Seismic behaviour of unsymmetrical structure with cantilever section

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Abstract— This project is about the performance of the torsionally balanced and torsionally unbalanced structure also called symmetrical and unsymmetrical structure. In this project, the effort is made to study the effect of eccentricity between the centre of mass (CM) and the centre of stiffness (CR) on the performance of the buildings. Three buildings of a storey (G+10) are used in this paper, likes Symmetrical, Unsymmetrical, and Unsymmetrical with cantilever section. The performance of a multi-storey framed building during study earthquake motions depends on the distribution of mass, stiffness, and strength in both the horizontal and vertical planes of the building. During earthquakes, there is strong earth-shaking, hence the earthquake-resistant design of structures is required. As now day's unsymmetrical structures with cantilever sections are used to utilize the area and available space in a very efficient way. So, it is required to study the seismic behavior of unsymmetrical structures with cantilever sections. In such types of structures, the centre of mass of the buildings does not correspond with the centre of resistance. This leads to inordinate edge deformation and shear forces in the unsymmetrical structure compared to a symmetrical structure. Hence, by reducing the difference between the centre of mass and the centre of stiffness, torsion effects can be minimized. The Dynamic response of the building during times of seismic irregularities depends on the stiffness characteristics of the building. The objective study is the comparison of sections used in large-span unsymmetrical cantilever structures to minimize the effect of torsion. The study is primarily focused on the deflections of cantilevers of large spans under different loading conditions such as dead load, live load, and seismic load. The study also focuses on, to identify an appropriate technique suitable for the analysis of large span cantilevers within the unsymmetrical structure.

Keywords— Cantilevers, seismic, Symmetrical Structure, unsymmetrical Structure, unsymmetrical Structure with cantilever section, response-spectrum Analysis, Staad pro.

I. INTRODUCTION

In the present scenario, the unsymmetrical structure with a large span cantilever section is being constructed which causes irregularities such as soft storey, unsymmetrical layout, torsion irregularity, etc. Therefore, seismic analysis of a large span cantilever in an unsymmetrical structure is important. As during earthquake, there is strong earth shaking therefore to resist this shaking, seismic analysis and design of structures is required. In this report, an attempt has been made to study the seismic behavior of unsymmetrical structures with cantilever sections. In this type of structure, the centre of mass of the building does not correspond with the centre of resistance, due to this there is inordinate edge deformation and shear force in unsymmetrical structures. As larger the eccentricity between the centre of stiffness and the centre of mass, the larger the torsion effects. Hence by reducing the difference between the centre of mass and the centre of stiffness the torsion effects can be minimized. This study also focuses on the deflection characteristics of cantilevers of large spans in unsymmetrical structures under different loading conditions. This study also focuses on the deflection characteristics of cantilevers of large spans in unsymmetrical structures under different loading conditions. Hence the study of seismic behavior of large span cantilevers is one of the major parts of seismic analysis and design of unsymmetrical structures. Unsymmetrical buildings are more vulnerable to damage due to seismic excitation or earthquakes because of the coupled torsional effects and unsymmetrical edge deformation. Eccentric mass due to temporary storage of materials leads to the unsymmetrical distribution of lateral loads causing torsional failures. A lack of symmetry produces torsional effects that are sometimes difficult to assess and can be very adverse. The problem of earthquake-induced torsion in buildings is quite old and although it has received a lot of attention in the past several decades, it is still open. This is evident not only from the variability of the pertinent provisions in various modern codes but also from conflicting results debated in the literature. In the past decade, however, more accurate multi-story inelastic building response has been. Based on such research, some interesting conclusions have been drawn, revising older views about the inelastic response of buildings based on one-story simplified model results.

II. Important Aspects of Unsymmetrical structure

- Unsymmetrical structures with cantilever sections are used to utilize the area and available space in a very efficient way.
- The most common reason for making an unsymmetrical structure it adds more visual interest from per architecture point of view.
- In an unsymmetrical structure, there is no repetition of arrangement and structural pattern which give a unique appearance to the structure.

III. OBJECTIVES

The main objective of this research is to study the seismic response of unsymmetrical structures with cantilever sections and analyze the behavior of the structures by adopting a methodology such as response spectrum analysis to minimize the effects caused by seismic forces.

- To study seismic behavior of unsymmetrical structure with cantilever section based on material and geometry.
- To study the effect of torsion for symmetric and asymmetric multi-storied R.C.C. building in a high seismic zone.
- To compare the response parameters such as story drift, base shear, joint displacement, a torsional moment of Symmetrical and conventional building.
- To analysis parameters such as bending moments and shear forces in unsymmetrical structures with cantilever sections.
- To study the response of the unsymmetrical structure with cantilever sections subjected to gravity loads and seismic loading using computer-aided software.

IV. MODELLING

MODEL 1: SYMMETRICAL STRUCTURE.

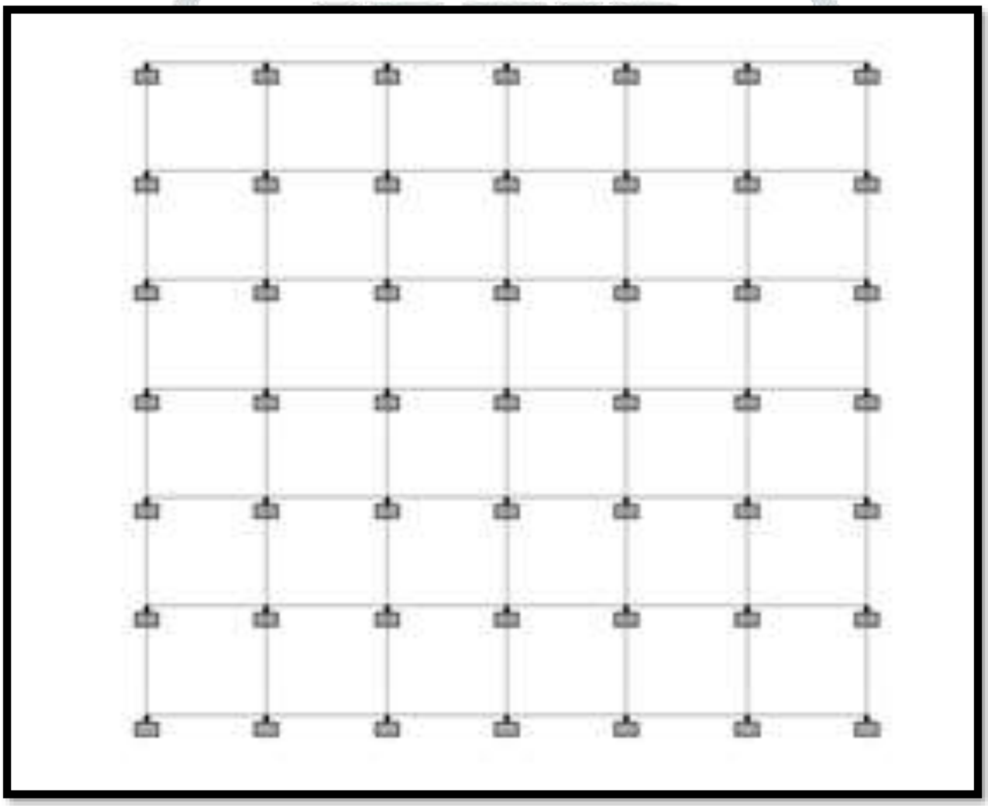

Fig. (1) Symmetrical structure plan.

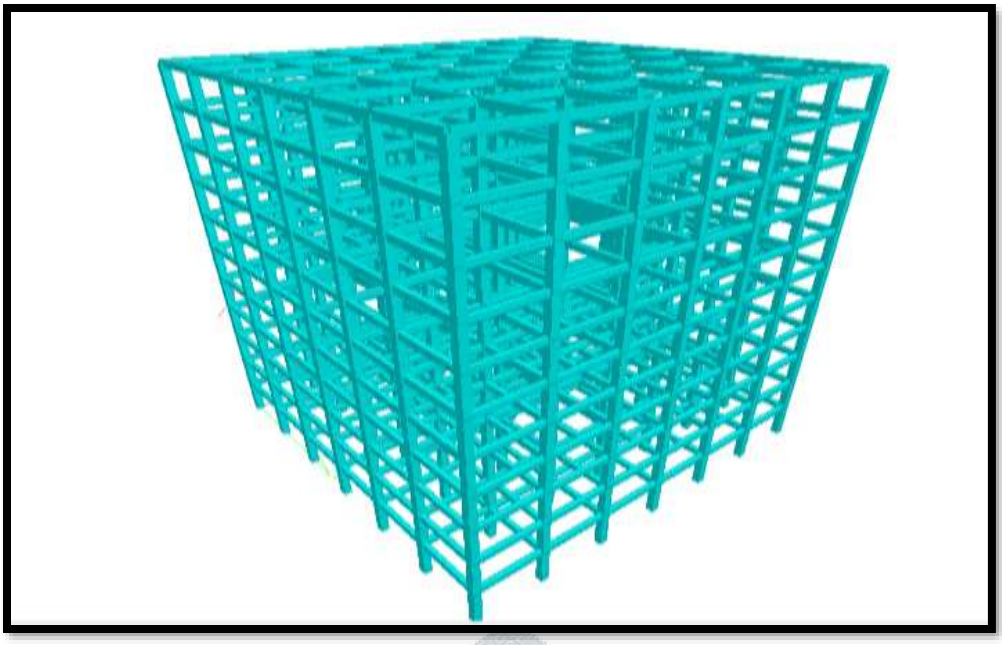

Fig.(2) Isometric view of Symmetrical structure model.

V. MODEL INFORMATION.

TABLE: 1

The objectives of research following aspects are:-

Symmetrical structure Model Data		
Seismic zones	III	IV
Total area	900m²	900m²
No. of stories	10	10
Typical storey height	3m	3m
Bottom storey height	3m	3m
Grade of concrete	M30	M30
Standard	INDIAN	INDIAN
Is code	IS 456	IS 456
Is code	IS1893 PART-1 (2016)	IS1893 PART-1 (2016)
Material	Concrete	Concrete
Type of Steel (Rebar)	HYSD 500	HYSD 500
Size of Beam	300X500	300X500
Size of Column	500X500	500X500
Wind speed	39 m/s	39 m/s
Parapet wall	1m	1m
Software	STAAD pro.	STAAD pro.
Type of building use	Commercial	Commercial
Zone factor	0.16	0.24
Importance factor	1.2	1.2
Response Reduction Factor (RF)	5	5
Dead Load	4 kN/m²	4 kN/m²
Live Load	3.5 kN/m²	3.5 kN/m²
Floor Finish Load	0.75 kN/m²	0.75 kN/m²
Number of Bays along X-direction	6	6
Number of bays along Z-direction	6	6
Bay Width along X-direction	5	5
Bay Width along Z-direction	5	5

TABLE 2

Beam section of both model.

S. NO.	ZONE 3			ZONE 4		
1	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)
	140.193	232.203	-66.494	171.575	310.709	-99.023

TABLE 3

Column section of both model.

S. NO.	ZONE 3			ZONE 4		
1	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)
	99.755	210.765	0	149.730	316.45	0

TABLE 4

Maximum displacement.

S. NO.	ZONE 3		ZONE 4	
1	**X**	4.46583E+00	X.	6.69874 E+00
2	**Y**	8.63858 E-02	Y.	1.29579 E-01
3	**Z**	1.66553 E-03	Z.	2.49830 E-03

TABLE 5

AXIAL FORCE, BASE SHEAR & SUPPORT REACTION.

S NO.	ZONE 3			ZONE 4		
1	AXIAL FORCE (kN)	BASE SHEAR (kN)	SUPPORT REACTION (MT)	AXIAL FORCE (kN)	BASE SHEAR (kN)	SUPPORT REACTION (MT)
	2943.87	2943.87	361.447	4415.81	4415.81	361.447

VI. MODELLING

MODEL 2: UNSYMMETRICAL STRUCTURE.

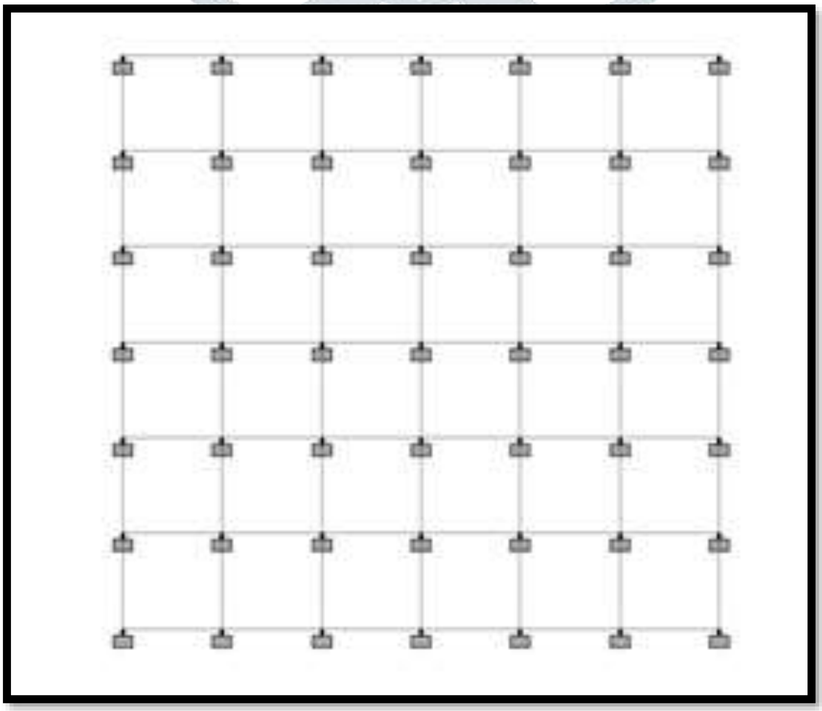

fig. (3) Unsymmetrical structure plan.

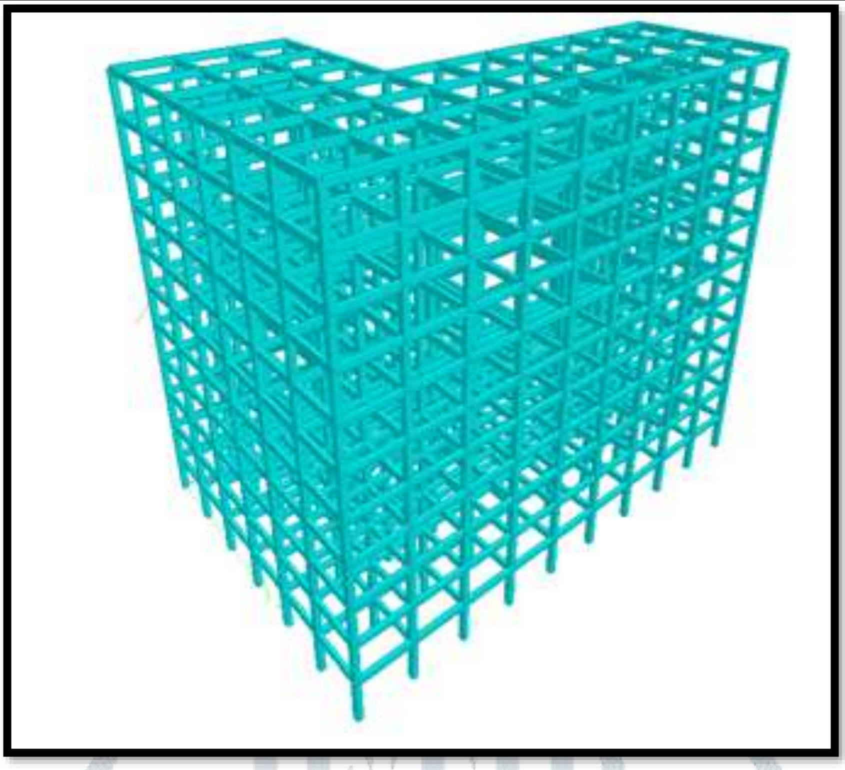

Fig. (4) Isometric view Unsymmetrical building model.

TABLE 6

COLUMN SECTION OF BOTH MODEL

S. NO.	ZONE 3			ZONE 4		
1	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)
	96.989	204.22	0	145.430	306.199	-0.091

TABLE 7

BEAM SECTION OF BOTH MODEL

S. NO.	ZONE 3			ZONE 4		
1	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)
	137.307	224.361	-64.138	167.460	299.752	-95.418

TABLE 8

MAXIMUM DISPLACEMENT OF BOTH MODEL.

S. NO.	ZONE 3		ZONE 4	
1	**X.**	4.30318 E+00	X.	6.45476 E+00
2	**Y.**	8.42038 E-02	Y.	1.26306 E-01
3	**Z.**	1.19957 E-01	Z.	1.79936 E-01

TABLE 9

AXIAL FORCE, BASE SHEAR & SUPPORT REACTION.

S NO.	ZONE 3			ZONE 4		
	AXIAL FORCE (kN)	BASE SHEAR (kN)	SUPPORT REACTION (MTON)	AXIAL FORCE (kN)	BASE SHEAR (kN)	SUPPORT REACTION (MTON)
1	-3039.87	3039.87	359.385	-4559.81	4559.81	359.385

VII. MODELLING

MODEL 3: UNSYMMETRICAL STRUCTURE WITH CANTILEVER SECTION.

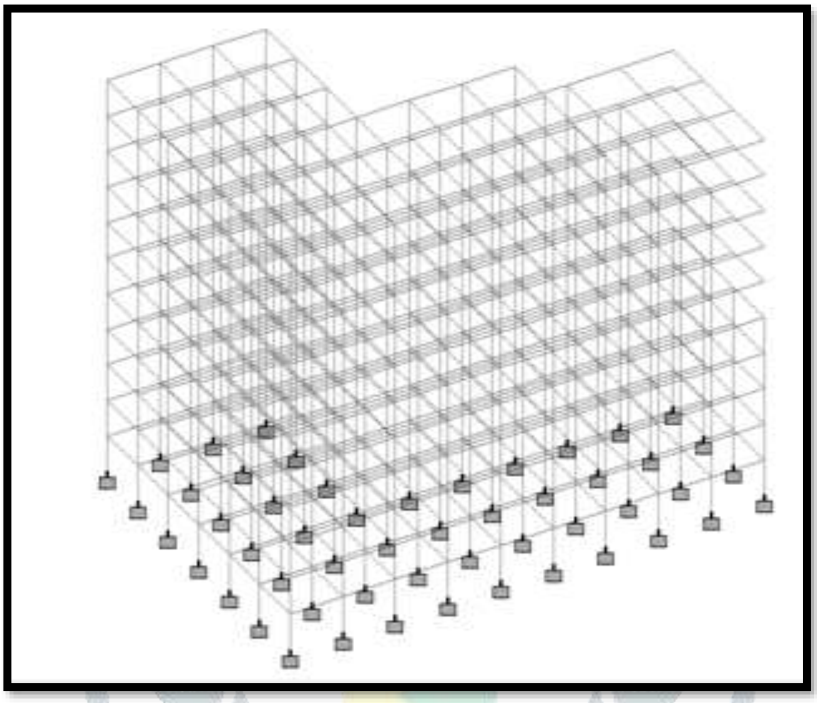

Fig. (5) Unsymmetrical structure with cantilever section plan.

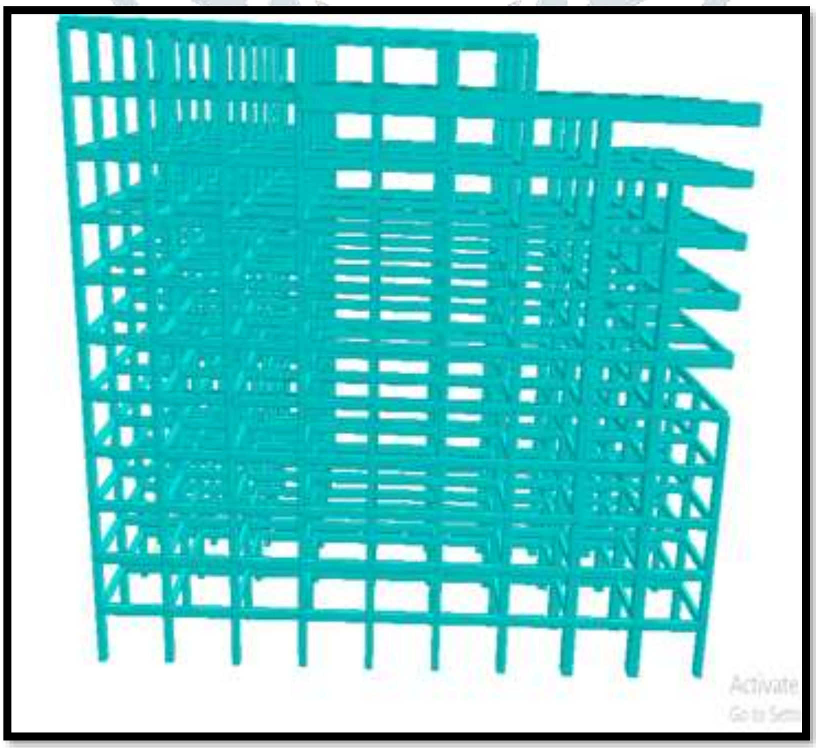

Fig. (6) Isometric view of Unsymmetrical structure with cantilever section model.

VIII. MODEL INFORMATION

TABLE 10

The objectives of Unsymmetrical structure with cantilever section following aspects are:-

Seismic zone	III	IV
Total area	900m^2	900m^2
No. of stories	10	10
Top floor cantilever span	10m	10m
Rest floor cantilever span	5m	5m
Typical storey height	3m	3m
Bottom storey height	3m	3m
Grade of concrete	M30	M30
Standard	INDIAN	INDIAN
Is code	IS 456	IS 456
Is code	IS 1893 part-1 2016	IS 1893 part-1 2016
Material	concrete	concrete
Type of Steel (Rebar)	HYSD 500	HYSD 500
Size of Beam	(300x500),(750x1000)mm	(300x500),(750x1000)mm
Size of Column	(500x500),(750x750)mm	(500x500),(750x750)mm
Wind speed	39 m/s	39 m/s
Parapet wall	4ft	4ft
Software	STAAD pro.	STAAD pro.
Type of building use	Commercial	Commercial
Zone factor	0.16	0.24
Importance factor	1.2	1.2
Response Reduction Factor (R)	5	5
Dead Load	4 kN/m^2	4kN/m^2
Live Load	4 kN/m^2	4 kN/m^2
Floor Finish Load	0.75 kN/m^2	0.75 kN/m^2
Number of Bays along X-direction	9	9
Number of bays along z-direction	6	6
Bay Width along X-direction	5	5
Bay Width along z-direction	5	5

IX. Reading of Unsymmetrical structure with Cantilever Section.

TABLE 11
BEAM SECTION OF BOTH MODEL

S. NO.	ZONE 3			ZONE 4		
1	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)
	1009.607	5654.474	68.982	1009.607	5654.474	-97.687

TABLE 12
COLUMN SECTION OF BOTH MODEL

S. NO.	ZONE 3			ZONE 4		
1	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)	Shear force (kN)	Bending moment (kN-m)	Displacement (mm)
	773.622	252.357	10.709	776.816	252.293	9.971

TABLE 13
MAXIMUM DISPLACEMENT OF BOTH MODEL.

S. NO.	ZONE 3		ZONE 4	
1	**X**	4.22851 E+00	X.	6.34277 E+00
2	**Y**	7.72306 E-01	**Y.**	-1.15846 E+00
3	**Z**	2.2086 E-01	Z.	3.30428 E-01

TABLE 14
AXIAL FORCE, BASE SHEAR & SUPPORT REACTION.

S NO.	ZONE 3			ZONE 4		
1	AXIAL FORCE (kN)	BASE SHEAR (kN)	SUPPORT REACTION (MTON)	AXIAL FORCE (kN)	BASE SHEAR (kN)	SUPPORT REACTION (MTON)
	-3065.83	3065.83	475.153	-4598.75	4598.75	475.153

X. ANALYSIS AND DISCUSSION OF SYMMETRICAL STRUCTURE:-

The variation of bending moment in beam throughout the span of symmetrical structure with respect to the seismic zone is shown in fig (7). The bending moment is found to be higher in the case of seismic zone 4, in the symmetrical structure when analysis by dynamic analysis respectively.

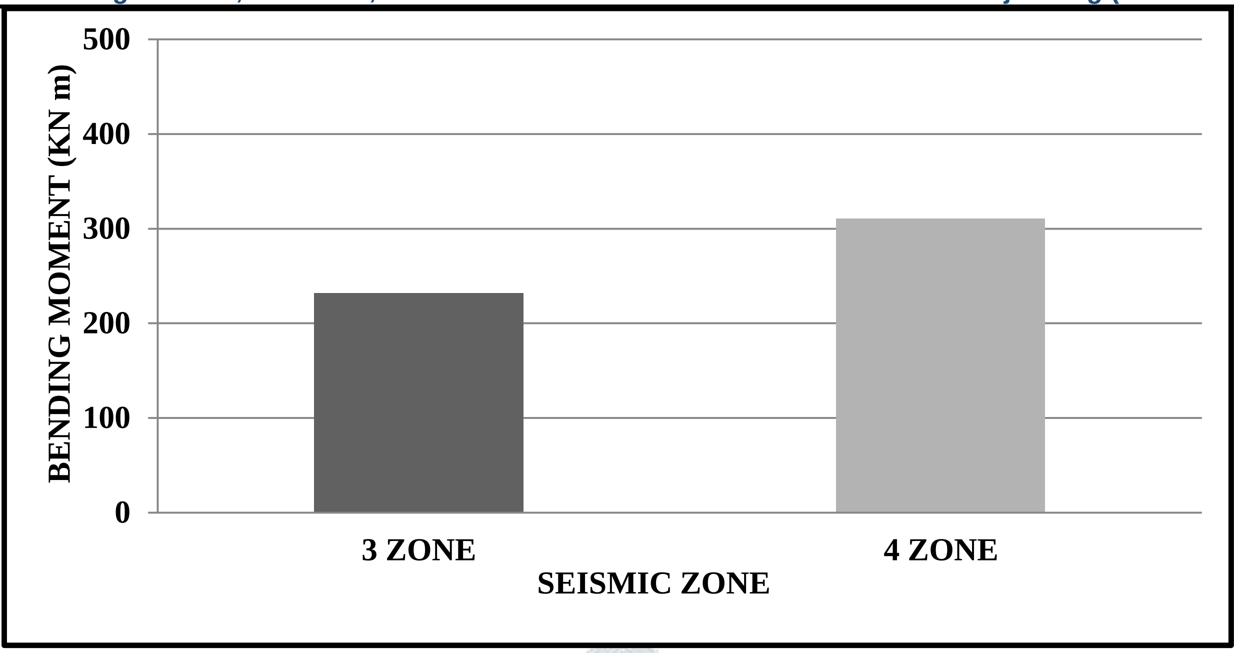

Fig. 7

The variation of shear force in the beam section of symmetrical structure with respect to the seismic zone is shown in Fig.(8) . The shear force is found to be higher in the case of seismic zone 4, in the symmetrical structure when analysis by dynamic analysis respectively.

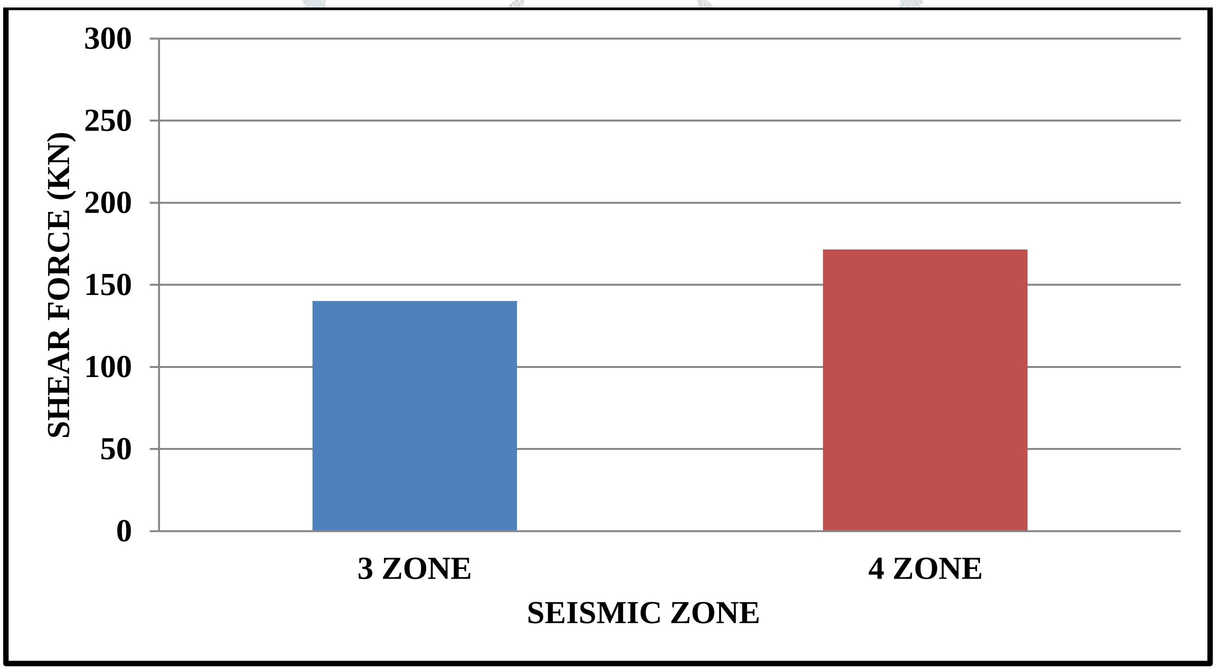

Fig. 8

The variation of bending moment in column throughout the height of the symmetrical structure with respect to the seismic zone is shown in Fig.(9) . The bending moment is found to be higher in the case of seismic zone 4, in the symmetrical structure when analysis by dynamic analysis respectively.

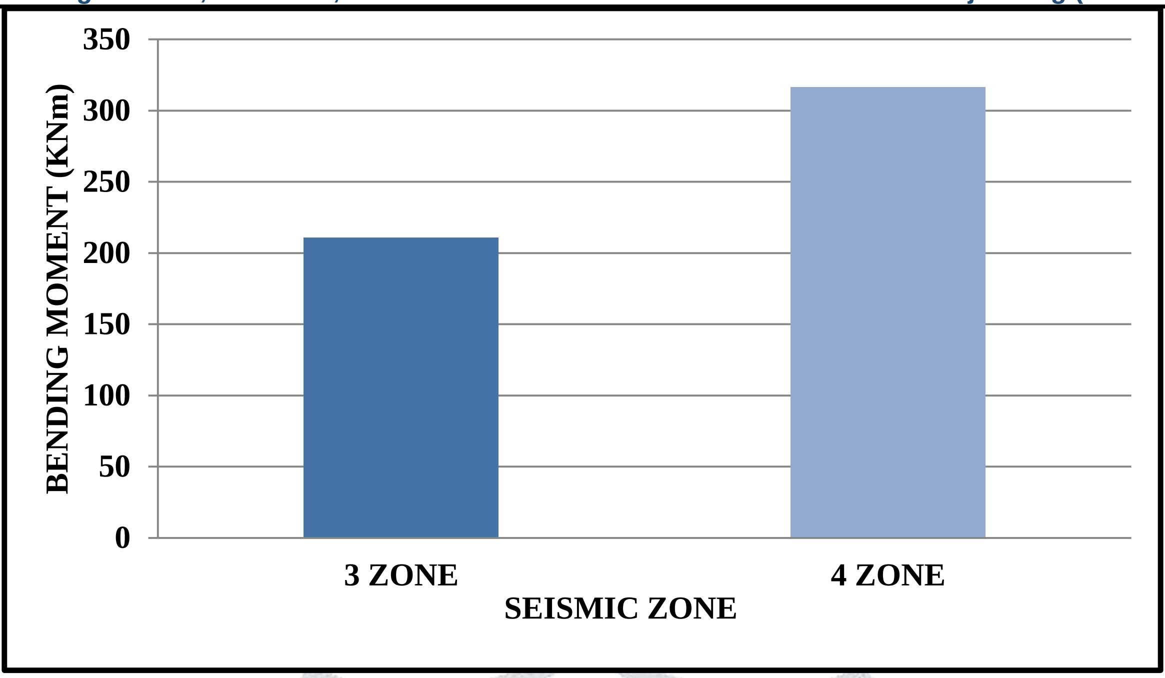

Fig. 9

The variation of shear force in the column section of symmetrical structure with respect to the seismic zone is shown in Fig.(10). The shear force is found to be higher in the case of seismic zone 4, in the symmetrical structure when analysis by dynamic analysis respectively.

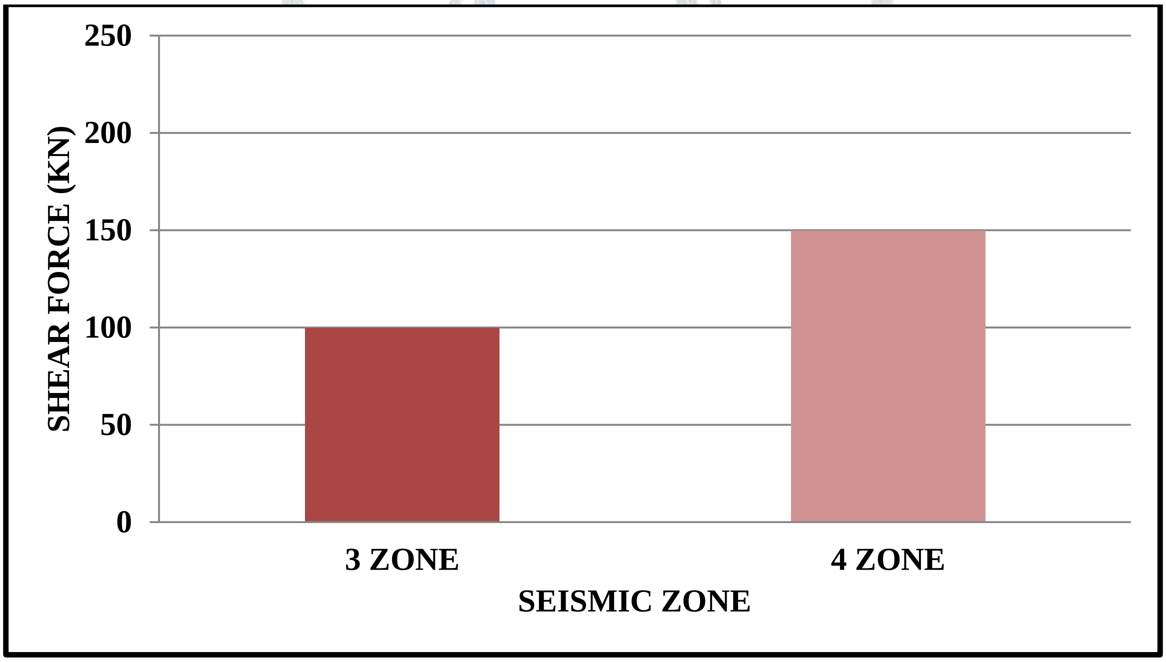

Fig. 10

The variation of base shear in whole symmetrical structure with respect to seismic zone shown in Fig.(11). The base shear is found to be higher in the case of zone 4, in the symmetrical structure when analysis by dynamic analysis respectively.

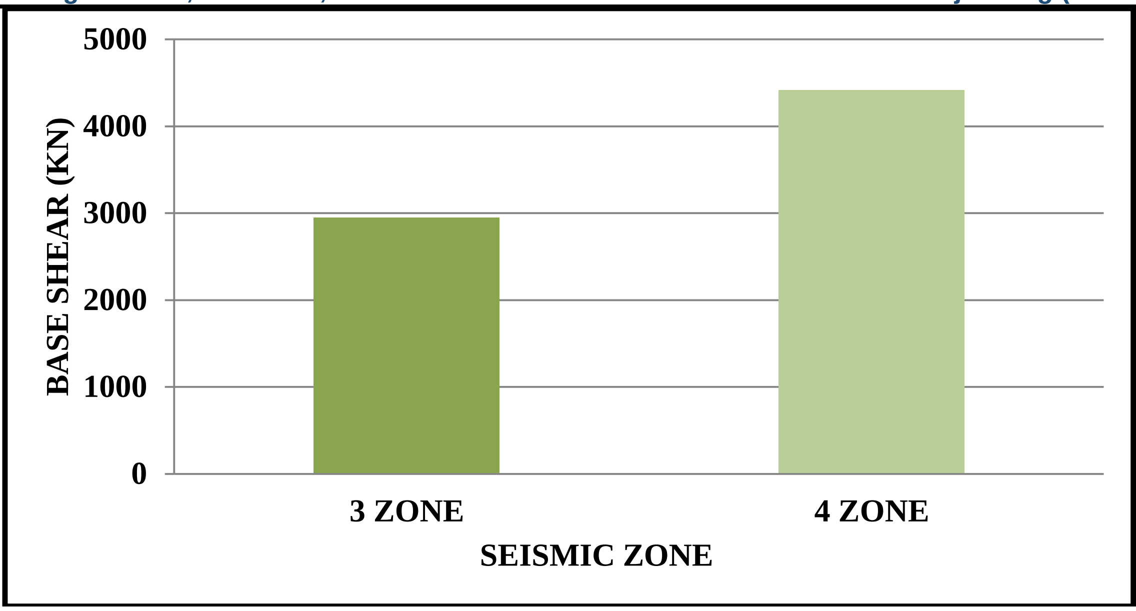

Fig. 11

The variation of displacement throughout the height of the symmetrical structure with respect to no. of the storey in the structure is shown in Fig.(12). The maximum displacement is found to be higher in the highest storey of the structure, in symmetrical structure with seismic zone 3.

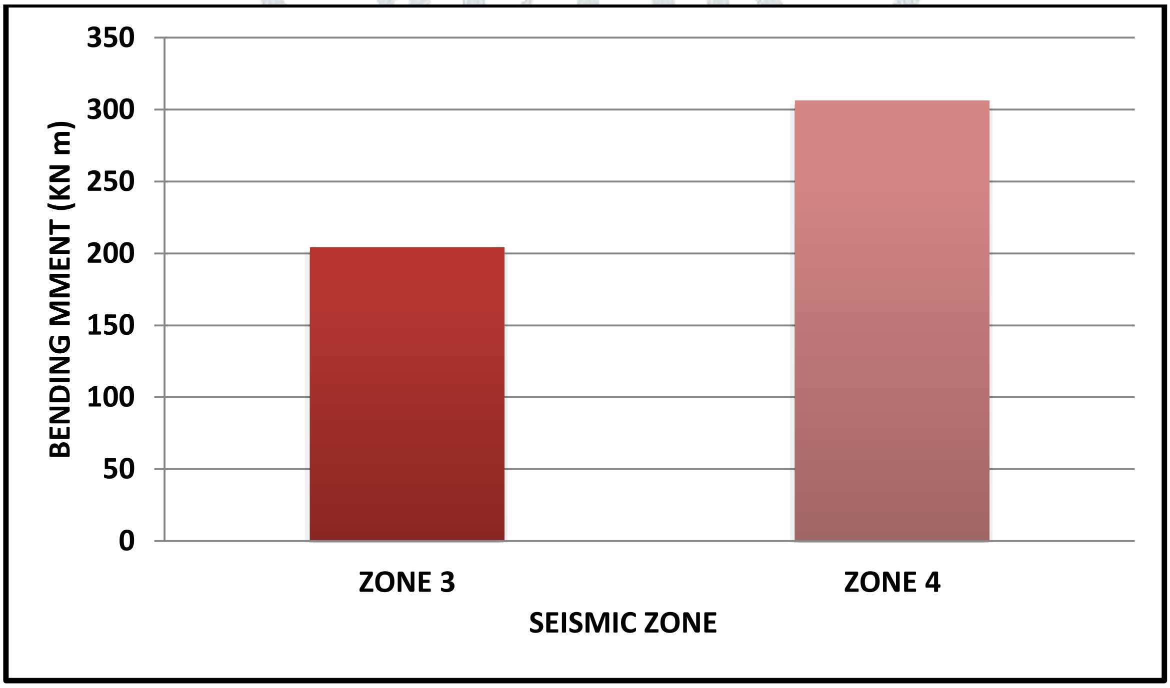

Fig. 12

XI. ANALYSIS AND DISCUSSION OF UNSYMMETRICAL STRUCTURE:-

The variation of shear force in column section of unsymmetrical structure with respect to seismic zone is shown in Fig.(13). The shear force is found to be higher in the case of seismic zone 4, in the unsymmetrical structure when analysis by dynamic analysis respectively.

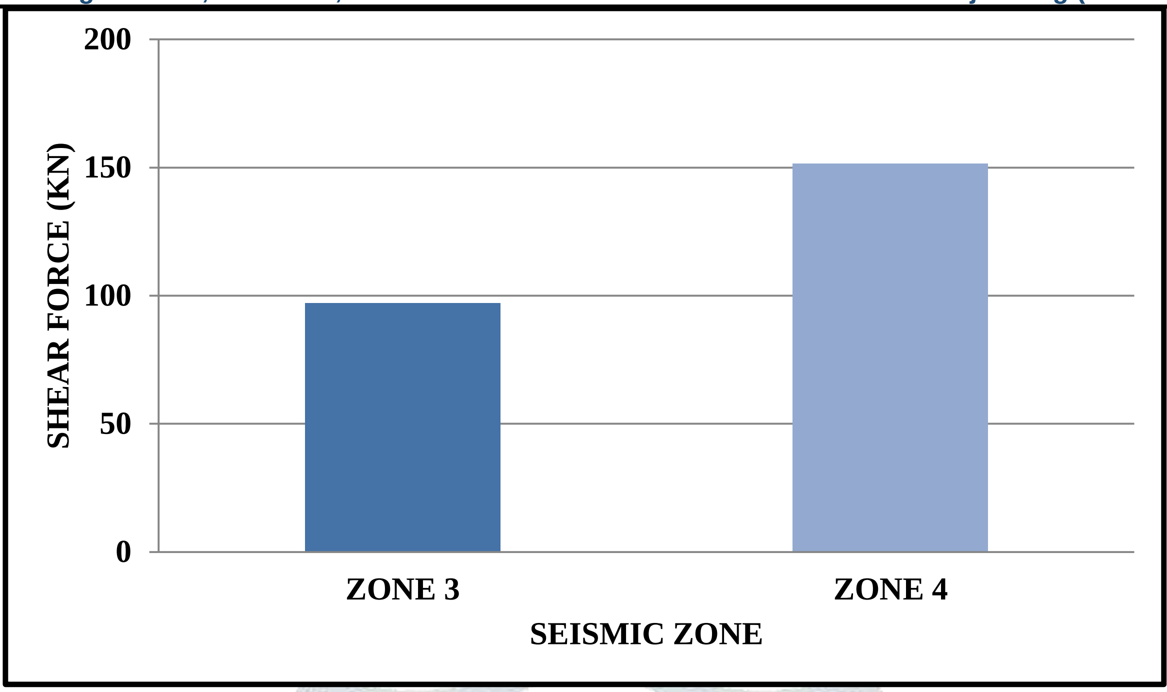

Fig. 13

The variation of bending moment in beam throughout the span of unsymmetrical structure with respect to seismic zone is shown in Fig.(14). The bending moment is found to be higher in the case of seismic zone 4, in the unsymmetrical structure when analysis by dynamic analysis respectively.

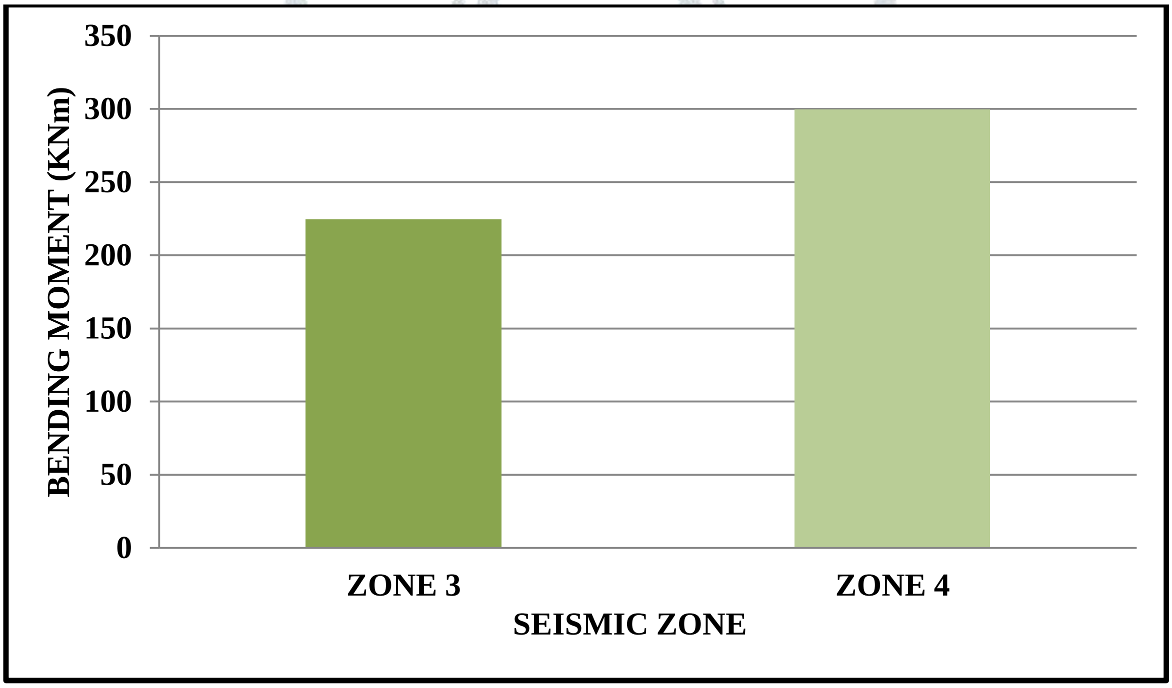

Fig. 14

The variation of shear force in the beam section of unsymmetrical structure with respect to the seismic zone is shown in Fig.(15). The shear force is found to be higher in the case of seismic zone 4, in the unsymmetrical structure when analysis by dynamic analysis respectively.

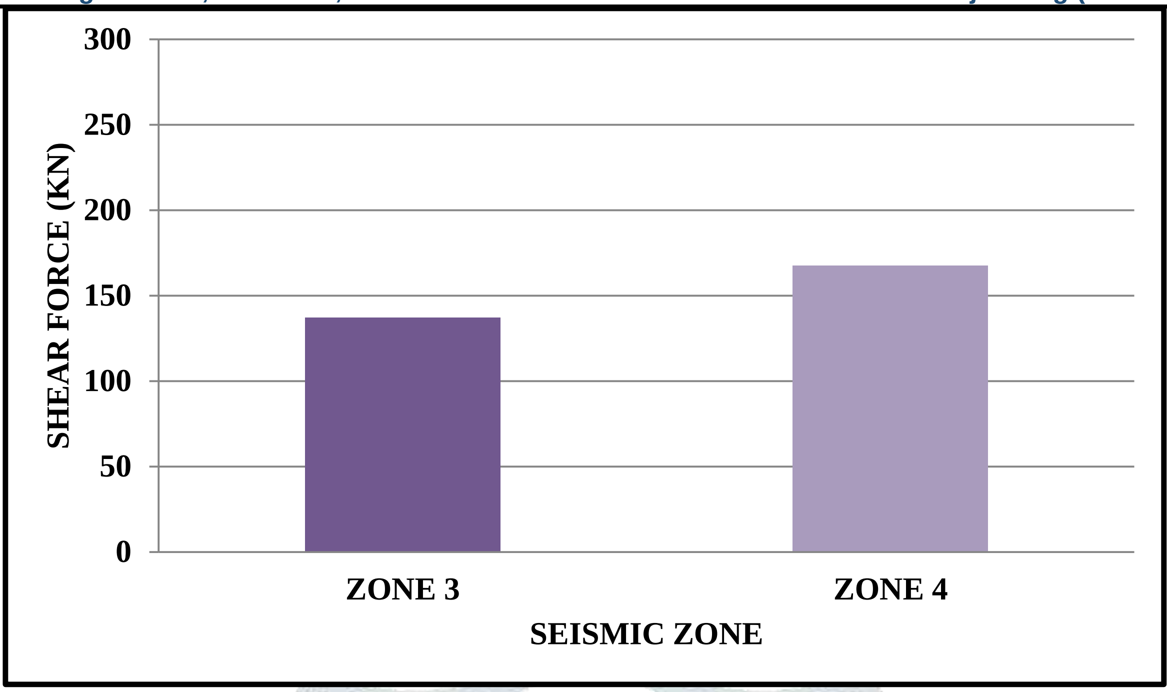

Fig. 15

The variation of base shear in whole unsymmetrical structure with respect to seismic zone shown in Fig.(16). The base shear is found to be higher in the case of zone 4, in the unsymmetrical structure when analysis by dynamic analysis respectively.

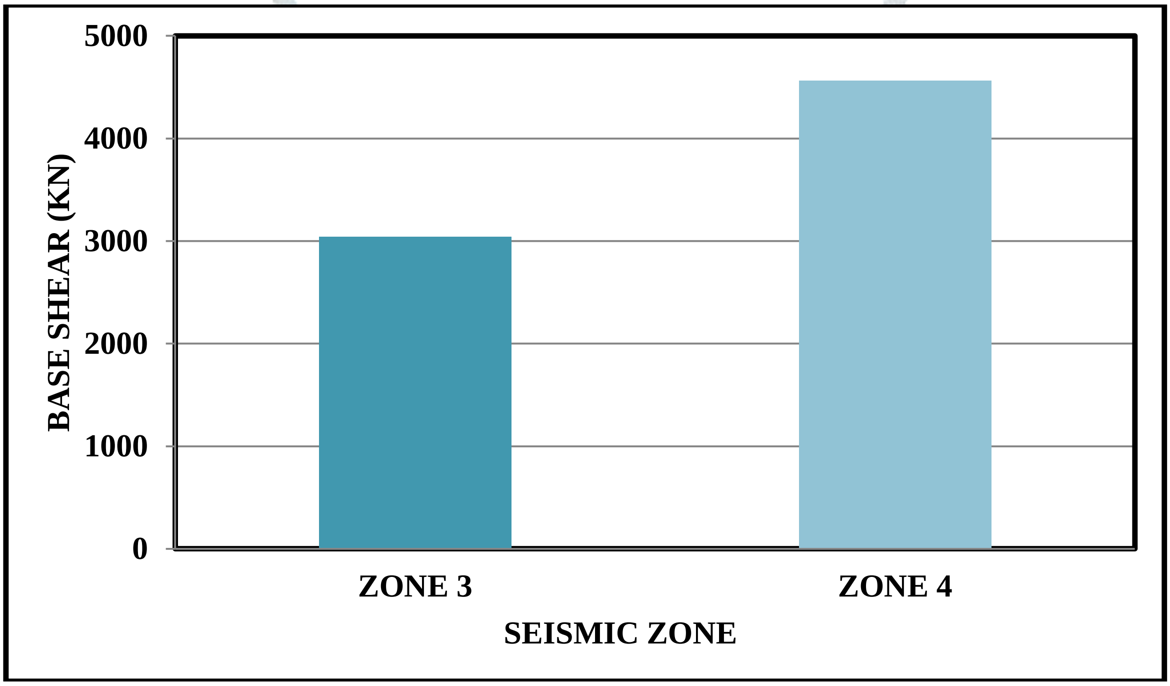

Fig. 16

The variation of displacement throughout the height of unsymmetrical structure with respect to no. of storey in the structure shown in fig (17) . The maximum displacement is found to be higher in the highest storey of the structure, in unsymmetrical structure with seismic zone 3.

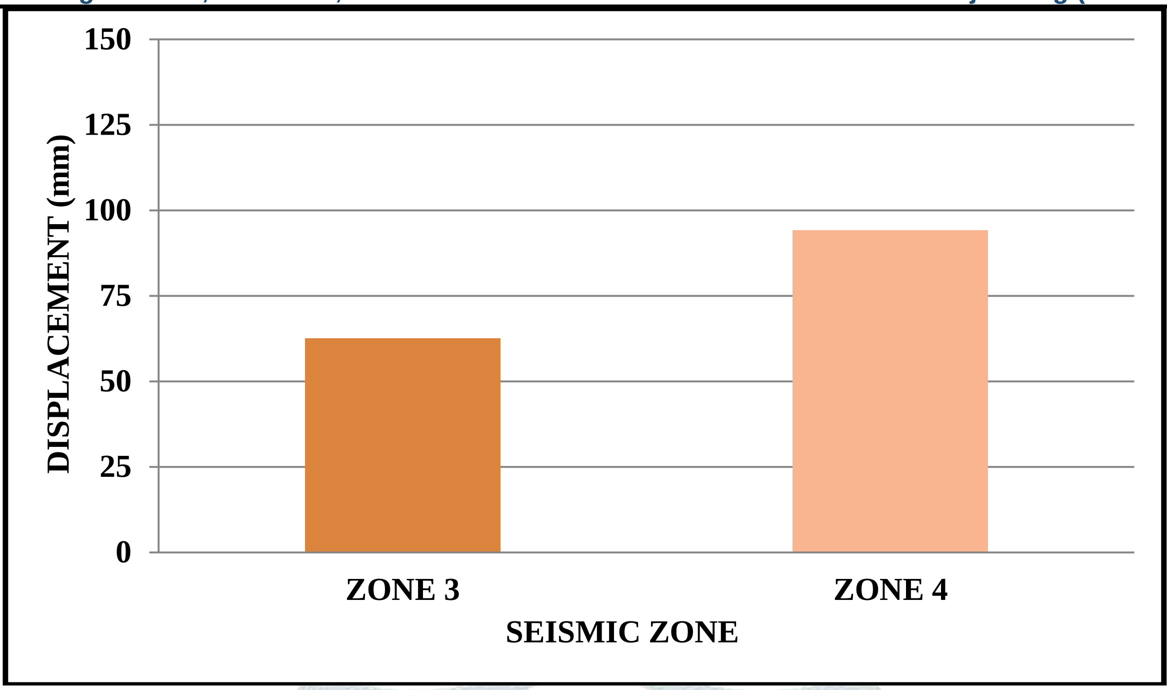

Fig. 17

XII. COMPARISION OF STOREY DRIFT SHOWN IN FIG. (18) OF SYMMETRICAL STRUCTURE, UNSYMMETRICAL STRUCTURE & UNSYMMETRICAL STRUCTURE WITH CANTILEVER SECTION IN ZONE 3:-

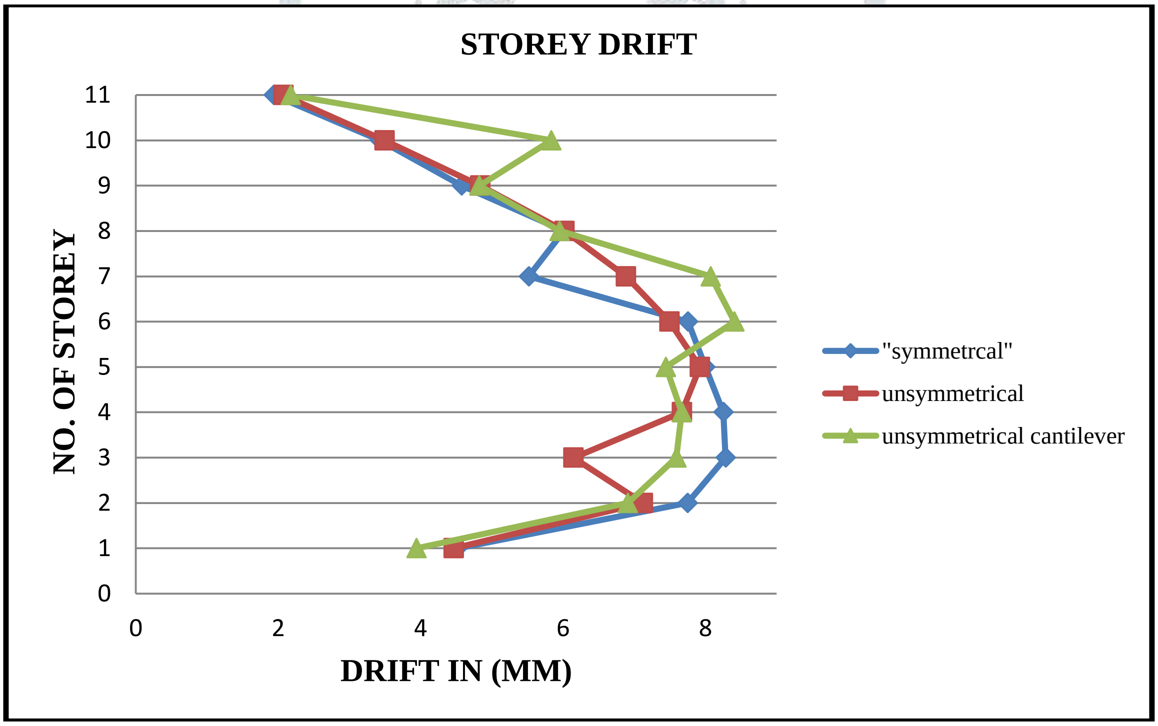

Fig. 18

XIII. COMPARISION OF STOREY DRIFT SHOWN IN FIG. (19) OF SYMMETRICAL STRUCTURE, UNSYMMETRICAL STRUCTURE & UNSYMMETRICAL STRUCTURE WITH CANTILEVER SECTION IN ZONE 4:-

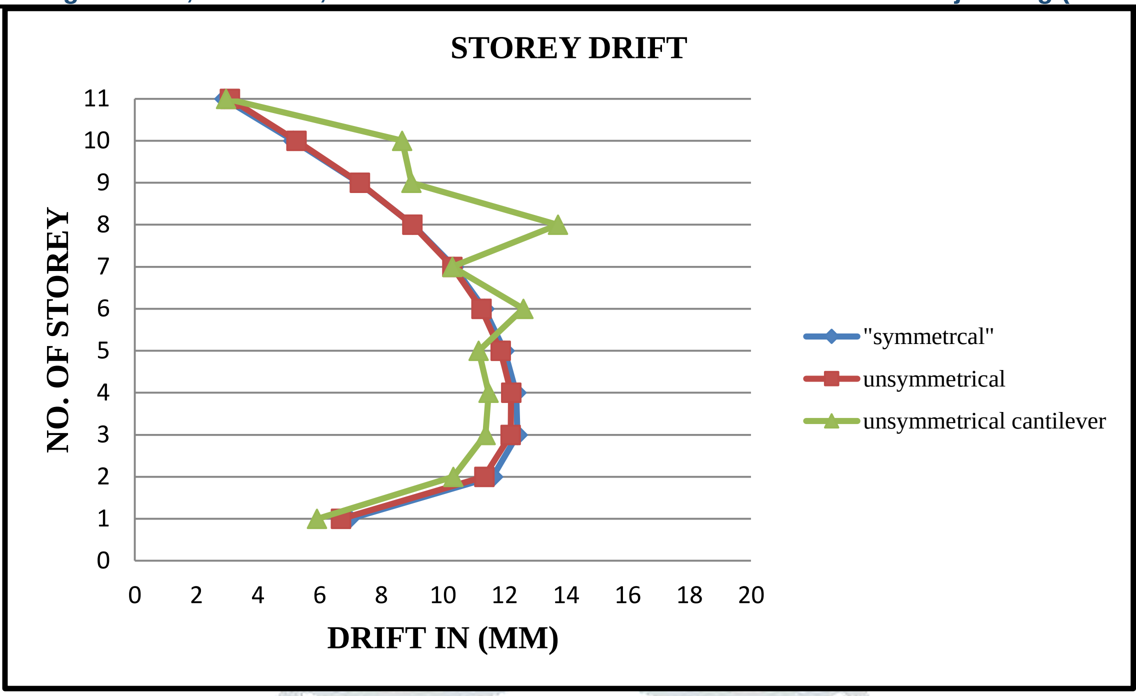

Fig. 19

XIV. COMPARISION OF STOREY DISPLACEMENT SHOWN IN FIG. (20) OF SYMMETRICAL STRUCTURE, UNSYMMETRICAL STRUCTURE & UNSYMMETRICAL STRUCTURE WITH CANTILEVER SECTION IN ZONE 3:-

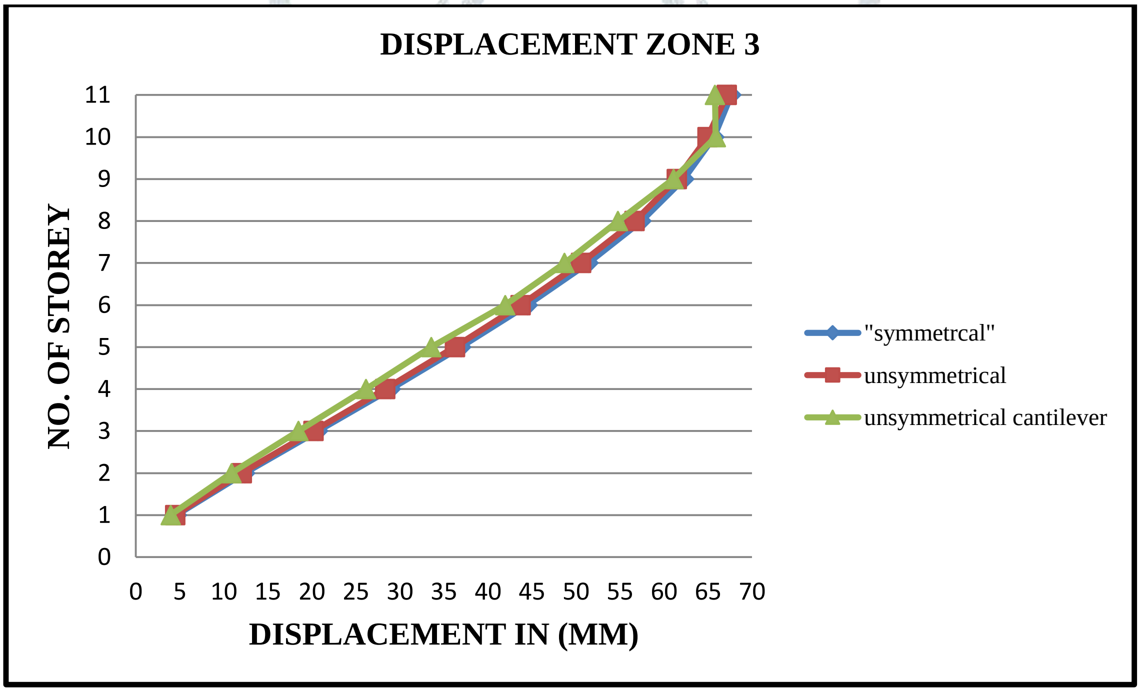

Fig. 20

XV. COMPARISION OF STOREY DISPLACEMENT SHOWN IN FIG. (21) OF SYMMETRICAL STRUCTURE, UNSYMMETRICAL STRUCTURE & UNSYMMETRICAL STRUCTURE WITH CANTILEVER SECTION IN ZONE 4:-

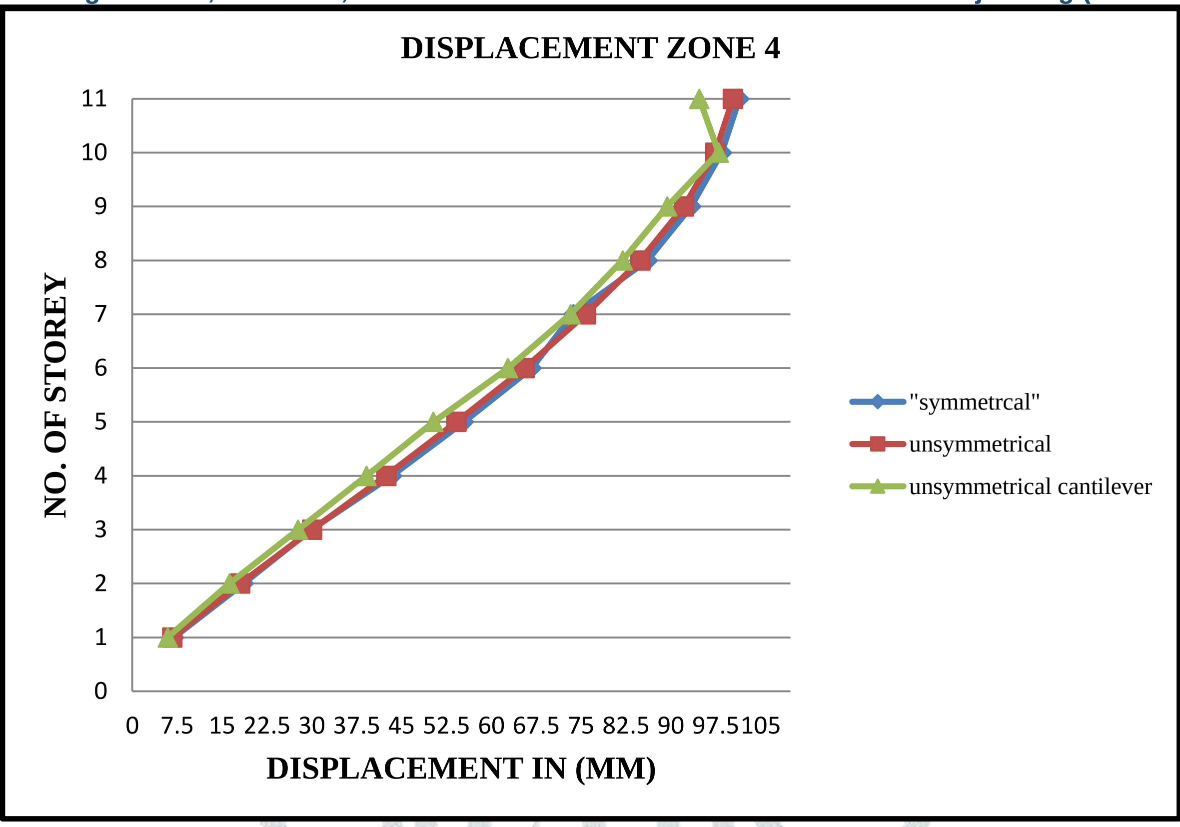

Fig. 21

XIII. METHODOLOGY

This research work includes various stages for analysis and design of unsymmetrical frame with cantilever section.

Stage-1 Planning of structure.

- SYMMETRICAL STRUCTURE.
- UNSYMMETRICAL STRUCTURE.
- UNSYMMETRICAL STRUCTURE WITH CANTILEVER SECTION.

Stage-2 Modelling of structure frame.

- Identification of material & geometric properties in all structures.
- Assessment of the loads & load combinations on frames similarly in all structures.

Stage-3 Analysis of all structure frames.

Stage-4 Design of all structures.

XIV. VALIDATION THROUGH SOFTWARE

The importance of software are as follows:

- Software is necessary for comparison of manual calculation and calculation done by software which helps in being confident about the work done.
- This also helps for further work on software with confidence. Otherwise, it will be difficult to trust the validity and correctness of the results and outputs given by the software.
- This section deals with the software for understanding the behavior of unsymmetrical structure with cantilever section subjected to seismic loading in zones (III, IV).

XV. OBSERVATIONS OF RESULT

The result has been represented,

- In the comparison of Symmetrical building and Unsymmetrical building, the time period is more for Symmetrical building than unsymmetrical building.
- The natural time period increases as the height increases (no. of storey).
- The Symmetrical model provides more Gross Leasable Area (GLA) as compared to the Unsymmetrical model. Hence, Area Utilization will be more.
- The Load Distribution in the Symmetrical model is more uniform as compared to the Unsymmetrical model.
- The requirement of reinforcement is more in the Unsymmetrical frame than the symmetric frame.
- The Symmetrical model is More Cost-Effective with respect to the Unsymmetrical model as the volume of material being used is more in the Unsymmetrical model.

XVII. CONCLUSION

From the literature review, it can be concluded that the seismic analysis of unsymmetrical structure with cantilever depends upon factors which are load distribution, joint displacements, eccentricity between the centre of stiffness and the centre of mass, etc. The seismic behavior of unsymmetrical structures with cantilever sections may cause interruption of force flow and stress concentration. This produces torsion effects in the structure which leads to an increase in shear force, lateral deflection and ultimately causes failure. Hence it is necessary to identify an appropriate technique suitable for the analysis of large span cantilevers in unsymmetrical structure. The seismic response of large span cantilevers in the unsymmetrical structure under different loading conditions is required to study under various failure criteria. The failure of such a structure is hazardous therefore safety of a structure is important.

- The column sizes behavior changes differently for unsymmetrical and Symmetrical structures, as the height of the building increases.
- The base shear of the Symmetrical structure is more as compare to the unsymmetrical structure.
- The torsional moment in unsymmetrical structure is more than symmetrical structure.
- The Symmetric model provides more Gross Leasable Area (GLA) as compared to the Unsymmetrical model. Hence, Area Utilization will be more.
- The Load Distribution in the Symmetric model is more uniform as compared to the Unsymmetrical model.
- The requirement of reinforcement is more in the Unsymmetrical frame than the symmetric frame.
- The Symmetric model is More Cost-Effective with respect to the Unsymmetrical model as the volume of material being used is more in the Unsymmetrical model.
- The performance of a Symmetrical building is better than an unsymmetrical building.
- In a comparison of the torsional moment in beam, the result shows that for unsymmetrical building the torsional moment is more than symmetrical therefore it is necessary to design the beam and column for torsional moment.
- Structural parameters such as lateral displacement, time period for unsymmetrical structure are higher as compared to Symmetrical structure.

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