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COMPARATIVE ANALYSIS FOR THE EFFECT OF LATERAL LOAD RESISTING SYSTEMS ON TALL STRUCTURES

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Abstract— The high rise architecture in the twenty and twenty-first centuries shows such a wide diversification as to defy distinct classification. Nevertheless, its development can be traced, perhaps somewhat imprecisely, in five phases. Every building is a unique response to a particular set of conflicting demands. Therefore, less efficient structural systems often need to be studied in the interest of bringing in the total project cost within the allotted budget. This study is concentrated on the analysis and design of multi-storey structure based on three different configurations of load resisting systems. The building is subjected to the earth quake load and gravity load. The member sizes are decided on the basis of design results of ETABS V 18 and also top storey displacement's limitations. This study is carried out for selected geometry and loading. But it will give the general performance of the shear wall, outriggers and diagrid while using in the combination for super tall construction. In tall structure growth this analysis will help to understand the behavior of shear wall, outriggers and diagrid structural system and optimization of efficient structural designs.

Keywords-Tall buildings, Diagrid system, Diagrid structural system, Shear wall system, Tube system, Beam Column System, lateral loads, Optimum design, Parametric Study, ETABS, etc.

1. INTRODUCTION

Introduction of Tall Structures

As expansion of vertical construction is now a need of urban culture due to population growth increases rapidly and required landscape for habitation remains limited hence focusing on different structural concepts to satisfy the need of safety has become important. High rise structures have always been a fascination of human being and that is also one of the reason that to develop the ideas of innovation in art and to develop availability of risk free structural configuration.

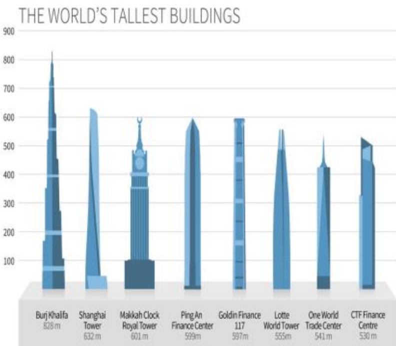

Fig 1 World's Tallest Buildings

Classification of tall structure can be made on the preferential terms height in comparison of surrounded structures or number of stores. As per the engineer's concept if the height of the structure suffers large amount of lateral force effect then it should be classified as high rise structure. Tall buildings are usually heavier structure and hence require large size of components and high strength of material which directly affects to the economy of the construction.

Structural Overview Of Existing Tall Structures

Looking over the present of tall structures we can list out the tall structures existing around the world with special type of combination of structural frame.

BURJ – KHALIFA: The Burj Khalifa consists the height of 848 m including the antenna. The Y shaped floor plan provides high performance and maximize view of the Persian Gulf. The shape along with the upward spiraling pattern of setbacks in the wing helps to reduce the wind force on the tower. The shape was determined based on extensive wind tunnel test. The structural system can be described as a buttress core and consisting high performance concrete wall construction.


Fig-2 Burj Khalifa Building

Each of the wing buttress the others via a hexagonal central core. This central core provide the torsional resistance for the structure similar to closed pipe or axel. The corridor was extends from the central core up to the end of wing. These walls behave like the web and flanges of the beam to resist the wind shears and moments. There are also a few perimeter columns supporting flat plates at the end. The perimeter columns are connected at mechanical floors to outrigger walls thus allowing the perimeter columns also to resists the lateral wind loads. The three storey high outriggers tie the tower at different height periodically. The tower does not contain any of structural transfers.

- At the tallest point the tower sways total of 1.5m
- The first mode has the period of 11.3 sec.

CN TOWERS: Wonder of the modern world the CN tower is Canada's most celebrated architectural triumph with Toronto's most spectacular view day and night. This Toronto must see is a world class entertainment and dining destination.

Fig-3 CN Towers

Explore to an observation level up to 346 m, the world famous glass floor at 342 m with outdoor sky terrace.

OSTANKINO TOWERS: The structure is located in the city Moscow in Russia. It was completed in time duration of 5 years.

Fig 4- Ostankino Towers

The Ostankino tower consume the total floor area of 15000 m^2. Total height of the tower was found as 540 m and weight was 55000 tons. Depth of tower kept below the ground is 3.5 m. It was designed for maximum wind velocity of 43 m/s which could produce the max deflection of 1.5 m the diameter of shaft used was 18 m whereas the min was 8.2 m.

SHANGHAI WORLD OFFICE: The building consist of 381600 m^2 area, 101 number of floors and 494.4 m of height including antenna. The design concept is taken in account of gravity and lateral loads as concrete shear wall of the service core together with major columns diagonals and belt trusses in outer frame is the lateral force resisting system. This outer frame helps to decrease the thickness of the shear walls of service core as well as a decrease in the weight of structural steel I the perimeter walls while maintaining a good structural stability in lateral load resisting.

Fig 5- Shanghai World Office

Further by making use of outrigger trusses coupled to the columns of the mega structure, a further reduction of shear wall was realized. The diagonal of the mega structure are form of welded box of structural steel. These steel boxes are filled with concert, thus providing increased stiffness nonlinear structural behavior and structural damping as well as the upper reaches of the building and enhance with stud shear connectors. The concrete is used to stabilize against buckling of the thin plates of the diagonal.

I. PROBLEM DEFINITION

Geometry and Structural Detail

The plan has been taken as symmetrical about both "X" and "Y" axis and height varies along the height in "Z" axis with particular systems to withstand the seismic forces and to minimize the structural response.

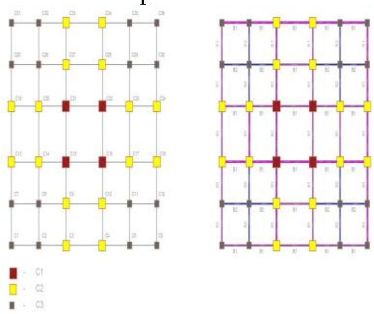

Fig 6- 3D View of the Model Plan Layout of Column and Beam

Schedule of building frame property:

DESCRIPTION	MULTI - STOREY FRAME
Type of structure	Multi - Storey rigid joint 3D frame
Seismic Zone	III
Number of Storey	20, 40 and 60
Floor Height	4.5 m
Footing Height	3.0 m
Building Height	93 m, 183 m and 273 m
Infill Wall	0.23 m thick wall and 0.15 m partition wall
Parapet Wall	1.5 m high
Imposed Load	3.0 kN/m^2
Floor Finish Load	1.0 kN/m^2
Material	M60, M40, HYSD550, Fe345
Specific weight of concrete	25.00 kN/m^3
Specific weight of infill	20.00 kN/m^3
Type of Soil	II - Medium
Response Spectrum	As per IS:1893 - 2016
Wind Zone	39 m/s

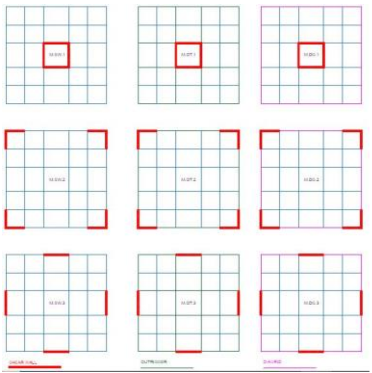

Fig 7- Plan Layout to Illustrate the Location of Shear Wall, Outrigger and Diagrid

List of model frames analyzed for seismic forces: -

Model No.	Model Code	Storey	Description
1	M.CO.20.1	20	Beam Column system
2	M.SW.20.1	20	shear wall at central core of frame
3	M.SW.20.2	20	shear wall at corner of periphery
4	M.SW.20.3	20	shear wall at centre of side periphary
5	M.OT.20.1	20	shear wall at central core of frame with 4 outriggers
6	M.OT.20.2	20	shear wall at corner of periphery with 4 outriggers
7	M.OT.20.3	20	shear wall at centre of side periphary with 4 outriggers
8	M.DG.20.1	20	shear wall at central core of frame with bracing at periphery
9	M.DG.20.2	20	shear wall at corner of periphery with bracing at periphery
10	M.DG.20.3	20	shear wall at centre of side periphary with bracing at pheriphery
11	M.CO.40.1	40	Beam Column system
12	M.SW.40.1	40	shear wall at central core of frame
13	M.SW.40.2	40	shear wall at corner of periphery
14	M.SW.40.3	40	shear wall at centre of side periphary
15	M.OT.40.1	40	shear wall at central core of frame with 4 outriggers
16	M.OT.40.2	40	shear wall at corner of periphery with 4 outriggers
17	M.OT.40.3	40	shear wall at centre of side periphary with 4 outriggers
18	M.DG.40.1	40	shear wall at central core of frame with bracing at periphery
19	M.DG.40.2	40	shear wall at corner of periphery with bracing at periphery
20	M.DG.40.3	40	shear wall at centre of side periphary with bracing at pheriphery
21	M.CO.60.1	60	Beam Column system
22	M.SW.60.1	60	shear wall at central core of frame
23	M.SW.60.2	60	shear wall at corner of periphery
24	M.SW.60.3	60	shear wall at centre of side periphary
25	M.OT.60.1	60	shear wall at central core of frame with 4 outriggers
26	M.OT.60.2	60	shear wall at corner of periphery with 4 outriggers
27	M.OT.60.3	60	shear wall at centre of side periphary with 4 outriggers
28	M.DG.60.1	60	shear wall at central core of frame with bracing at periphery
29	M.DG.60.2	60	shear wall at corner of periphery with bracing at periphery
30	M.DG.60.3	60	shear wall at centre of side periphary with bracing at pheriphery

II. MODELLING ANALYSIS

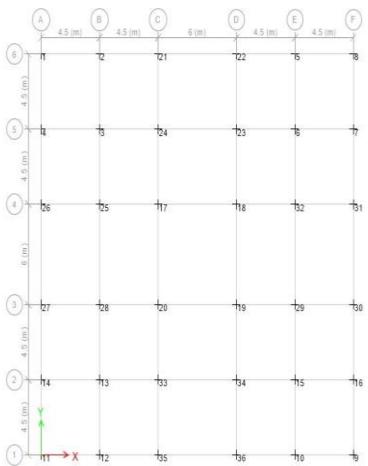

Fig-8 Grid Lines of Soil Structure Interaction Joints of Frame in Plan

In the figure the green colored mark of cross shows the fixed support of structure assumed to be a joint on the top of the foundation.

Definition structural components material

MATERIAL can be defined from the define menu in tool bar. Define>Material>Add new material

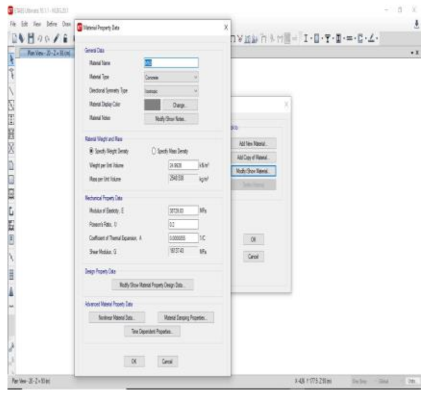

Fig-9 Definition Structural Components Material

Any of the material for reinforcement, steel section and concrete section can be defined from the software provision.

BEAM AND COLUMN

These frame sections are defined from the define menu>section properties>frame section>add new section

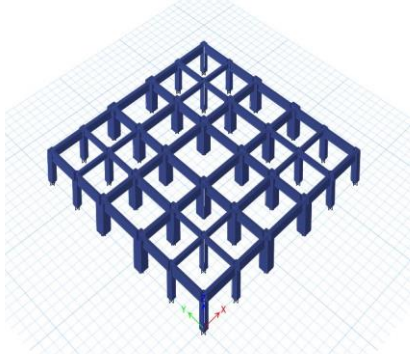

Fig-10 Beam & Column

SLAB

Follow the commands as define>section properties>slab sections

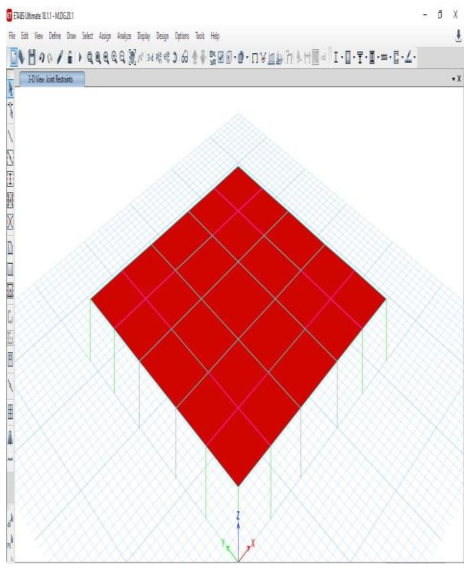

Fig-11- SLAB Design

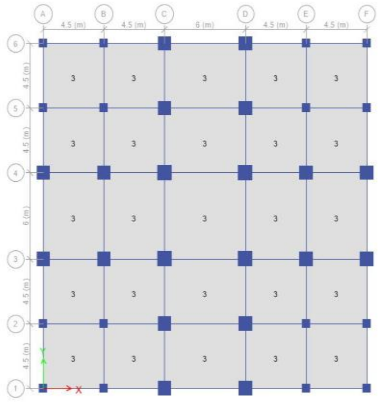

Fig 12- Imposed Load Application

Dead load = self-weight + floor finish
Live load = 3.0 kN/m
Live load is taken as 10% reducible live load

Floor level	Reduction	Live load (kN/m^2)
GF	0	3
1st	10%	2.7
2nd	20%	2.4
3rd	30%	2.1
4th to 9th	40%	1.8
10th to onwards	50%	1.5
Terrace level		1.5

LOAD:
FRAME LOAD DEFINITION
WALL LOAD ON PERIPHERY OF GEOMETRY

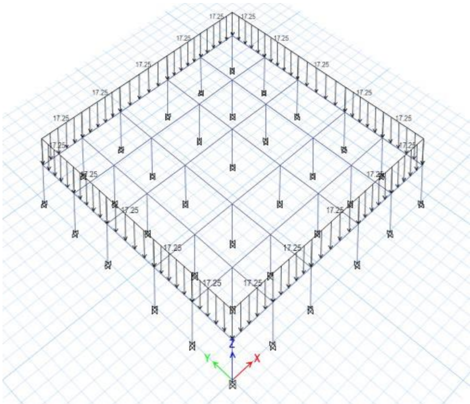

Fig 13- Frame Load Design
Wall load calculation for periphery
= (4.5 – 0.75) * 0.23 * 20
=17.25 kN/m

WALL LOAD ON INTERIOR WALL OF GEOMETRY
Wall load calculation for internal wall
= (4.5 – 0.75) * 0.15 * 20
= 11.25 kN/m

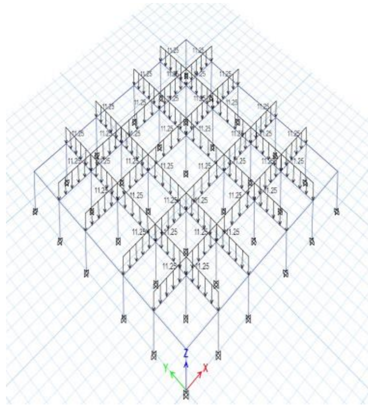

Fig 14-Wall Geometry Design
WALL LOAD ON PARAPET SECTION:
Parapet wall load calculation
= 1.5 * 0.23 * 20
= 6.9 kN

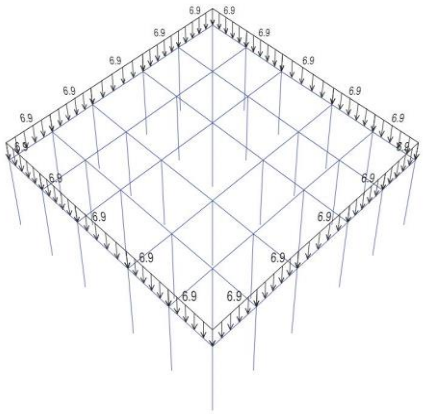

Fig 15- Wall Load on Parapet Section Design

SEISMIC LOAD DEFINITION IN ETABS V18:
Follow the command line of define>Load Pattern > EQX > Add new load

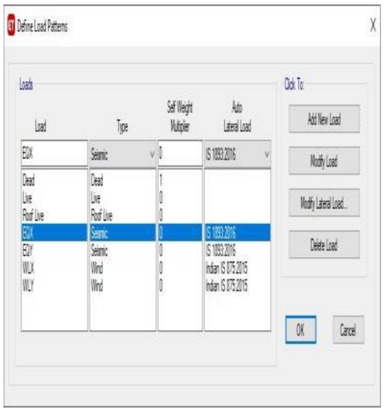

Fig 16- Seismic Load Design tool

IV. RESULTS COMPARISON AND DISCUSSION

SEISMIC CO-EFFICIENT METHOD
This method is performed as per IS: 1893-2016 with help of software. The mass source is defined to consider seismic weight of building frame as dead load and particular amount of live load i.e. Dead Load + 0.25 (Live Load).
Fundamental time period is taken as
$T_n = 0.09*h / \sqrt{D}$

T_n = Natural time period
h = Height of building frame
D = Width of frame

Frame	20 - storey	40 - storey	60 – storey
T_n	1.708 sec	3.361 sec	5.015 sec

Z = 0.16
$S_a/g = 1/T_n$
R = 5%
I = 1.0

RESPONSE SPECTRUM METHOD

This method is applied along the code specifications of IS: 1893 – 2002 with considering the modal combination method of square Root of sum of Square Method.
Function Damping ratio = 0.05
Z = 0.16
Initial Scale Factor (I.S.F.) = 1.2 * g/R = (1/2 * 9.81/5) = 0.981
Final Scale Factor(F.S.F.) = I.S.F. * (V_B /V_B)

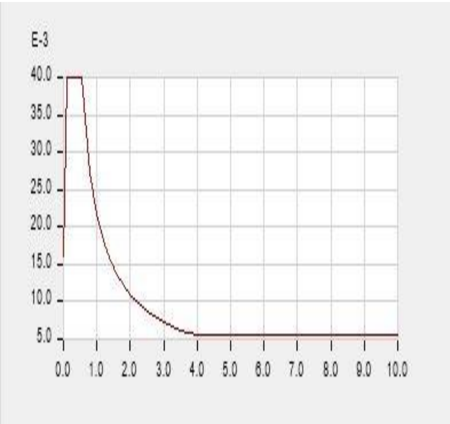

Fig-17 Function Curve

ANALYSIS OPTIMIZATION

BASE SHEAR

The base shear is obtained for the lateral force of earth quake, response spectra and time history component in X direction only. As the building is symmetrical in both in plane direction.

TOP STOREY DISPLACEMENT

The upper most node of the structural frame on the right side of the frame in plane frame XZ-section, the top storey displacement has been considered for each of the lateral X directional force due to earth quake, response spectra and time history forces.

MODAL TIME PERIOD

The modes of 20, 40 and 60 storey frames are taken as 10, 30 and 50 respectively. Due to the application of lateral forces by earth quake and response spectra the time period for the first mode consisting above 90% of the modal mass has been considered into the account.

INTERNAL FORCES

For the columns as shown in the figure are taken in the same sequence to obtain the internal forces of the frame in columns at the ground floor level.

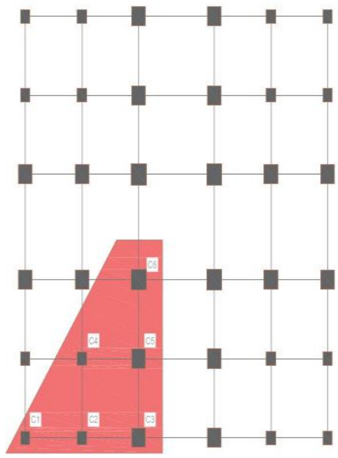
Fig-18 Internal Design of Forces

ASSUMPTIONS MADE FOR THE PRESENT STUDY.

- The geometry for all of the model frames is considered same.
- The column sizes reduces accordingly throughout the building height at regular intervals of storey number. As shown in the geometry there are three different column sizes in plan.

20 storey frame (m)			40 storey frame (m)			60 storey frame (m)		
7 Storey	C1	1.1 X 1.1	14 Storey	C1	1.2 X 1.2	20 Storey	C1	1.52 X 1.52
	C2	1.0 X 1.0		C2	1.1 X 1.1		C2	1.25 X 1.25
	C3	0.6 X 0.6		C3	0.75 X 0.75		C3	0.85 X 0.85
14 Storey	C1	0.9 X 0.9	27 Storey	C1	1.0 X 1.0	40 Storey	C1	1.2 X 1.2
	C2	0.75 X 0.75		C2	0.9 X 0.9		C2	1.0 X 1.0
	C3	0.5 X 0.5		C3	0.6 X 0.6		C3	0.75 X 0.75
20 Storey	C1	0.75 X 0.75	40 Storey	C1	0.75 X 0.75	60 Storey	C1	1.0 X 1.0
	C2	0.6 X 0.6		C2	0.7 X 0.7		C2	0.9 X 0.9
	C3	0.5 X 0.5		C3	0.5 X 0.5		C3	0.5 X 0.5

- The all members of outrigger truss and diagrid are restricted to withstand the axial forces only. No moments or torsion action is allowed to transfer thought these members hence they are given a pin joints at the both ends of the members.
- The bottom of ground floor columns are connected with ground and are given fixed joint restrain as it is assumed to be rigidly connected with the ground.

TOP STOREY DISPLACEMENT-

Method of Analysis	M.CO.1	M.SW.1	M.SW.2	M.SW.3	M.OT.1	M.OT.2	M.OT.3	M.DG.1	M.DG.2	M.DG.3
20 - Storey Building Frame (m)										
Seismic Analysis	0.1579	0.0632	0.0847	0.0794	0.0298	0.0412	0.0332	0.0266	0.0210	0.0246
Response Spectrum	0.1229	0.0357	0.0505	0.0478	0.0199	0.0283	0.0232	0.0179	0.0155	0.0171
40 - Storey Building Frame (m)										
Seismic Analysis	0.74569	0.43308	0.4541	0.47548	0.3184	0.33998	0.32919	0.24638	0.17104	0.21508
Response Spectrum	0.20477	0.11484	0.13267	0.13433	0.08221	0.09769	0.09062	0.05912	0.04372	0.05267
60 - Storey Building Frame (m)										
Seismic Analysis	1.22483	0.92027	0.76474	0.87602	0.85959	0.71252	0.79891	0.74807	0.49572	0.71344
Response Spectrum	0.31802	0.25523	0.2239	0.24813	0.23658	0.2076	0.22421	0.19646	0.13418	0.18847

MODAL TIME PERIOD

Method of Analysis	M.CO.1	M.SW.1	M.SW.2	M.SW.3	M.OT.1	M.OT.2	M.OT.3	M.DG.1	M.DG.2	M.DG.3
20 - Storey Building Frame (sec)										
Seismic Analysis	4.911	2.788	3.283	3.173	1.988	2.385	2.14	1.862	1.715	1.818
Response Spectrum	4.911	2.788	3.283	3.173	1.988	2.385	2.14	1.862	1.715	1.818
40 - Storey Building Frame (sec)										
Seismic Analysis	8.356	6.365	6.797	6.775	5.481	5.928	5.669	4.785	4.148	4.511
Response Spectrum	8.356	6.365	6.797	6.775	5.481	5.928	5.669	4.785	4.148	4.511
60 - Storey Building Frame (sec)										
Seismic Analysis	10.725	9.56	9.178	9.468	9.223	8.848	9.03	8.557	7.249	8.43
Response Spectrum	10.725	9.56	9.178	9.468	9.223	8.848	9.03	8.557	7.249	8.43

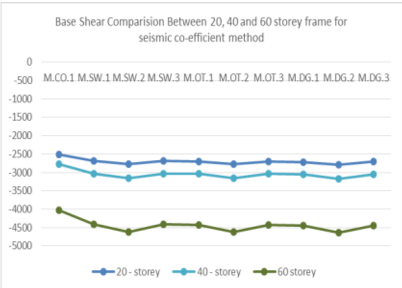

Fig-19 Base Shear Comparison

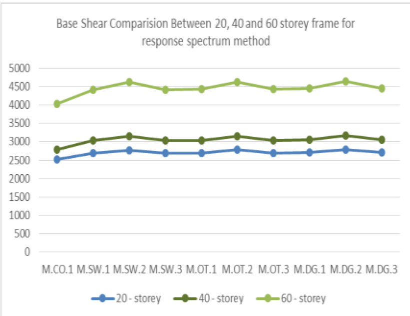

Fig-20 Base Shear Comparison

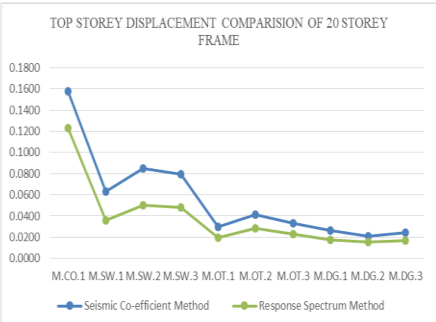

Fig -21 Top Storey Displacement

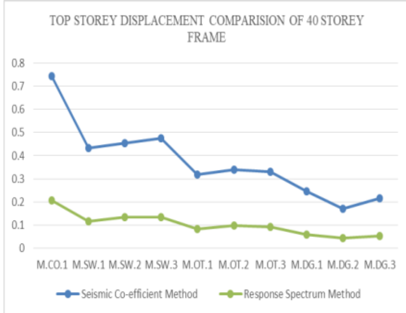

Fig -22 Top Storey Displacement

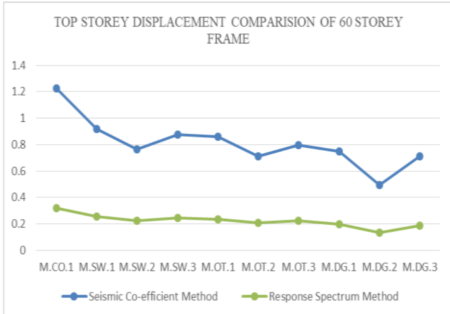

Fig -23 Top Storey Displacement

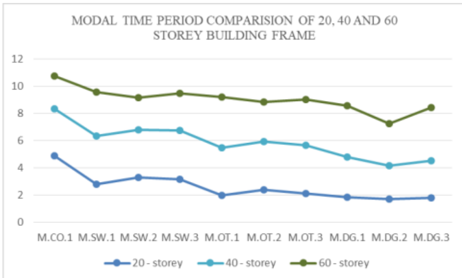

Fig-24 Modal Time Period

5. CONCLUSION

Looking through the analysis one can conclude few things as follow:

- Shear wall gives best performance while used at the corner of the symmetric structural perimeter.
- Using outrigger in tall structures improve the performance. To obtain the best performance of structure enough required number of outrigger should be used and coupled properly to the shear wall located at corner periphery if it is the requirement.
- Using diagrid system combined with the shear wall may further improve the performance of the structural frame of high rise building.
- In highly seismically active zone , less stiff structural members should be avoided and outriggers and diagrid should apply wisely and properly.
- Diagrid structure combined with shear wall shows the best performance of tall structure.

Hence as a conclusion of the dissertation the tall structural frames should be given an appropriate lateral load resisting system using outrigger and diagrid system in combination with shear wall component.

REFRENCES

1. Kyoung-sun Moon, Jerome J. Conner, John E. Fernandez, "Diagrid structural system for tall buildings: characteristics and methodology for preliminary design". The Structural Design of Tall and Special Building, 2007, Page no. 205-230.
2. Elena Mele, Maurizio Toreno, "Diagrid structure for tall buildings: case studies and design considerations". The Structural Design of Tall and Special Buildings, 2014, Page no. 124-145.
3. G. M. Montuori, Elena Mele, "Secondary Bracing Systems for diagrid Structures in tall building". Structural Engineering, 2014.
4. Nilesh M. Gautami, Sumant B. Patel, "Comparison of various structural systems for tall steel buildings in Indian scenario". Journal of Information, Knowledge and Research in Civil Engineering, 2012, Page no. 78 - 82.
5. Harish Varsani, Dipesh Gandhi, "Comparative Analysis of diagrid structural system and conventional structural system for high rise steel building". International Journal of Advance Research in Engineering, Science & Technology, January-2015.
6. Khushbu Jani, Paresh V. Patel, "Analysis and design of diagrid structural system for high rise steel buildings". ELSEVIER, 2013, Page no. 92- 100.
7. Nishith B. Panchal, V. R. Patel, "Optimum angle of diagrid structural system". International Journal of Engineering and Technical Research, June- 2014.
8. IS 875 (part-3) – 1987. "Code of practice for design loads (other than earthquake) for building and structures, wind load". Bureau of Indian Standard, New Delhi.
9. G. M. Montuori, Elena Mele, "Geometrical pattern for diagrid buildings: Exploring alternative design strategies from the structural point of view". Engineering Structures, 2014.
10. J. Kim, Y. Jun, "Seismic Performance Evaluation of Diagrid System Buildings", 2nd Specialty Conference on Disaster Mitigation, Manitoba, June 2010.
11. Pallavi Bhale, P. Salunke, "Analytical study and design of diagrid building and comparison with conventional frame building", International Journal of Advanced Technology in Engineering and Science, Vol. No. 4, Issue No. 01, 2016.
12. IS: 875(Part-I, II, III)-1987, Code of Practice for Design Loads (other than Earthquake) for Buildings and Structures,
13. IS: 1893(Part-I)-2002, Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standard, New Delhi.
14. IS: 456-2000. Plain and Reinforced Concrete- Code of Practice (Fourth Revision), Bureau of Indian Standard, New Delhi.
15. Bureau of Indian Standard, New Delhi.

