SUSTAINABILITY EVALUATION FOR SELECTING THE BEST OPTIMIZED STRUCTURAL FORMS FOR TALL BUILDING

ANIL KUMAR R[1], VARUN HR[2], KRISHNAGOWDA PATIL[3].

Article History: Received: 07-07-2023 Revised: 05-08-2023 Accepted: 2 0 - 0 8 - 2 0 2 3

Abstract

In this comprehensive study, we delve deep into the exploration of diverse structural forms [1] specifically designed for the construction of towering edifices, aiming to pinpoint their ideal conditions to ensure a thorough and effective comparison. Our research meticulously takes into account a range of standard parameters, modeling buildings of varying heights and with different numbers of stories. This approach ensures a holistic evaluation, encompassing a broad spectrum of potential real-world scenarios. The driving force behind this investigation is to ascertain the most efficient structural form that possesses the resilience and strength to counteract the devastating forces of earthquakes. Earthquakes, with their unpredictable nature and immense power, pose a significant threat to tall structures. Therefore, it's imperative to design buildings that not only meet aesthetic and functional requirements but also prioritize safety, especially in earthquake-prone regions [21][22][23]. While it's evident from preliminary observations that all the considered structural systems showcase a commendable capability in resisting the tremors of earthquakes and effectively minimizing lateral displacements, our study goes a step further. We aim to juxtapose these systems, critically analyzing them based on pivotal parameters. These include the extent of displacement a building undergoes during an earthquake, the story drift which refers to the relative movement between two consecutive stories, and the base shear, a crucial factor that represents the total horizontal force at the base of a structure [20][21][22].

By meticulously examining these key indicators, our study endeavors to not only highlight the strengths and weaknesses of each structural form but also to identify the one that stands out as the most robust and reliable system for the construction of tall buildings [22][23] in earthquake-prone areas.

Keywords: Core wall, peripheral shear wall, outrigger, Diagrid, ETABS, Story drift, Deflection, Base shear.

[1]Assistant Professor, Department of Civil Engineering, MSRIT, Bangalore, India
[2] P.G Research scholar, Department of Civil Engineering, MSRIT, Bangalore, India
[3]P.G Research scholar, Department of Civil Engineering, MSRIT, Bangalore, India

DOI: 10.48047/ecb/2023.12.8.709

INTRODUCTION:

1.1. General:

The development of tall structures has evolved over time [2], from traditional rigid frames [3] to modern technologies such as outriggers and diagrids. Initially, the focus was on increasing rentable office space vertically and improving natural lighting, leading to innovations in load-bearing walls and the introduction of curtain walls [4]. The race for height began with buildings like the Park Row and Empire State buildings, which featured steel rigid frames with wind bracing [5]. However, these early structures were overdesigned due to limited understanding of advanced structural analysis methods. In the 1960s, tubular systems emerged, driven by architectural and technical requirements. This led to changes in structural forms [6] and the adoption of facade traits from postmodern, historical, diagrid [7][8][9], and de-constructivist expressions. Advances since then include mixed steel-concrete systems, damped structures, tube systems, mega frames, and core and outrigger systems [10][11][12].

STRUCTURAL SYSTEMS CONSIDERED FOR PRESENT STUDY:

- Beam-Column structural system
- Core Wall structural system
- Peripheral shear wall system
- Outrigger structural system
- Diagrid structural system

METHODOLOGY

Models of all 5 structural forms was modelled in ETABS for 50, 80, 100 stories loading is applied according to IS 875 (par1&2). Parameters such as deflection, Story drift, Base shear is analyzed by graphical method and also maximum values is obtained. The values are compared to come out with the most efficient structural form

SOFTWARE CONSIDERED FOR PRESENT ANALYSIS

ETABS

ETABS is a widely used software program in the building sector, known for its user-friendly interface and regular updates. In this project, ETABS was utilized for modeling and analysis purposes. It is an advanced yet accessible design tool specifically designed for building systems. With a single database, ETABS provides unparalleled modeling, analytical, and design capabilities. Its graphical interface is both fast and powerful. ETABS stands out for its ability to handle large and complex building models, including a wide range of nonlinear behaviors [13]. This makes it the preferred tool for structural professionals in the global construction industry.

MODELLING DETAILS

4.1 Beam-Column RC Frame Structural Model

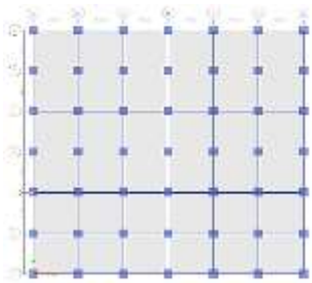


Figure 1: Plan of RC frame Building

Figure 2: Elevation of RC frame Building

Figure 3 3D View of the RC frame Building

Number of floors	50/80/100
Height of each floor	3 m
Size of the column	(800 X 800) mm/(1000 X 1000) mm/(1200 X 1200) mm
Size of the beam	300 mm X 450 mm
Thickness of the slab	175 mm
Grade of concrete	M50
Grade of reinforcing	Fe550
Density of concrete	25 kN/m3

4.2 Core Wall Structural Model

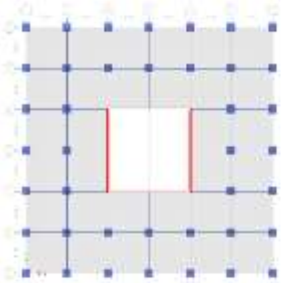


Figure 4.2.1 - Plan of Building with Core Wall

Figure 4 - Elevation of Building with Core Wall

Figure 5- 3d View of Building with Core Wall

Number of floors	50/80/100
Height of each floor	3 m
Size of the column	(800 X 800) mm/(1000 X 1000) mm/(1200 X 1200) mm
Size of the beam	300 mm X 450 mm
Thickness of the slab	175 mm
Thickness of Core Wall	300 mm
Grade of concrete	M50
Grade of reinforcing steel	Fe550
Density of concrete	25 kN/m3

4.3 Peripheral Shear Wall Structural Model

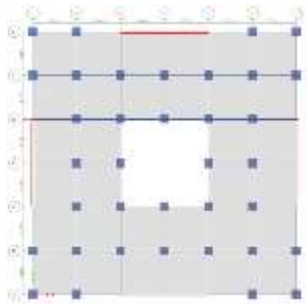


Figure 6: Plan of the Building with Peripheral Shear Wall

Figure 7- Elevation of Building with Peripheral Shear wall

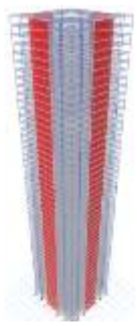


Figure 8 - 3D view of the Building with Peripheral Shear Wall

Number of floors	50/80/100
Height of each floor	3 m
Size of the column	(800 X 800) mm/(1000 X 1000) mm/(1200 X1200)mm 1200)
Size of the beam	300 mm X 450 mm
Thickness of the slab	175 mm
Grade of concrete	M50
Grade of reinforcing steel	Fe550
Density of concrete	25 kN/m3

4.4 OUTRIGGER STRUCTURAL MODEL

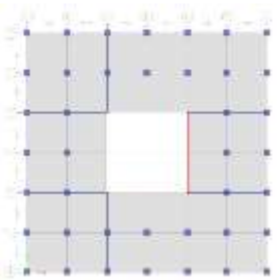


Figure 9 - Plan of Building with Outrigger

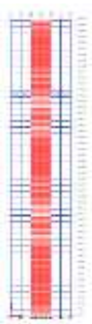


Figure 10 - Elevation of the building with Outrigger

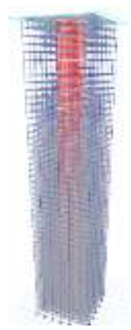


Figure 11 - 3D view of the Building with Outrigger

Number of floors	50/80/100
Height of each floor	3 m
Size of the column	(800 X 800) mm/(1000 X 1000) mm/(1200 X 1200) mm
Size of the beam	300 mm X 450 mm
Thickness of the slab	175 mm
Thickness of Shear Wall	300 mm

4.5 DIAGRID STRUCTURAL MODEL

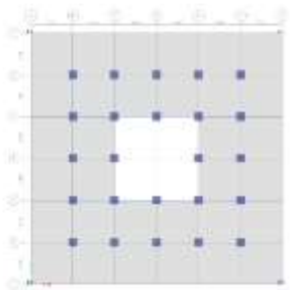


Figure 11 - Plan of the building with Diagrid

Figure 12 - Elevation of the building with Diagrid

Figure 13- 3D view of the building with Diagrid

Number of floors	50/80/100
Height of each floor	3 m
Size of the column	(800 X 800) mm/ (1000 X 1000) mm/ (1200 X 1200) mm
Size of the beam	300 mm X 450 mm
Thickness of the slab	175 mm
Diagrid section (Steel)	ISWB 600
Grade of concrete	M50
Grade of reinforcing steel	Fe550
Density of concrete	25 kN/m3

LOADING DETAILS

Dead loads

Floor Finish 1 kN/m2

Live loads

Load on the Slab 2.5 kN/m2

Seismic Loads

The seismic loads are applied to the structural models using the response spectrum technique of analysis, according to the Indian Standard Criteria for Earthquake Resistant Design of Structures, IS 1893 Part 1: 2002.

Seismic Zone -	Zone V
Soil Type -	Medium Soil (Type II)
Importance Factor -	1
Response reduction Factor -	5

ANALYSIS OF RESULTS

For all distinct structure types with 50 storeys, the highest values of story displacement [14], story drift, and base shear were recorded from the ETABS plots mentioned above. Then, using MS-Excel, the following findings were tabulated and compared

Table 1: Max. Storey Displacement in mm (50 Storey) in X-direction

Type of system	Max deflection, mm	% Reduction
Beam-column	387	-
Shear Wall	231	40.310
Core Wall	183	52.713
Outrigger	135	65.116
Diagrid	110	71.576

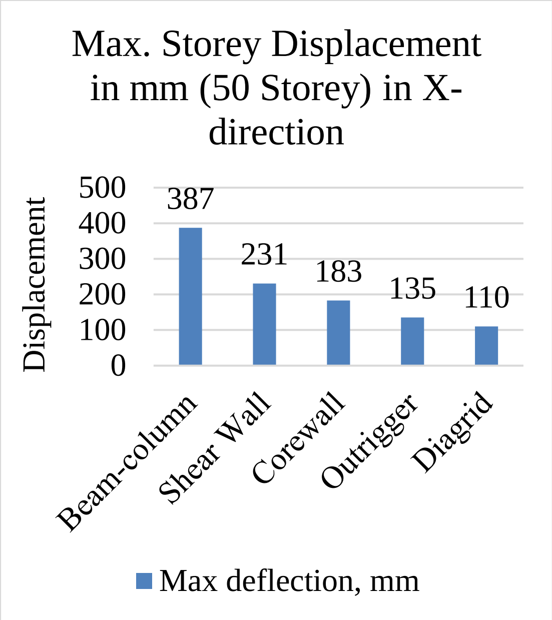


Figure 5.16.1 Maximum Story Displacement for 50 story in X-Direction

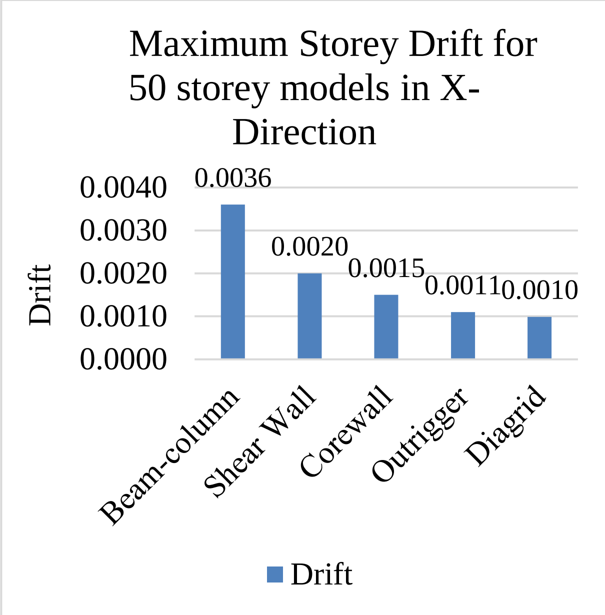


Figure 5.16.2 Maximum Story Drift for 50 story in X-Direction

Here we can observe that Beam column model gives the maximum deflection compared to other models.

Here we can observe that Beam column model gives the maximum Story drift compared to other models

Table 5.16.2 Maximum Story Drift for 50 story models in X-Direction

Maximum Storey Drift for 50 storey models in X-Direction		
Type of system	Drift	% Reduction
Beam-column	0.0036	-
Shear Wall	0.0020	44.444
Core wall	0.0015	58.333
Outrigger	0.0011	69.444
Diagrid	0.0010	72.500

Table 5.16.3 Base Shear for 50 story in X-Direction

Base Shear for 50 stores in X-Direction		
Type of system	Base shear	% Increase
Beam-column	5744	-
Shear Wall	6343	10.428
Core wall	7795	35.707
Outrigger	7862	36.873
Diagrid	7733	34.627

Max. Storey Displacement in mm (80 Storey) in X-direction		
Type of system	Max deflection, mm	% Reduction
Beam-column	952	-
Shear Wall	788	33.277
Core wall	722	38.865
Outrigger	568	51.905
Diagrid	556	52.921

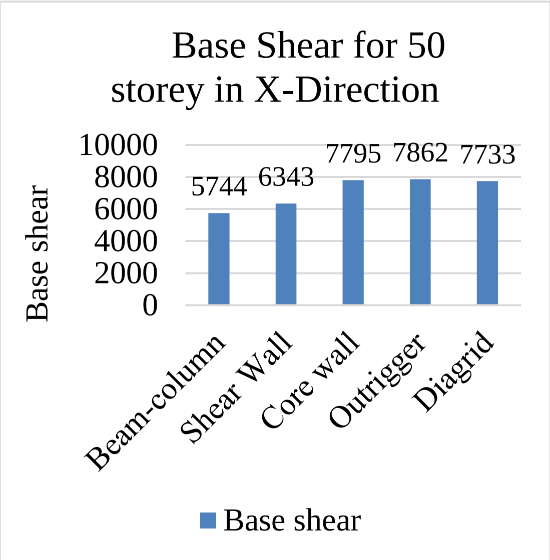


Figure 5.16.3 Base Shear for 50 storeys in X-Direction

Here we can observe that outrigger model gives the maximum Base shear compared to other models

5.17 COMPARISON OF DIFFERENT PARAMETERES FOR DIFFERENT STRUCTURAL SYSTEMS WITH 80 STOREYS IN X-DIREXTION

Table 5.17.1 - Maximum Story Displacement for 80 story in X-Direction

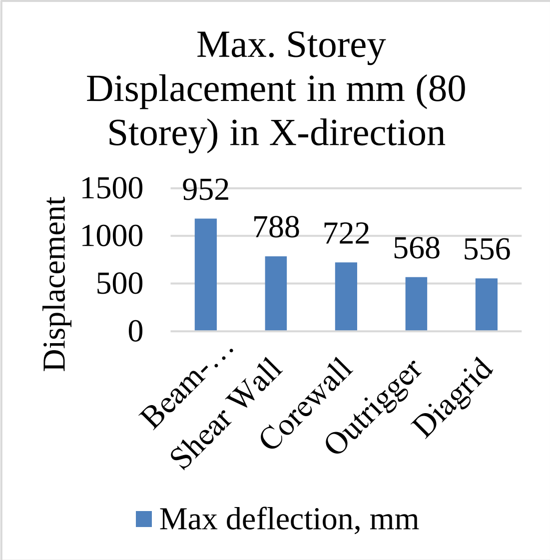


Figure 5.17.1 Maximum Story Displacement for 80 story in X-Direction

Here we can observe that in 80 story Beam column model gives the maximum Displacement compared to other models

Table 5.17.2 - Story drift for 80 stories in X-Direction

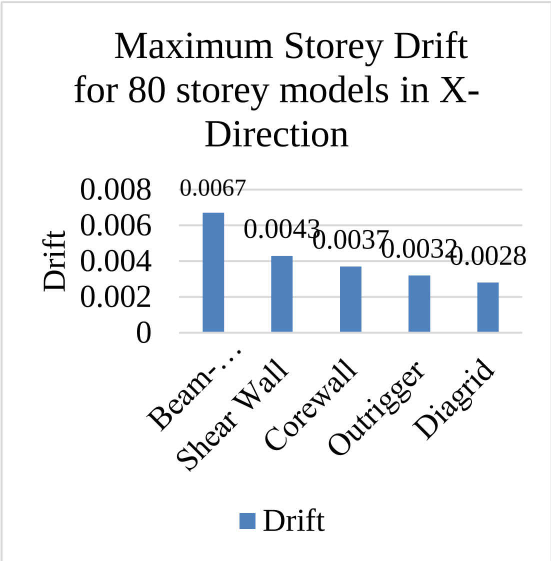


Figure 6.17.2 Maximum Story Drift for 80 story in X-Direction

Here we can observe that in 80 story Beam column model gives the maximum story drift compared to other models

Table 6.17.3 - Base Shear for 80 stories in X-Direction

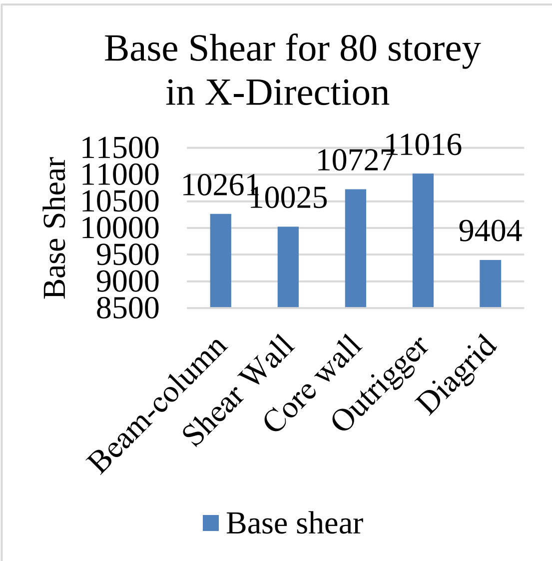


Figure 6.17.3 Base Shear for 80 storeys in X-Direction

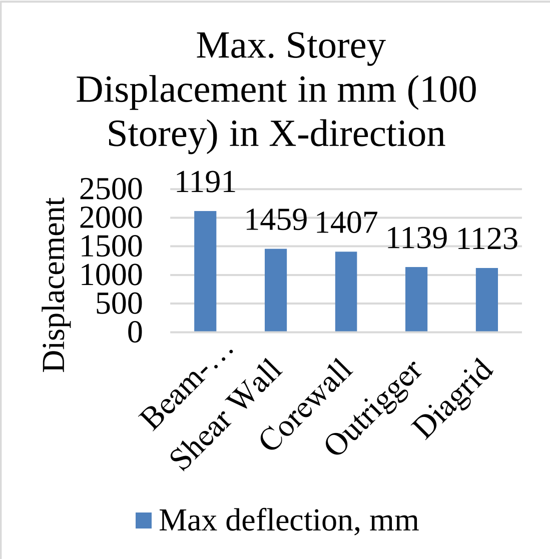
Here we can observe that in 80 story outrigger model gives the maximum Base shear compared to other models

5.18 COMPARISON OF DIFFERENT PARAMETERES FOR DIFFERENT STRUCTURAL SYSTEMS WITH 100 STOREYS IN X-DIREXTION

Table 5.18.1 Maximum Story Displacement for 100 story in X-Direction

Max. Storey Displacement in mm (100 Storey) in X-direction		
Type of system	Max deflection, mm	% Reduction
Beam-column	1191	-
Shear Wall	1459	31.114
Core wall	1407	33.569
Outrigger	1139	46.223
Diagrid	1123	46.978

Maximum Storey Drift for 80 storey models in X-Direction		
Type of system	Drift	% Reduction
Beam-column	0.0067	-
Shear Wall	0.0043	35.821
Core wall	0.0037	44.776
Outrigger	0.0032	52.239
Diagrid	0.0028	58.209



Here we can observe that in 100 story Beam column model gives the maximum deflection compared to other models

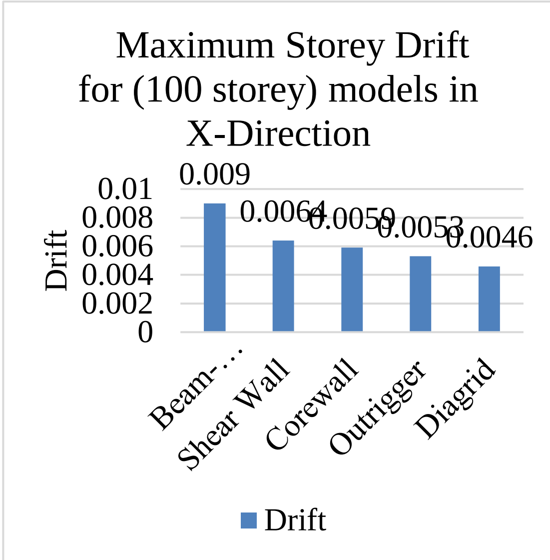


Figure 5.18.2 Maximum Story Drift for 100 story in X-Direction

Here we can observe that in 100 story Beam column model gives the maximum Story drift compared to other models

Maximum story drift for 100 story in X-direction

Maximum Storey Drift for (100 storey) models in X-Direction		
Type of system	Drift	% Reduction
Beam-column	0.009	-
Shear Wall	0.0064	28.889
Core wall	0.0059	34.444
Outrigger	0.0053	41.111
Diagrid	0.0046	48.889

Base Shear for 80 storeys in X-Direction		
Type of system	Base shear	% Increase
Beam-column	10261	-
Shear Wall	10025	-2.300
Core wall	10727	4.541
Outrigger	11016	7.358
Diagrid	9404	-8.352

Table 5.18.3 Base Shear for 100 story in X-Direction

Base Shear for (100 storey) in X-Direction		
Type of system	Base shear	% Increase
Beam-column	14770	-
Shear Wall	13982	-5.335
Core wall	14423	-2.349
Outrigger	15053	1.916
Diagrid	11582	-21.584

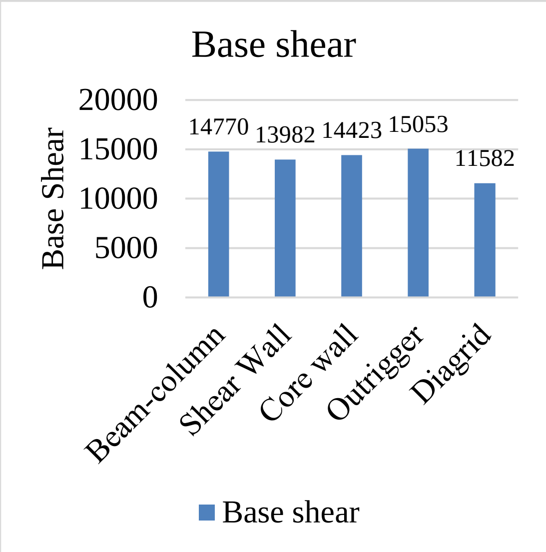


Figure 5.18.3 Maximum Base Shear for 100 story in X-Direction

Here we can observe that in 100 story outrigger model gives the maximum Base shear compared to other models

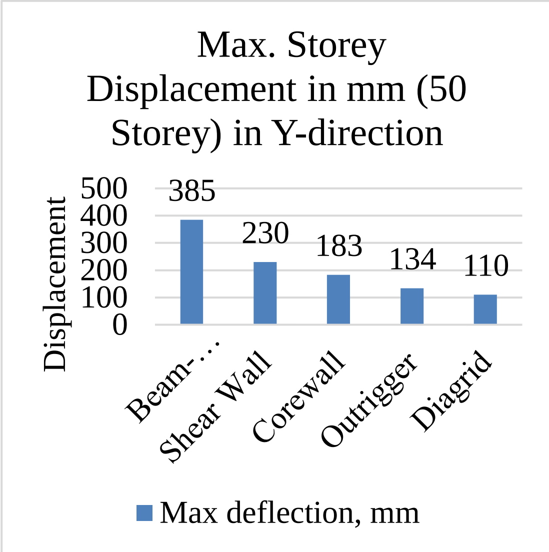


Figure 5.19.1 Maximum Story Displacement for 50 story in Y-Direction

Here we can observe that in 50 story Beam column model gives the maximum deflection compared to other models in Y-direction

COMPARISON OF DIFFERENT PARAMETERES FOR DIFFERENT STRUCTURAL SYSTEMS WITH 50 STOREYS IN Y-DIREXTION

Table 5.19.1 Maximum Story Displacement for 50 story in Y-Direction

Max. Storey Displacement in mm (50 Storey) in Y-direction		
Type of system	Max deflection, mm	% Reduction
Beam-column	385	-
Shear Wall	230	40.568
Core wall	183	52.713
Outrigger	134	65.375
Diagrid	110	71.576

Table 5.19.2 Maximum Story Drift for 50 story in Y-Direction

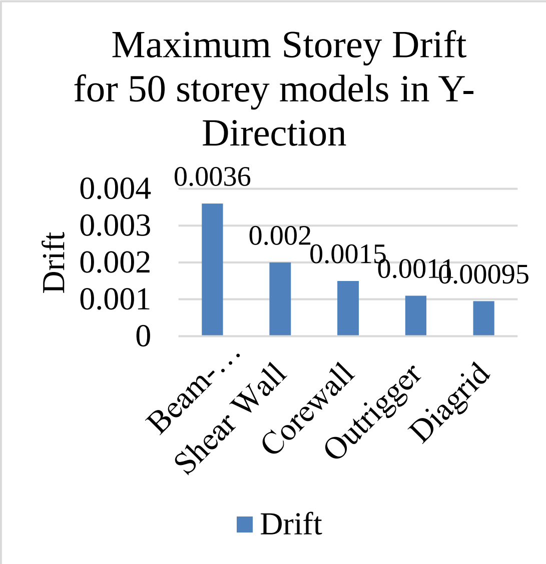


Figure 5.19.2 Maximum Story Drift for 50 story in Y-Direction

Here we can observe that in 50 story Beam column model gives the maximum story drift compared to other models in Y-direction

Table 5.19.3 Base Shear for 50 story in Y-Direction

Base Shear for 50 storeys in Y-Direction		
Type of system	Base shear	% Increase
Beam-column	5709	-
Shear Wall	6305	9.767
Core wall	7748	34.889
Outrigger	7634	32.904
Diagrid	7686	33.809

Maximum Storey Drift for 50 storey models in Y-Direction		
Type of system	Drift	% Reduction
Beam-column	0.0036	-
Shear Wall	0.002	44.444
Core Wall	0.0015	58.333
Outrigger	0.0011	69.444
Diagrid	0.00095	73.611

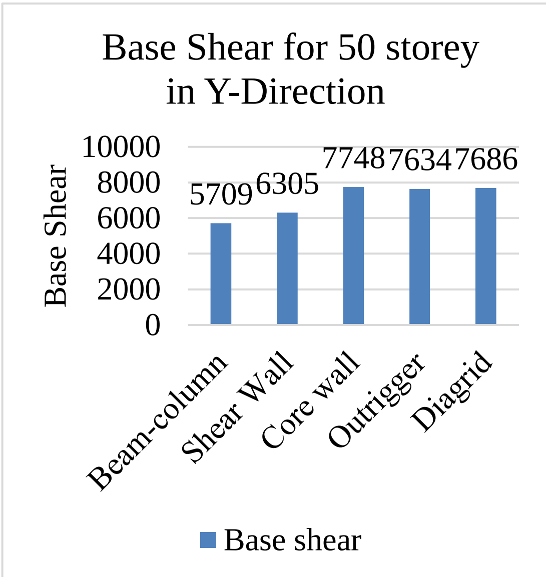


Figure 5.19.3 Base Shear for 50 story in Y-Direction

Here we can observe that in 50 story Core wall model gives the maximum Base shear compared to other models in Y-direction.

COMPARISON OF DIFFERENT PARAMETERES FOR DIFFERENT STRUCTURAL SYSTEMS WITH 80 STOREYS IN Y-DIREXTION

Table 5.20.1 Maximum Story Displacement for 80 story in Y-Direction

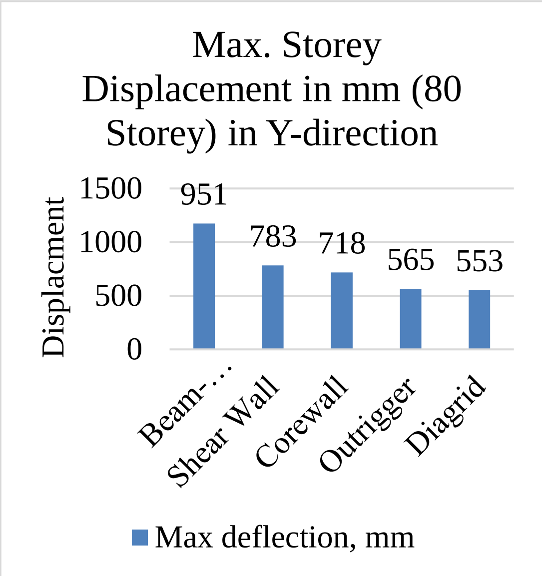


Figure 5.20.11 Maximum Story Displacement for 80 story in Y-Direction

Here we can observe that in 80 story Beam column model gives the maximum deflection compared to other models in Y-direction

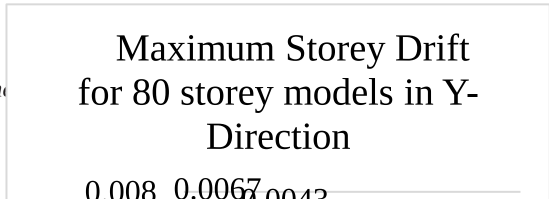
Table 5.20.2 Maximum Story Drift for 80 story in Y-Direction

Max. Storey Displacement in mm (80 Storey) in Y-direction		
Type of system	Max deflection, mm	% Reduction
Beam-column	951	-
Shear Wall	783	33.700
Core wall	718	39.204
Outrigger	565	52.159
Diagrid	553	53.175

Figure 5.20.2 Maximum Story Drift for 80 story in Y-Direction

Here we can observe that in 80 story Beam column model gives the maximum story drift compared to other models in Y-direction

Table 5.20.3 Base Shear for 80 story in Y-Direction



Maximum Storey Drift for 80 storey models in Y-Direction		
Type of system	Drift	% Reduction
Beam-column	0.0067	-
Shear Wall	0.00434	35.224
Core wall	0.0037	44.776
Outrigger	0.0032	52.239
Diagrid	0.0028	58.209

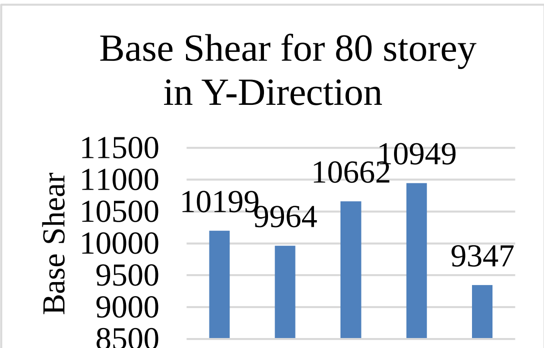


Figure 5.20.3 Base Shear for 80 story in Y-Direction

Here we can observe that in 80 story outrigger model gives the maximum base shear compared to other models in Y-direction

5.21 COMPARISON OF DIFFERENT PARAMETERS FOR DIFFERENT STRUCTURAL SYSTEMS WITH 100 STOREYS IN Y-DIRECTION

Table 5.21.1

Base Shear for 80 storeys in Y-Direction		
Type of system	Base shear	% Increase
Beam-column	10199	-
Shear Wall	9964	-2.894
Core wall	10662	3.908
Outrigger	10949	6.705
Diagrid	9347	-8.908

Maximum Story Displacement for 100 story in Y-Direction

Max. Storey Displacement in mm (100 Storey) in Y-direction		
Type of system	Max deflection, mm	% Reduction
Beam-column	1192	-
Shear Wall	1153	31.539
Core wall	1146	33.994
Outrigger	1132	46.553
Diagrid	1116	47.309

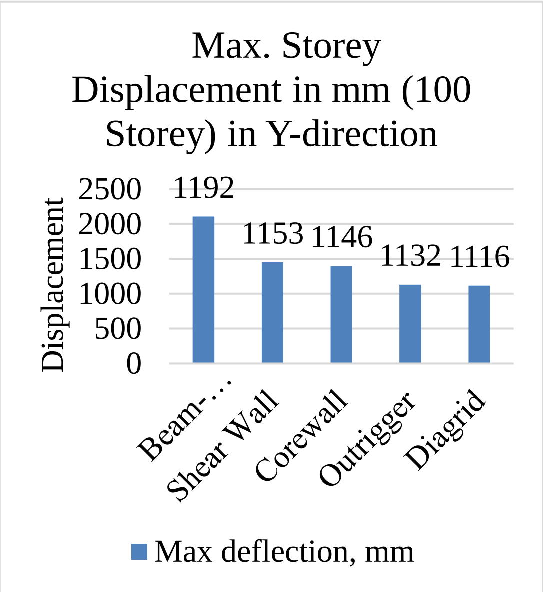


Figure 5.21.1 Maximum Story Displacement for 100 story in Y-Direction

Here we can observe that in 100 story Beam column model gives the maximum displacement compared to other models in Y-direction

Table 5.21.2 Maximum Story Drift for 100 story in Y-Direction

Maximum Storey Drift for (100 storey) models in Y-Direction		
Type of system	Drift	% Reduction
Beam-column	0.0096	-
Shear Wall	0.0064	28.889
Core wall	0.0058	34.889
Outrigger	0.0052	42.222
Diagrid	0.0046	48.889

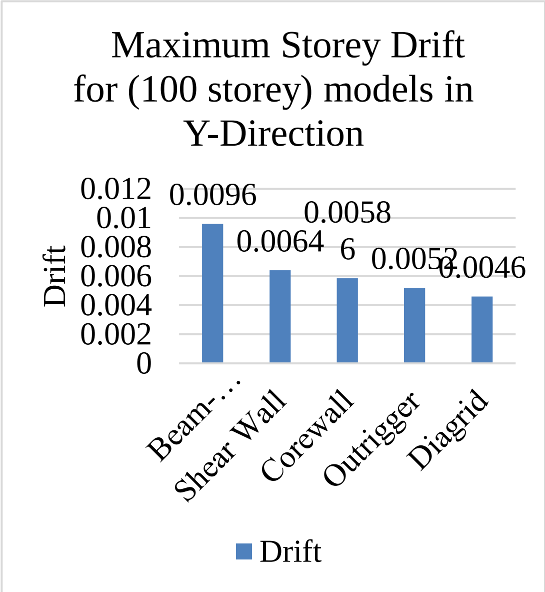


Figure 5.21.22 Maximum Story Drift for 100 story in Y-Direction

Here we can observe that in 100 story Beam column model [18] gives the maximum story drift compared to other models in Y-direction

Table 5.21.3 Base Shear for 100 story in Y-Direction

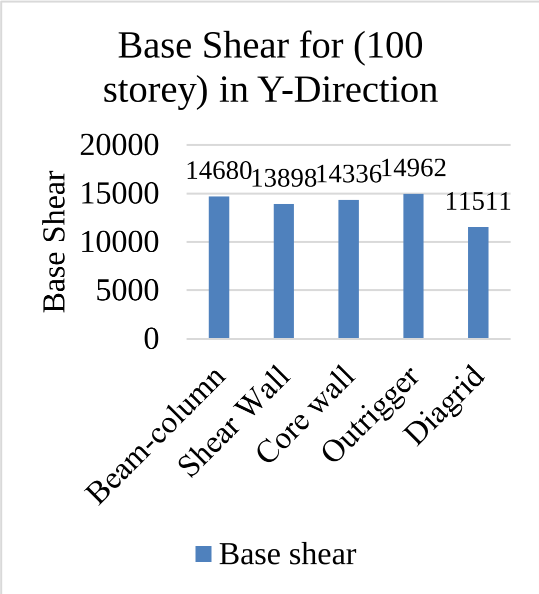


Figure 5.21.3 Base Shear for 100 story in Y-Direction

Here we can observe that in 100 story outrigger model [17] gives the maximum base shear compared to other models in Y-direction.

CONCLUSIONS

The diagrid [15][16] system uses diagonal

Base Shear for (100 storey) in Y-Direction		
Type of system	Base shear	% Increase
Beam-column	14680	-
Shear Wall	13898	-5.904
Core wall	14336	-2.938
Outrigger	14962	1.300
Diagrid	11511	-22.065

elements to resist lateral forces through axial action, providing strong resistance. Triangular diagrid elements support gravity loads [19] and lateral forces, with steel diagrids countering shear and the central part acting as a cantilever, adding stiffness. Peripheral diagrid elements [20] transform lateral stress, resisting torsion. This system minimizes maximum story displacement and drift effectively.

- The study shows that there are many factors to take into account when building sustainable tall structures, but the structural form used during construction is one of the most important.
- The maximum story displacement for a 50-story 3D RC frame building is found to vary depending on the structural forms used. The displacement for a typical Beam-Column construction is determined to be 387mm in the X direction.
- In compared to a standard Beam-Column structure, the maximum story displacement is reduced by 40.31% for a peripheral Shear Wall system, 52.71% for a Core Wall system, 65.16% for an Outrigger system, and 71.57% for a Diagrid system. As a result, it may be said that the Diagrid structural form is more resilient to displacement brought on by seismic pressures.
- According to IS 1893, the maximum story drift must not exceed 0.004 times the story height, which works out to be 0.012 for all the models taken into consideration in this study, the maximum story drift for a 50 story Beam-Column structure is found to be 0.0036.
- In compared to a standard Beam-Column structure, the maximum story drift for a peripheral Shear Wall system is reduced by 44.44%, by 58.33% for a Core Wall system, by 69.44% for an Outrigger system, and

by 72.50% for a Diagrid system. When considering story drift as well as displacements, the Diagrid structural structure proved to be more durable against earthquake forces.

- The Base Shear for a typical Beam-Column structure is determined to be 5744 KN, which increased owing to an increase in structural mass by 10.42% for a Shear Wall system, 35.707% for a Core Wall system, 36.87% for an Outrigger system, and 34.62% for a Diagrid system.
- Similarly, for structural models with 80 stories, the maximum story displacement is reduced by 33.27% for shear wall systems, 38.86% for core wall systems, 51.90% for an outrigger system, and 52.92% for diagrid systems, compared to normal Beam-Column systems, and for structural models with 100 stories, the reduction is 31.11%, 33.56%, 46.22%, and 46.92% in the same order.
- When compared to a Beam-Column structural system, the maximum story drift for an 80-story building is reduced by 35.82% for a Shear Wall system, 44.77% for a Core Wall system, 52.23% for an Outrigger system, and 58.20% for a Diagrid system. For 100-story buildings, the reductions are 28.88%, 34.44%, 41.11%, and 48.88%, respectively.
- Maximum story displacement and maximum story drift are found to be significantly reduced by at least 50% for an Outrigger and Diagrid structural system compared to a normal Beam-Column system, proving the two systems to be the most sustainable systems even when the height of the building increases with an increase in the number of stories.
- Based on the results, it can be deduced that the Outrigger and Diagrid systems are the most efficient systems when compared to all other systems considered in this study; however, upon closer inspection, it is clear that the Diagrid system yields the lowest values for maximum story displacement and drift, making it the most efficient structural system in tall structures.
- Another finding from the current study is that the Diagrid system yields a lower Base shear value than the Outrigger system due to the replacement of the large concrete columns at the building plan's periphery with ISWB600 steel Diagrid elements and the removal of the concrete core wall, which reduced the mass of the Diagrid system.

References:

[1]. Mir M Ali & Kyoung Sun Moon, “Structural Developments in Tall Buildings: Current Trends and Future Aspects, 2018

[2]. Kheir Al-Kodmany, Mir M. Ali, and Tingwei Zhang “IMPORTING URBAN GIANTS: Re-Imaging Shanghai and Dubai with Skyscrapers” International Journal of Architectural Research, July 2013.

[3] Sepideh Korsavil and Mohammad Reza Maghareh, “The Evolutionary Process of Diagrid Structure Towards Architectural, Structural and Sustainability Concepts: Reviewing Case Studies”, J Archit Eng Tech 2015,

[4]. Vishal A Itware & Dr Uttam B Kalwane, “Effects of openings in Shear Wall on Seismic Response of Structure”, IJERA ISSN: 2248-9622, July 2015

[5]. Srinivas Suresh Kogilgeri & Beryl Shanthapriya, “A Study on Behavior of Outrigger system on High Rise Steel Structure by varying Outrigger Depth”, IJRET eISSN: 2319-1163, July 2015

[6]. Ravi K Revankar & R G Talasadar, “Pushover Analysis of Diagrid Structure”, IJEIT ISSN: 2277-3754, September 2014

[7]. Nishith P Panchal & Vinubhai R Patel, “Diagrid Structural System: Strategies to reduce Lateral forces on High Rise Buildings”, IJRET eISSN: 2319-1163 April 2014

[8]. Rohit Kumar Singh, Dr Vivek Garg & Dr Abhay Sharma, “Analysis and Design of Concrete Diagrid building & its comparison with Conventional Frame Building”, IJSET ISSN: 2348-4098, August 2014

[9] Er. Nishant Rana1, SiddhantRana2 “Structural Forms Systems for Tall Building Structures” SSRG International Journal of Civil Engineering (SSRG-IJCE), September 2014.

[10] Giulia Milana, Konstantinos Gkoumas* and Franco Bontempi “Sustainability Concepts in the Design of High-Rise buildings: the case of Diagrid Systems” International Workshop on Design in Civil and Environmental Engineering, August 21-23, 2014,

[11] Kheir Al-Kodmany1, † and Mir M. Ali2 “An Overview of Structural and Aesthetic Developments in Tall Buildings Using Exterior Bracing and Diagrid Systems” International Journal of High-Rise Buildings December 2016, Vol 5, No 4, 2013

[12] Sunagar, P., Nayak, S. G., & Vikas, K. C. (2021). Analysis and Design of Water Storage Tank. Design Engineering, 13576-13602.

[13] Sunagar, P., Nayak, S. G., & Jyothi, M. R. (2021). Analysis and Design of Water Treatment Plant Elements. Design Engineering, 13544-13575.

[14] Sunagar, P. (2021). Seismic vulnerability and Resilience of Steel-Reinforced Concrete (SRC) and Composite Structures. Design Engineering, 11455-11469.

[15] Sunagar, P., Kumari, T. G., Rajegowda, A. H. B., & Dharek, M. S. (2021). Innovative Design Approaches for the Seismic Response Control of Tall Buildings by Various Interior and Exterior Structural Forms. NEW ARCH-International Journal of Contemporary architecture, 8(2), 468-478.

[16] Sunagar, P., Gowda, R. S., Dharek, M. S., & Sreekeshava, K. S. Sustainable Structural Retrofitting Of Rc Building By Non-Linear Static Analysis.

[17] Rana, A. B., Mr Shubhesh Bista, and Mr Prashant Sunagar. "Analysis of Tuned Liquid Damper (TLD) in controlling earthquake response of a building using SAP2000." Int Res J Eng Technol 5, no. 10 (2018): 79-96.

[18] Numerical Investigations on Steel Plate Shear Walls – Stiffened and Un-stiffened by Prashant Sunagar priya, Publication date 2015/8, International Journal of Innovative Research in Science, Engineering and Technology,Volume 4, Issue 8 Pages 7156-7165

[19] Dynamic Response Of 3D Steel Frame, prashant Sunagar, Publication date 2014/. International Journal of Scientific & Engineering Research, Volume 5, Issue 6, ISSN 2229-5518

[20] Sunagar, P., Dharek, M. S., Nruthya, K., Sreekeshava, K. S., Nagashree, B., & Ramegowda, R. S. (2020, November). Non-Linear Seismic Analysis of Steel Plate Shear Wall Subjected to Blast Loading. In IOP Conference Series: Materials Science and Engineering (Vol. 955, No. 1, p. 012025). IOP Publishing.

[21] Sunagar, P., Bhashyam, A., Dharek, M. S., Sreekeshava, K. S., Ramegowda, R. S., & Lakshmi, H. S. (2020, March). Blast resistance of steel plate shear walls designed for seismic loading. In IOP Conference Series: Materials Science and Engineering (Vol. 814, No. 1, p. 012041). IOP Publishing.

[22] Sunagar, P., Bhashyam, A., Shashikant, M., Sreekeshava, K. S., & Chaurasiya, A. K. (2021). Effect of Different Base Isolation Techniques in Multistoried RC Regular and Irregular Building. Trends in Civil Engineering and Challenges for Sustainability, 391-403.

[23] Sunagar, Prashant, Aravind Bhashyam, B. R. Neel, and Abhishek Kumar Chaurasiya. "Sustainability concepts in the design of tall structures." In International Conference on Emerging Trends in Engineering (ICETE), pp. 270-277. Springer, Cham, 2020.

[24] Sunagar, P., & Shivananda, M. S. (2012, June). Evaluation of Seismic Response Modification Factors for RCC Frames by Non-Linear Analysis. In International Conference on Advances in Architecture and Civil Engineering (pp. 322-327).