Performance of Lateral Loads Resisting Systems for Tall Steel Structure

Amit K. Mali[(1)], Hiral R. Luhar[(2)], Dipak N. Mali[(3)], Rajesh V. Sonagara[(4)], Snehal V. Mevada[(5)],

1, 2, 3, 4-B.Tech. Civil Engineering Student, Birla VishvakarmaMahavidyalaya, VallabhVidyangar, Gujarat, India
5-Assistant Professor, Structural Engineering Department, Birla VishvakarmaMahavidyalaya, VallabhVidyangar, Gujarat, India

Article History: Received:
Online:

Abstract: In modern age, as the construction of high-rise buildings and mega structures increases which decreases availability of land and increases land cost, to overcome that problems engineers have to go vertically by constructing tall structures. There are various lateral load resisting systems for tall structure, among them bracing systems, shear wall systems, outrigger systems and diagrid systems are selected for this work.For G+19 storied building, the structure is not provided with any lateral load resisting system then it is difficult to construct conventional structure. Parametric study and detailed comparison of various lateral load resisting system with respect to conventional structure was carried out for regular buildings. In this study bracing systems, shear wall systems, outrigger systems and diagrid systems are analyzed and designed. The study mainly focused on to determining the most effective and economical lateral load resisting system which can resist lateral forces effectively. Various parameters like maximum top lateral displacement, maximum base shear, Structure weight, maximum storey displacement and maximum storey drift are considered in this study. Bracing system was most economical and lighter structural system as compared to conventional systems and all other lateral load resisting systems.

Keywords: High Rise Buildings, SMRF, Bracing, Shear Wall, Outrigger, Diagrid, Optimum Design

1. Introduction

Now days the innovation is developing step by step with that development of tall structure and mega structure, cost of land and other product also increases. So that advanced construction technology is needed for economic and speedy development. Earlier the priority is given to vertical load systems only. But this system is limited to some height, after that this system is not safe. The new technique was introduced which is given by the Fazlur Rahman Khan (1929 – 1982) who initiated various lateral load-resisting systems for skyscrapers, high rise buildings etc. Lateral load resisting systems such as bracing, shear wall, diagrid, and outrigger was provided to resist lateral forces.In this Research work, behavior of various lateral load resisting systems for G+19 tall steel structure was compared with conventional systems in terms of different parameters such as storey displacement, storey drift, top storey displacement, weight of the structure, base shear using STAAD CONNECT VER. 22 software.

2. Objective of the study

- To Study the behavior of various lateral load resisting systems and comparing the results with conventional structure (comparison of displacement, storey drift, Story displacement, Base shear, Story forces in both vertical and horizontal direction)
- To determine the economical and optimum lateral load resisting system.
- To observe the performance of different lateral loads resisting systems under seismic loading, wind loading and gravity loading.
- To study the effect of lateral forces for critical zone-V as per IS 1893-2016.
- To study the effect of wind forces for critical condition as per IS 875 Part-3(2015).

3. Literature Review

Parikh., (2018) analyzed that steel bracings can be used in multi-storey structure of 10 to 20 storey height whereas Shear wall system can perform better for 20 to 35 storey height. Diagrid system was most effective and economical for tall structure having storey height more than 35.Gore and Mhatre (2018) analysed that the efficient height of outrigger system is 150m and outrigger system provides horizontal stability to the structure.Dhoke et al., (2017) analyzed that the diagrid system is more beneficial than other lateral load resisting system. Diagrid system has good aesthetic appearance as well as effective in performance as compared to other systems.

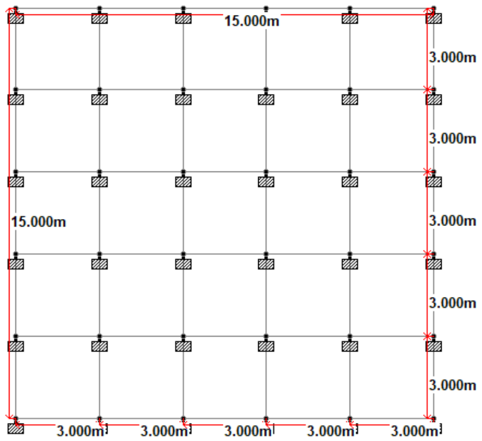
4. Numerical Study

4.1 Types of structure under a study

The structure under consideration was a special moment resisting frame (SMRF). It was design and detailed as per IS 800, and meeting special requirements for ductile behaviour as per IS 800.

4.2 Description of Conventional structure (SMRF)

The structure consists of a symmetrical model of 5 bays of each 3m long. X and Z direction is considered for analysis of structure of G+19 storey tall steel structure. The building model is situated in seismic zone V and assuming structure is situated on soft soil. Dimensional details of conventional system are given in table 1.



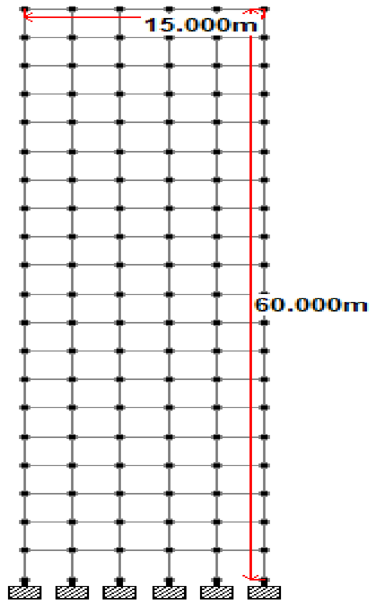


Figure 1. Plan of Conventional structureFigure 2. Height of the structure

4.3 General Data of the Steel Structure

The Dimensional details of the steel structure was given in below table,

Table 1. General Data of structure

Type of Structure	**Steel Structure**
No of Storey	20 (G+19)
Total Height of Structure (Ht)	60m
Height of Floor	3 m
Slenderness Ratio $\left(\frac{Ht}{Bt}\right)$	4
Width of The Structure (Bt)	15 m
Length of The Structure (Lt)	15 m
Plan Area Ratio $\left(\frac{Bt}{Lt}\right)$	1 $(\left(\frac{Bt}{Lt}\right)< 5)$
No of Bay Along Length and Width	5
Structure Size	15m x 15m x 60m

4.4 Structural Details of steel structure

The structural Details of Conventional Model (SMRF) was given below,

Table 2. Structural details

Trial section for beam	ISMB400 with cover plate of size 250mmx10mm at top and bottom
Trial section for Column	ISHB450H with cover plate of size 300mmx25mm at top and bottom
Thickness of concrete slab	120mm
Thickness of outer masonory wall	230mm
Thickness of inner masonory wall	115mm

4.5 Loads and Load Combination

In this study all the important loads have been viewed as like Dead Load, Imposed Load, Wind Load, Seismic loads (static and dynamic). The load combination was done as per IS 456:2000 And IS: 1893:2016.

4.6 Output Result of conventional structure
The output results from staad pro are given below:

Table 3. Output of conventional structure

Description	Output Value
Steel Weight	7984.006 kN
Base shear (Vb)	2049.84 kN
Displacement of top node	213.788 mm
Design result	54 nos. of the members are failing.

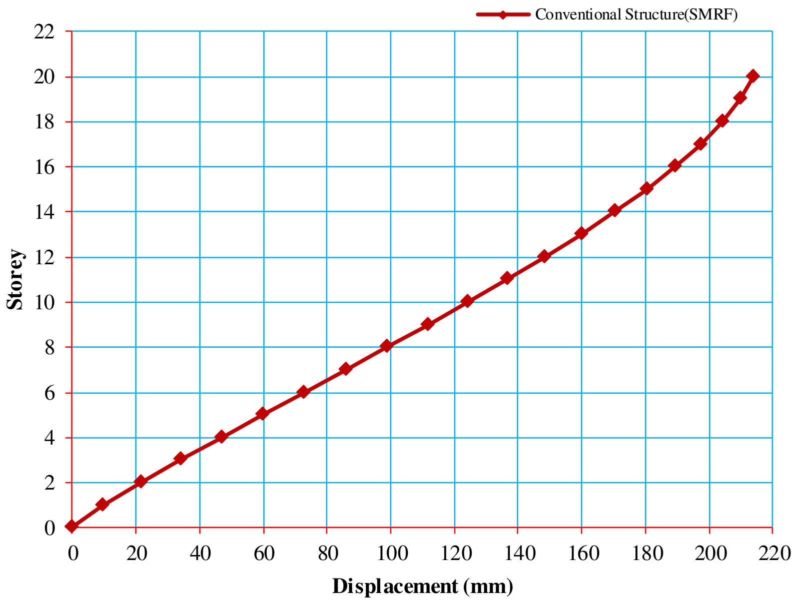


Figure 3. Storeyvs displacement for conventional structure

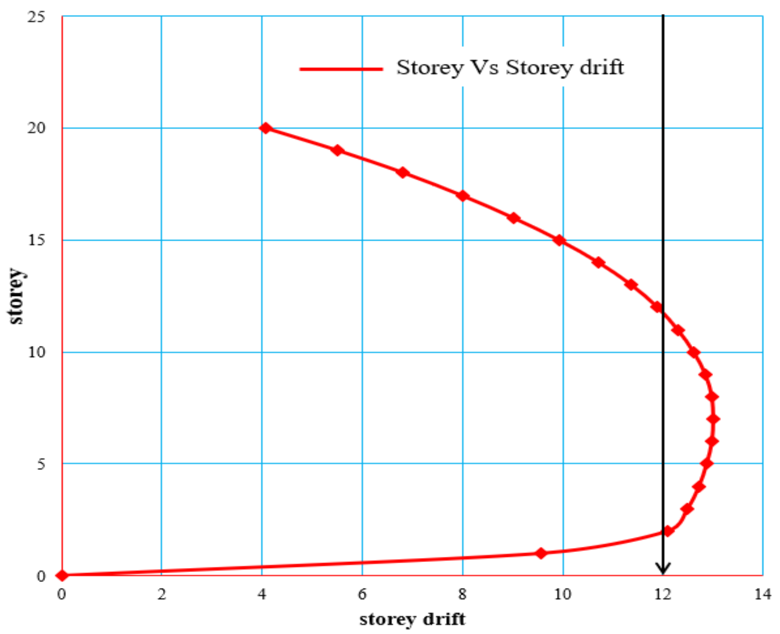


Figure 4. Storeyvsstorey drift for conventional structure

From the conventional (SMRF) structure it was observed that conventional structure was failed in design as well as in storey drift as per IS 1893:2016, so to overcome that problems Lateral load resisting systems are required.

5.Various Lateral load resisting system for tall steel structure
In this study different lateral load resisting systems (Bracing systems, Shear wall systems, Diagrid systems and Outrigger systems) are used. All the system having a different arrangement, Actually four bracing systems have been used (Bracing symmetrically placed in plan, bracing symmetrically placed at corner, bracing symmetrically placed in plan and corner, cross bracing at whole), four Shear wall systems (Shear wall symmetrically placed in plan , Shear wall symmetrically placed in corner, Combination of shear wall and shear wall with special arrangement), four diagrid systems (diagrid at 67.4°,72.7°,78.2° and 84.1°), four outrigger systems (outrigger at 10th and 20thstorey, outrigger at each 5th storey, outrigger with belt truss at 10th and 20thstorey and outrigger with belt truss at each 5th storey), from the above 17 systems, only four most effective economical systems and those systems are shown below. All the systems are optimized based on reducing member's sizes from bottom to top storey.

5.1 Bracing symmetrically placed in plan

5.2 Shear wall symmetrically placed in plan

5.3 Diagrid at 67.4°

5.4 Outrigger at 10th and 20thstorey

5.1 Bracing symmetrically placed in plan
In this system bracings are provided at middle portion of the conventional structure. Bracing member was to transfer only axial load. Total no of bracing utilized in this structure was around 80 no's.

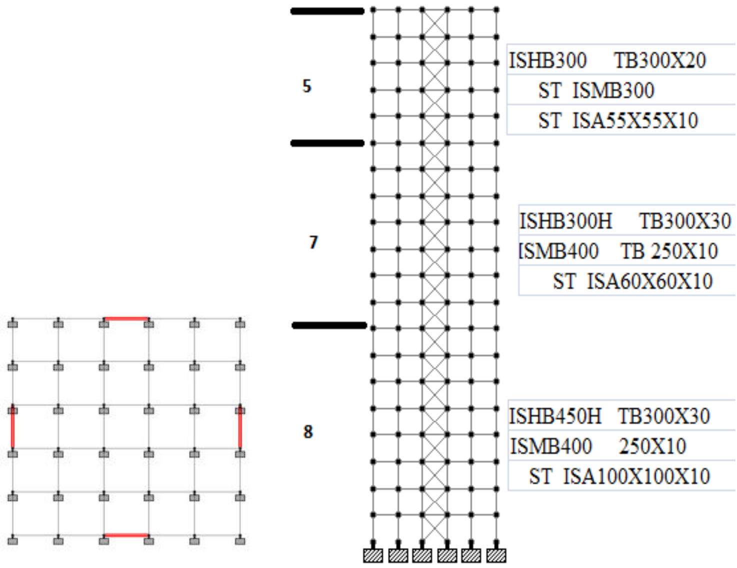


Figure 5. Bracing symmetrically placed in plan with optimization

Table 4. Output of optimized bracing system

Description	Output Value
Steel Weight	7130.995 kN
Base shear (Vb)	2021.86 kN
Displacement of top node	199.77 mm
Design result	All members are passing.

5.2Shear wall symmetrically placed in plan
In this system shear walls are provided symmetrically in plan as shown in figure 6. It is a continuous vertical diaphragm effective to transfer lateral forces induced due to wind loading and seismic loading. This system was effective to transfers the lateral load from outer walls, floors, and roofs to the foundation. This system effective and economical for tall structure. In this steel plates are used as a shear wall.

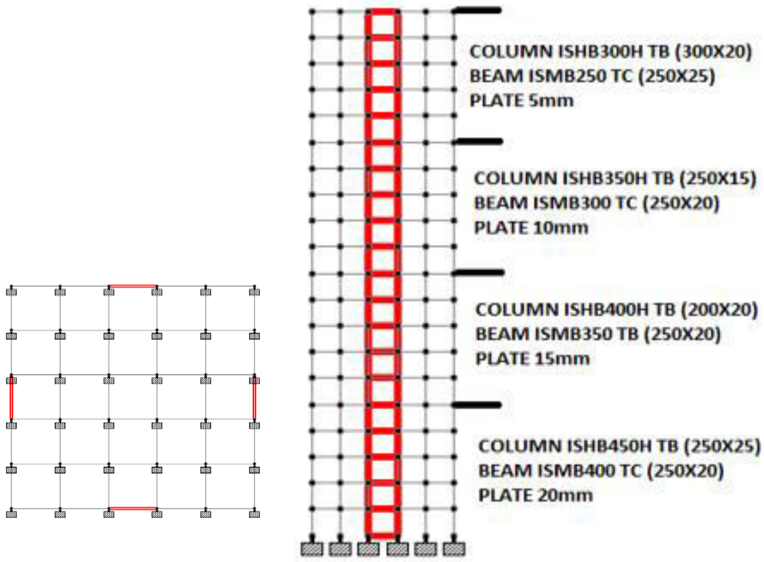


Figure 6. Shear wall symmetrically placed in plan with optimization

Table 5. Output of optimized shear wall system

Description	Output Value
Steel Weight	8413 kN
Base shear (Vb)	2010.68 kN
Displacement of top node	153.173 mm
Design result	All members are passing.

5.3 Diagrid at 67.4°

In this system various arrangement of diagrid systems are provided at different angle (diagrid at 67.4°,72.7°,78.2° and 84.1°) among them diagrid at 67.4° is discussed in this paper. In this system only four columns are provided at central portion and remaining are eliminated as shown in Figure 7. It transfers the lateral force and gravity force through triangular configuration of diagrid. Diagrid is an axial member. Generally in a diagrid systems angle of diagrid was important for the present study diagrid at 67.4° was most economical diagrid system.

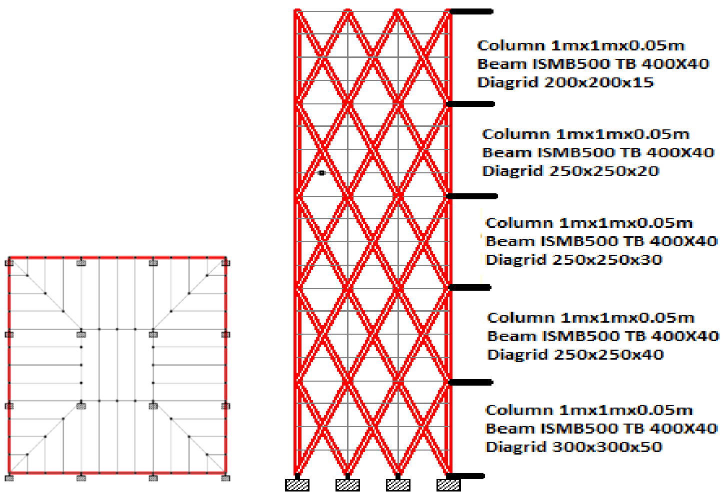


Figure 7. Diagrid at 67.4° with optimization

Table 6. Output of optimized diagrid system

Description	Output Value
Steel Weight	19777.24 kN
Base shear (Vb)	2904.54 kN

Displacement of top node	149.127 mm
Design result	All members are passing.

5.4 Outrigger at 10th and 20th storey

In this system outrigger systems are provided at various levels (outrigger at 10th and 20th storey, outrigger at each 5th storey, outrigger with belt truss at 10th and 20th storey and outrigger with belt truss at each 5th storey) among them outrigger at 10th and 20th storey level was considered in this paper. In this system central steel core wall was provided with outrigger.This system was effective to decreas excessive storeydrift,storey displacement and over turning moment.

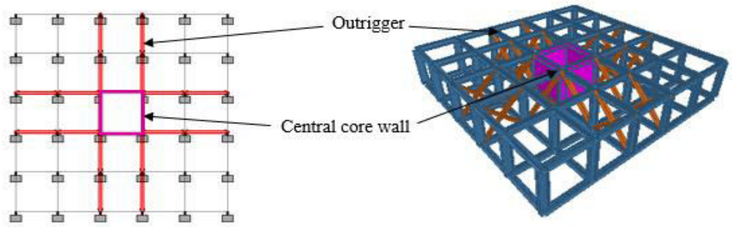


Figure 8. Plan of outrigger system

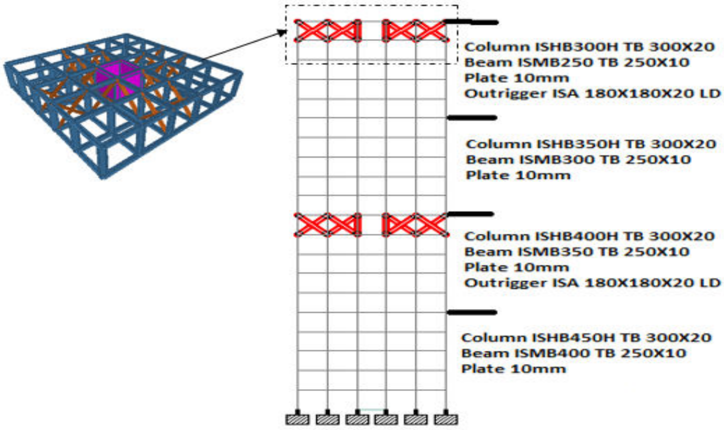


Figure 9. Outrigger at 10th and 20th storey with optimization

Table 7. output of optimized outrigger system

Description	**Output Value**
Steel Weight	7716.32 kN
Base shear (Vb)	1355.59 kN
Displacement of top node (756)	116.44 mm
Design result	All members are passing.

6.Result and discussion

In this study, the comparison of various optimized systems was done by comparing steel weight, base shear, and displacement of top node, storey displacement and storey drift

6.1 Steel weight, Base shear and displacement of top node

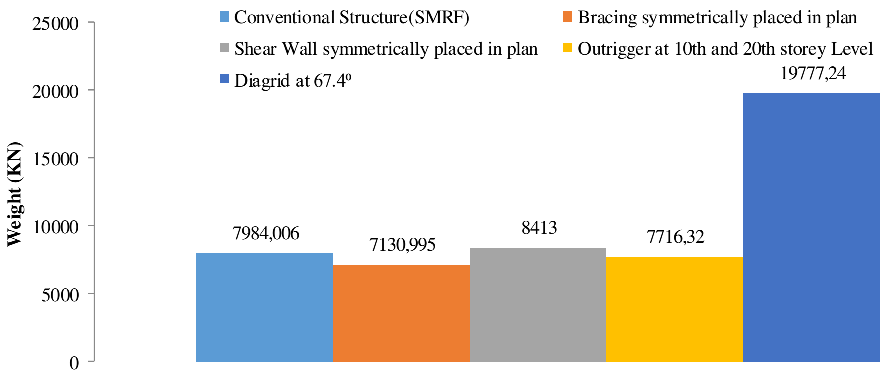


Figure 10. Comparison between steel weight

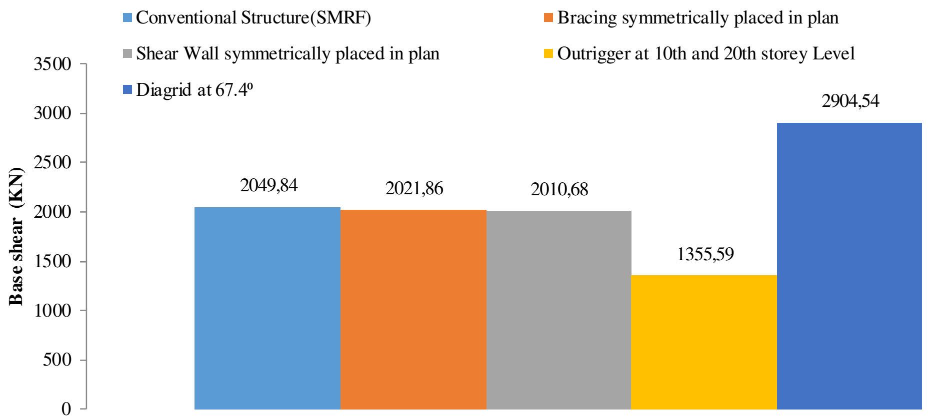


Figure 11. Comparison between base shear

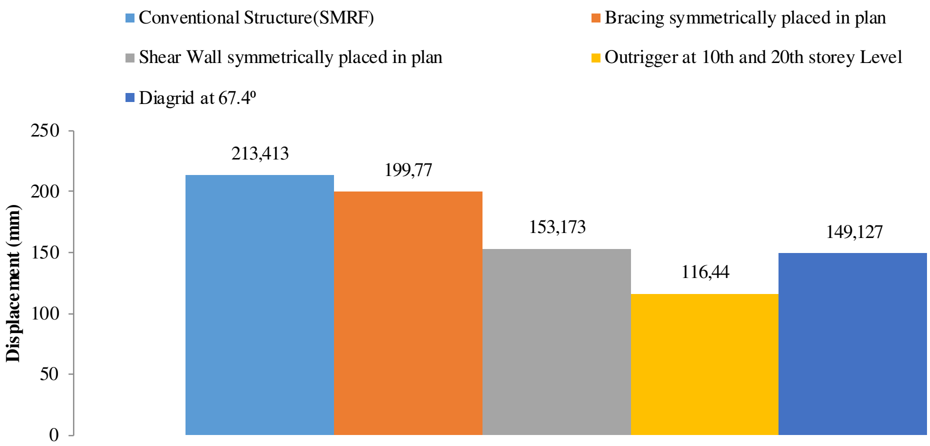


Figure 12. Comparison between displacements of top node

6.2 Storeyvsstorey displacement and storeyvsstorey drift

The comparisons are shown below:

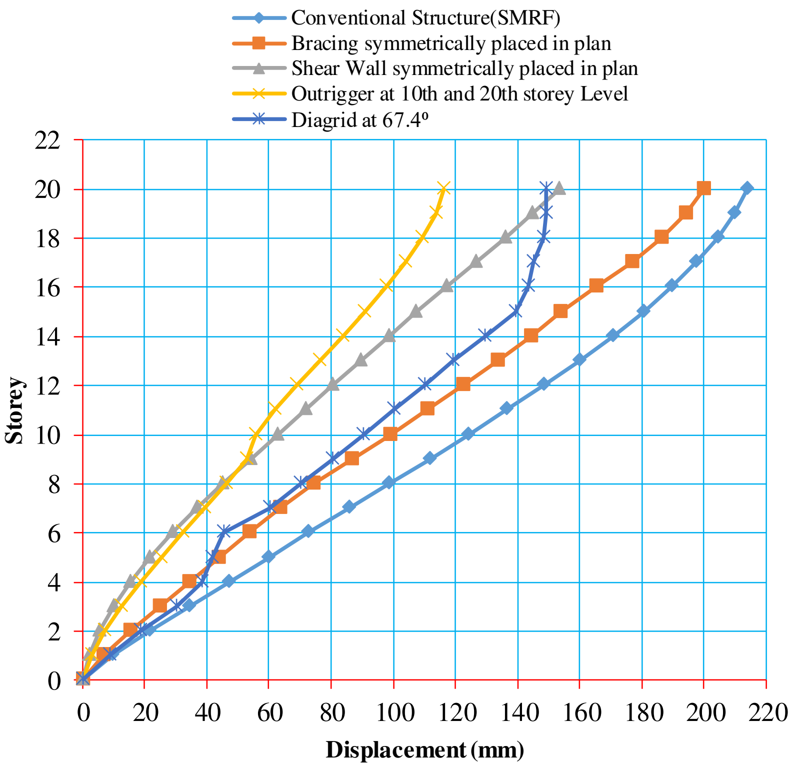


Figure 13. Comparison of storeyvs displacement between conventional system and various systems

In this study, it was observed that from the graph (Figure 13) also there are sudden changes at some storey level, which was due to stiffness variation at that storey level. If the structure was optimized then size of the member will change which create sudden stiffness change. If stiffness of upper storey will be lesser than lower storey so at that level floor will displace more as compared to lower floor.

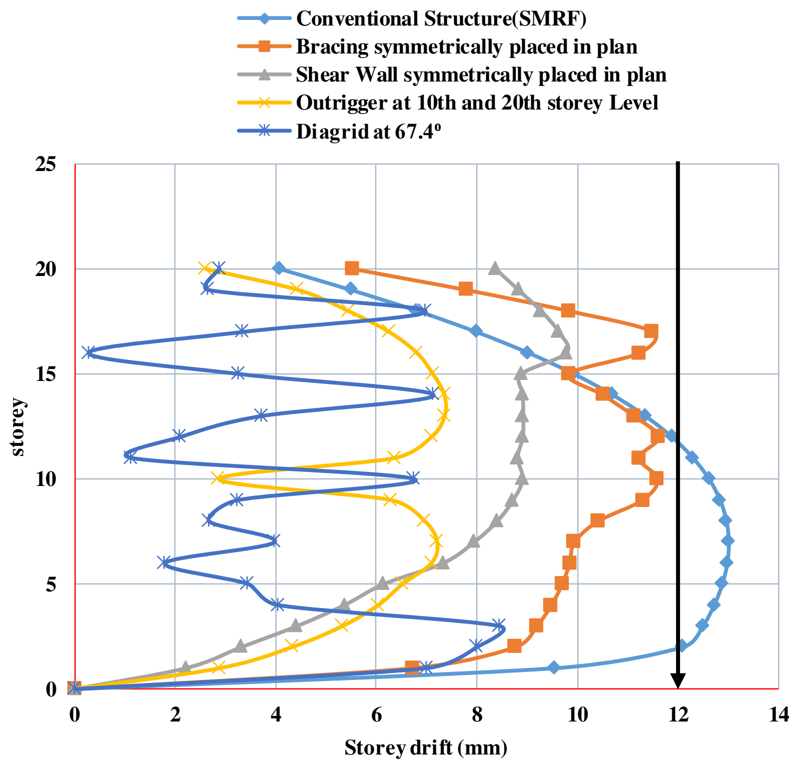


Figure 14. Comparison of storeyvsstorey drift between conventional system and various systems

7. Conclusion

This study includes the comparisons of G+19 storey building (SMRF) with various systems such as bracing systems, shear wall systems, outrigger systems and diagrid systems have been considered.

From the current study below conclusions are made:

- Bracing system is the most economical and lighter structural system as compared to conventional systems and all other lateral load resisting systems.
- The base shear and displacement of top node in outrigger system at 10^{th} and 20th storey level is less as compared to other systems.
- Displacements and storey drift in outrigger system were less as compared to other systems.

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