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ANALYSIS OF EFFECT OF WIND & SEISMIC FORCE ON MULTISTORIED BUILDING WITH OUTRIGGER FRAMING SYSTEM

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Abstract - *This paper considers the static and dynamic analysis of a high-rise building focusing on their load consideration, suitable structural system under the lateral loads using Outrigger framing system. Design considerations for the tall buildings involve a comprehensive assessment of various factors, especially when the building have a slenderness ratio is above 10 then the design of the buildings are majorly guided by the gust wind / dynamic wind. Here we are using Etabs20 to do the modelling and do the finite element analysis, performance based design of the structure.*

[1] *Here the building (2B+G+44) is too much slender and the sway under the gust forces are beyond the limiting values. In this scenario, we have to increase the stiffness of the buildings to cater the sway and we are introducing the outrigger at different levels of the buildings. There are 23 % reduction by the use of three outrigger* at *the effective level. Whereas 28% drop is achieved by the use of total five outrigger levels with respect to without outrigger structure.*

Based on this we found a stable framing for this building and can check for further criteria.

***Key Words*:** **Tall building, Outrigger framing system, Deflection check, Storey drift, etc.**

1. INTRODUCTION

Here an analytical process will be followed to achieve a stabilized framing scheme as per Indian standards. This standard covers the following design aspects of reinforced concrete (RC) buildings of height greater than 50 m but less than or equal to 250 m. Generally, this standard is based on prescriptive approach and covers the following design aspects of tall buildings:

a) Selection of appropriate structural system;
b) Geometric proportioning of the building;
c) Integrity of structural system;
d) Resistance to wind and earthquake effects; and
e) Other special considerations related to tall buildings

1.1 This standard addresses the following typical structural systems of tall concrete buildings:

a) Structural wall systems
b) Moment frame systems
c) Moment frame — Structural wall systems
d) Structural wall — Flat slab floor systems with perimeter moment frame
e) Structural wall — Framed tube systems
f) Framed-tube system
g) Tube-in-tube system
h) Multiple tube system
Hybrid system; etc.

Core and Outrigger Structural System

A structural system comprising core elements and perimeter columns, resisting the lateral and vertical loads. Essentially, the perimeter columns are for resisting gravity loads only. The core element is connected to select perimeter column elements (often termed outrigger columns) by beam elements, known as outriggers, at discrete floor locations along the height of the building. This type of structure is an extension of the core structure, to enhance the lateral stiffness for taller structures, which mobilizes the perimeter columns, and offers increased leverage for push-pull action through the framing action offered by the deep beam connecting the core to the outrigger columns. The global lateral stiffness is sensitive to: flexural stiffness of the core element, the flexural stiffness of the outrigger elements and the axial stiffness of the outrigger columns.

Core, Outrigger and Belt Wall System

A structural system, which is an extension to the core and outrigger structure to enhance the lateral stiffness further, where the outrigger column(s) is linked to the adjacent columns by deep beam elements (often known as belt truss), typically at the same level as the outrigger elements. The sharing of loads between multiple columns has the dual function of enhancing the axial stiffness and mobilizing greater number of gravity columns to counteract the induced tension loads generated by the overall lateral loads.

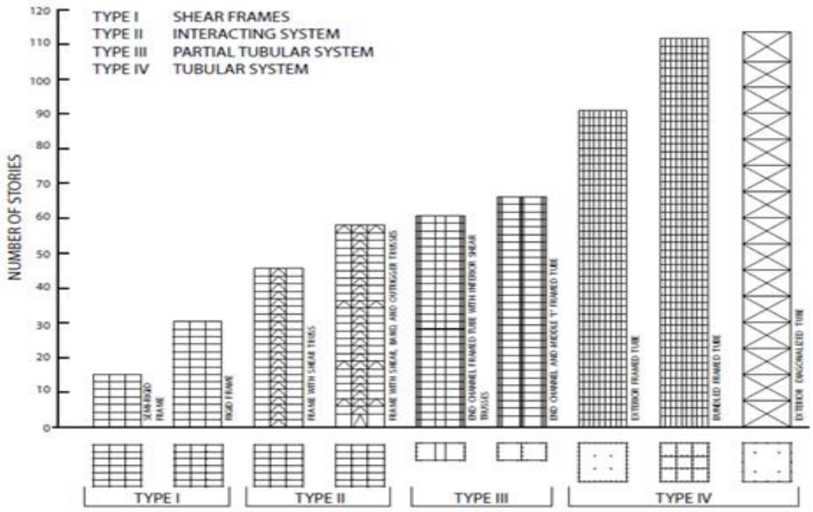


FIG. 1 Structural system comparison table from the 1970s @CTBUH

2.0 OBECTIVE

The design of tall and slender structures is controlled by three governing factors, strength (material capacity), stiffness (drift) and serviceability (motion perception and accelerations), produced by the action of lateral loading, such as wind.

Here the objective is to achieve an efficient framing system for multistoried buildings by an analytical comparison among multiple framing system with respect to all lateral resisting factors.

The outrigger system is a structural component used in tall buildings to enhance their lateral stability and reduce lateral sway caused by wind or seismic forces. Its primary objective is to improve the overall performance and safety of the building.

Here are the main objectives of using outriggers in tall buildings:

Lateral stability: Tall buildings are subject to significant wind forces, especially at higher altitudes. Without proper lateral stability, the building could sway excessively, leading to discomfort for occupants and potential structural damage. The outrigger system helps to mitigate this swaying, making the building more stable during wind events.

3.0 METHODOLOGY

Outriggers are rigid horizontal structures designed to improve building overturning stiffness and strength by connecting the building core or spine to distant columns. A relatively new concept that has evolved within the past two decades is the technique of using a belt truss on a braced core combined with exterior columns.If a building is to have one or more floors devoted to mechanical equipment, rather than lease space, large belt or outrigger trusses can be placed in the perimeter,one storey in height.

In this paper a different standard of methods will be used for analyzing a multi-storied building.Then a result comparison can be made. Here the structure is considered to be a RC Structure.

A (2B+G+44) storied reinforced concrete building is analyzed using ETABS 20.3.0 software. The structure is assumed to be located at Kolkata. The lateral loads to be applied on the buildings were based on NBC and IS codes. The building was analyzed for Kolkata considering its respective seismic zone basic wind speed. To improve the performance of the building under lateral load, outrigger isprovided. The analysis was carried out for building with same layout of outrigger at different floors. At first analysis was carried out without any lateral load resisting systems. After that, analysis was carried out by providing outrigger systems. Outrigger was introduced at middle position, 3/7 position and ⅓ position respectively of the building. After that, first position of outrigger was fixed at the top of the building and second position was find out by providing outrigger at different story to find out optimum position. Conventional outrigger systems were connected to central core and belt truss was at the periphery of the building.

Table -1: Outrigger Placement Specification In Model

MODEL TRIALS	MODEL-1	MODEL-2	MODEL-3
Number of floors of Outrigger	-	Three floors	Five floors
Floors of Outrigger	-	15^{TH} (1/3 H) Floor 20^{TH} (3/7 H) Floor 25^{TH} (1/2 H) Floor	15^{TH} (1/3 H) Floor 20^{TH} (3/7 H) Floor 25^{TH} (1/2 H) Floor 30^{TH} (2/3 H) Floor 40^{TH} (7/8 H) Floor
Building Height	157930 mm		

Loading Parameters:

Self-Weights:

Self –weight of the structural members will be considered as per IS: 875 Part -I.

Live loads will be considered as per IS: 875 Part -II.

Other Loads:

- Lift machine room load 1.0 T/m2 machine load is considered.

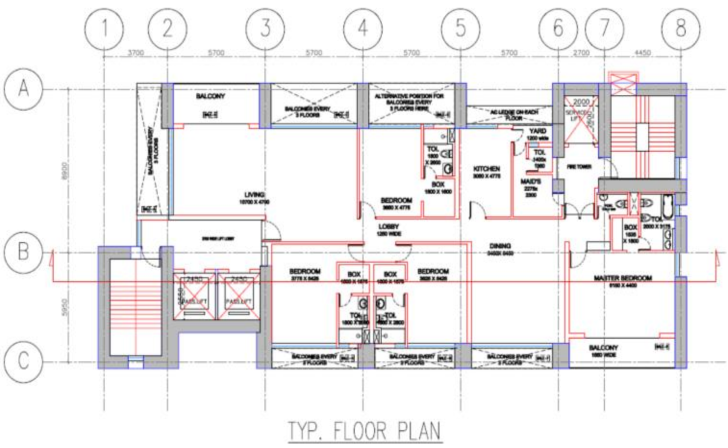


FIG. 2 ARCHITECHTURAL LAYOUT PLAN

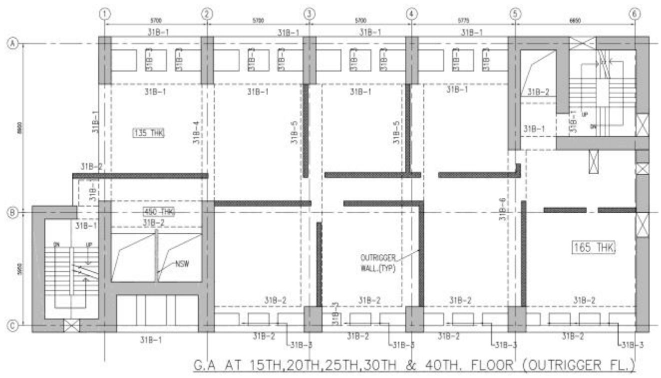


FIG. 3 STRUCTURAL PLAN WITH OUTRIGGERS

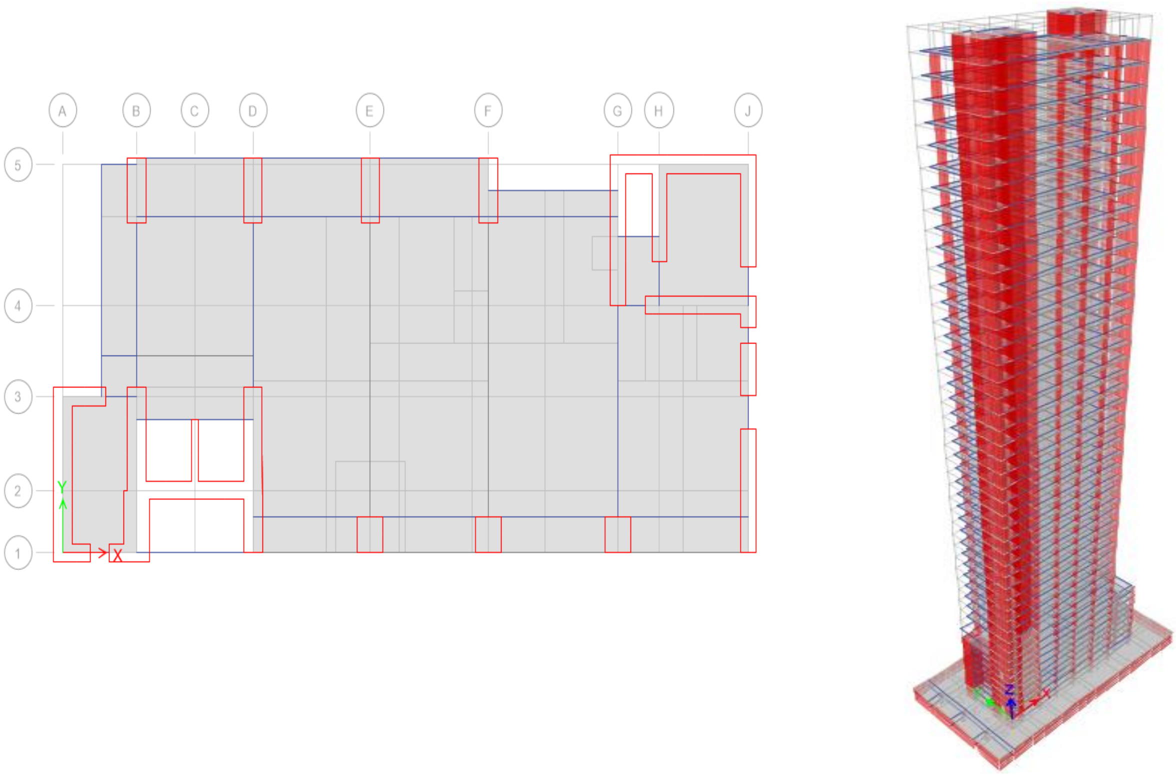


FIG. 4 2D MODEL & ELEVATION VIEW -TYPICAL FLOOR

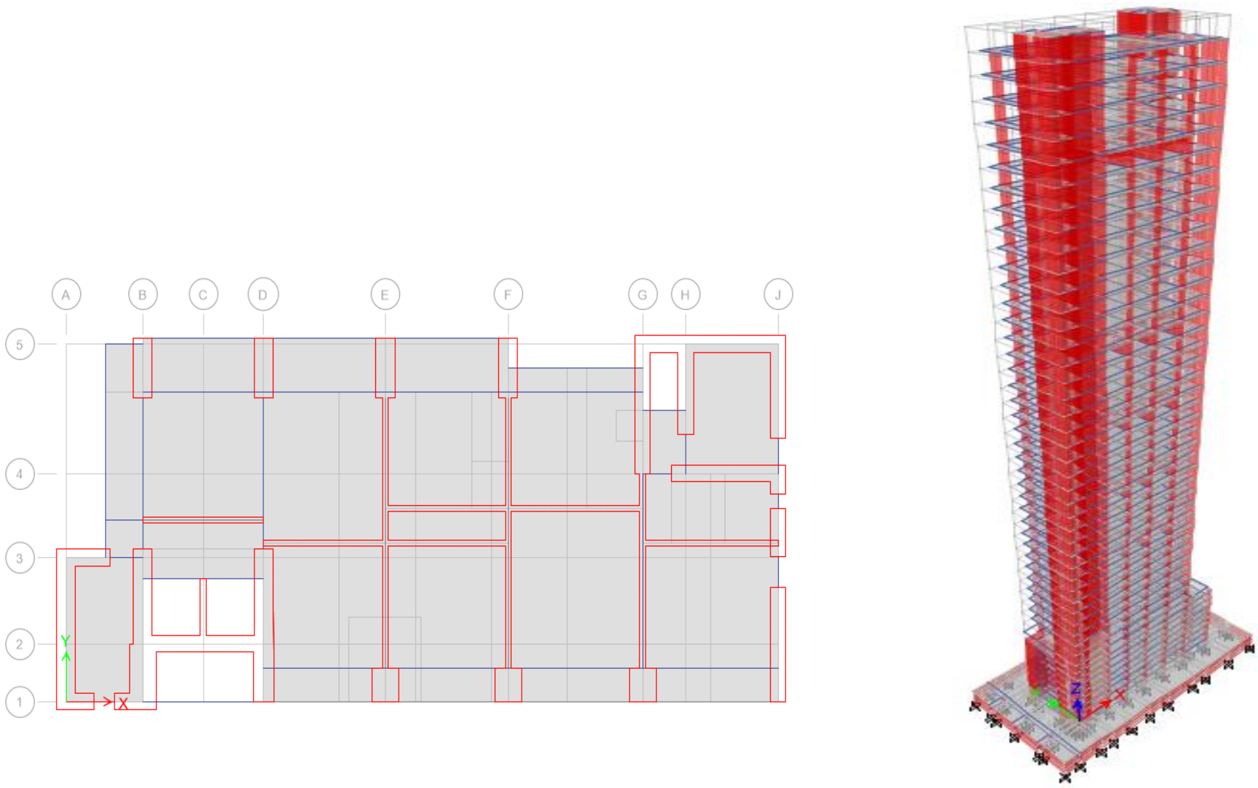


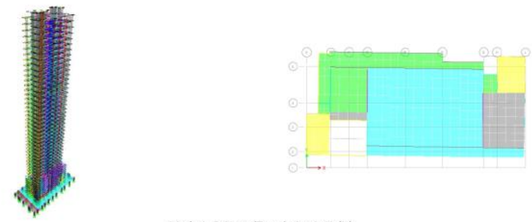
FIG. 5 2D MODEL & ELEVATION VIEW VIEW-TYPICAL FLOOR WITH OUTRIGGERS

4.0 POST ANALYSIS RESULTS AND DISCUSSION

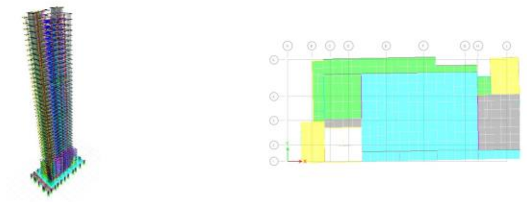
MODEL-WITHOUT OUTRIGGER

Building Modes and Modal Participation Mass Ratio

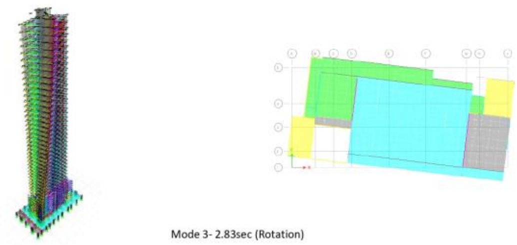
Mode	Time periods	UX	UY	SumUX	SumUY	RZ	Sum RZ
1	5.607	0.0011	0.5936	0.0011	0.5936	0.0109	0.0109
2	4.41	0.6093	0.0024	0.6104	0.596	0.0055	0.0164
3	2.831	0.0085	0.0052	0.6189	0.6012	0.52	0.5364
4	1.248	0.0021	0.1514	0.621	0.7526	0.0009	0.5372
5	1.073	0.1387	0.0044	0.7597	0.7569	0.0024	0.5396
6	0.742	0.0014	0.0124	0.7611	0.7693	0.1087	0.6483
7	0.533	0.0027	0.047	0.7637	0.8164	0.0042	0.6526
8	0.471	0.0509	0.0016	0.8146	0.818	0.0013	0.6539
9	0.358	0.0002	0.0071	0.8148	0.825	0.0393	0.6932
10	0.298	0.0013	0.0223	0.8162	0.8473	0.0056	0.6988
11	0.277	0.0284	0.0003	0.8446	0.8476	0.0009	0.6997
12	0.219	0.0001	0.0036	0.8447	0.8513	0.0208	0.7205



Mode 1- 5.61sec (Translation in Y-dir)



Mode2-4.41sec (Translation in X-dir)



Mode 3- 2.83sec (Rotation)

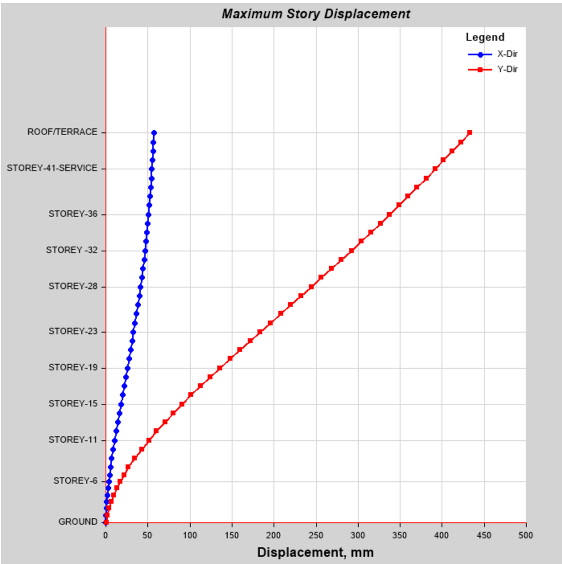
Serviceability check in terms of Deflection

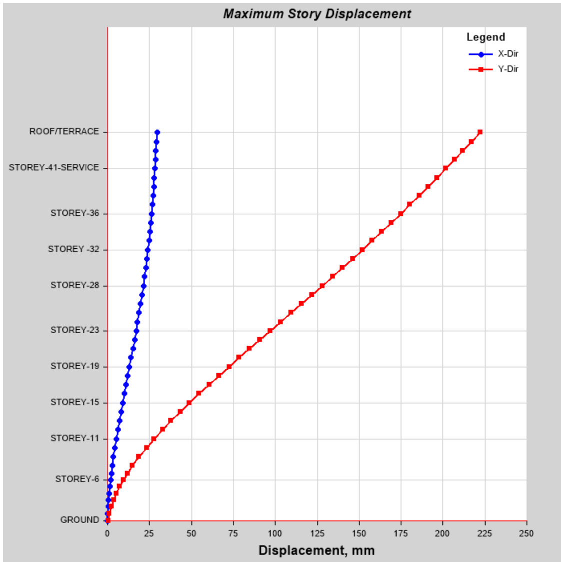
DEFLECTION CHART			
LOAD CASE	DEFLECTION (mm)	IN TERMS OF 'H'	REMARKS
SEISMIC 'X'	96.296	H/1640	WITHIN LIMIT
SEISMIC 'Y'	125.708	H/1256	WITHIN LIMIT
SPEC 'X'	74.927	H/2107	WITHIN LIMIT
SPEC 'Y'	95.039	H/1661	WITHIN LIMIT
WIND STATIC 'X'	93.122	H/1696	WITHIN LIMIT
WIND STATIC 'Y'	356.457	H/443	OUT OF LIMIT
WIND DYNAMIC 'X'	432.689	H/365	OUT OF LIMIT
WIND DYNAMIC 'Y'	222.04	H/771	WITHIN LIMIT
H= HEIGHT OF THE BUILDING FROM GROUND TO ROOF = 157930 MM			

(Lateral deflection should not exceed (H/500) as per clause 20.5 of IS 456:2000)

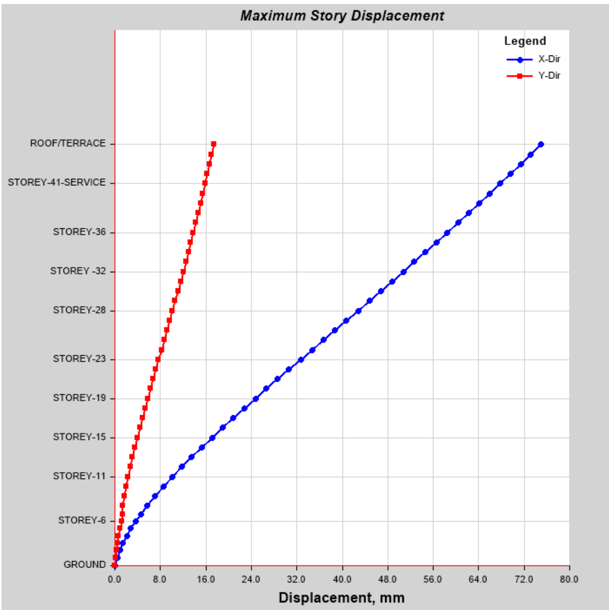
Story Response - Maximum Story Displacement

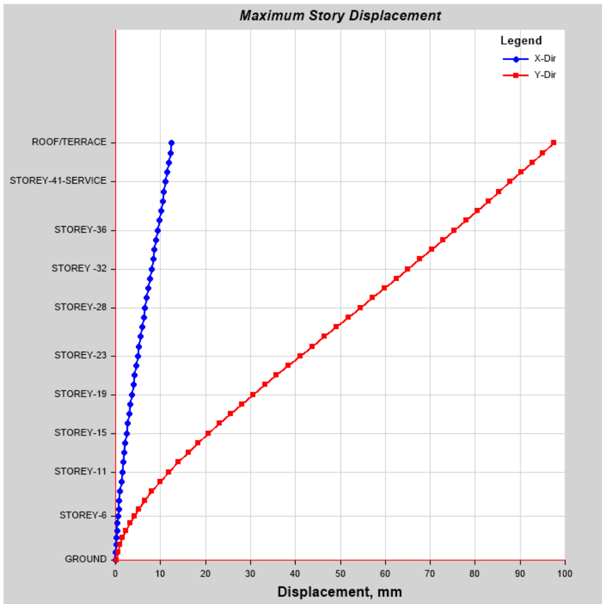
Name	StoryResp1	Top Story	ROOF/TERRACE
Display Type	Max story displacement	Bottom Story	GROUND
Load Case	**DWLX**	**DWLY**	





SPECX **SPECY**

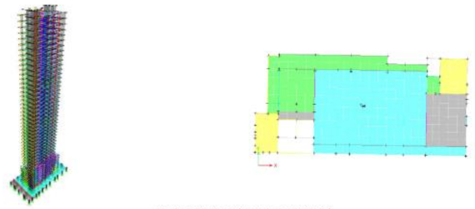




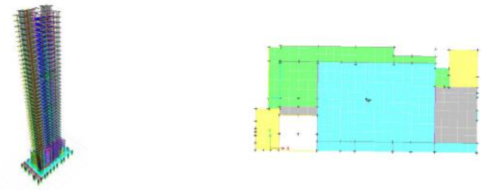
MODEL-WITH OUTRIGGERS

Building Modes and Modal Participation Mass Ratio

Mode	Time periods	UZ X	UY	Sum UX	Sum UY	RZ	Sum RZ
1	4.94	0.0394	0.5587	0.0394	0.5587	0.0153	0.0153
2	3.194	0.6165	0.0491	0.6559	0.6079	0.0006	0.0159
3	2.735	0.0039	0.04	0.6598	0.6558	0.5258	0.5417
4	1.125	0.006	0.1589	0.6659	0.7748	0.0026	0.5443
5	0.927	0.1138	0.0022	0.7797	0.777	0.0007	0.545
6	0.732	0.0014	0.0126	0.7811	0.7896	0.107	0.6519
7	0.466	0.0016	0.036	0.7827	0.8256	0.0069	0.6589
8	0.42	0.0404	0.001	0.8231	0.8266	0.0001	0.6589
9	0.349	0.0003	0.0057	0.8234	0.8323	0.0386	0.6975
10	0.264	0.0031	0.0172	0.8265	0.8494	0.0055	0.703
11	0.252	0.0231	0.0033	0.8496	0.8528	0.0000	0.703
12	0.214	0.0003	0.0038	0.8498	0.8566	0.0207	0.723



Mode 1- 4.94 sec (Translation in Y-dir)



Mode2-3.19 sec (Translation in X-dir)

Mode 3- 2.73 sec (Rotation)

Number of modal were considered until the modal participation reached minimum 90% as per

clause 7.7.5.2 of IS 1893 (P1): 2016

Summation of mass participation of first three mode (>65%) as per Table-6 of IS 1893 (P1):2016:

Sum Ux= 66
Sum Uy= 66

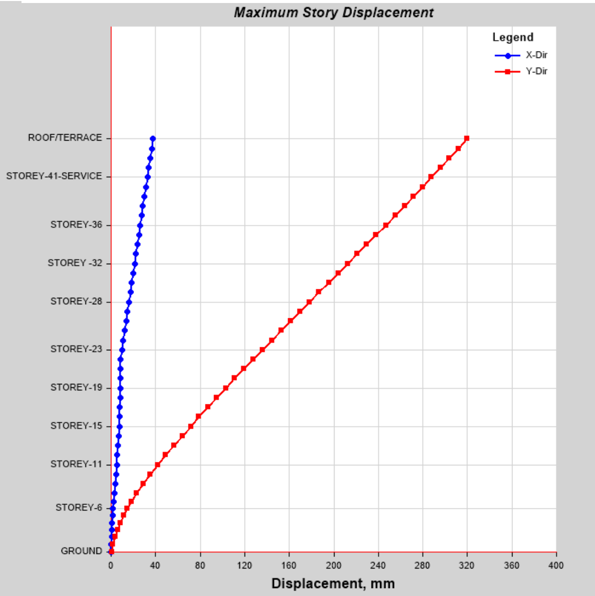
DEFLECTION CHART			
LOAD CASE	**DEFLECTION (mm)**	**IN TERMS OF 'H'**	**REMARKS**
SEISMIC 'X'	53.032	H/2978	WITHIN LIMIT
SEISMIC 'Y'	95.56	H/1652	WITHIN LIMIT
SPEC 'X'	45.526	H/3469	WITHIN LIMIT
SPEC 'Y'	75.1	H/2102	WITHIN LIMIT
WIND STATIC 'X'	52.445	H/3011	WITHIN LIMIT
WIND STATIC 'Y'	269.55	H/586	WITHIN LIMIT
WIND DYNAMIC 'X'	311.664	H/507	WITHIN LIMIT
WIND DYNAMIC 'Y'	160.30	H/985	WITHIN LIMIT
H= HEIGHT OF THE BUILDING FROM GROUND TO ROOF = 157930 MM			

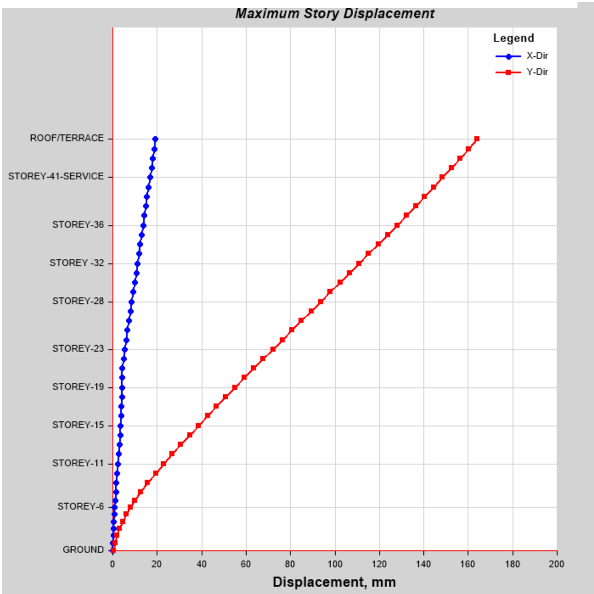
Serviceability check in terms of Deflection

(Lateral deflection should not exceed (H/500) as per clause 20.5 of IS 456:2000

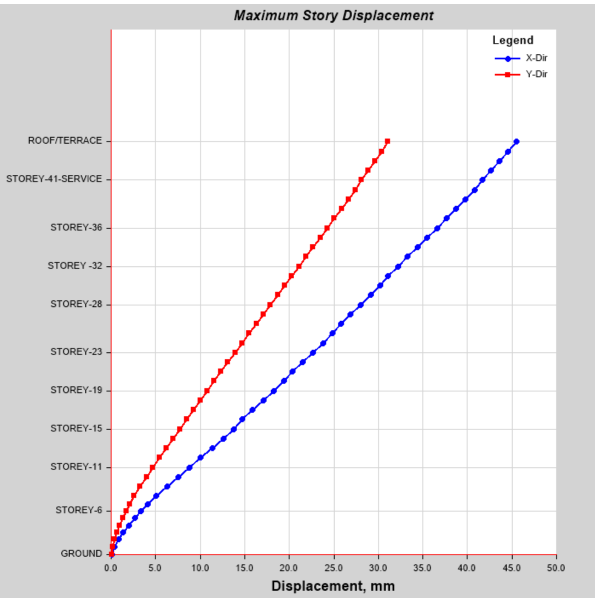
Story Response - Maximum Story Displacement

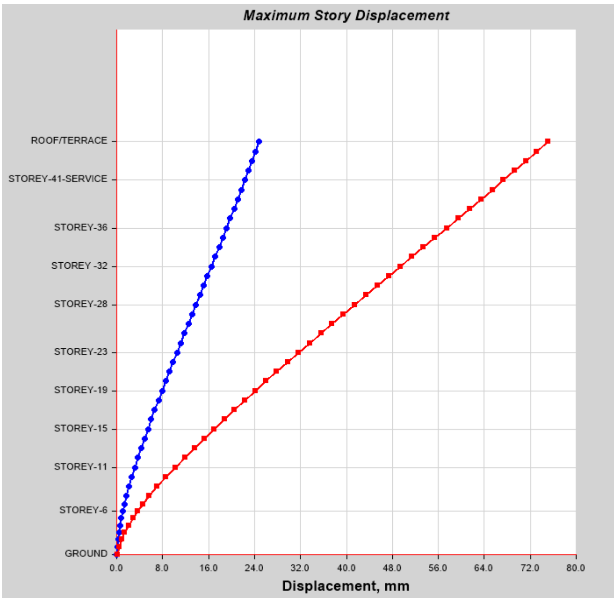
Name	StoryResp1	Top Story	ROOF/TERRACE
Display Type	Max story displacement	Bottom Story	GROUND
Load Case	DWLX		DWLY





SPECX **SPECY**





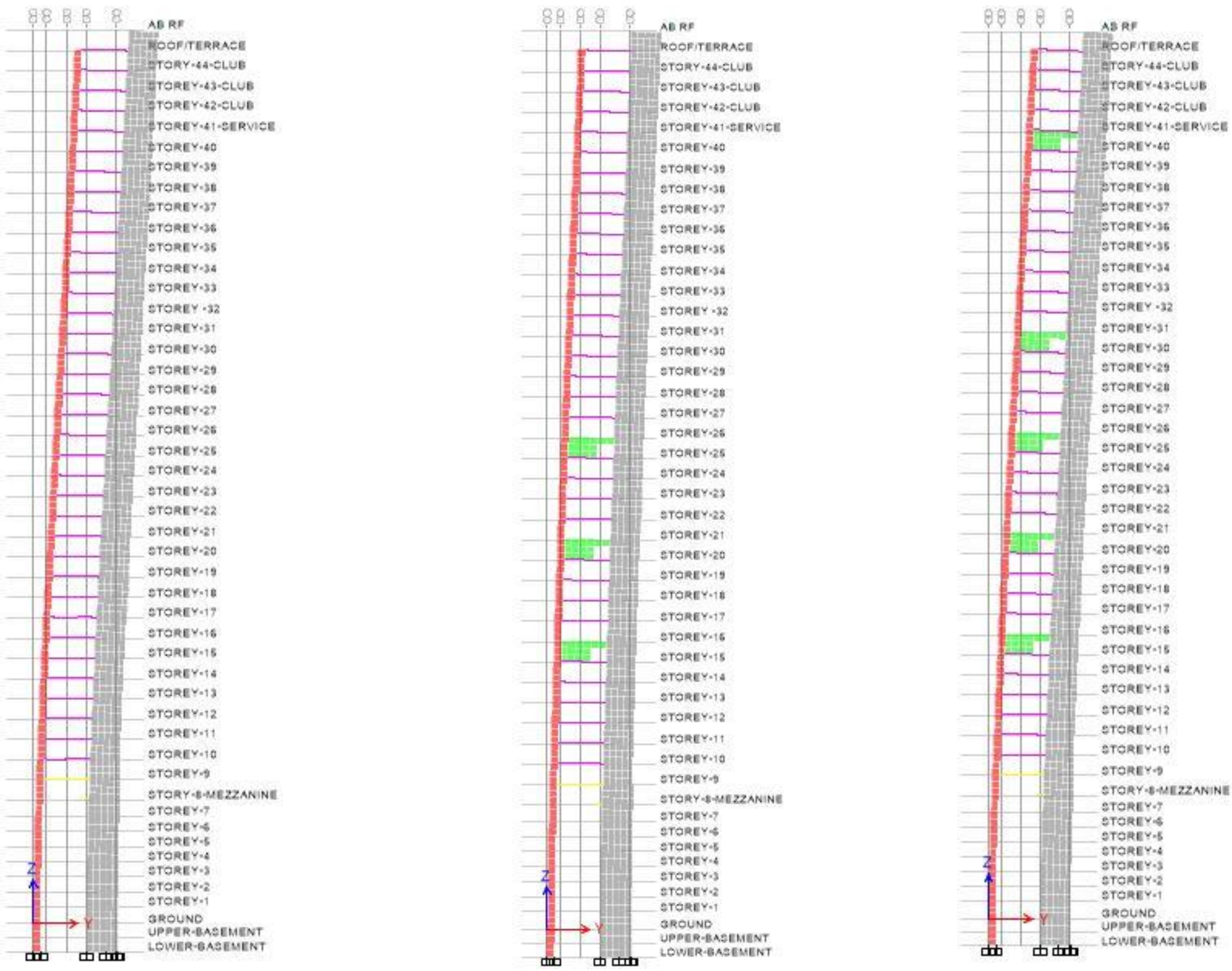


FIG.7 MAXIMUM DEFLECTION (ELEVATION)IN DYNAMIC WIND CASE

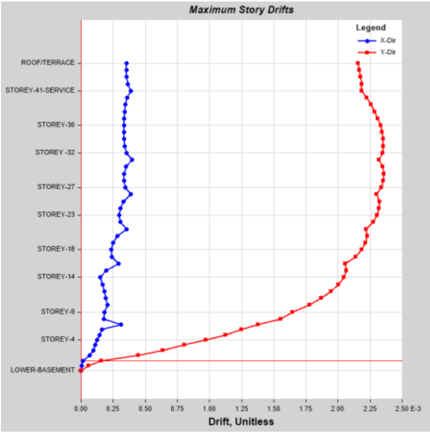
LATERAL DRIFT

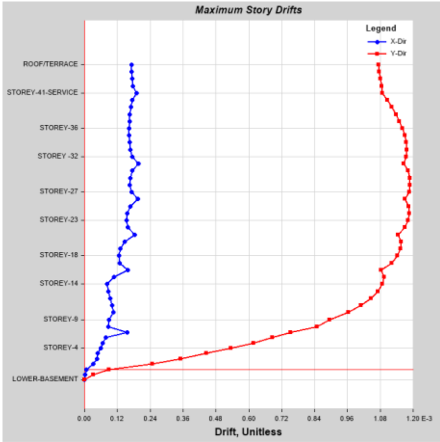
When design lateral forces are applied on the building, the maximum inter-storey elastic lateral drift ratio (Δmax /hi) under serviceability loads (wind load with return period of 20 years), which is estimated based on the sectional properties for serviceability loads, shall be limited to H/500. For a single storey the drift limit may be relaxed to hi/400. For the design earthquake load, the drift shall be limited to hi/250.

MAXIMUM STOREY DRIFT

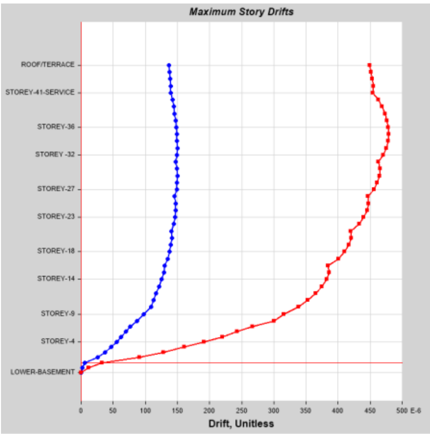
Load Case	Maximum Storey Drift	Direction	Storey
SPECX	**0.000245**	X-dir	9th -14th
SPECY	**0.000479**	Y-dir	32nd to 36th
DWLX	**0.002355**	Y-dir	27th -32nd
DWLY	**0.001189**	Y-dir	27th -32nd

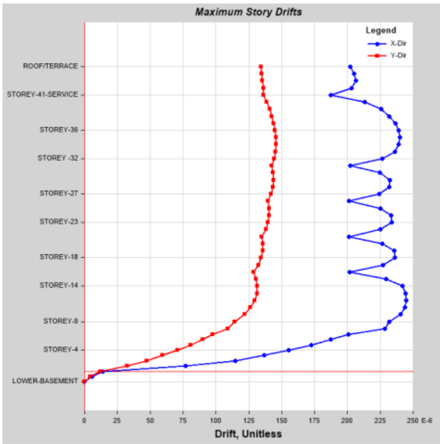
STORY RESPONSES - MAXIMUM STORY DRIFTS





Maximum Story Drifts IN DWLX & DWLY





Maximum Story Drifts SPECX & SPECY

DISCUSSION

TABLE-7 MAXIMUM LATERAL DEFLECTION IN DIFFERENT OPTIONS AND REDUCTION %

Number of outrigger floors	CASE-1 No-outrigger provided	CASE-2 Three no outrigger floors	CASE-3 Five no outrigger floors
Maximum lateral deflection (mm)	433	337	311
Reduction % of lateral deflection	--	23 %	28 %

The use of outrigger has increases the stiffness of the structure by connecting the building core to the distant column and makes the whole system to act as a single unit in resisting the lateral load and improved the serviceability of the structure. Three options are compared in Table , including the structure without any outriggers and the result show appreciable decline in the lateral deflection with the use of outrigger system. There are 23 % reduction by the use of three outrigger at the effective level. Whereas 28% drop is achieved by the use of total five outrigger levels with respect to without outrigger structure. The outrigger system is not only proficient in controlling the overall lateral deflection but also very capable of reducing the inter-story drift of the tall slender buildings.

6.0 CONCLUSION

After implementing outriggers in a building project, we can draw several conclusions regarding their effectiveness and impact on the structure. The outriggers, which are structural elements attached to the building's core, play a crucial role in enhancing stability and mitigating lateral forces, particularly in tall and slender structures.

The use of outriggers has significantly improved the overall structural performance of the building. By connecting the core and the perimeter columns, outriggers distribute the lateral loads more efficiently, reducing the building's vulnerability to wind-induced sway and seismic forces. This improved stability enhances occupant comfort and safety.

6.1 Future Scope

This paper discusses the evolution of the outrigger from the history of its usage in canoes to the new concept of the damped outrigger with novel control system concepts. There is a new area of research in the damped outrigger structural control. As vibration control of the structural system is upcoming technology and is a new innovative area in research, this has a huge potential in construction industries.

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I. S. Codes:

(a) IS: 456 – 2000 - Code of Practice for Plan & Reinforcement concrete.
(b) IS: 875 – 1987 - Code of Practice for Design Loads per building & Structures.
Part 1 - Dead Loads
Part 2 - Imposed Loads
Part 3 - Wind Loads (2015)
Part 4 - Load Combinations
(c) IS: 1893:2016 [Part-1] - Criteria for Earthquake Resistant Design of structures
(d) IS: 13920-2016 - Ductile detailing of reinforced concrete structures Subjected to seismic forces
(e)IS: 16700-2017 - Criteria for Structural Safety of Tall Concrete Building
(e) SP- 22 - Explanatory Handbook on codes for Earthquake Engineering.
(f) SP – 16 – 1980 - Design Aids for Reinforced concrete to IS: 456
(g) SP–34(S&T)-1987 - Handbook on Concrete Reinforcement & Detailing
(h) SP64(S&T)-2001 - Explanatory Hand Book on codes for Wind Engineering.
Structural Analysis & Design of Tall Buildings - Bangale S. Taranath