 | 0.001335 |
| 20 | 0.0011 | 0.00108 | 0.001146 | 0.001335 |
| 15 | 0.0011 | 0.00108 | 0.001146 | 0.001335 |
| 10 | 0.0011 | 0.00101 | 0.001123 | 0.001219 |
| 5 | 0.00089 | 0.00085 | 0.000864 | 0.001060 |
| 0 | 0 | 0 | 0 | 0 |




**Graph2: Maximum Story Drift and No. of story**

## V. CONCLUSION

This study evaluate the behavior of outrigger belt truss system with change of shape of outrigger belt truss system for single outrigger belt truss system (30-story) , double outrigger belt truss system (45 story) and triple outrigger belt truss system (60 story) and variation of position of outrigger belt truss system in 30 story building in which belt truss are placed in 10th story , 15th story & at top floor under seismic loads. The conclusion obtained from the above results: From above result that is from table 3, 4 & 5, for 30-storey, 45-story and 60-story building we can say X-Shape outrigger belt truss system is more efficient than V-Shaped outrigger belt truss system and N-Shape outrigger belt system. The Variation of displacement and story drift of 30 story building for single belt truss outrigger system for X-shape belt truss is controlled by 14.54% and 17.60% as compared to bare frame structure. The Variation of displacement and story drift of 45 story building for double belt truss outrigger system for X-shape belt truss is controlled by 17.65% and 27.09% as compared to bare frame structure. The Variation of displacement and story drift of 60 story building for double belt truss outrigger system for X-shape belt truss is controlled by 2038% and 33.69% as compared to normal frame structure. From above result that is from table 6 & 7, for 30-storey building when outrigger belt is placed at 10th story, 15th story and at top story as compared to bare frame structure, So the best location for outrigger belt is 15th story in 30 story building. The variation displacement and story drift is controlled by 14.54% and 17.60% as compared to bare frame structure.

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## AUTHORS PROFILE

**Ritu Khandelwal**, Student Computer Aided Structural Designing and Drafting, Civil Engineering Department, Ujjain Engineering College, Ujjain, M.P. India, Email: ritukhandelwal767@gmail.com

**Dr Raghvendra Singh**, (M Tech, PhD (Geotechnical Engg.,), IIT Kharagpur) Professor :Department of Civil Engineering 22 years teaching experience, 12 year research experience Guide: 20 B Tech., 20 M Tech., 02 PhD students. Research papers: 25 national & international journal, 35 national & international conferences. One ASCE paper was nominated for final selection.