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Seismic Analysis and Design of Structural Lightweight Concrete High Rise Building with and Without Retrofitting

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Abstract:- Natural frequency of a structure depends upon mass and stiffness of the structure, structural lightweight concrete (SLWC) doesn't shows good response in high seismic zones and critical soil conditions due to its lesser modulus of elasticity when compared to normal weight concrete but gives an economical design results which reduces the construction cost, the responses of structure like story drifts and stiffness of the structure can be enhanced by global retrofitting technique i.e. by providing the bracings at the critical locations of the structure. The maximum storey stiffness of the retrofitted structural lightweight concrete building was found to be three times the unretrofitted structural lightweight concrete building; the maximum bending moment value for an slwc braced structure is nearly 160 kN-m less than the unbraced structure. Results showed that storey drift of retrofitted slwc building is less than 0.4% of storey height. After non-linear dynamic analysis, it is found that pseudo-spectral acceleration for a braced slwc building is 1.65×103 mm/sec^2 whereas for an unbraced slwc building is 9×103 mm/sec^2. The maximum cross-sectional size of the beam and column for a braced building is 30% and 20% less than the unbraced building, the maximum reinforcement ratio of unbraced to braced in beams and columns is 1.24 and 0.67 respectively. Due to the lesser modulus of elasticity for structural lightweight concrete (SLWC) the structure made with this has less stiffness when compared to normal weight concrete building, if we can enhance the elastic modulus of slwc then the structure made with slwc will show the best performance during an earthquake.

KEYWORDS:- Storey drifts, Storey stiffness, Overturning moment, Bracings, Natural frequency, time period and pseudo-spectral acceleration.

I. INTRODUCTION

The structure's natural frequency depends on the mass and stiffness of the structure, the natural frequency of a building is directly proportional to its stiffness and inversely proportional to the square root of mass, So, if we can significantly reduce the building mass, the natural frequency of the structure will increase and stiffness of the structure can be enhanced by global retrofitting technique. In global retrofitting the bracing systems are primarily classified into two types those are horizontal bracing and vertical bracing, in rcc building slabs itself act as a diaphragm by which lateral loads are transferred to the columns and don't require any horizontal bracings in it.

As structural lightweight concrete buildings show more drift and lateral displacement in high seismic zones, if we can able to retrofit the structure in these conditions then it shows best results even in high seismic zones and structure becomes economical when compared to RC after the designing. For concrete constructions vulnerable to damage and failure by seismic forces seismic retrofitting techniques are required. Every year moderate to severe earthquakes have taken place around the world over the past thirty years, such events result in damage to concrete structures and failures. The needs of seismic retrofitting are given below.

- To provide safety and security to important buildings like hospitals, malls, and companies e.t.c.
- Structures which are damaged locally after the occurrence of an earthquake.
- Inadequate prediction of the probability of an earthquake during the design of a structure,
- To enhance the lateral stability of the structure at higher seismic zones.

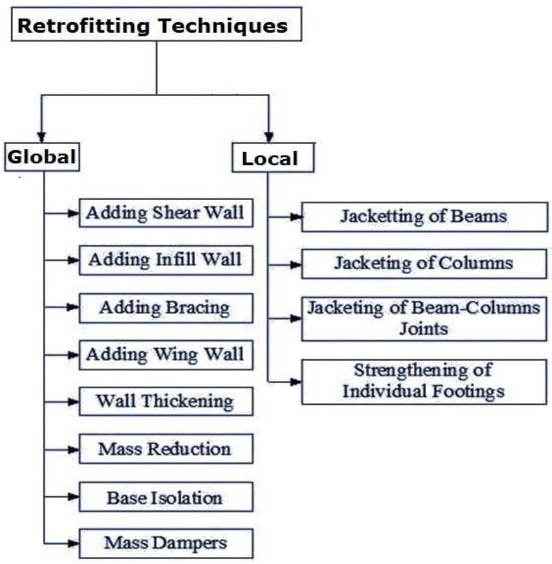

Fig 1: Retrofitting techniques

Retrofitting techniques are generally classified into two types they are global and local retrofitting. Earthquake causes major destruction to structures, loss of life and loss of money. So updating the present buildings is necessary to enhance their resistance to seismic conditions, Retrofitting the structure is the most suitable and economical procedure than replacing the structure. A braced frame is generally adopted for the structure which is subjecting to the lateral force like wind and

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seismic loads, the bracings are commonly made up of steel members so as to tackle the load in both tension and compression. By providing bracings to the structure we can enhance the stiffness and natural frequency of the structure by which structural performance during the earthquake is improved. As far as vertical bracings are concerned there are many types in it some of them are listed below.

1. Cross-braced
2. Inverted V-braced
3. Single diagonal braced
4. Eccentric bracings

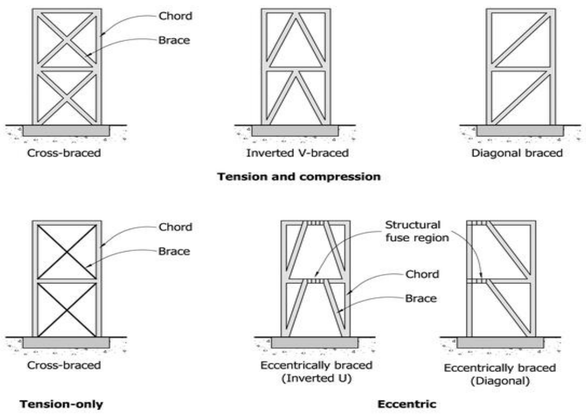

Fig 2: Types of bracings

II. OBJECTIVE

A G+15 high rise building is analyzed in critical soil conditions and critical seismic zones i.e zone IV and soil type III to identify the following mentioned objectives.

- To identify the seismic behavior of braced and unbraced structural lightweight concrete high rise building at critical conditions.
- Analyzing the slwc structure with Non-linear dynamic method (Time history method) and to identify the structural response.
- Identifying the variation of maximum reinforcement and the member sizes after designing for both braced and unbraced structure.
- To identify the variation of structural responses between the braced and unbraced type of structure.

III. ANALYTICAL STUDY

A. Modeling and material properties:-

A G+15 high-rise building is modelled in Etabs (Extended three-dimensional analysis of building system), With the height of each storey 3m, the structure length is 20.5 m in the X direction and 20.58 m in the Y direction. The overall structure height is 45 m and the sizes of the members vary according to the design requirements. The slab thickness is 150 mm; the outer and inner wall thicknesses are 230 mm and 115 mm respectively. The model is analyzed in zone IV of soft soil condition and then designed according to IS 456-2000 code. The structural lightweight concrete (SLWC) density is 1800 kg / m^3, the poisons ratio of SLWC is taken as 0.21, Compressive strength is taken in between 30 to 40 Mpa and the elasticity module for SLWC is calculated by the ACI code. The ACI-318 Building Code provides the mechanical properties of structural lightweight aggregate concrete, Most experimental studies concluded that SLWC and normal concrete poison ratios are almost equal. In various experimental studies, the thermal expansion coefficient for normal concrete and lightweight aggregate concrete is found to be 12×10^{-6} and 17×10^{-6} respectively. In ACI 318-14, Table 19.2.4.2 for various types of lightweight concrete, the strength reduction factor or modification factor (λ) is given.

Steel grade of Fe250 is used as a bracing material property and the tubular cross-sectional bracings are taken with the size of the cross-section as 150×150×10 mm. The bracings are provided at the locations where the much number of structural members are getting failed at that particular location, by providing bracings in such a pattern as shown in Fig 3 the stiffness of structure got increased significantly.

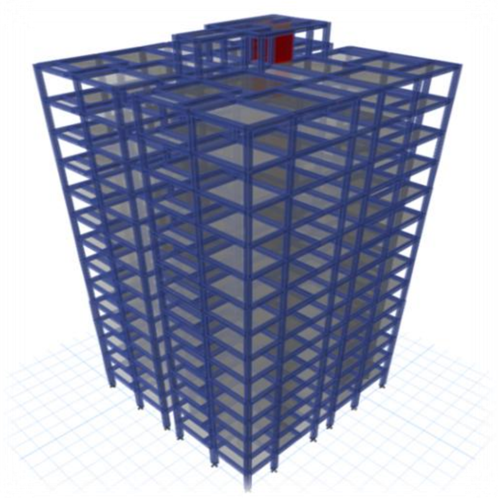

Fig 3: Model of the unbraced building

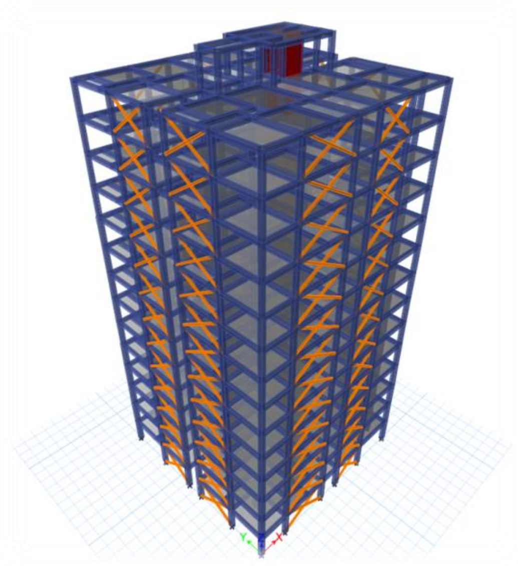

Fig 4: Model of the braced building

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B. Loads and combinations:-

Code books which are considered for the dead and live load are IS 875 part-1 and part-2, seismic analysis is done in accordance to IS 1893-2002 (part 1)

Table 1: Load data

Type of Load	Intensity of Load
Live load	3 kN/m^2 (IS 875 part 2)
Floor finishing	1.1 kN/m^2 (IS 875 part 1)
Wall loads on beams	External = 14 kN/m Internal = 7 kN/m
Seismic Zones	Zone IV
Type of soil	Soft soil condition

The load combination to be considered as per IS 1893 part 1(2002) code when designing the structure in seismic zones is shown below.

a.) 1.5 (DL±EL)
b.) 0.9DL±1.5EL
c.) 1.5 (DL±LL)
d.) 1.2 (DL±LL±EL)

IV. RESULTS

A. Analysis results:-

Seismic analysis is done in critical soil conditions and higher seismic zone with linear and non-linear dynamic methods. The structural responses like lateral displacement, overturning moment, storey drift and storey stiffness are identified, for time history analysis pseudo-spectral acceleration curve has been identified, all results have shown a good variation between braced and unbraced slwc high-rise building.

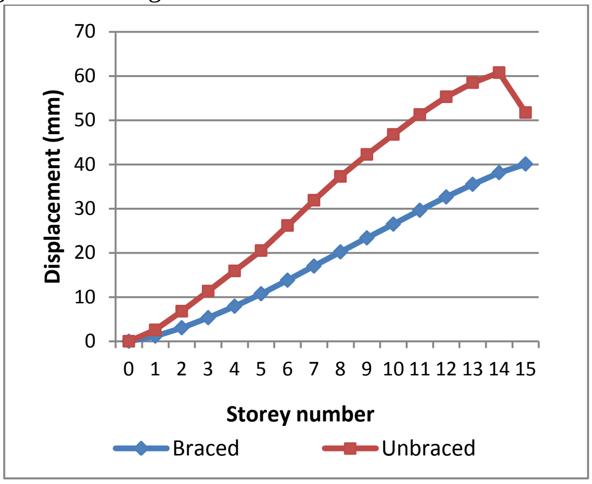

Fig 5: Lateral displacement of braced and unbraced structure

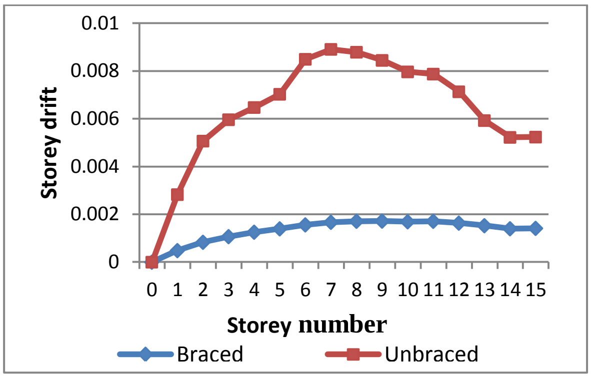

Fig 6: Maximum storey drift of braced and unbraced structure

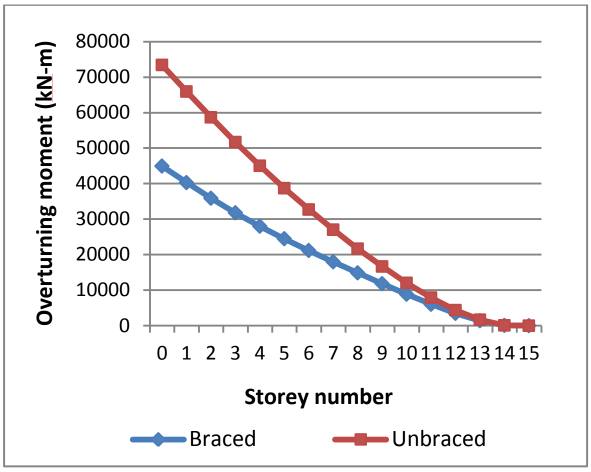

Fig 7: Maximum overturning moment of braced and unbraced structure

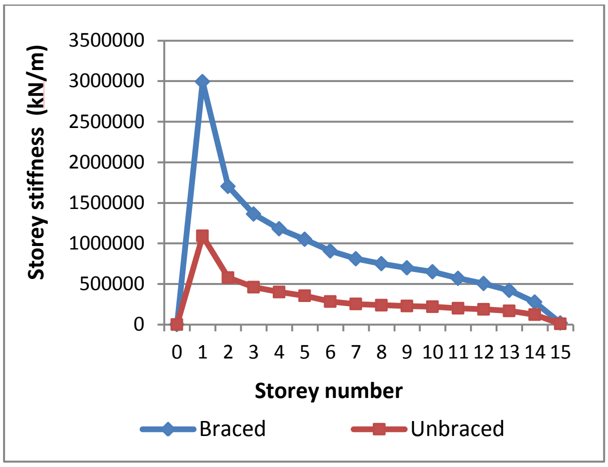

Fig 8: Storey stiffness of braced and unbraced structure

B. Natural frequency and time period:-

Since the building consists of 15 floors, the total number of modes obtained for the building is 45. The modal frequency and time period for both types of structure are shown in the table below, the time period given to Etabs is calculated from formulas given in IS 1893 (part 1) 2002.

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Table 2: Modal period and frequency

Type of structure	Mode	Time period (sec)	Frequency (cycle/sec)
Unbraced	1	2.093	0.478
	29	0.07	14.204
	40	0.043	23.331
Braced	1	1.993	0.502
	29	0.05	20.568
	40	0.036	27.599

C. Time history result:-

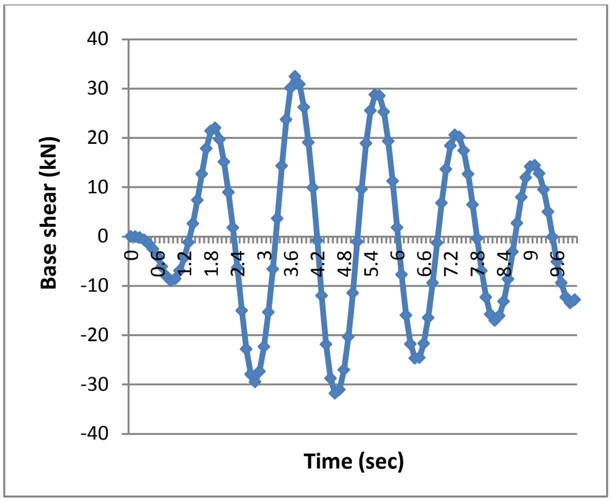

Fig 9: Time history plot for unbraced structure

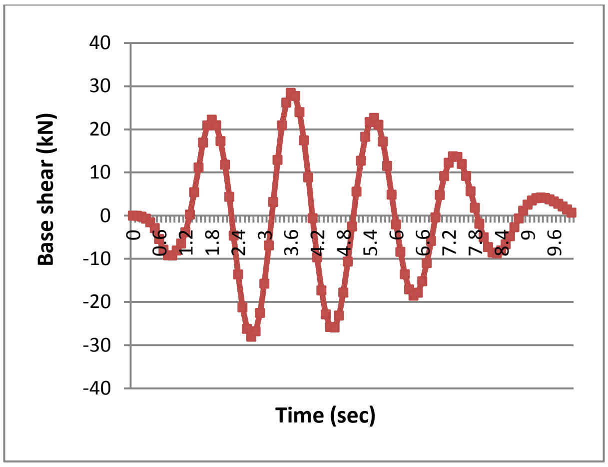

Fig 10: Time history plot for braced structure

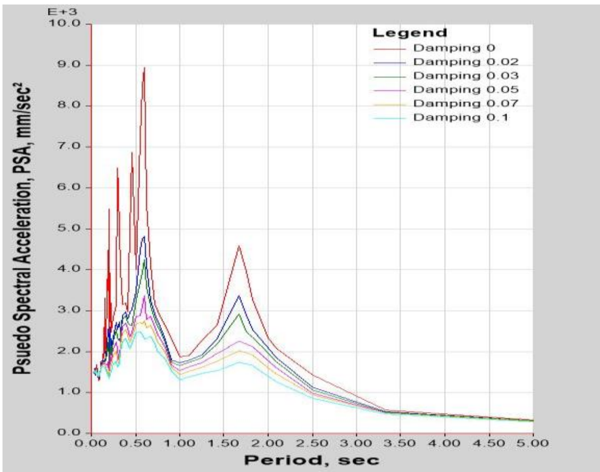

Fig 11: Response spectrum curve for braced

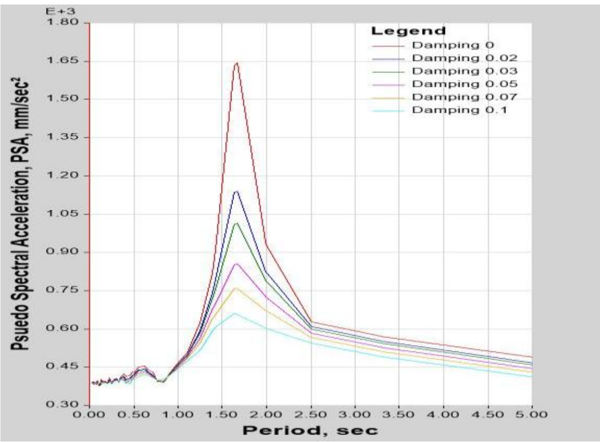

Fig 12: Response spectrum curve for Unbraced

Table 3: Seismic design results of beams (Maximum values)

Type of structure	Section	(+/-) Moment kN-m	Load Combination	As Top mm²
Unbraced	550 × 300	281.4846	1.5(DL-EQX)	1673
	550 × 300	-360.0083	1.5(DL-EQX)	2234
Braced	400 X 300	-202.5657	1.5(DL-EQx)	1800
	400 X 300	176.8699	1.5(DL+EQx)	1436

Table 4: Seismic design results of columns (Maximum values)

Type of structure	Section	P kN	M Major kN-m	M Minor kN-m	PMM Combo	PMM Ratio or Rebar %
Unbraced	600 × 400	5159.68	-25.71	-103.1937	1.5(DL+LL)	2.31 %
	550 × 400	-1019.46	4.6927	-20.3891	0.9DL+1.5EQx	1.59 %
Braced	500 X 400	5243.78	-15.13	104.87	1.5(DL+EQy)	4.13 %
	500 X 400	-809.746	2.05	-16.19	0.9DL+1.5EQx	1.42 %

V. DISCUSSION OF RESULTS:-

- After the dynamic analysis has been done it is observed that maximum lateral displacement of braced structure reduced by 20mm when compared to the unbraced type of structure.
- The maximum storey drifts exceed the permissible limits for unbraced structure as given in IS 1893 code, whereas
- for braced structure maximum storey drifts are within the limit as given by IS code.
- The maximum overturning moment obtained for braced and unbraced structures are 44937 kN-m and 73410 kN-m respectively, it is observed that overturning of the structure gets reduced by bracing.
- The stiffness of the structure after the application of bracing is observed to be increased by 1.9×10^{6} kN/m, stiffness is more for braced structure when compared to unbraced.
- The natural frequency of the braced structure is increased because the stiffness of the structure is enhanced by providing bracings.
- After non-linear dynamic analysis, it is found that pseudo-spectral acceleration for a braced slwc building is 1.65×103 mm/sec^{2} whereas for an unbraced slwc building is 9×103 mm/sec^{2}.
- The design results which are obtained shows that structure becomes economical by using lightweight concrete for high rise buildings.

VI. CONCLUSION

Structural lightweight concrete high rise building are generally suitable to construct at low seismic zones rather than high seismic zones because of storey drift for the unbraced structure is more than the allowable limit which is recommended by the Indian code, it is one of the reason for which this type of structures are undesirable in high seismic zones. After providing the bracings to the structure storey drifts are observed to be within the allowable limits and other responses of the structure are also got enhanced. It can be concluded that lightweight concrete structures in higher seismic zones and soft soil conditions gives economical design results and performance of structural lightweight concrete in high seismic zones can be enhanced by providing bracings or by retrofitting the structure globally.

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