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Analytical Structural Health Monitoring of Shear Wall Building

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Abstract: Structural health monitoring techniques have been utilized to inspect the current conditions of structures, as well as their post-earthquake performances. The dynamic characteristics of a building, such as modal periods, shapes and damping ratios can be obtained by analysing the ambient vibration data. It is well-known that dynamic characteristics generated from the finite element model (FEM) and vibration data, even for the intact building, show remarkable differences. Assumptions made in the FEM are one of the main reasons for those differences. To examine feasible solutions to such problems mentioned above Here an attempt has been made to study the behaviour of different structures of reinforced concrete with different heights with and without shear walls. Coupled shear walls have also been studied to understand the comparative merit or demerit of framed structures with shear wall structures. Studies have been carried out on sample model structures and analysis has been carried out by ETABS software. It has been ensured to consider sample models that represent the current practices in structural design to include different structural configurations. Models having varied structural configurations like framed, shear wall, coupled shear wall, central core shear wall, core in core etc. have been taken into consideration. The inherent asymmetry present in the structures have also been dealt. Natural frequencies and mode shapes of the structure were determined by frequency domain decomposition method. In addition, identification of damping was performed due to the fact that damping ratio plays a significant role in the magnitude of inter-story drift during an earthquake. The FEM of the structure was constructed based on design drawings and updated to represent the real mode shapes and frequencies of the structure. By using the updated FEM with standard damping ratio in Indian Earthquake Code and the identified damping ratio, seismic performance assessment of the building for a possible earthquake.

High rise building structures are both a necessity and a matter of sophistication and pride for structural engineers. Buildings crossing 25 to 30 storeys are a common phenomenon these days. But what happens to a structure as it crosses these height limits? Forces of nature in the form of earthquakes and cyclones starts playing brutal games with the structures. Higher the structure goes; higher it attracts the forces and wrath of nature in the form of seismic force.

Keywords: Shear wall, Seismic load, Structure Health Monitoring, Response Spectrum, Wind load.

I. INTRODUCTION

In recent decades, due to a lack of adequate construction sites, tall buildings have been the dominant means of accommodation and places of business in metropolises where economy and population grows fast. Compared to ordinary buildings, tall buildings are more densely populated, resulting in a bigger impact on the economy. In seismically prone areas, such as San Francisco, Tokyo and Istanbul, the safety of such buildings should be known prior to an earthquake and any damage due to the earthquake should be detected. To meet such necessities, tall building initiatives have been active especially in California to establish a framework for the selection of input motions, modelling approaches and performance criteria (Moehle, 2007). Structural Health Monitoring (SHM) systems allow us to understand the dynamic characteristics of the buildings. SHM systems are based on data acquisition systems consisting of acceleration sensors and data recorders. Based on the ambient vibration data records, the dynamic characteristics of a building such as modal periods, shapes and damping ratios can be determined. Taking those characteristics into account, the existence of any damage and verification of design assumptions can be determined. In addition, the finite element model (FEM) of the building can be updated to represent the true behaviour of the building. Californian seismic design guidelines recommend SHM systems to be installed on tall buildings as these systems make crucial contributions to the understanding of the dynamic behaviour of buildings and enhance the capability of engineers for damage detection

More and more people are shifting to bigger cities for better lifestyle and easy livelihood. This causes concentration of population in cities. Constant effort is being made to find habitable land. As habitable land is constant and not increasing to meet the ever-growing demands of increasing population in cities.

Horizontal growth is not possible. This leaves us with only option, rise vertically. This gives rise to tall high-rise structures. High rise building structures are both a necessity and a matter of sophistication and pride for structural engineers. Buildings crossing 25 to 30 storeys are a common phenomenon these days. But what happens to a structure as it crosses these height limits? Forces of nature in the form of earthquakes and cyclones starts playing brutal games with the structures. Higher the structure goes; higher it attracts the forces and wrath of nature in the form of seismic force.

Seismic force, predominantly being an inertia force depends on the mass of the structure. As the mass of the structure increases the seismic forces also increase causing the requirement of even heavier sections to counter that heavy forces. And these heavy sections further increase the mass of the structure leading to even heavier seismic forces. Structural designers are met with huge challenge to balance these contradictory physical phenomena to make the structure safe. The structure no more can afford to be rigid.

This introduces the concept of ductility. The structures are made ductile, allowing it yield in order to dissipate the seismic forces. A framed structure can be easily made ductile by properly detailing of the reinforcement. But again, as the building height goes beyond a certain limit, these framed structure sections (columns) get larger and larger to the extent that they are no more practically feasible in a structure. There comes the role of shear walls. Shear walls provide ample amount of stiffness to the building frame resisting loads through in plane bending. But they inherently make the structure stiffer. So, there must be a balance between the amount of shear walls and frame elements present in a structure for safe and economic design of high-rise structures.

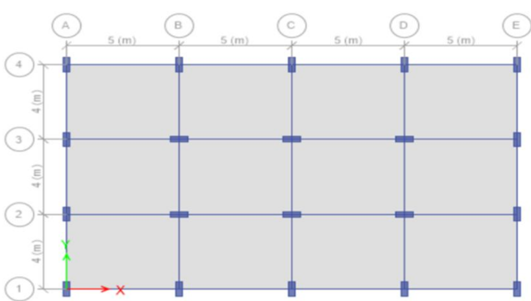
II. OBJECTIVE

Following are the main objectives of the work:

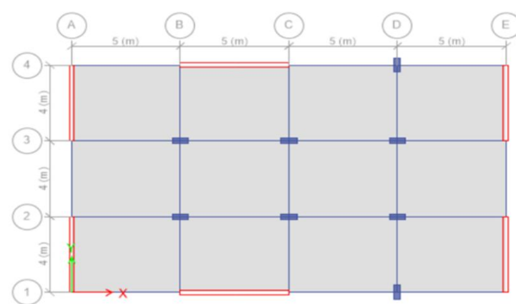
1) Comparison of Effects of Seismic & Wind Forces on High Rise Buildings with different structural configuration and to compare the key parameters.
2) Comparison of behavior of different structures of reinforced concrete with different heights, with and without shear walls.
3) Coupled shear walls have also been studied to understand the comparative merit or demerit of framed structures with shear wall structures.

III. MODELS CONSIDERED FOR ANALYSIS

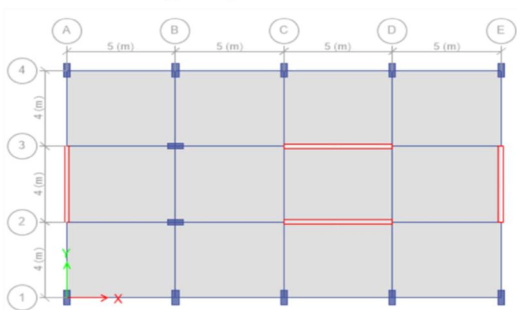
Following six types of models have been considered for analysis. It was attempted to choose models that are representative of actual building types that are being constructed nowadays. Type A is regular framed structure with columns. Type B hybrid framed structure with shear wall in periphery and columns. Type C hybrid framed structure with shear wall in centre and columns. Type D is tube structure. Type E is hybrid framed structure with lift core in centre. Type F is tube in tube system.



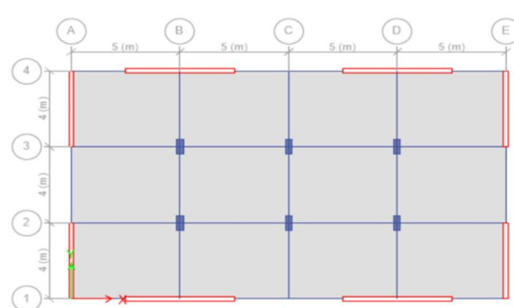
Type A: regular framed structure



Type B: hybrid framed structure with shear wall in periphery and columns



Type C: hybrid framed structure with shear wall in center and columns



Type D: tube structure

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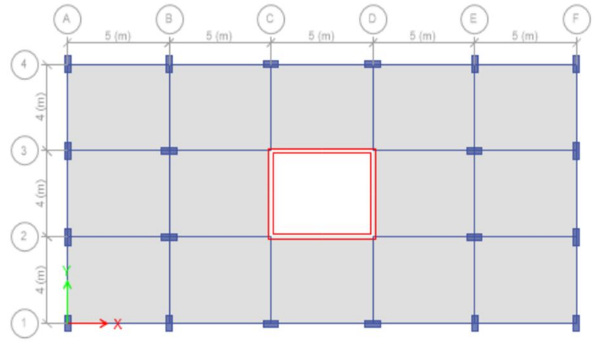
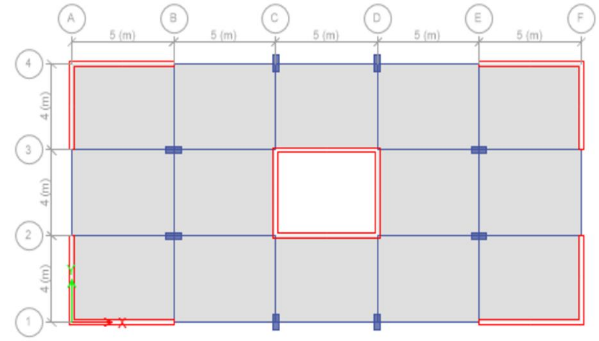


Type E: is hybrid framed structure with lift core in center



Type F: tube in tube system

Fig:1 Models Considered

IV. STATIC AND DYNAMIC PARAMETERS

1) *Design Parameters:* Here the Analysis is being done for G+10, G+25, G+35, G+50, (rigid joint regular frame) building by computer software using ETABS.
2) *Design Characteristics:* The following design characteristics are considered for Multistorey rigid jointed frames

Table 1 Design Data of RCC Frame Structures

S.No	Particulars	Dimension/Size/Value
1.	Model	G+10, G+25, G+35, G+50
2.	Seismic Zones	IV
3.	Floor height	3M
4.	Basement	4M
5.	Building height	41.6m,86.6m,113.6m & 161.6m
6.	Plan size	20mx12m
8.	Size of columns	0.3mx0.75m
9.	Size of beams	0.3mx0.75m &0.3mx0.6m
10	Shear Walls	0.23m
11.	Thickness of slab	125mm
12.	Earthquake load	As per IS-1893-2002
13.	Type of soil	Type -II, Medium soil as per IS-1893
14.	E_c	5000√fck N/ mm2(E_c is short term static modulus of elasticity in N/ mm^2)
15.	F_{ck}	0.7√fc k N/ mm2(F_{ck} is characteristic cube strength of concrete in N/ mm2
16.	Live load	2 kN/ m2
17.	Floor finish	1.00kN/ m2
18.	Services	1.00kN/ m2
19	Specific wt. of RCC	25.00 kN/ m2
20.	Specific wt. of infill	20.00 kN/ m2
21.	Material used	Concrete M-25, M-30and Reinforcement Fe-500(HYSD Confirming to IS-1786)

A. Seismic Load

As per IS: 1893, Noida is located in Seismic Zone IV.
Design base shear, V = Z I W Sa/2 R g
The values of the salient coefficients are tabulated below:

Table 2 Seismic parameters

Sl.	Description	Value	Reference
01	Seismic Factor for Zone: IV	0.24	IS-1893
02	Structure importance	1.0	IS-1893
	coefficient, I.		
03	Response reduction factor, R	5.00	IS-1893
04	Damping	5%	IS-1893
05	Time period	Variable	IS-1893

B. Wind Load

The wind velocity at Delhi is 47m/s. The other parameter of wind load as per IS: 875 (Part-3) is summarized below:

Table 3 Wind parameters

Sl.	Description	Value	Reference
01	Terrain category.	3	IS-875
02	Class of structure.	C	IS-875
03	Probability factor, k1.	1.0	IS-875
04	Terrain, height and structure size factor, k2.	As/Height	IS-875
05	Topography factor, k3.	1.0	IS-875

V. ANALYSIS RESULTS AND DISCUSSIONS

The analysis of different models of varying heights produced a large set of data. Microsoft excel was used for tabulation plotting and analysis of results obtained by ETABS analysis. The first objective was to figure out the key parameters that affected the building. Tabulation was done for different key parameters for all the models. A sample tabulation has been shown below for Type A structures having 10 storeys. Looking at most of the curves above it is evident that Wind plays a vital role in the behaviour of the building, especially when going beyond 10 storeys. It is clearly seen that the response of almost all types of building shows critical for earthquake loads for buildings up to 10 storeys and not wind loads. But we go beyond 10 storeys the response due to wind load starts exceeding the response due to earthquake loads. The similar trend can be seen for structures in the 25-storey range. For structures in the range of 35 and 50 storeys, wind loads clearly are the governing cases.

A. Comparison of 25 Storey Buildings

Base Reaction

Table 4 Base Reaction

Load Case/Combo	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	0	0	48022.89	288137.3	-480229	0
Live	0	0	6060	36360	-60600	0
EQX	-1290.55	0	0	0	-40514.6	7743.301
EQY	0	-1290.55	0	40514.62	0	-12905.5
SPECX Max	629.9654	1.02E-05	0	1.53E-05	16214.81	3779.792
SPECY Max	1.22E-05	669.8013	0	17147.68	3.33E-05	6698.013
WIND 1	-697.436	0	0	0	-16667.3	4184.614
WIND 2	0	-1162.39	0	27778.88	0	-11623.9

Modal Period

Table 5 Modal Period

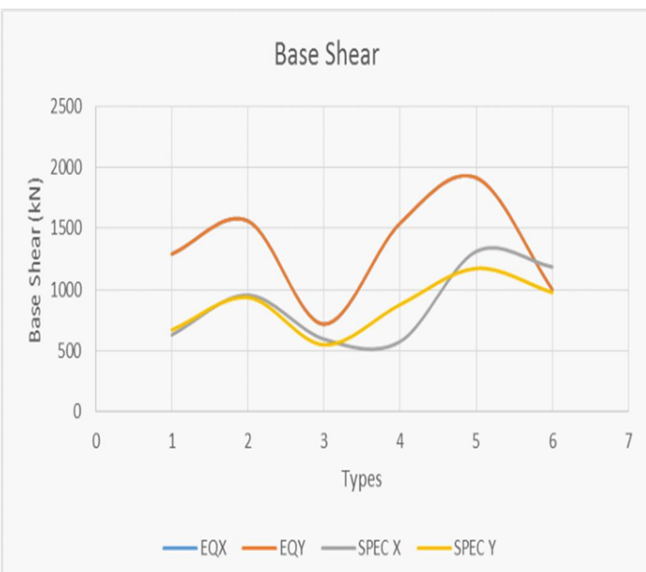
Case	Mode	Period	Frequency	Circular Frequency	Eigenvalue
		sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	2.317	0.432	2.7117	7.3532
Modal	2	2.164	0.462	2.903	8.4274
Modal	3	1.85	0.541	3.3961	11.5333
Modal	4	0.715	1.398	8.7818	77.1202
Modal	5	0.665	1.503	9.4418	89.1483
Modal	6	0.575	1.74	10.9297	119.4573
Modal	7	0.398	2.513	15.7911	249.3589
Modal	8	0.356	2.81	17.6571	311.7744

B. Comparison of 25 Storey Buildings

Base Shear

Table 6 Base Shear

Base Shear (kN)						
Load	Type A	Type B	Type C	Type D	Type E	Type F
EQX	1290.55	1560.97	717.63	1542.54	1914.97	1000.23
EQY	1290.55	1560.97	717.63	1542.54	1914.97	1000.23
SPEC X	629.9654	954.4855	595.0223	574.9217	1311.5169	1184.827
SPEC Y	669.8013	935.0808	548.095	876.7248	1172.8936	975.8446



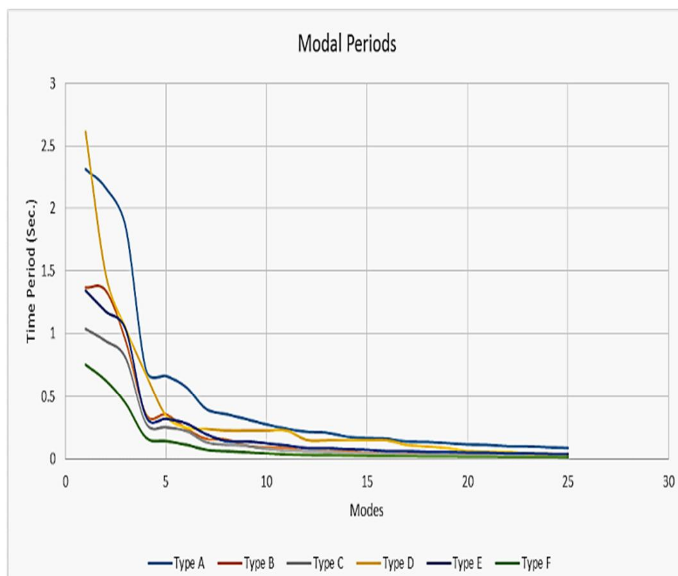


Fig:2 Comparison of Base shear and Modal period for 25 Storey Buildings

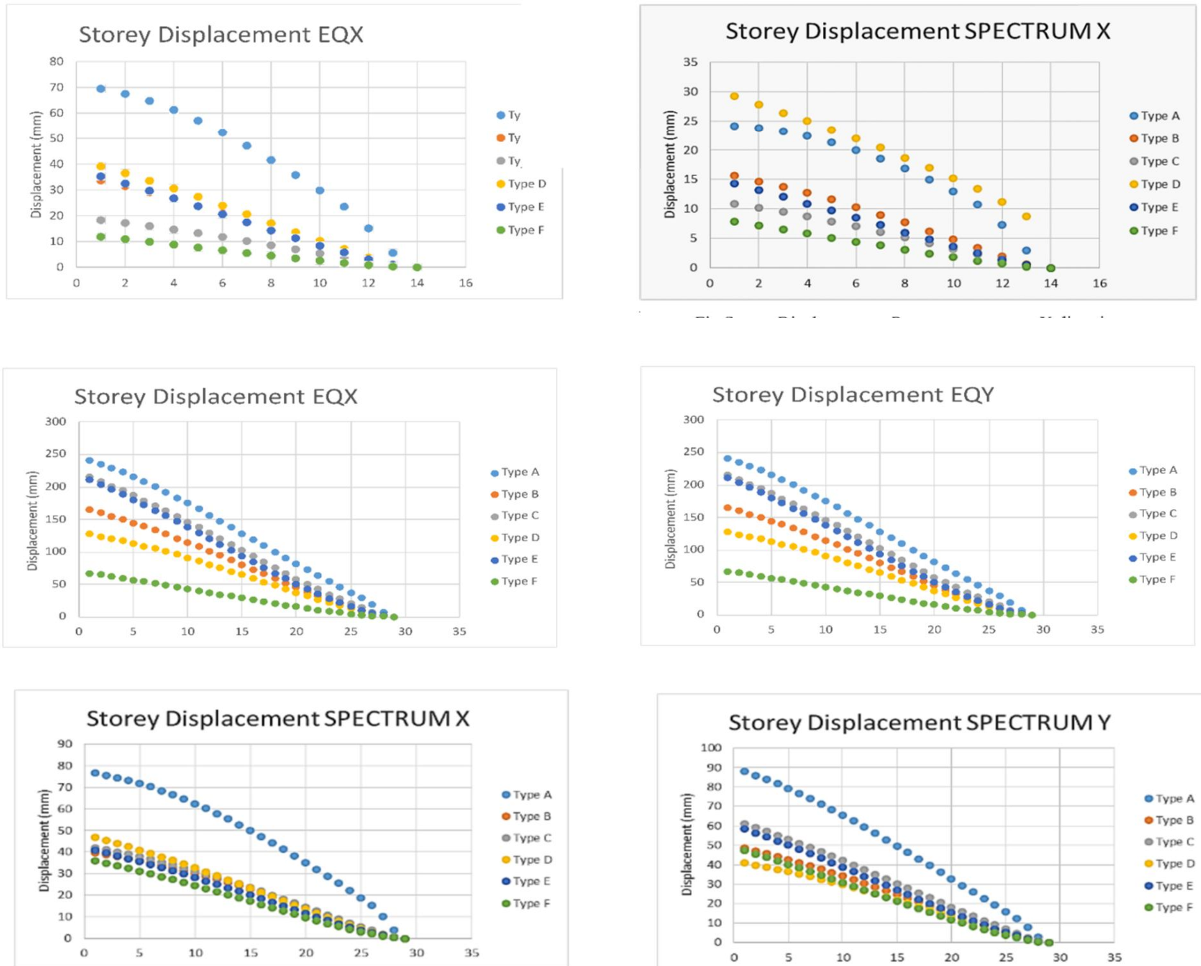


Fig:3 Comparison of storey displacement period for 25 Storey Buildings

C. *Comparison of 50 Storey Buildings*

1) *Modal Period*

Table 7 Comparison of Modal period 50 Storey Buildings

Period (Sec.)							
Case	Mode	Type A	Type B	Type C	Type D	Type E	Type F
Modal	1	16.128	10.994	14.041	9.929	13.955	6.483
Modal	2	12.347	8.467	9.141	9.394	9.071	4.307
Modal	3	8.316	5.18	6.552	5.539	4.205	2.432
Modal	4	3.578	2.585	2.898	2.573	2.728	1.501
Modal	5	3.395	2.346	2.458	2.36	2.259	1.173
Modal	6	2.539	1.568	1.948	1.602	1.371	0.74
Modal	7	1.773	1.225	1.347	1.229	1.203	0.665
Modal	8	1.739	1.189	1.228	1.144	1.055	0.552
Modal	9	1.434	0.835	1.038	0.813	0.811	0.39
Modal	10	1.229	0.774	0.859	0.735	0.721	0.385

Base Shear (kN)						
Load	Type A	Type B	Type C	Type D	Type E	Type F
EQX	2438.884	2352.892	2390.501	2321.685	2889.0486	1472.083
EQY	2438.884	2352.892	2390.501	2321.685	2889.0486	1472.083
SPEC X	1329.422	1301.593	1306.518	1904.936	1612.8568	979.9861
SPEC Y	1258.852	1262.631	1248.717	1909.054	1539.8733	933.4433

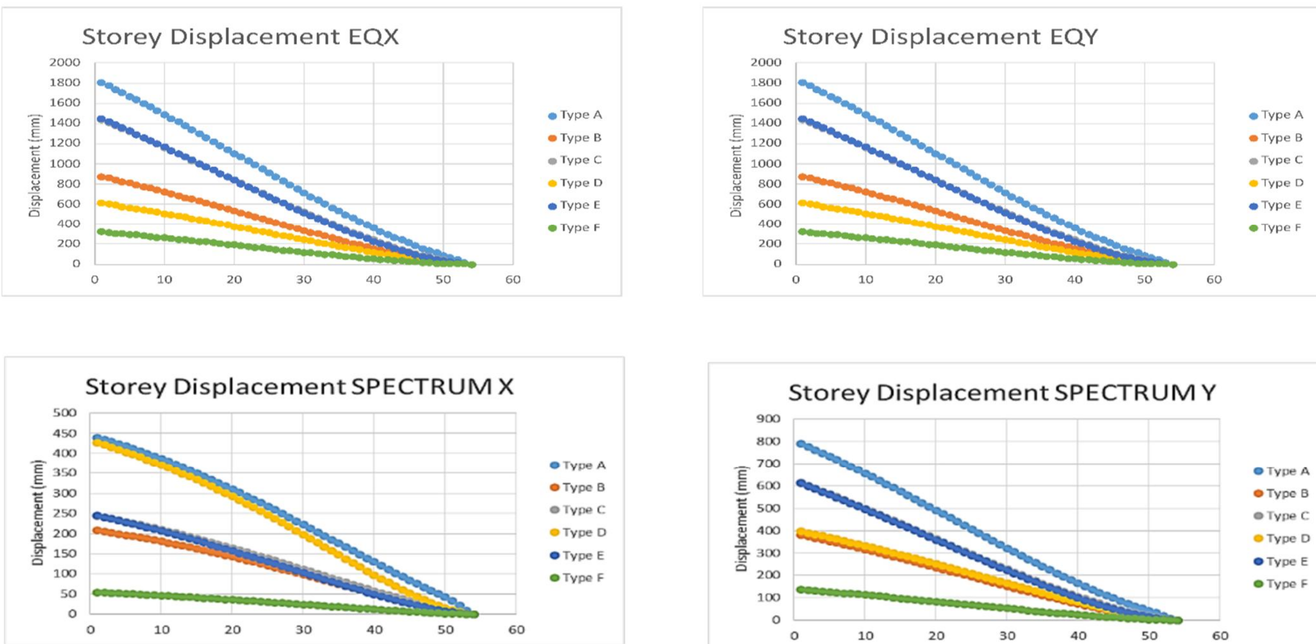


Fig: 4 Comparison of storey displacement period for 50 Storey Buildings

VI. CONCLUSIONS

The choice of any particular type of structure will ultimately depend upon the storey range, type of materials available, architectural requirements, functional use and the economy involved.

Looking at most of the comparisons with Wind forces, it is evident that Wind plays a vital role in the behaviour of the building, especially when going beyond 10 storeys. It is clearly seen that the response of almost all types of building shows critical for earthquake loads for buildings up to 10 storeys and not wind loads. But we go beyond 10 storeys the response due to wind load starts exceeding the response due to earthquake loads. The similar trend can be seen for structures in the 25-storey range. For structures in the range of 35 and 50 storeys, wind loads clearly are the governing cases. The response is way more than the earthquake loads.

The approach for design of structures for wind and earthquake are diagonally apart. Wind forces are generally push forces that tries to topple or bend the structure vertically. They are applicable on the exposed face of the structures. In order to safeguard the structure for wind, one very simple solution can be to make the structure heavier. Heavier the structure, better its ability to resist wind forces.

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But earthquake forces are totally different. They are basically inertia forces, which depend on the mass of the structures. The structures on action of earthquake forces rarely topple over or fall down. They actually collapse just under its own vertical axis. Since earthquake forces depend upon the weight/mass of the structure, heavier the structure, more earthquake force it attracts. The idea is to make the structure lighter. Lighter the structure, better it is for the structure to resist earthquake forces

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Structures within 10 storey are generally governed by earthquake loads and wind does not play a vital role. Generally, in this range type A framed are preferred over shear wall structures. Provision of shear walls with lift core as given in Type C are also common. But here the shear walls alone do not impact the lateral stability of the structures considerably. Tube structures and tube in tube structures are not required in this height zone. They are often less economical than simple framed structures.in general hybrid structures with combinations of shear walls and columns are provided. The economy of the structures often depends upon the relative presence of shear walls and columns in appropriate ratios. Overall, it can be concluded that framed structures are economical for structures below 10 storeys.

Structures in the range of 25 storey are supposed to be sufficiently ductile to dissipate higher level of base shear but just enough stiffness not to attract seismic forces. Type A framed structures can be constructed but it is often seen that the section requirement at the bottom storey is very high this causes accessibility issues as often parking is planned at these levels. Coupled shear wall structures & hybrid structures with shear walls at center and periphery are best suited for this storey range. Tube structures and tube in tube structures are not required here here also the economy of the structures often depends upon the relative presence of shear walls and columns in appropriate ratios. Overall, it can be concluded that hybrid structures with shear walls at center and periphery are best suited.

Structures in the range of 35 storey are expected to vibrate in higher modes of vibrations and the effect of higher modes of vibration often causes the lateral load resisting elements requiring huge sections at middle half of the building. consequently, the columns size requirements at the bottom storeys does not remain feasible at all. However, hybrid structures with shear walls at center and periphery can be constructed but the requirement of shear walls is enhanced which further causes increase in base shear. so, the sections required for shear walls also are very high at the bottom storey. additionally, presence of too many shear walls to tackle huge base shear causes the structures to be very rigid which in itself is not a desirable feature. Tube and tube in tube structures are suitable for this storey range.

Structures in the range of 50 and above stories are expected to vibrate in even higher modes of vibration. This causes the use of simple framed, or simple shear wall structures practically impossible to design. We have to go for innovative structural configurations like braced shear walled framed structures, tension structures, pretension structures etc. No particular structural configuration can be assumed to behave satisfactorily in this storey range. Tube and Tube in Tube structures with spandrel beams may prove to be useful, but the decision of the structural configuration depends on the structure at hand. Engineering judgement, innovation and practical application should be the guiding factors for these structures.

To be able to balance, these two contradictory principles of design is a real challenge for structural engineers.

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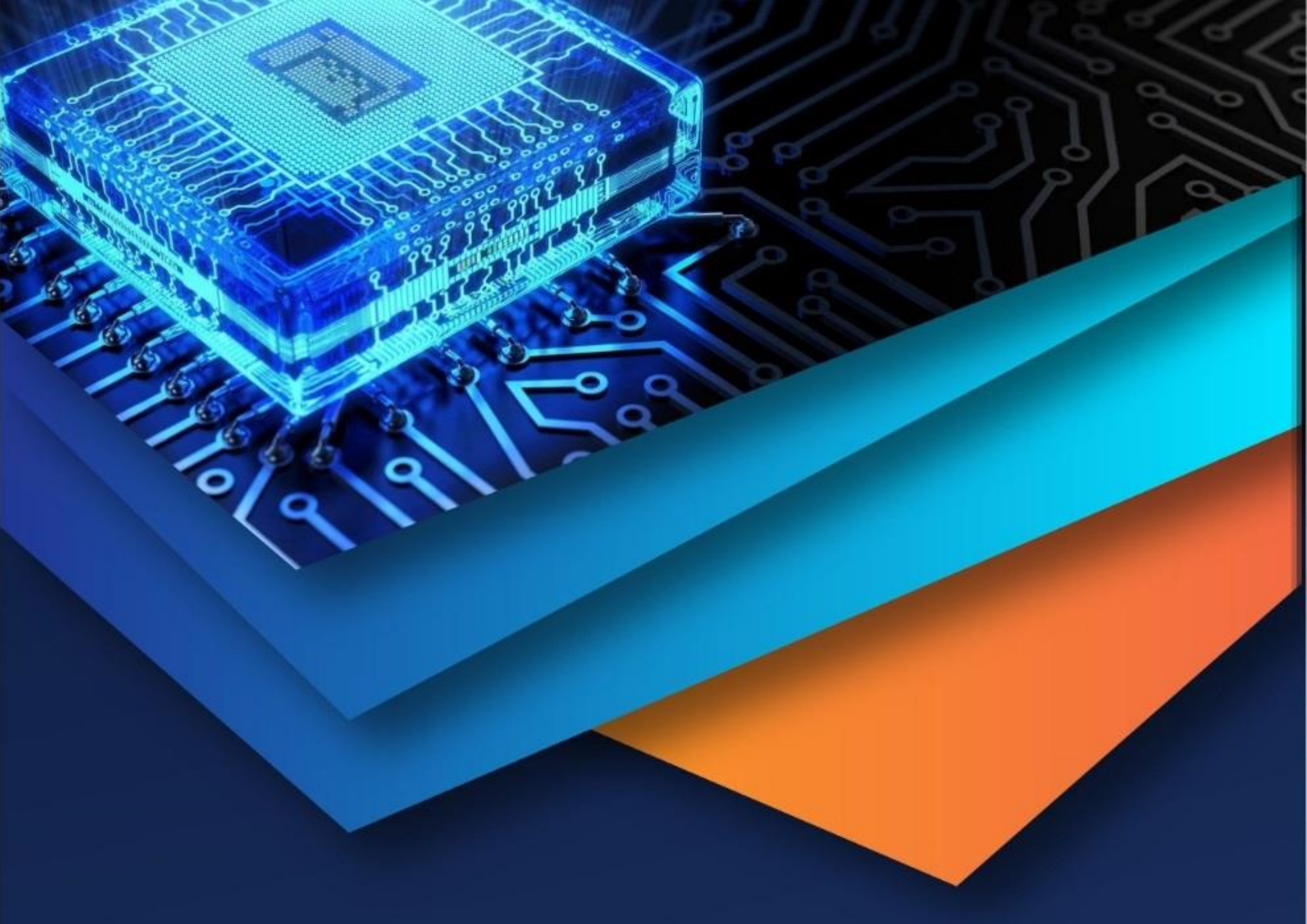

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