

Performance of Different Bracing Patterns for Moderately Tall Steel Buildings Subjected to Lateral Load

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Paper ID - 140480

Abstract

In the present work, a model of moderately tall steel building G+20 storied, has been developed and then analysed for lateral load using design software STAAD Pro. Performance of different types of bracing systems are checked under gravity load and wind load. Various results such as bending moment, shear force, lateral deflections, storey drift, axial load on columns are extracted from this analysis and studied meticulously. In few cases of brace pattern effect of providing eccentricity are also studied to suggest optimum positioning of these bracing systems.

Keywords: Bracing pattern, Eccentricity, Failure, Gravity load, Lateral load, Moderately tall buildings, Wind load

1. Introduction

Steel structure buildings are very efficient for very tall and moderately tall buildings due to high strength/weight ratio, ease in fabrication, material saving, longevity and less maintenance. These buildings have wide application wherever storage space, workspace and living accommodation is required [1], [2].

Very often these structures are greatly impacted by wind load. Lateral load in form of wind blow can cause three folds effect on structures that is static, dynamic and aerodynamic. Further issue like global warming has caused rapid changes in climatic conditions of different zones. This has caused changes like high wind speed and patterned change in cyclone cycle, which boosts wind load on tall and moderately tall buildings [3], [4]. Moderately tall buildings have huge demand in urban areas due to lack of land space. Failure of these buildings are often thought of as in form of collapse of entire structure or local failure like buckling of any member or large deflection [5]. However, in the context of structural reliability analysis, a structure is said to be failed once a present limit is reached (like stress, displacement etc), even though it may not have collapsed completely. This makes the investigation or search of an efficient structural system a necessity which can reduce these structural quantities. Structural engineers can reduce the impact of wind load on moderately tall buildings by proper selection and application of an efficient structural systems. Literature review shows that many works have been already done in this direction with very tall or high-rise buildings. Sangle et. al. [6] worked on effect of seismic load on high rise steel structures with and without bracing patterns. On the other hand, Aly et. al. [7] investigated the

impact of both wind load and seismic load on high rise buildings. Comparative study work was done by Longarini et. al. [8] on very slender buildings subjected to wind load effect using various methods. But these studies are mainly revolving around either RCC buildings or high-rise steel frame buildings with X, K and V bracing. This also highlights the fact that a detailed comparison of various bracing systems for moderately tall steel buildings subjected to wind load over one plate form is either missing or very few.

In the present work different bracing systems like X, V, inverted V, K, diagonal and cross bracings are selected for further investigation as a part of this efficient structural technique. Few cases of eccentricity for K brace, inverted V brace and diagonal brace are taken up.

It has been found from past literatures that bracing systems can be very useful to control the buckling of main beams at the time of construction [9]. At the same time selection of appropriate bracings can protect the structure from being deviated from original geometry [10]. Vijayan et. al.[11] investigated on different bracing systems like X-bracings, eccentric bracings, and diagonal bracings to find an efficient and economical ways to reduce response factors of steel structures using SAP 2000. Some researchers [12] has also been focused on seismic analysis of concentrically braced steel frames with bolted connections.

Based on information gathered from above literature review, in the present research work extensive comparative study has been done on performance of different brace patterns using STAAD Pro software. Outcome of storey

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drift, bending moment, shear force, axial load, lateral deflections at different story level are also analysed. Objective of this research work is to find out best bracing system or pattern for moderately tall steel buildings. This bracing system should be helpful in reducing response quantities of structure subjected to both gravity load and wind load, thereby helping in reducing dead weight and ultimately help in material saving.

2. Structural Modelling

A moderately tall steel building G+20 of square plan form 20 m x 20 m along x and z directions respectively has been developed using STAAD Pro design software. Columns are assumed to be fixed at ground level. While development following details has been used:

- Floor to floor height- 3m
- Number of bays along x and z directions- 5 x 4 m each
- Lateral load considered- Wind load (according to IS 875 - III-2015)
- Basic wind speed- 39 m/s
- Soil strata- medium

Table-1 Column schedule:

Floor	Column Section
1 to 11	UPT12 section
12 to 14	ISWB600
15 , 16	ISWB600
17 , 18	ISWB550

Table-2 Beam schedule:

Floor	Beam Section
All (inner beam and outer beam)	ISLB400
Bracing angle section	ISA 120 x 80 x 12

3. Details of Building Plan and Bracing Systems

3.1 Building plan

Plan of the main steel building used for the present study is given below in Fig.1

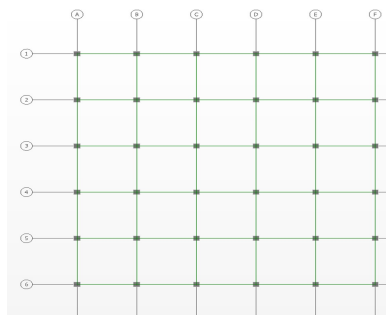


Fig. 1- Plan of G+20 steel building

3.2 Details of different bracing systems

Different types of bracing systems used in this present study work are given in following figures.

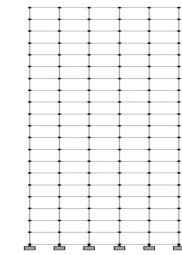


Fig. 2 -Unbraced

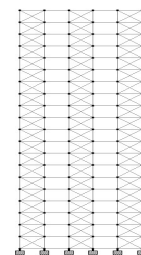


Fig.3-X Brace

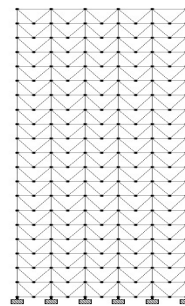


Fig. 4- V Brace

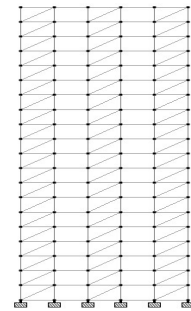


Fig. 5- Diagonal Brace

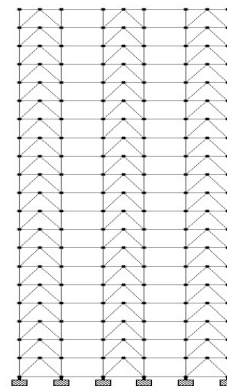


Fig. 6- Inverted V Brace

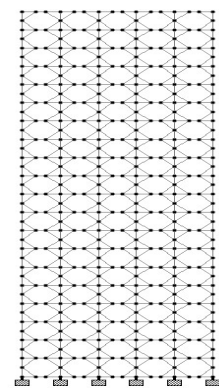


Fig. 7- K Brace

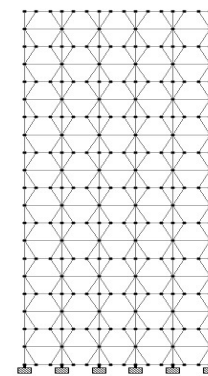


Fig. 8- Two Storey K Brace

3.3 Details of eccentric bracing patterns

Few cases of eccentric bracing pattern are also taken up for present study work. Details are given in Figures.

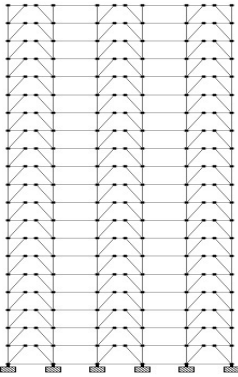


Fig. 9 Inverted V Brace
e=1m

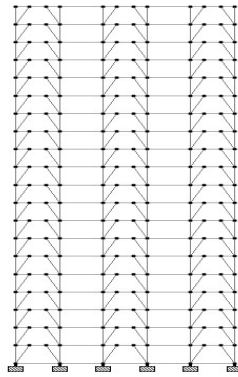


Fig. 10 Inverted V Brace
e=1.5m

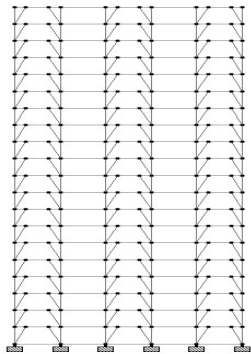


Fig. 11 Inverted V Brace
e = 2.0 m

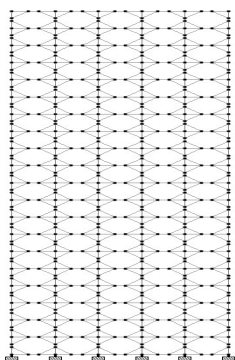


Fig. 12 K Brace
e = 0.5 m

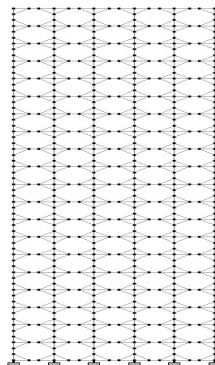


Fig. 13 K Brace
e = 1.0 m

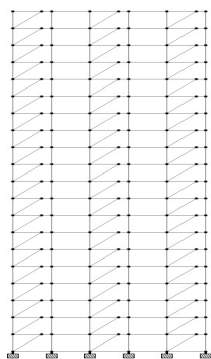


Fig. 14 Diagonal Brace
e = 1.0 m

4. Computation

Lateral load effect on steel building is calculated referring [3].

Design wind speed= $V_b k_1 k_2 k_3 k_4$

Table- 3 Details of different factors

V_b Basic wind speed	39 m/s
K_1 Probability factor	1.06
K_2 Terrain factor	Category 3
K_3 Topography factor	1.0
K_4 Importance factor for cyclonic region	1.15

5. Results and Discussion

Developed model of G+20 storied steel building has been analyzed using STAAD Pro, which is a structural analysis and design software.

Analysis results are sectioned here.

Table 4 maximum lateral displacement (mm) in x direction (without eccentricity)

Bracing Pattern	Floor level		
	20	10	Ground
Unbraced	202.679	101.698	3.235
X Brace	148.365	68.030	1.581
V Brace	175.963	90.360	2.34
Diagonal Brace	159.013	85.266	1.883
Inverted V Brace	179.229	93.327	2.645
K Brace	163.362	86.375	1.948
Two storey K Brace	162.235	89.235	2.018

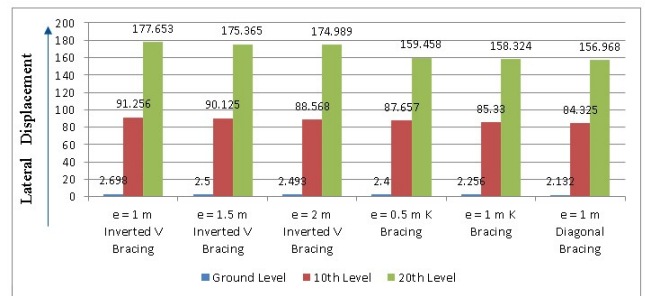


Fig.15 Maximum lateral displacement (mm) of eccentric bracing systems along X-direction

Table 5. Maximum lateral displacement (mm) in Z direction (without eccentricity)

Bracing Pattern	Floor level		
	20	10	Ground
Unbraced	283.763	169.644	7.846
X Brace	189.036	97.235	3.256
V Brace	268.100	148.385	5.332
Diagonal Brace	239.295	129.963	4.141
Inverted V Brace	270.423	152.963	6.196
K Brace	243.619	134.568	4.898
Two storey K Brace	256.562	146.879	5.984

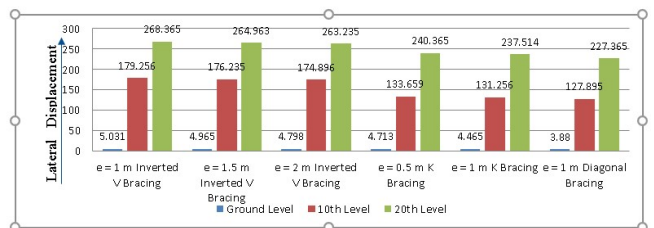


Fig. 16 Maximum lateral displacement (mm) of eccentric bracing systems along Z-direction

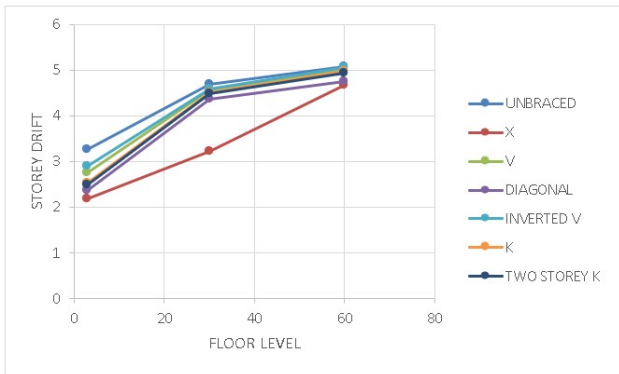


Fig. 17 Storey drift (mm) along X direction for wind load

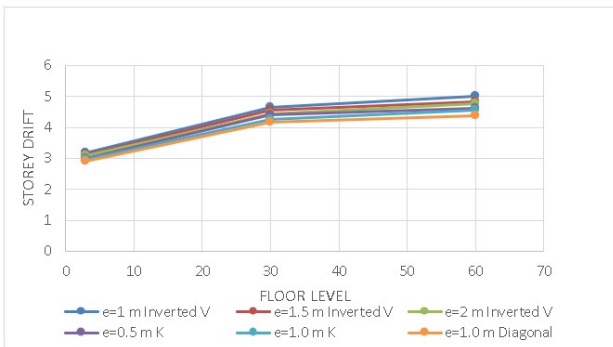


Fig. 18 Storey drift (mm) of eccentric bracing systems along X direction for wind load

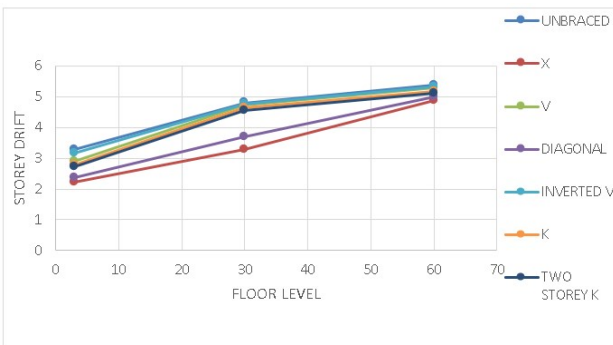


Fig. 19 Storey drift (mm) along Z direction for wind load

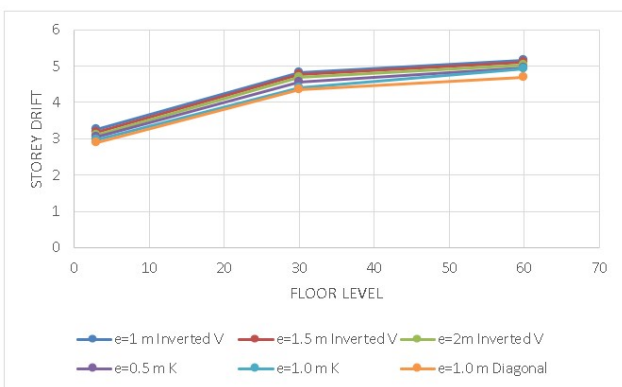


Fig. 20 Storey drift (mm) of eccentric bracing systems along Z direction for wind load

5.1 Considering Lateral Displacement and Storey Drift

It has been observed (Table 4, 5 and Fig. 17, 19) that performance of X Bracing is better as compared to other bracing system. It is also evident from results of Fig. 15, 16 and Fig. 18, 20 that if eccentricity (e) of inverted V bracing and K bracing is increased then it helps in reducing the lateral displacement and storey drift towards top stories. Here also provision of 1 m eccentricity among diagonal braces, reduce both the lateral deflection and storey drift to a maximum level.

5.2 Considering Maximum Bending Moment

If the results of the maximum bending moment for without eccentricity (Table 6 and 7) structures are observed then the performance of K bracing is found to be better as compared to rest of bracing structures. This is true for both X and Z directions. If eccentricity (e) of inverted V bracing and K bracing is increased then it helps in reducing the bending moment of eccentric structures subjected to wind load. Here also diagonal bracing system with eccentricity of 1.0 m shows best performance (see Fig. 21, 22).

Table 6- Maximum bending moment (kNm) in columns for wind load in X Direction (without eccentricity bracing structure)

Bracing Pattern	Floor level		
	Base to Ground	9 th to 10 th	19 th to 20 th
Unbraced	94.456	16.557	3.807
X Brace	98.135	21.470	4.985
V Brace	102.345	18.634	2.853
Diagonal Brace	97.936	16.457	4.070
Inverted V Brace	108.369	18.527	4.857
K Brace	95.245	13.012	2.265
Two storey K Brace	96.031	13.312	2.463

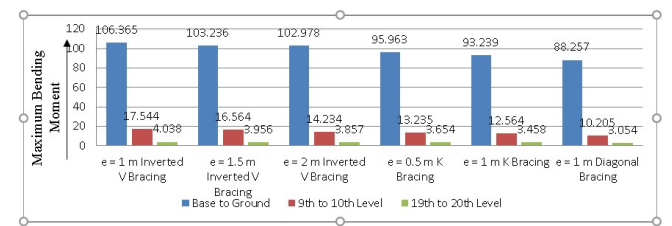


Fig. 21- Maximum bending moment (kNm) in columns for wind load in X Direction of eccentric bracing structures

Table-7 Maximum bending moment (kNm) in columns for wind load in Z Direction (without eccentricity bracing structure):

Bracing Pattern	Floor level		
	Base to Ground	9 th to 10 th	19 th to 20 th
Unbraced	34.607	10.814	0.893
X Brace	35.872	7.621	1.781
V Brace	38.271	9.192	1.344
Diagonal Brace	31.998	7.455	1.376
Inverted V Brace	40.849	10.797	1.235
K Brace	35.565	6.869	1.232
Two storey K Brace	35.650	7.345	1.358

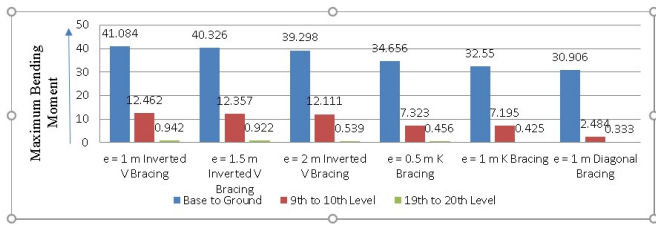


Fig. 22- Maximum bending moment (kNm) in columns for wind load in Z Direction of eccentric bracing structures

Table-8 Maximum shear force (kN) in columns for Wind load in X direction (without eccentricity bracing structure):

Bracing Pattern	Floor level		
	Base to Ground	9 th to 10 th	19 th to 20 th
Unbraced	17.689	5.905	0.843
X Brace	18.575	5.599	1.124
V Brace	18.880	6.051	1.505
Diagonal Brace	18.744	5.845	1.402
Inverted V Brace	19.804	6.065	1.791
K Brace	20.256	6.125	1.559
Two storey K Brace	21.974	6.138	1.660

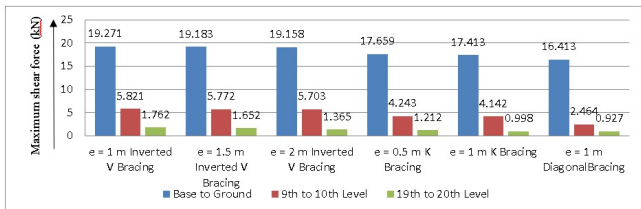


Fig. 23- Maximum shear force (kN) in columns for Wind load in X direction of eccentric bracing structures

Table-9 Maximum shear force (kN) in columns for Wind load in Z direction (without eccentricity bracing structure)

Bracing Pattern	Floor level		
	Base to Ground	9 th to 10 th	19 th to 20 th
Unbraced	16.254	6.606	0.306
X Brace	7.485	1.015	0.721
V Brace	14.546	6.710	0.867
Diagonal Brace	13.730	2.080	0.804
Inverted V Brace	11.253	6.588	0.900
K Brace	11.256	6.568	0.752
Two storey K Brace	12.252	0.963	0.785

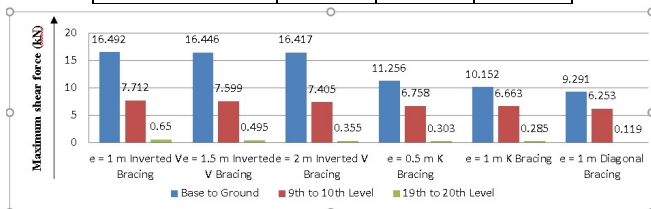


Fig. 24 - Maximum shear force (kN) in columns for Wind load in Z direction of eccentric bracing structures

5.3 Considering Maximum Shear Force

It is evident from the results of Table 8, 9 that the maximum shear force for frames with different brace patterns but without eccentricity, performance of X bracing is better as compared to other bracing structures under effect of wind load. If eccentricity (e) of inverted V bracing and K bracing is increased, then it helps in reducing the shear force

of eccentric structures under wind load. Here also diagonal bracing system with e=1.0 m reduces the shear force to a highest level (refer Fig. 23, 24).

Table 10- Maximum axial force (kN) in columns for Wind load in X direction (without eccentricity bracing structure)

Bracing Pattern	Floor level		
	Base to Ground	9 th to 10 th	19 th to 20 th
Unbraced	134.389	52.412	0.669
X Brace	181.957	70.035	0.757
V Brace	138.378	50.563	0.251
Diagonal Brace	138.507	53.705	0.503
Inverted V Brace	145.758	55.045	0.696
K Brace	131.236	48.532	0.196
Two storey K Brace	135.212	49.702	0.268

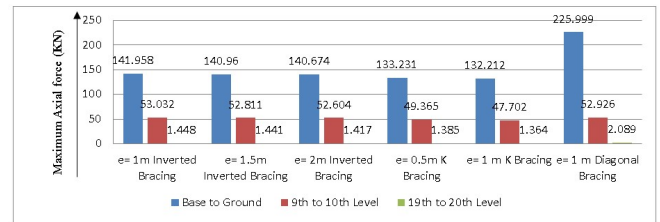


Fig. 25- Maximum axial force (kN) in columns for Wind load in X direction of eccentric bracing structures

Table 11- Maximum axial force (kN) in columns for Wind load in Z direction (without eccentricity bracing structure)

Bracing Pattern	Floor level		
	Base to Ground	9 th to 10 th	19 th to 20 th
Unbraced	178.042	52.947	0.053
X Brace	398.494	88.401	3.135
V Brace	179.196	62.717	0.621
Diagonal Brace	345.169	74.519	1.711
Inverted V Brace	181.225	63.803	0.783
K Brace	176.567	59.365	0.135
Two storey K Brace	178.147	61.539	0.319

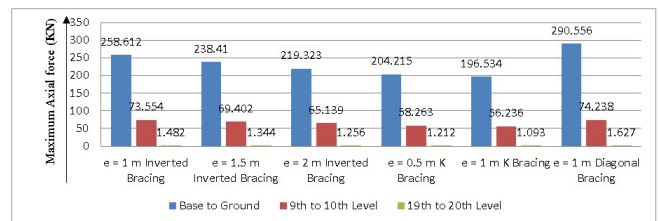


Fig. 26- Maximum axial force (kN) in columns for Wind load in Z direction of eccentric bracing structures

5.4 Considering Maximum Axial Force

Considering the maximum axial force (Table 10 and 11) for without eccentricity structures it has been observed that performance of K bracing is better as compared to other bracing structures. If eccentricity (e) of Inverted V bracing and K bracing is increased (Refer Fig. 25, 26) then it helps in reducing the axial force of structures subjected to wind load. Among structures with eccentricity, results of K bracing system is better as compared to other bracing patterns.

6. Conclusions

Following points have been concluded from above study work:

1. Steel braces are one of the most suitable way to strengthen and retrofit the newly constructed or existing steel structures.
2. It is clear from the present analysis work that, steel brace patterns help to reduce lateral displacement, storey drift, bending moment, shear force and axial load on columns.
3. Among the various existing brace patterns overall performance of X brace is better followed by K brace.
4. Lateral displacement, storey drift, bending moment, shear force and axial load can be reduced by introducing eccentricity in many types of brace pattern.
5. Among all the bracing patterns with eccentricity overall performance of diagonal brace pattern with eccentricity of 1 m is best.

Disclosures

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