Various Bracing System Based Comparative Analysis of an Irregular Tall Building using STAAD

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***Abstract*- Structure must be designed with the utmost proficiency and safety to remain functional under the most extreme combinations of gravity and lateral loads it may encounter. As the height of a structure increases, ensuring stability against overturning becomes increasingly critical. Wind loading is a key factor influencing the design of tall buildings over 10 stories. Typically, buildings taller than 10 stories require additional load-resisting systems. A braced frame enhances the efficiency of a pure rigid frame by balancing shear racking and bending. Braced frame systems are broadly categorized into concentric and eccentric types.**

This study reviews 40 research papers from various journals, conferences, and other sources on braced frame systems. It provides a comprehensive analysis of these papers, identifying their strengths, weaknesses, and gaps. The problem statement and objectives are formulated to analyze the efficiency of braced frame systems in resisting lateral displacement, torsion, bending moments, and axial forces under wind loads.

The study also evaluates the performance of different braced frame patterns placed at various locations within a structure, focusing on their efficiency and structural weight. For this purpose, an irregular G+11 multi-story structure located in a high wind zone with a basic wind speed of 50 m/s was analyzed. The performance of three types of concentric braced frame systems (K, X, and V) was investigated when installed in different locations to provide lateral stiffness and strength against horizontal forces. Bracings were applied in both the X and Z directions. The structures were analyzed using the Equivalent Static Analysis method with STAAD.Pro V8i software. The results of braced frame models were compared with those of a bare frame model to evaluate the effectiveness of each bracing system in controlling displacement and member forces. Results were assessed in terms of shear force, bending moment, node displacement, support reaction, axial force, torsion, and structural weight. Among the systems studied, X-type bracing was found to be the most effective in providing lateral strength and stiffness to the structure.

Keywords: - Braced frame system, lateral stiffness, Equivalent Static analysis, lateral loads, STAAD Pro

I. INTRODUCTION

Tall structure is relative and cannot be universally quantified by specific heights or number of stories. From the perspective of a structural engineer, a tall structure is characterized by its height making it significantly affected by lateral forces, such as wind or earthquakes, to the extent that these forces play a dominant role in its structural design. For instance, a tall structure is one where the efficiency in resisting lateral loads outweighs the efficiency against gravity loads during the design process. The evolution of modern multi-story buildings, which began in the late 19th century, has been primarily driven by their commercial and residential utility. The growth of high-rise construction has closely paralleled the development of cities. Urbanization, which began during the industrial revolution, continues to progress, particularly in developing nations like India. Industrialization has triggered migration to urban centers and towns, where opportunities for employment are more abundant, further fueling the rise of high-rise structures.

Steel braced frames are structural systems used to resist lateral loads in multi-story buildings. They are cost-effective, space-efficient, and easy to construct, offering the necessary strength and stiffness for such structures. While braced frames effectively resist lateral loads, they may interfere with architectural components and are typically placed in vertically aligned spans. This system significantly improves stiffness with minimal weight addition, making it ideal for retrofitting structures with poor lateral stiffness. This project aims to study various steel bracing configurations and their positions to identify the most efficient system in terms of load resistance and economic viability, providing an optimized solution. The report explores the impact of lateral loads on structures and demonstrates how braced frames can mitigate these effects. Additionally, it proposes environmentally and economically sustainable measures to retrofit weak structures vulnerable to seismic and wind hazards.

Objectives

- To identify the location with relatively high wind speed.
- To acquire all the necessary wind details for zone with relatively high basic wind speed.
- To design & analyze a multistorey G+11 irregular RC bare frame structure.
- To identify the most vulnerable Beams & Nodes in Bare frame model subjected to the applied wind load.
- To install three different types of concentric bracing patterns (K, X & V) at various locations.
- To analyze & compare the results in various different strength & stiffness parameters.

II. LITERATURE REVIEW

In this study, Parag Y Sonule et al. (2024) highlighted the importance of bracings in mitigating dynamic forces, reducing sway, and enhancing the resilience of tall steel structures. Their study emphasized diverse bracing configurations tailored to project-specific requirements, with a focus on innovations like Finite Element Analysis (FEA) and sustainable design techniques for improved efficiency. Prateek Roshan et al. (2023) analyzed bracing systems in 34-story buildings, showing that X-bracing significantly reduced story displacement and lateral deflection, making it the most effective system. Their STAAD Pro-based analysis demonstrated the necessity of appropriate bracing systems, especially in earthquake-prone regions. Praful Barge et al. (2022) analyzed G+13 steel buildings with various bracing patterns, showing that X-bracing effectively reduced lateral displacements during seismic events while maintaining similar base shear and weight. Nitin Vishwakarma et al. (2018) found that X-bracing systems in G+20 shear wall structures reduced lateral displacements by 35-45% and improved seismic performance. Yamini Komath et al. (2017) emphasized the benefits of eccentric bracing and advanced materials like Shape Memory Alloys (SMAs), highlighting their energy dissipation and ductility. Collectively, these studies underscore bracings' critical role in enhancing seismic resilience in high-rise structures. Khadani et al. (2016) analyzed an eight-story steel frame with various bracing configurations using ETABS, finding that X and V-bracing systems significantly reduced lateral displacements (up to 62.5%), improved energy absorption, and minimized bending moments and column shear forces. Concurrent bracing enhanced structural stability, while V-type bracing allowed the least lateral displacement. Kamble et al. (2016) performed nonlinear static pushover analysis on a G+5 unsymmetrical RC frame using SAP2000, evaluating diagonal, X, V, and K bracings. Results showed that X-bracing provided at the overall face was most effective, reducing top-story displacement by 73% and controlling drift ratio within IS 1893:2002 limits. Both studies highlight the efficacy of X-bracing in enhancing lateral stability, energy dissipation, and seismic resilience of structures. Maruthi et al. (2016) analyzed G+4 steel frame with various bracing configurations using SAP2000 and pushover analysis to evaluate seismic parameters such as base shear, roof displacement, storey drift, and performance point. The structure was modeled with 3 bays in both directions and a height of 3m per storey, located in seismic zone 5. X-bracing showed the most effective reduction in storey drift and improved the performance point compared to other bracing systems, making it the optimal choice for enhancing lateral stiffness. P. Gupta et al. (2016) analyzed a 30-storey building using static and dynamic methods in ETABS to compare lateral force-resisting systems, including braced core, shear wall, and bracing at the periphery. Inverted V-bracing at the periphery proved most effective, reducing lateral displacement by 78.46% and offering a cost-effective solution. The study highlighted the superiority of dynamic analysis over static analysis in accurately predicting displacement. N. Murthy et al. (2016) studied on T-shaped G+19 irregular multi-storey building under seismic and wind loads using STAAD.Pro. Five bracing systems were evaluated, with inverted V-bracing reducing displacement by 26.42% and significantly enhancing lateral stiffness. Axial loads on columns increased with the use of V-bracing (41.67%) and knee bracing (44.37%), demonstrating improved structural performance compared to the unbraced model. M. T. Khaleel et al. (2016) investigated the impact of various bracing configurations on a G+9 steel-framed building was investigated using ETABS. Analysis revealed that X-bracing achieved the greatest reduction in storey displacement (83.13% for regular and 83.67% for irregular buildings) while enhancing stiffness. Cross bracing had the highest base shear, and knee bracing the least, indicating that bracing systems must be carefully blended with other seismic-resisting systems for optimal performance and cost-effectiveness.

III. METHODOLOGY

For this study purpose an irregular (G+11) reinforced concrete structure was modelled & analyzed in STAAD.Pro. The structure consisted of 6 bays of 4.2m along x direction & 4 bays of 4.2 m along z direction. The no bays along z direction first reduced after 8th storey & then after 10th storey. The analysis of 10 different models were completed in 6 steps.

Design of Bare Frame model.		
Step 1		• Model G+11 Bare frame structure
		• Provide all the essential properties (Beams & Columns)
		• Assign fixed support at the bottom of each column
		• Apply the load combinations.
Design of 9 Braced Frame models.		
Step 2		• Apply 3 different types bracing system on 9 different models (all properties & dimension similar to bare frame model) to increase their lateral stiffness & strength.
Analysis by using ESA method.		
Step 3		• Equivalent static analysis is carried on all the 10 models by using STAAD.Pro software
Results		
Step 4		• Obtain the results for all the 9 braced models in terms of Shear force, bending moment, node displacement, axial force, reactions & torsion.
Comparison of Results		
Step 5		• Compare the results of braced frame models against bare frame model
Ranking of systems.		
Step 6		• Rank the bracing patterns in terms of performance & cost efficiency.

Load combination for limit state of collapse as per IS 456-2000.

- 1.5(D+L) 1.5(D+L)
- 1.5(D+W) 1.5(D+W in X +ve)
- 1.5(D+W in Z +ve)
- 1.5(D-W) 1.5(D+ W in X -ve)
- 1.5(D+ W in Z –ve)
- 1.2(D+L+W) 1.2(D+L+W in X +ve)
- 1.2(D+L+W in Z +ve)
- 1.2(D+L-W) 1.2(D+L-W in X –ve)
- 1.2(D+L+W in Z –ve)
- 6. 0.9D+1.5W 0.9D +1.5W in X +ve
- 0.9D+1.5W in Z +ve)
- 7. 0.9D-1.5W 0.9D -1.5W in X –ve
- 0.9D-1.5W in Z-ve

Table 1: Building description

Type of frame	Ordinary moment resisting frame
No of storey	12 (G+11)
Location	Bhuj, Gujrat
Seismic zone, zone factor	V, 0.36
Importance factor	1
Response reduction factor	5
Type of building	Residential
Wind speed	50m/s
Plan dimension (in m)	25.2x16.8
No of bays	x-6, z-4
Total height	41.13m
Materials used	M25, Fe 415
Bracing dimension (in mm)	ISA 110x110x12

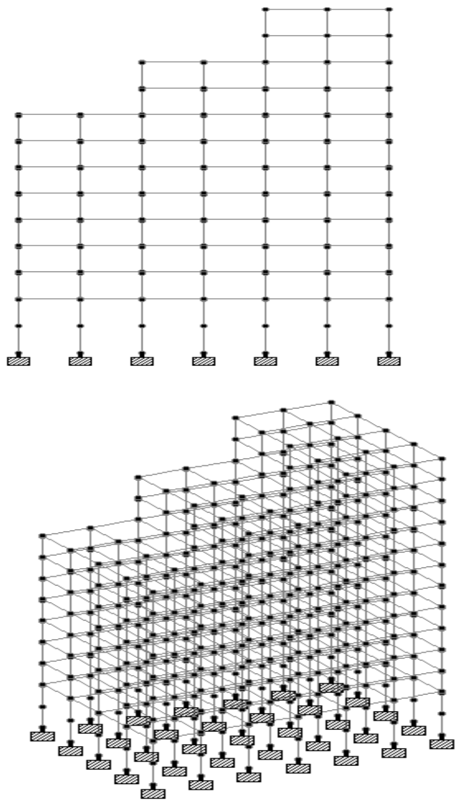

Fig 1 Elevation of the Structure (a) X view (b) isometric view

Three major types of bracing system (K, X & V) are examined & compared with respect to unbraced reference model. Total 10 models were analyzed in this study. They are as follows:

Model 1: Bare frame model.
Model 2: Building with k bracing arranged in pattern 1.
Model 3: Building with k bracing arranged in pattern 2.
Model 4: Building with k bracing arranged in pattern 3.
Model 5: Building with x bracing arranged in pattern 1.
Model 6: Building with x bracing arranged in pattern 2.
Model 7: Building with x bracing arranged in pattern 3.
Model 8: Building with v bracing arranged in pattern 1.
Model 9: Building with v bracing arranged in pattern 2.
Model 10: Building with v bracing arranged in pattern 3.

IV. RESULTS AND DISCUSSION

Results were compared for all the 9 Braced frame models in terms of Shear force, bending moment, node displacement, reactions, axial force & torsion against Bare frame model to rank the different models in terms of their efficiency. Results shows the efficiency comparison of different models against Bare frame model in percentage.20.156 kN-m (hard soil) to 27.883 kN-m (soft soil) in Delhi, and higher values observed in Jaipur due to stronger winds. Base shear also increases with softer soils, ranging from 543.605 kN (hard soil) to 899.03 kN (soft soil) in Delhi. However, in Jaipur, base shear values are nearly uniform (~795 kN), reflecting the dominance of wind forces over soil variability.

Maximum Shear Force & Bending Moment Value along X, Y & Z direction

Table 2 Comparison of Maximum S.F (KN) & B.M (KN) values

Model	Fx	Fy	Fz	Mx	My	Mz
BF	4721.638	150.422	9.52	9.547	501.017	516.018
K1	4660.393	395.35	238.889	16.3333	475.775	585.007
K2	4648.891	345.356	75.433	27.077	474.747	601.602
K3	4344.253	386.08	162.056	16.03333	465.399	590.591
X1	4465.007	406.556	258.156	18.755	469.399	621.139
X2	4475.904	387.504	96.09	19.281	474.496	625.113
X3	4457.758	407.396	158.248	18.748	469.808	621.781
V1	4504.014	378.446	144.57	17.116	461.416	608.56
V2	4500.212	321.347	60.491	17.534	457.77	607
V3	4482.522	330.606	52.99	22.872	472.666	616.171

Table 3 Efficiency in % to resist S.F & B.M

S.F & B.M	Fx	Fy	Fz	Mx	My	Mz
K1	1%	162%	238%	71%	5%	13%
K2	1%	129%	69%	183%	5%	16%
K3	7%	156%	160%	71%	7%	14%
X1	5%	169%	155%	96%	6%	20%
X2	5%	157%	90%	101%	5%	21%
X3	5%	170%	156%	96%	6%	20%
V1	4%	151%	142%	79%	7%	17%
V2	4%	113%	53%	80%	9%	16%
V3	5%	119%	456%	139%	5%	19%

Maximum Node displacement & rotation value along X, Y & Z direction

Table 3 Comparison of Maximum Node displacement values

Models	X	Y	Z	MAX Rst	rX	rY	rZ
BF	255.214	2.857	406.714	480.144	0.035	0	0
K1	187.332	15.614	371.506	415.946	0.032	0.001	0.011
K2	185.743	21.955	370.351	414.753	0.033	0.001	0.012
K3	188.753	9.677	374.272	419.07	0.032	0.001	0.009
X1	170.566	3.256	350.412	388.624	0.031	0.002	0
X2	175.691	5.286	354.113	394.282	0.032	0.001	0
X3	168.892	3.267	347.972	386.71	0.031	0.002	0
V1	177.713	3.417	354.052	395.161	0.031	0.006	0.002
V2	176.912	4.77	356.886	398.213	0.032	0.005	0.003
V3	175.23	4.934	353.944	394.849	0.032	0.006	0.002

Table 4 Efficiency in % to resist Maximum Node displacement

N. D	X	Y	Z	MAX Rst	rX	rY	rZ
K1	26%	446%	8%	13%	8%	0%	0%
K2	27%	66%	8%	13%	5%	0%	0%
K3	26%	238%	7%	12%	8%	0%	0%
X1	33%	14%	13%	4.00%	11%	0.00%	0%
X2	31%	85%	12%	17%	8%	0%	0%
X3	33%	14%	14%	19%	11%	0%	0%
V1	30%	19%	12%	17.00%	11%	0%	0.00%
V2	30%	66%	12%	17%	8%	0%	0%
V3	31%	73%	12%	17%	8%	0%	0%

Maximum Support Reaction values along X, Y & Z direction

Table 5 shows the comparison of Maximum Reaction values of all the analyzed models, while efficiency in percentage of different models to support Reactions against Bare Frame is displayed in table 5.46.

Table 5 Comparison of Maximum Reaction values

Models	Fx	Fy	Fz	Mx	My	Mz
BF	1.019	4721.638	0.724	1.34	9.547	472.048
K1	1.536	4660.393	1.653	3.491	11.348	585.007
K2	1.504	4648.891	1.903	4.135	13.561	601.602
K3	1.542	4344.253	1.528	3.314	11.637	590.551
X1	1.249	4465.007	0.704	1.527	13.31	621.139
X2	0.985	4475.904	0.699	1.383	13.505	625.113
X3	1.226	4457.778	0.706	1.562	13.156	621.781
V1	1.072	4504.0144	0.873	1.521	12.268	608.56
V2	0.92	4500.212	0.696	1.415	13.522	607
V3	1.082	4482.547	0.694	1.303	14.831	616.171

Table 6 Efficiency in % of Structural Reaction

Reaction	Fx	Fy	Fz	Mx	My	Mz
K1	50%	1%	128%	160%	18%	22%
K2	37%	1%	162%	208%	42%	27%
K3	51%	7%	111%	147%	21%	25%
X1	21%	5%	2%	15%	37%	31%
X2	3%	5%	4%	3%	41%	32%
X3	20%	5%	2%	16%	37%	31%
V1	5%	4%	5%	13%	28%	28%
V2	9%	4%	3%	5%	41%	28%
V3	1%	6%	14%	2%	55%	30%

Maximum Axial force & Torsion value

Table 7 displays the comparison of Maximum A.F & Torsion values of all the analyzed models, while efficiency in percentage of different models checked against Bare Frame is displayed in table 5.48.

Table 7 Comparison of Maximum Axial Force & Torsion values

	Axial Force	Torsion
Model	Max Fx KN	Max Mx KN/m
BF	4721.638	9.547
K1	4660.393	16.333
K2	4648.891	27.077
K3	4344.253	16.339
X1	4465.007	18.755
X2	4475.904	19.281
X3	4457.778	18.748
V1	4504.014	17.116
V2	4500.113	17.523
V3	4482.542	22.872

Table 8 Efficiency in % to resist Axial Force & Torsion

Model	A. F	Torsion
K1	1%	71%
K2	1%	183%
K3	7%	71%
X1	5%	96%
X2	5%	101%
X3	5%	96%
V1	4%	79%
V2	4%	83%
V3	5%	139%

V. CONCLUSION

The review highlighted a key issue concerning the disparity between experimental and analytical approaches. An in-depth analysis of the literature was performed to extract common findings, strengths, weaknesses, and research gaps, forming the basis for the problem statement and objectives. Based on the identified gaps, a problem statement was developed to propose a novel methodology for designing lateral load-resisting structures using braced frame systems.

Following conclusions were drawn after analyzing 9 Braced frame models with Bare frame reference model.

•Total weight of the existing structure changed marginally around 3% after the application of Braced frame system.

•X type braced frame (7%) is found most efficient in terms of Shear Force along x direction.

•V type braced frame (113%) is found most efficient in terms of Shear Force along y direction.

•V type braced frame (45.6%) is found most efficient in terms of Shear Force along z direction.

•K type braced frame (40.9%) is found most efficient in terms of Bending moment along x direction.

•V type braced frame (9%) is found most efficient in terms of Bending moment along y direction.

•K type braced frame (6%) is found most efficient in terms of Bending moment along z direction.

•X type braced frame (33%) is found most efficient in terms of Node displacement along x direction.

•X type braced frame (85%) is found most efficient in terms of Node displacement along y direction.

•X type braced frame (14%) is found most efficient in terms of Node displacement along z direction.

•V type braced frame (9%) is found most efficient in terms of Support reaction along x direction.

•X type braced frame (5%) is found most efficient in terms of Support reaction along y direction.

•V type braced frame (4%) is found most efficient in terms of Support reaction along z direction.

•X type braced frame (5%) is found most efficient in terms of Axial force.

•K type braced frame (71%) is found most efficient in terms of Torsion.

•Concentric x type bracing is found most efficient in terms of providing overall lateral stiffness & strength to the structure

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