iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** VII **Month of publication:** July 2016

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Seismic Analysis of a Multistorey RC Building for Various Lateral Load Resisting Systems by Response Spectrum Method

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Abstract— ***The current work deals with analysis of Multi-storey RC building for earthquake effects that develops lateral loads on buildings by Response spectrum method. In this method, peak acceleration for an earthquake is acted upon the building models and analysis is done using software tool ETABSv.15. The models considered incorporates lateral stiffness systems such as Bracings and Shear-walls to resist lateral loads. They are located in different positions and their effect is studied based on seismic parameters: storey displacement, storey drift, storey shear and time period. The most effective lateral system based on performance and increase in stiffness is observed.***
Keywords— ***Lateral load resisting systems, Bracings, Shear walls, Response spectrum method, Seismic parameters.***

I. INTRODUCTION

Earthquake engineering is an interdisciplinary branch of engineering which deals with analysis and design of structures such as bridges, buildings and dams keeping in mind the effect of earthquake waves or lateral loading on the structures. The main objective of the design is to make it earthquake resistant. The design aims at building the structures that are not going to be damaged in minor shaking and avoids a catastrophe damage and complete collapse in a major earthquake. It is the scientific field concerned with protecting the society, natural environment and man-made or build environment from the earthquake by limiting the risk to socio-economically acceptable levels.

The main objectives in the design of earthquake resistant structures are:

To estimate the potential consequence of the major earthquakes in urban regions and the civil infrastructure.

Design, construct and maintain the structures for the expected performance and for the expose of earthquakes and in compliance with the design codes.

A properly designed structure need not be very expensive and very strong; it has to be designed properly to withstand the seismic effects by undergoing sustainable level of damage without any failure.

Seismic design is based on the accepted principles, design procedures and criteria meant to design the new structures and retrofit of the existing structures. These principles are consistent to the physical and empirical laws or contemporary knowledge on the earthquakes. In the seismic design one has to understand the possible modes of failure and ensure that these modes are avoided by imparting the necessary strength, ductility, stiffness and configuration.

Earthquake analysis is a dynamic analysis since earthquake force is dynamic in nature whose acceleration fairly changes with time compared to the structure's natural frequency. Dynamic analysis gives real time results for earthquake loading in terms of dynamic displacements, time history results and the modal analysis. The analysis is done manually for simple structures or by using Finite element analysis for complex structures to find out the mode shapes and frequencies.

To perform the seismic analysis of a structure the data of Time history is required but it is difficult to obtain that data at each and every location. Further, the design cannot be done entirely based on the peak value of acceleration of the ground, as the structural response depend on the frequency of the ground motion and its own dynamic properties.

To overcome these difficulties earthquake response spectrum is the most powerful tool for the design of structures. Since this method of analysis gives the maximum displacement by a structure and maximum value of member force for each mode of vibration by the use of smooth design spectrum obtained by averaging the several earthquakes motion.

II. LATERAL LOAD RESISTING SYSTEMS (LLRS)

Multi-storey structure consists of a number of basic kinds of lateral load resisting systems. A wall existing along with a framed structure although it is not used for gravity loads, can still be used to brace the frame for the lateral loads. Another two kinds of lateral resisting systems such as shear walls and braced frames are also used to brace a building in only one direction but a braced frame or rigid frame can be used in perpendicular directions.

Generally, multi-storey buildings have one type of lateral load resisting system, such as a rigid frame, or a rigid frame for the upper stories and a different system such as the box system for lower stories in order to reduce the deformation and take the greater loads in the lower portion of the building.

In most of the cases, it is not mandatory to make every wall as a shear wall and every frame as a braced frame. The principle lies in connecting the un-stabilized portions of the building with the lateral resisting systems. The connections be some load distributing elements like roof and floor diaphragms, horizontal members and so on.

The elements of the building construction which are not intended to function as bracing elements may sometimes act as lateral resisting system and take up some lateral loads. In the construction of frame, the surfacing elements like plaster, dry walls, wood paneling, masonry veneer and so on may take little bit of lateral load even though the frame is braced by the other means. This adds to additional relative stiffness though connections for load distribution is also considered.

The choice of having a lateral system depends on the loads and behavior required. It is also coordinated with the design for gravity loads and architectural considerations. There are many alternatives to the design situations but the choice is limited to the size of the building, magnitude of lateral loads, desire to have limited deformations, codal provisions and so on.

The various types of lateral load resistive systems (LLRS) are

A. Moment resisting frames
B. Braced frames
C. Shear walls based frames

III. METHODOLOGY

Dynamic analysis of medium rise (G+5) and high rise (G+14) building models are performed using the software tool ETABS v.15. The models are analyzed for bare frame and with the addition of lateral load resisting systems such as bracings and shear walls.

The models are analyzed dynamically by response spectrum method. The maximum displacement, maximum storey drift, time period and base shear values are extracted from the analyzed files from ETABS and obtained results are tabulated and the graphs are plotted.

The results for six storeys and fifteen storeys models thus obtained are compared. The best lateral force resisting system for a particular type of building and its position are concluded based on those parameters.

Procedure for Response spectrum analysis in ETABS

A. Design spectrum is selected from IS1893: 2002 (Part I)
B. Zone, Importance factor, Response reduction factor, time period, damping ratio and soil type are defined.
C. ETABS calculates Sa/g values for each mode defined utilizing the above data.
D. The peak responses are combined by CQC and SRSS method as defined by user.
E. The scale factor is set and the exactness of response spectrum method is checked and the scale factor is corrected.

A typical building plan considered in the present work is as shown in the figure. The bay spacing along x-direction is 5 m and along y-direction is 4 m for each bay.

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ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

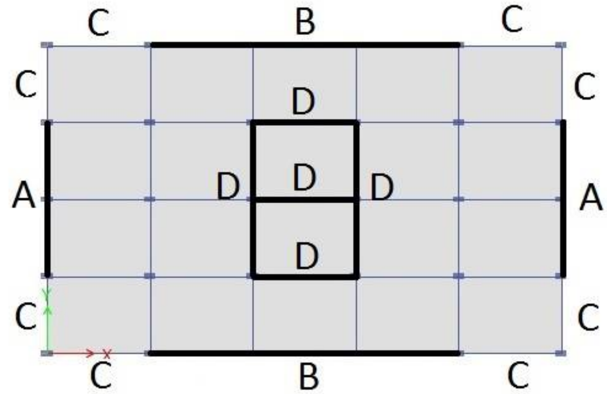

Fig. 1 Typical building plan considered for analysis

Table 1 Building Models

MODEL NUMBER	MODELS	MODEL DESCRIPTION G+5 STORIES and G+14 STORIES
1	M1-BF-DA	Bare Frame model
2	M2-CBF P_A	Concentrically braced frame with braces along shorter span direction at position A.
3	M3-CBF P_B	Concentrically braced frame with braces along longer span direction at position B.
4	M4-CBF P_AB	Concentrically braced frame with braces along both shorter and longer span direction at positions A and B.
5	M5-CBF P_C	Concentrically braced frame with braces along the corners at position C.
6	M6-SW P_A	Shear wall based frame with shear walls along shorter span direction at position A.
7	M7-SW P_B	Shear wall based frame with shear walls along shorter span direction at position B.
8	M8-SW P_AB	Shear wall based frame with shear walls along both shorter and longer span direction at positions A and B.
9	M9-SW P_C	Shear wall based frame with shear walls along the corners at position C.
10	M10-SW BOX	Shear wall based frame with shear walls at the centre like a core at Position D.

Table 2 Dimensions of the Beams, Columns and Slabs used in creating the model for medium rise buildings

Members	For lower 3 stories	For upper 3 stories
Column	230 x 450 mm	230 x 300 mm
Beam	230 x 450 mm	230 x 300 mm
Slab	150 mm	150 mm
Bracings	230 x 230 mm	230 x 230 mm
Shear walls	230 mm	230 mm

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Table 3 The dimensions of the Beams, Columns and Slabs used in creating the model

Members	For lower 6 stories	For middle 4 stories	For top 5 stories
Column	300 x 600 mm	230 x 450 mm	230 x 300 mm
Beam	300 x 450 mm	230 x 450 mm	230 x 300 mm
Slab	150 mm	150 mm	150 mm
Bracings	300 x 300 mm	230 x 230 mm	230 x 230 mm
Shear walls	230 mm	230 mm	230 mm

A. The loads are considered as area loads over the slabs and the magnitude of the loads considered

DL: Program calculated (ETABS software)
LL: 3.5 kN/m^2
FF: 1.5 kN/m^2

B. Load combinations selected as default for composite frame design

1) 1.5(DL+FF)
2) 1.5(DL+LL+FL)
3) 1.2(DL+LL+FF+EQx)
4) 1.2(DL+LL+FF-EQx)
5) 1.2(DL+LL+FF+EQy)
6) 1.2(DL+LL+FF-EQx)
7) 1.5(DL+FF+EQx)
8) 1.5(DL+FF-EQx)
9) 1.5(DL+FF+EQy)
10) 1.5(DL+FF-EQy)
11) 0.9(DL+FF) + 1.5EQx
12) 0.9(DL+FF) - 1.5EQx
13) 0.9(DL+FF) + 1.5EQy
14) 0.9(DL+FF) - 1.5EQy
15) 1.2(DL+LL+FF+SPECx)
16) 1.2(DL+LL+FF+SPECy)
17) 1.5(DL+FF+SPECx)
18) 1.5(DL+FF+SPECy)
19) 0.9(DL+FF) + 1.5SPECx
20) 0.9(DL+FF) + 1.5SPECy

IV. RESULTS AND DISCUSSION

From the selected building plan twenty models have been modelled, ten models of 6 storey buildings and ten models of 15 storey buildings. The models with LLRS such as bare frame, braced frame and shear wall based frame are analyzed using Response spectrum method. The analyzed result parameters such as maximum storey displacement, maximum storey drift, base shear and time periods are tabulated for each storey and all the models. These are plotted graphically and the inference is made based on the results obtained.

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A. Maximum Storey Displacement

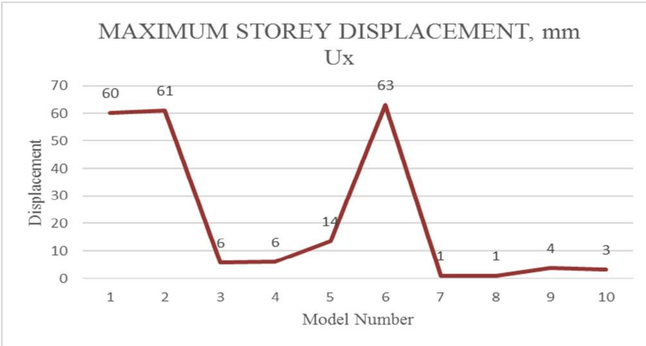

Fig. 2 Graph representing the maximum storey displacement in X direction

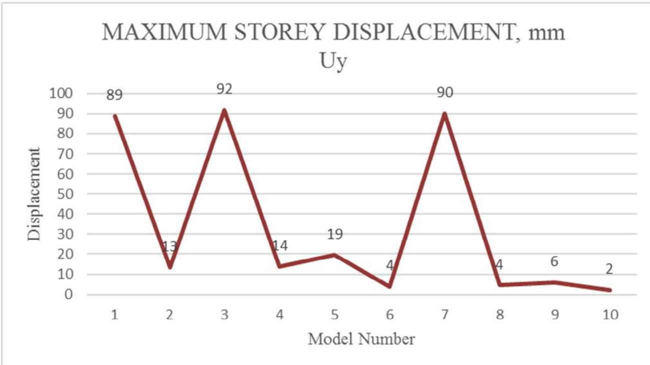

Fig. 3 Graph representing the maximum storey displacement in Y direction

From the Fig. 2 and 3, it is observed that the displacement continuously increases as we go up the stories. The maximum displacement is found at the top storey. The maximum displacement in the bare frame is 89 mm.

After analyzing the building models with bracings at position A, B, AB and C (Model 2-5), it is observed that by placing bracings at A, the displacement decreases but not significantly. When the bracings are placed at B the displacement is more than the displacement in the case of bare frame, hence it is not viable to place the bracings along x-direction. But when the bracings are placed in both the positions we see a significant change in the displacement value, which is only 15% of the displacement as seen in bare frames. The combined effect of bracings at A and B gives lesser displacement value. Similarly, when the bracings are placed at position C i.e. along the corners there is a significant decrease in displacement which is 21% of what is seen in bare frames.

By placing the braces in both the positions A and B we can have very less displacement but it becomes uneconomical. The difference is the displacement value is not much by using bracings at A and B than having bracings at corners i.e. position C, hence it forms an efficient and economical system compared to having bracings at any other place for a 6 storey building.

After analyzing the building models with shear walls at position A, B, AB, C and D (Model 6-10), it is observed that by placing shear wall at A, the displacement decreases but not significantly. When the shear walls are placed at B the displacement is more than the displacement in the case of bare frame, hence it is not viable to place the shear walls along x-direction. But when the shear walls are placed in both the positions we see a significant change in the displacement value, which is only 5% of the displacement as seen in bare frames. The combined effect of shear walls at A and B gives lesser displacement value. When the shear walls are placed at position C i.e. along the corners there is a significant decrease in displacement which is 7% of the displacements in bare frames. Similarly, the shear walls are placed at position D like a shear core there is a significant decrease in displacement which is only 4% of what is seen in bare frames.

From the above observation, it is found that shear core reduces the storey displacements significantly which is also very efficient and economical than having shear walls at any other locations.

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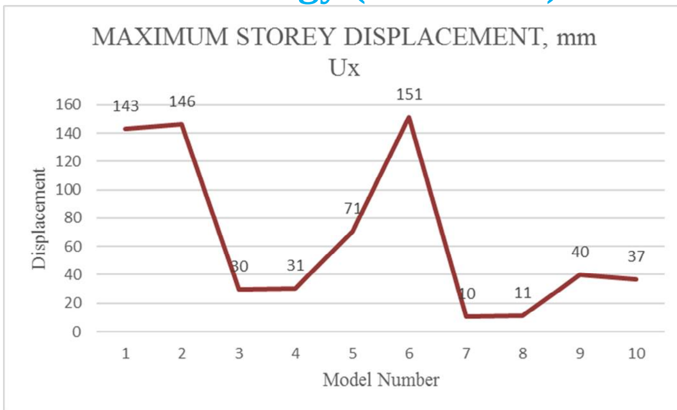

Fig. 4 Graph representing the maximum storey displacement in X direction

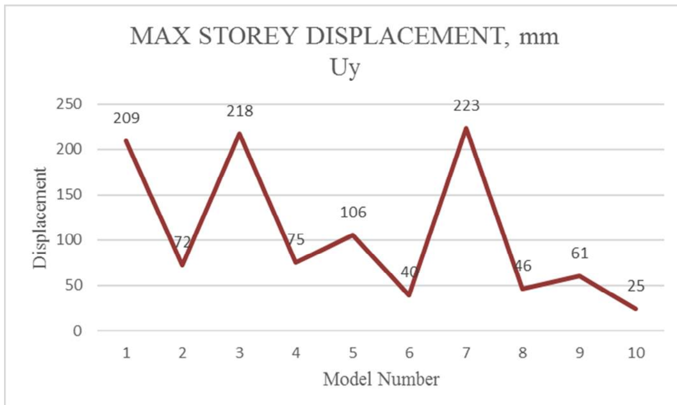

Fig. 5 Graph representing the maximum storey displacement in Y direction

From the Fig. 4 and 5, it is observed that the displacement continuously increases as we go up the stories. The maximum displacement is found at the top storey. The maximum displacement in the bare frame is 209 mm.

After analyzing the building models with bracings at position A, B, AB and C (Model 2-5), it is observed that by placing bracings at A, the displacement decreases but not significantly. When the bracings are placed at B the displacement is more than the displacement in the case of bare frame, hence it is not viable to place the bracings along x-direction. But when the bracings are placed in both the positions we see a significant change in the displacement value, which is only 36% of the displacement as seen in bare frames. The combined effect of bracings at A and B gives lesser displacement value. Similarly, when the bracings are placed at position C i.e. along the corners there is a significant decrease in displacement which is 50% of what is seen in bare frames.

By placing the braces in both the positions A and B we can have very less displacement than placing bracings at any other location, hence it forms a better lateral system when bracings at both the locations A and B are given for a 15 storey building.

After analyzing the building models with shear walls at position A, B, AB, C and D (Model 6-10), it is observed that by placing shear walls at A, the displacement decreases but not significantly. When the shear walls are placed at B the displacement is more than the displacement in the case of bare frame, hence it is not viable to place the shear walls along x-direction. But when the shear walls are placed in both the positions we see a significant change in the displacement value, which is only 22% of the displacement as seen in bare frames. The combined effect of shear walls at A and B gives lesser displacement value. When the shear walls are placed at position C i.e. along the corners there is a significant decrease in displacement which is 29% of the displacements in bare frames. Similarly, the shear walls are placed at position D like a shear core there is a significant decrease in displacement which is only 18% of what is seen in bare frames.

From the above observation it is found that shear core reduces the storey displacements significantly which is also very efficient and economical than having shear walls at any other locations.

B. Maximum Storey Drift

It is the difference between the displacement of the successive stories divided by the storey height and it is a unit less quantity.

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$$\text{Storey drift} = \frac{\text{Difference in displacements of the stories above and below}}{\text{Storey height}}$$

From the Tables 4.7 and 4.8 the storey drift in each storey of a 6 storey building model, it is observed that the storey drift is very much less when the bracings are placed along both the positions at A and B when compared to having bracings at any other location. But when the shear walls are used, the shear core system shows there is a significant reduction in the storey drift in each storey compared to having shear walls at any other locations. Hence shear core system makes an efficient lateral system. The case is no different for 15 storey models, similar pattern of variation is observed, here also shear core forms a better LLRS as seen from Tables 4.8 and 4.9.

C. Storey Shear

Table 4 Storey Shear in Each Storey of 6 Storey Models

STOREY	STOREY SHEAR, kN									
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7	MODEL 8	MODEL 9	MODEL 10
6	540.92	549.30	555.58	563.94	559.07	604.57	660.28	723.95	684.15	664.26
5	931.61	950.99	965.51	984.87	973.58	1048.37	1150.54	1267.31	1194.33	1157.84
4	1181.66	1208.07	1227.86	1254.27	1238.87	1332.41	1464.31	1615.06	1520.84	1473.73
3	1336.87	1367.27	1390.04	1420.44	1402.71	1506.72	1655.34	1825.19	1719.03	1665.96
2	1407.06	1439.23	1463.33	1495.50	1476.74	1585.40	1741.45	1919.79	1808.32	1752.59
1	1424.60	1457.22	1481.65	1514.26	1495.25	1605.07	1762.97	1943.44	1830.65	1774.25
Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5 Storey Shear in Each Storey of 15 Storey Models

STOREY	STOREY SHEAR, kN									
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7	MODEL 8	MODEL 9	MODEL 10
15	324.91	330.71	335.04	340.80	337.45	360.70	392.05	427.90	374.74	394.29
14	619.29	634.07	645.14	659.89	651.29	692.84	757.20	830.76	757.57	761.80
13	873.11	895.65	912.52	935.02	921.90	979.23	1072.06	1178.13	1087.66	1078.69
12	1089.39	1118.53	1140.35	1169.46	1152.48	1223.25	1340.34	1474.11	1368.93	1348.70
11	1271.12	1305.80	1331.78	1366.45	1346.24	1428.30	1565.76	1722.82	1605.27	1575.58
10	1436.87	1476.19	1505.66	1544.97	1522.05	1613.19	1767.41	1943.63	1816.04	1778.43
9	1573.46	1616.56	1648.85	1691.94	1666.82	1765.27	1933.06	2124.78	1989.10	1945.04
8	1681.39	1727.47	1762.00	1808.06	1781.20	1885.44	2063.94	2267.92	2125.84	2076.69
7	1764.02	1812.39	1848.62	1896.97	1868.78	1977.44	2164.15	2377.51	2230.53	2177.49
6	1830.86	1881.44	1919.32	1969.88	1940.40	2051.12	2243.83	2464.04	2313.54	2257.59
5	1878.89	1931.34	1970.65	2023.09	1992.51	2103.88	2300.74	2525.71	2372.79	2314.80
4	1909.62	1963.29	2003.49	2057.15	2025.86	2137.65	2337.17	2565.18	2410.70	2351.42
3	1926.91	1981.25	2021.97	2076.31	2044.62	2156.64	2357.66	2587.38	2432.03	2372.02
2	1934.60	1989.24	2030.18	2084.82	2052.96	2165.09	2366.76	2597.25	2441.51	2381.17
1	1936.52	1991.23	2032.23	2086.95	2055.04	2167.20	2369.04	2599.72	2443.88	2383.46
Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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ISSN: 2321-9653
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From the Tables 4.13 and 4.14 for a 15 storey building model, the base shear is increased with the addition of LLRS when compared with the base shear value for bare frames.
In the case of bracings at positions A and B, the increase in base shear observed is only 8%, but the displacement reduced to 36% of what is seen in bare frames.
In the case of shear walls as a shear core system, the increase in base shear observed is 23%, but the displacement reduced to only 18% of what is seen in bare frames.
Thus the addition of base shear with the inclusion of LLRS won’t matter much until it reduces the displacement values significantly.

D. Time Period

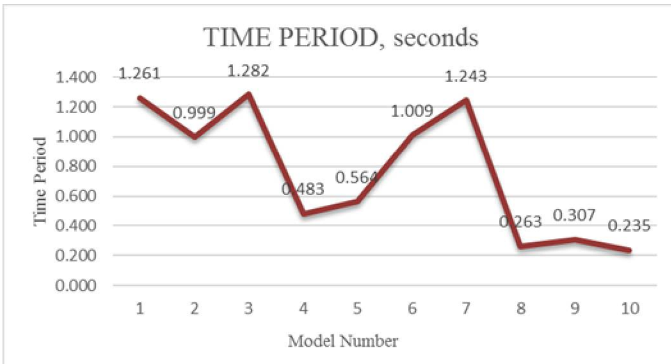

Fig. 6 Graph representing the time periods in 6 storey models

From Fig. 6 for 6 storey models, it is observed that the bare frame model gives a very large time period and as a result the displacement will be more. When the bracings at both locations A and B are placed there is a significant reduction in time period which is only 40% of time period in bare frames. Further, when the shear core is used the time period further decreases to only 20% of what is observed in the case of bare frames.

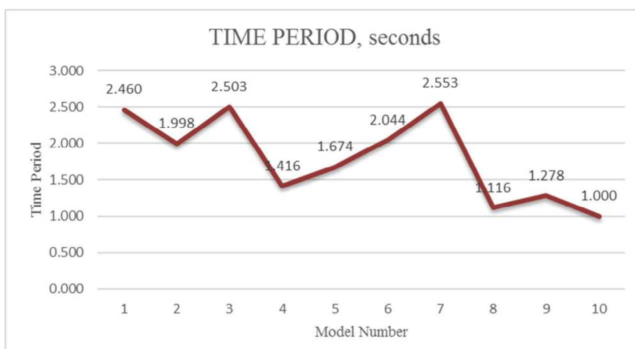

Fig. 7 Graph representing the time periods in 15 storey models

From Fig. 7 for 15 storey models, it is observed that the bare frame model gives a very large time period and as a result the displacement will be more. When the bracings at both locations A and B are placed there is a significant reduction in time period which is only 58% of time period in bare frames. Further, when the shear core is used the time period further decreases to only 40% of what is observed in the case of bare frames.

V. CONCLUSIONS

Dynamic analysis of 6 and 15 stories building models are analyzed by response spectrum method using ETABS. The seismic parameters such as displacement, drift, base shear and time period results are discussed and the following conclusions are made from the current work.

A. The displacement increases as the height of the stories increases and the maximum displacement is observed in the top storey.
B. When the bracings are used in the buildings it yielded better results when the bracings are placed in the middle periphery of the building Model 4 than placing it at any other positions.

C. When the shear walls are used in the buildings it yielded better results when the shear walls are placed in the middle of the building as a shear core Model 10 than placing at the middle periphery of the building as in Model 8.

D. There is a significant decrease in storey displacement, storey drift and time period when the shear core is used.

E. The use of LLRS increases the elastic stiffness of the buildings rather than just having the bare frames.

F. Shear wall core LLRS is found to be more efficient lateral system than any other systems.

G. Concentrically braced frames like V bracings or inverted V bracings can be used instead of usual X bracings and study the seismic parameters.

H. Instead of shear core the models can be analyzed by having braced core system and comparing with the shear core system.

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