LINEAR AND NON LINEAR ANALYSIS OF LEANING TOWER

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By

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DECLARATION

I, Sujit Jha (11501941), hereby declare that this thesis report entitled **"Linear and Nonlinear analysis of leaning tower "**submitted for the fulfillment of the requirements for the award of degree of Master of Civil Engineering, in the School of Civil Engineering, Lovely Professional University, Phagwara, is my own work. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: **Sujit jha**

Place:

CERTIFICATE

Certified that this project report entitled " Linear and nonlinear analysis of leaning tower" submitted individually by student of School of Civil Engineering, Lovely Professional University, Phagwara , carried out the work under my supervision for the Award of Degree. This report has not been submitted to any other university or institution for the award of any degree.

Signature of Supervisor

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ABSTRACT

Now a day the interest for construction of complex and leaned structures is growing rapidly. The main aim of this study is, behind it is the growing competition in the world. Theoretical calculations for such structures are very cumbersome and hence the demand for faster and quick software's is growing drastically.

This project work basically uses the computer programs like STAAD. Pro and ETABS for the designing and analysis of the leaning tower. The code used for the study is the Indian Design Codes (IS 456 2000). The structure taken is an RCC structure with G+ 30 stories. Two types of leaned towers are being used viz. with shear core and without shear core. Results are obtained and compared for linear and nonlinear analysis of structure which consists of P-delta analysis, Time history analysis .STAAD. ProV8i is used for the concrete design, time history analysis and p-delta analysis. ETABS may be used in future for the push over and response spectrum analysis.

The P-Delta analysis showed that the storey drift in case of shear cored leaning tower is 5.755 lesser than the normal structure. The base shear in case of normal structure is 38.46% greater than the shear cored structure. The self-weight of structure in case of shear cored structure is 3.84% lesser then the normal leaning tower. The centre of gravity is get shifted slightly towards the centre of structure and also towards the ground hence, reducing the chance of overturning. From the Response spectrum analysis result it's clear that the story displacement in the structure is below the max. Allowable limit.

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ABBREVIATION USED

%	Percentage
min	Minutes
mm	Millimeter
cm	Centimeter
m	Meter
sec	Second
Kg/m^3	Kilogram per meter cube
MPa	Mega Pascal
Φ	Diameter
N	Newton
KN	Kilo Newton
KNm	Kilo Newton meter
3D	Three dimensional
etc	End of thinking capacity
RCC	Reinforced cement concrete
FBD	Force based design
DBD	Displacement based design
Fig.	Figure
No.	Number
&	And

CHAPTER 1

INTRODUCTION

1.1 General

Now a day the leaning towers are becoming an area of interest as more and more creative designs and problems are forthcoming the construction and design of such structure is becoming important both from the view of technological development and also worldwide point of focus and center.

1.2 History behind Development of Leaning Towers

Human beings are tend to make mistake. The first known mistake of leaning tower was happened in 11^{th} century during construction of 14500 ton tower of Pisa, now well known as leaning tower of Pisa. Over passage of time various leaning defects occurred in structures and being rectified. Now a day's engineers and architects are moving towards the construction of very complex shaped structure like leaning towers to make them as an icon symbol and to increase the engineering technologies and solutions.

Fig 1.1: Leaning Tower Of Pisa

Fig 1.2: Capital Gate Abu Dhabi

1.3 Motive behind leaning tower analysis

With the development of technologies around the world, new and complex structures are being constructed and designed. Introduction of software in market has now made it easier to go for different shaped structures, also the work gets faster. So with the help of STAAD. ProV8i my aim is to analyses a leaning structure and to make it safe. Also the cost analysis in comparison with same specifications normal structure would be done.

1.4 Analysis of Leaning Towers

For the purpose of analysis a hypothetical leaned structure is being designed on STAAD. Pro with and without shear core and the various analyses like P-Delta analysis, time history analysis, cost analysis etc are being done.

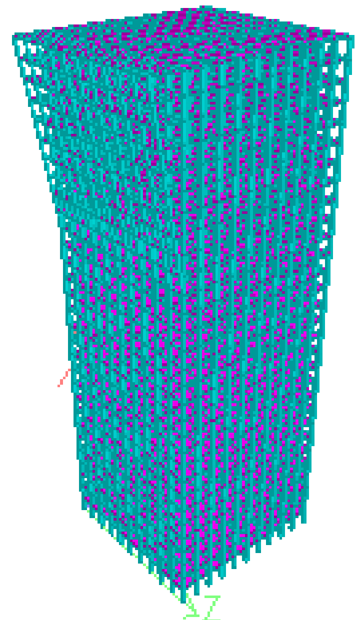

Fig 1.3: 3d View of leaning tower

1.5 World Wide Current Scenario

Currently leaning towers are becoming very popular worldwide as a sign of technological advancement and capacity. Number of leaned towers is being constructed now a day's worldwide. Few of the examples are leaning tower of Madrid, Capital gate Abu Dhabi etc. More and more efforts are being made in this field of construction with and without the help of software's.

Fig 1.4: Leaning Tower Of Madrid

1.6 Benefits and Advantages

As the area of land is decreasing drastically the need of high rise buildings is getting higher. So the benefit of leaning towers is that more and more space can be covered with it. Also it serves as an icon symbol for the region and shows the growth of the nation. By studying the leaned structures the present problem of overturning in conventional structures can also be rectified.

CHAPTER 2

LITERATURE REVIEW

D.R. Deshmukh et al. (2016) studied the analysis and design of G+19 building using Staad. ProV8i and found that Staad.Pro is a powerful tool for the analysis and design of multistoried buildings where manual calculation can be very cumbersome and complex.

Table 2.1: Structural Specification (D. R. Deshmukh Et Al., 2016)

PARTICULARS	DIMENSION
COLUMN	0.30X0.60m
BEAM	0.45 X 0.45m
SLAB	0.15m thick
PARAT WALL	0.1m
LIVE LOAD	2KN/M2
FLOOR FINISH	1KN/M2
GRADE OF CONCRETE	M30
GRADE OF STEEL	Fe415
STOREY HEIGHT	3.6m
PLAN	33.6 X 18.8m

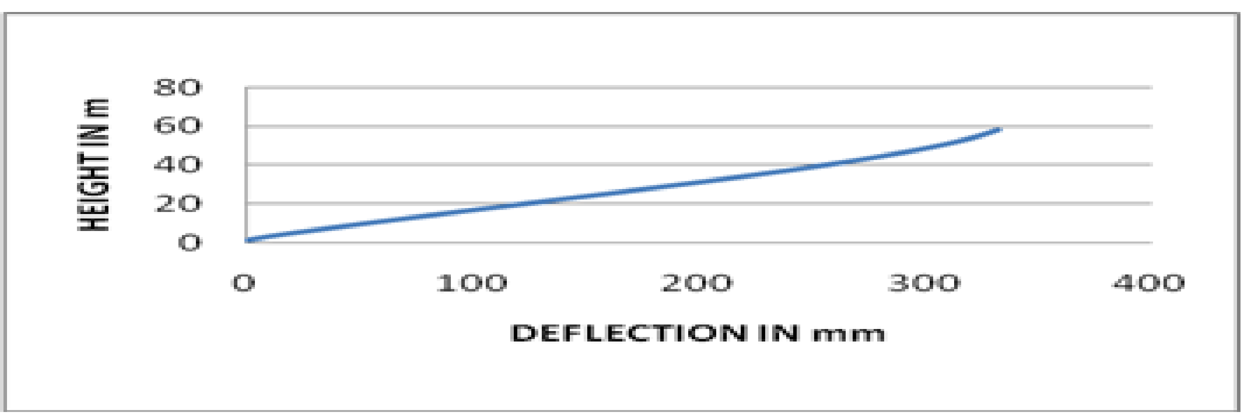

Fig 2.1: Height V/S Deflection (D.R. Deshmukh Et Al., 2016)

Chang-Hai Zhai et al. (2015) studied the effect of main shock, after shock on nuclear power plant and found that after shock imparts effect over structures. So, multiple shocks are to be determined and processed to get the response of structure.

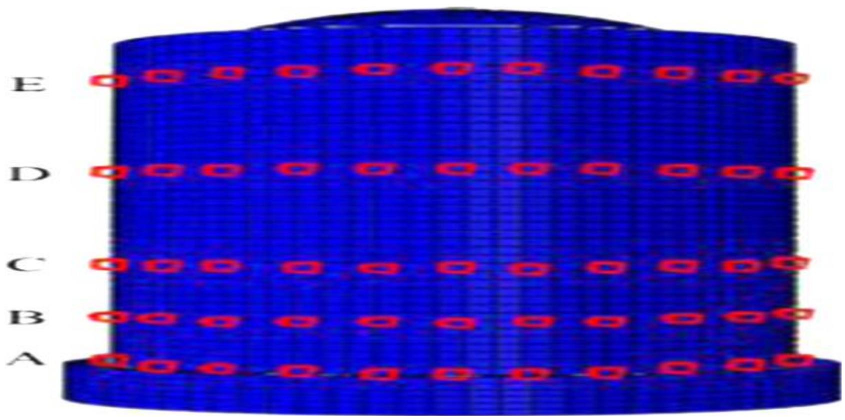

Fig 2.2: 3d View of Npp Rc Containment (Chang-Hai Zhai Et Al., 2015)

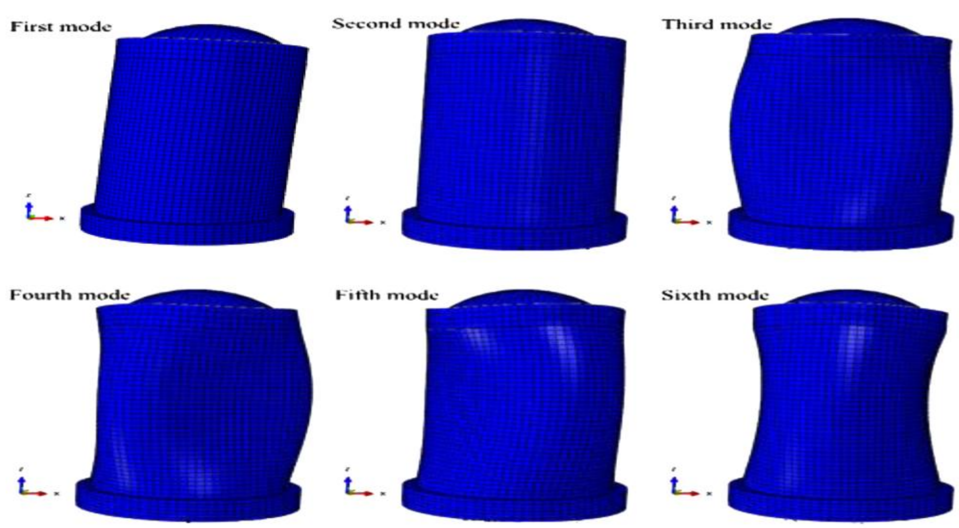

Fig 2.3: Mode Shape (Chang- Hai Zhai Et Al., 2015)

Under sequential seismic load damage is greater than single seismic loading. The lateral displacement may rise up to 30 % at sequential load

Hossein Agha Beigi et al. (2015) studied about factors influencing repair cost of soft storey. They took an RC frame building and analyzed the seismic retrofit of it. It's found that soft storey with partial infill wall have greater tendency to collapse. Due to the soft storey formation at the first floor the deformation at the top floor gets increased hence by providing proper infill walls at first floor the deformation could be prevented to a greater extent. Amongst the three variants of structure viz. RC framed, partially in filled, fully infilled, the partial infill walls storey was most likely to deform under seismic loading.

Kyoung Sun Moon (2015) studied the Lateral stiffness of diagrid , tubular braced and out rigged twisted tall buildings and it was found that lateral stiffness reduces on incorporating twist to the building. Tilted diagrid and braced tube structure has greater resistance as compared to rigged one.

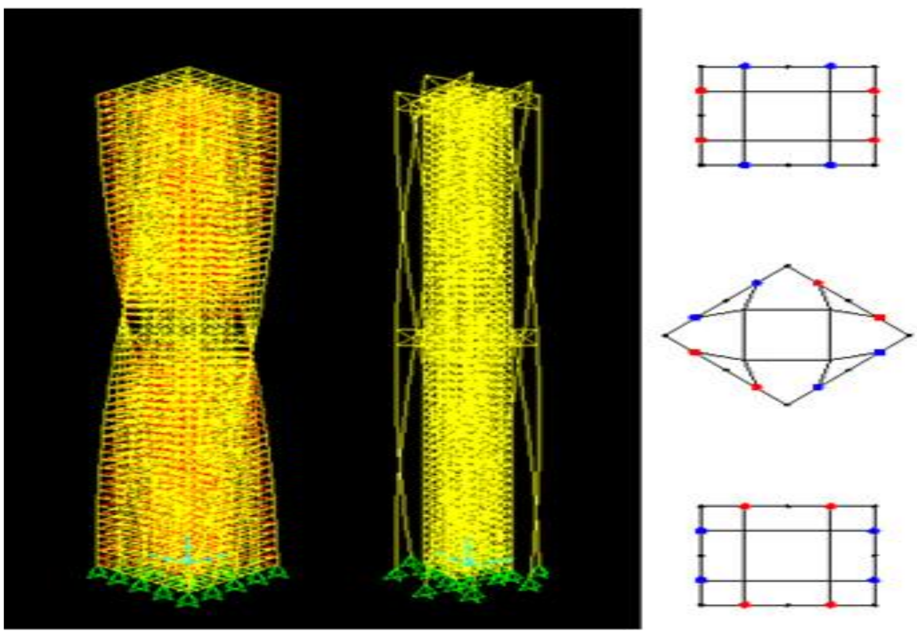

Fig 2.4: Outrigged Twisted 60 Storey Building with 1.5 Degree Twist Per Storey

With increasing rate of twist lateral stiffness decreases. Twist doesn't affect diagrid and tubular braced structure to greater extent up to 13 degrees.

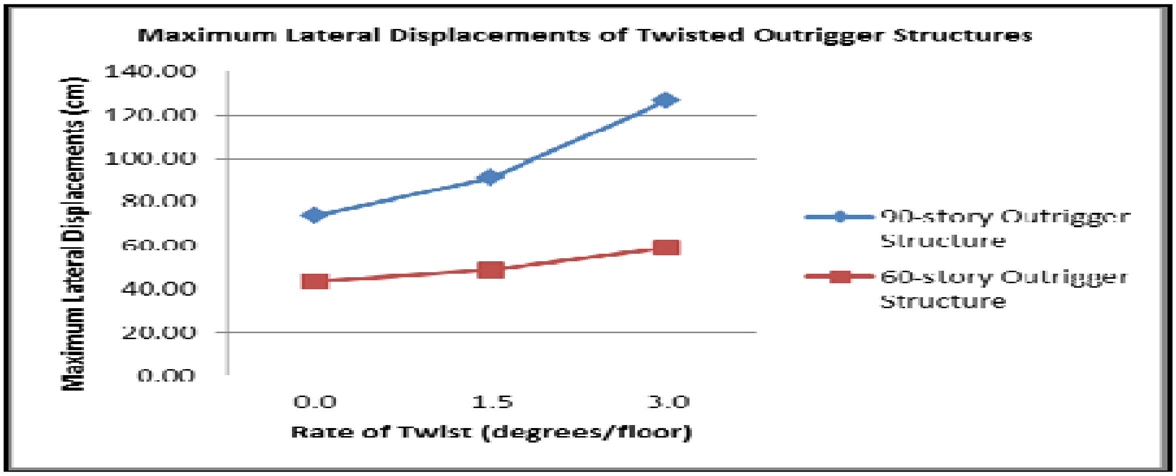

Fig 2.5: Displacement V/S Twist In Out Rigger Structure (Kyoung Sun Moon 2015)

Ima Muljati et al. (2015) studied the performance of displacement based design and force based design on concrete frame. They concluded that displacement based design is superior in predicting the seismic demand (storey drift) than force based design. The DBD designs structure for a particular performance while the FBD does several iterations to justify the codal provisions.

F. Cherifi et al. (2015) evaluated seismic vulnerability of structures. Location was Tizi Ouzou city in Algeria.It was concluded that buildings made before 35 years are more susceptible to damage than buildings made after this period. The main reason could be the poor level of structure design and not following the codal provisions. ETABS software was used for the evaluation of damage.

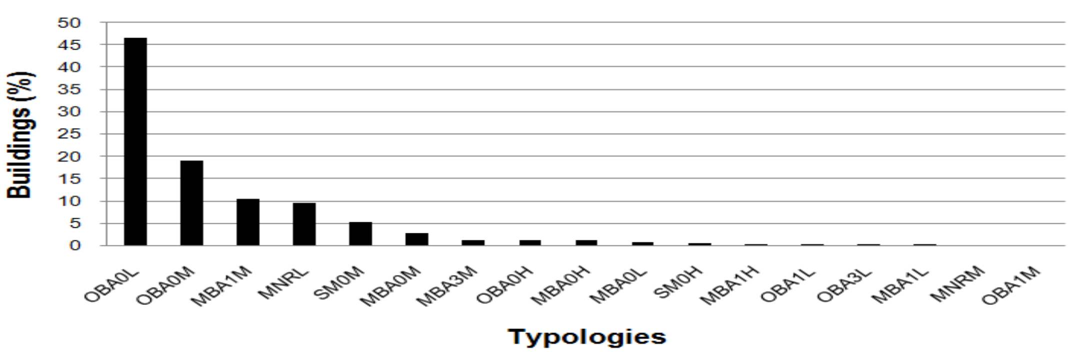

Fig 2.6: Topography V/S Buildings (F. Cherifi Et Al., 2015)

The OBA0L topography (1- 3storey) has maximum buildings percentage. So the majority of buildings in the city are shorter in height.

Mohit Sharma et al. (2014) studied effect of static and dynamic load on multistoreyed rcc buildings. They took a G+30 building and analysed it using STAAD. Pro . It was found that axial force for building in seismic zone 2 and 3 under static and dynamic load in not much varying .

Also it's concluded that torsion in beams for static load is negative while it's positive during dynamic force. Dynamic force imparts more displacement to structure (17-28 %).

Yousuf Dinar et al. (2014) did the push over analysis of an RCC structure on ETABS 9.7.2 and found the nonlinear characteristic of the structure. Various shear wall configurations and infill type affects the performance of structure. Soft story is formed more at the lower floors than the upper floors, so proper infill's and core is needed to be provided at lower stages.

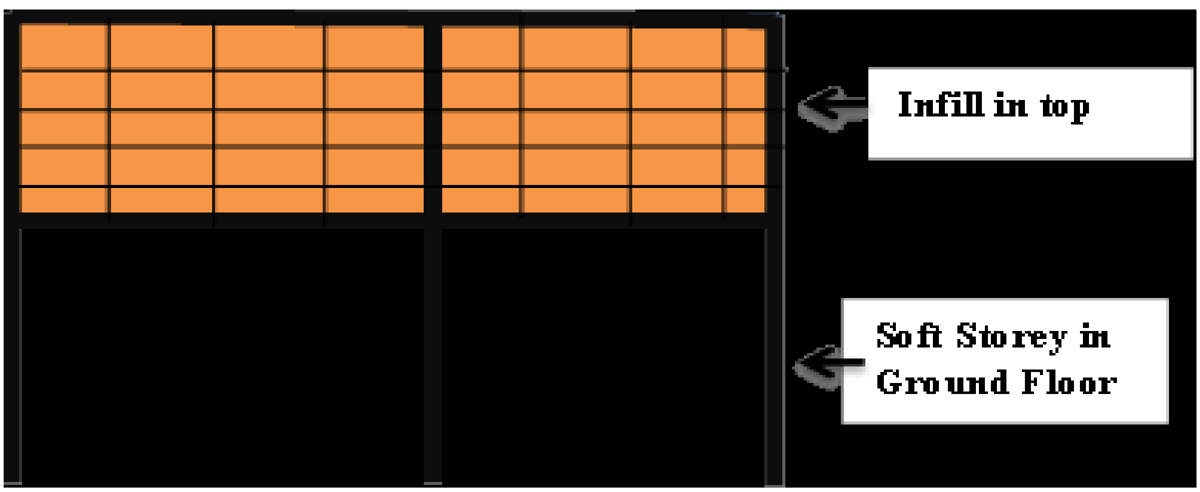

Fig 2.7: Soft Storey Formation (Yousuf Dinar Et Al 2014)

It's found that periphery shear wall is good as compared to parallel shear walls. Shear wall resists the horizontal forces.

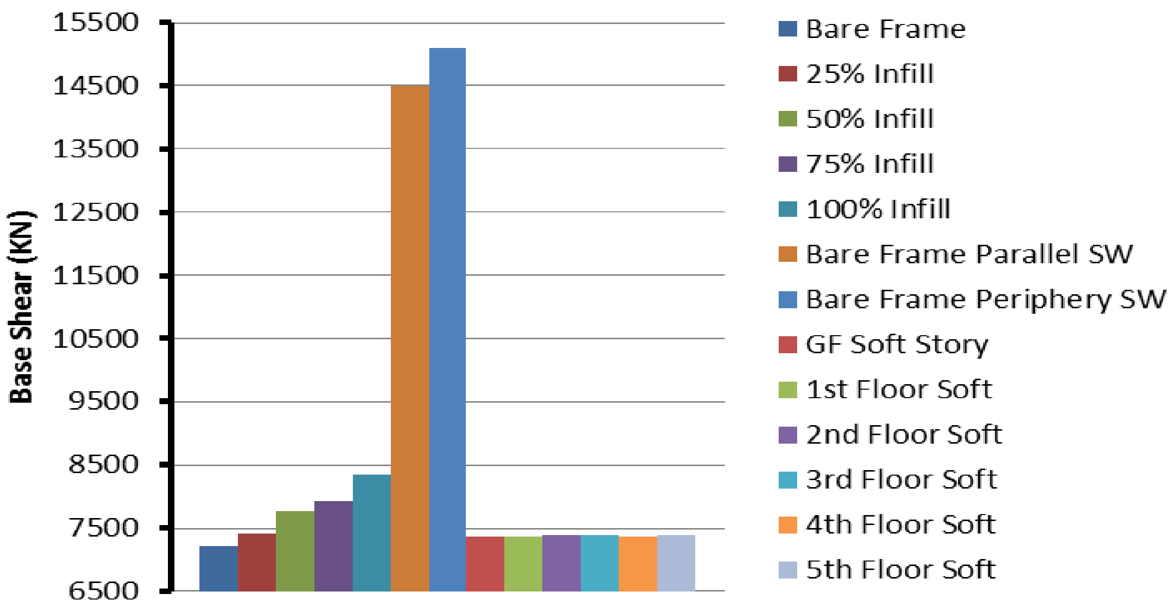

Fig 2.8: Base Shear (Yousuf Dinar Et Al., 2014)

M.S. Ainawala et al. (2014) designed a multi storey RCC building using ETABS v 9.0.7 it was concluded that giving shear walls at corners results in minimum storey drift and shear for various storey heights.

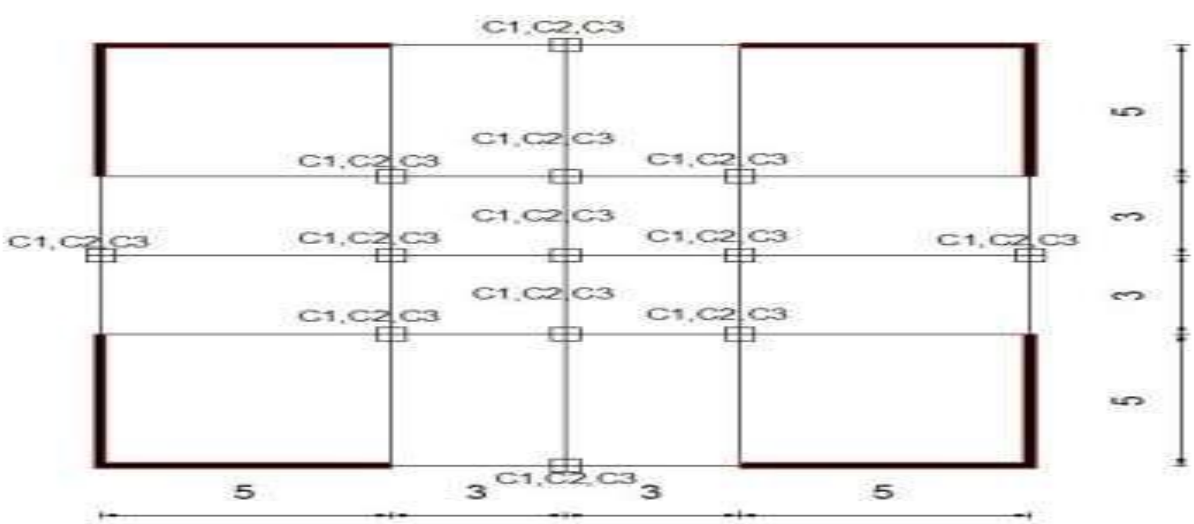

Fig 2.9: Shear Walls at Corners (M.S. Ainawala Et Al., 2014)

Without shear wall the varying storey height affects the storey drift, while shear wall incorporated building has no effect due to varying storey height on drift.

Dia Eddin Nassani (2014) studied the vibration period of steel structure using conventional methods and STAAD. Pro. It's concluded that the software gives better and faster result than the conventional methods and formulas proposed by various codes of practices.

A S Patil et al. (2013) did time history analysis of RCC buildings using various earthquake intensities. The software used was SAP 2000. It's found that for earthquake intensities V – X the response increased in accordance with the intensity.

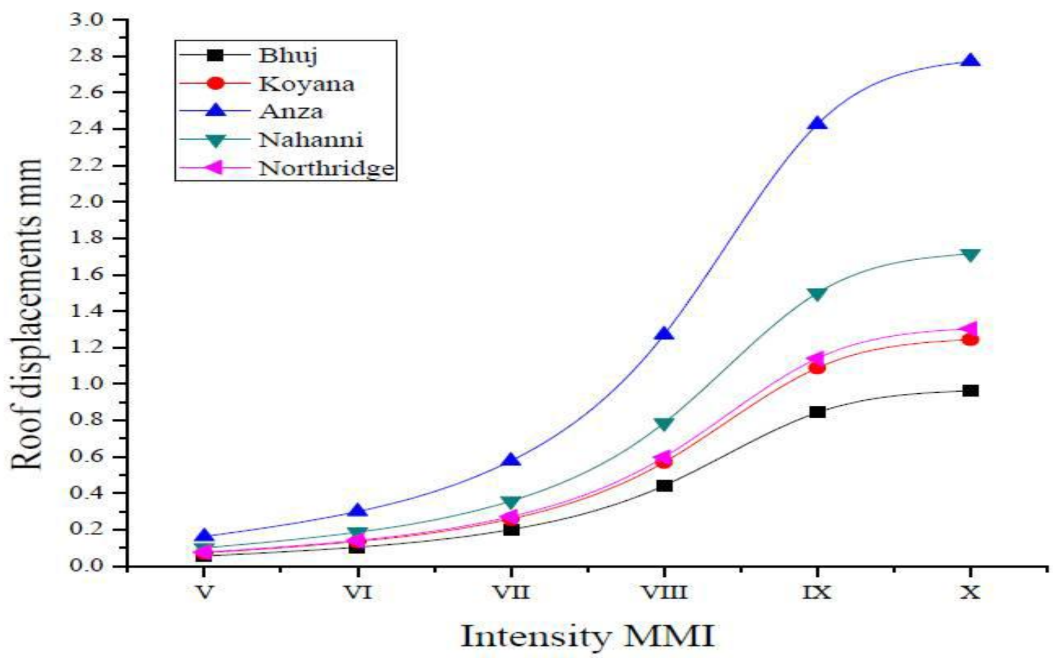

Fig 2.10: Intensity V/S Roof Displacement (A S Patil Et Al., 2013)

The time history analysis provides a suitable way to provide check to the structure safety, the main reason could be being its realistic input data.

Hendramawat A Safarizki et al. (2013) studied the effect of steel bracings over RCC buildings at seismic loading. It's found that steel bracings could be used as retrofit of earthquake forces.

However the effect of steel member length couldn't be found out

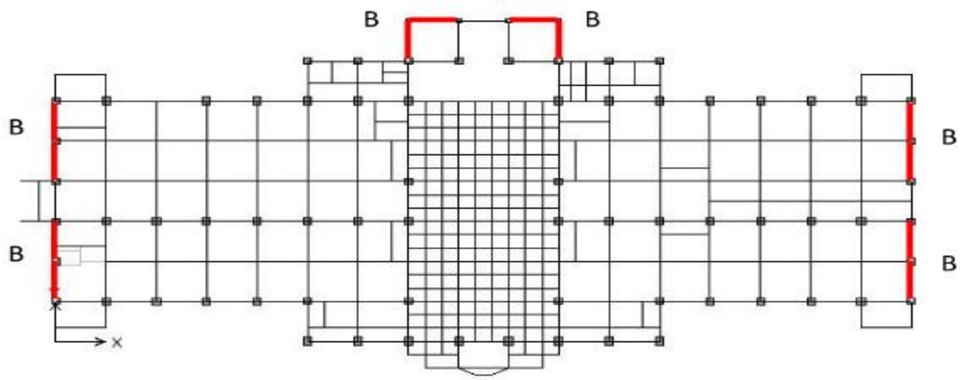

Fig 2.11: Steel Retrofit (Hendramawat A Safarizki Et Al. 2013)

Ketan Patel et al. (2013) studied effect of lateral force on CFT, STEEL and RCC buildings. It's found that the concrete filled steel tube building showed better performance that the rest two. Up to 30 storey RCC building lateral drift was permissible but beyond that it's not up to the mark. Load carrying capacity is greater in CFT structure by 1-8%.

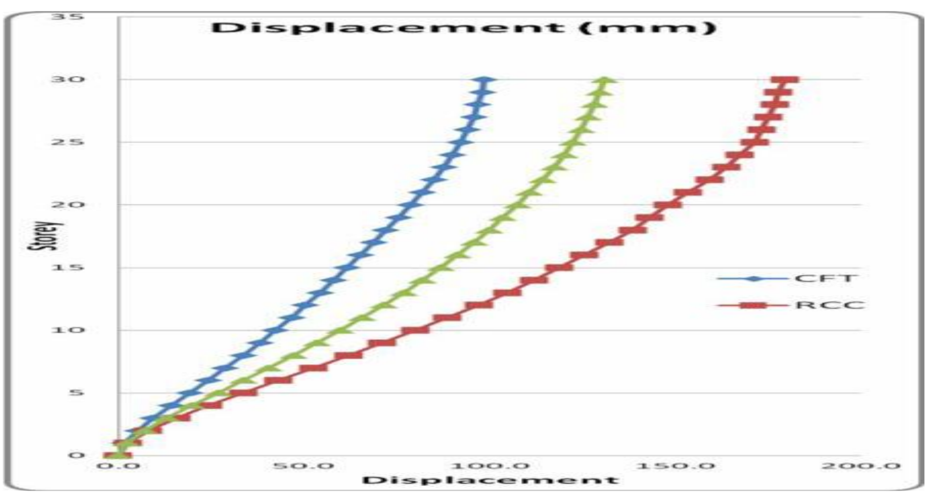

Fig 2.12: Storey V/S Displacement (Ketan Patel Et Al., 2013)

Khushbu Jani et al. (2013) studied effect of diagrid on high rise steel buildings. It was found that lateral load was majorly taken by diagrid columns. While the gravity load was taken by all the columns. Software used was ETABS; the building was 36 storey and 36*36 m's in plan.

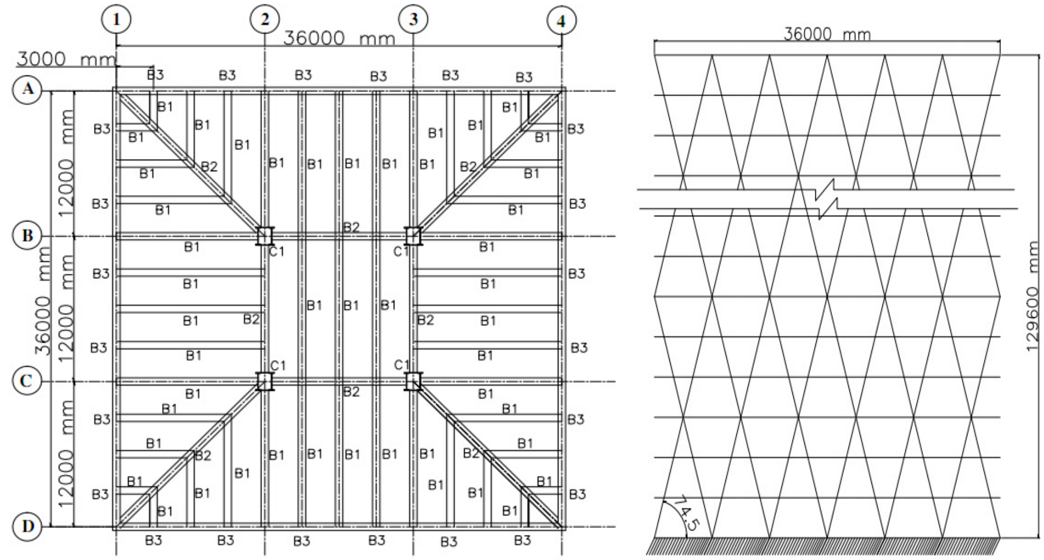

Fig 2.13: Plan Of Floor (Left), Elevation (Right) (Khushbu Jani Et Al. 2013)

B Suresh et al. (2012) studied behavior of a structure with and without earthquake forces. The building taken was 6 stories. Conclusion obtained from the study using STAAD Pro was that for earthquake resistant construction the cost increases up to 3- 17 % of total cost. It's found that structure without lateral force consideration is highly prone to collapse during earthquake.

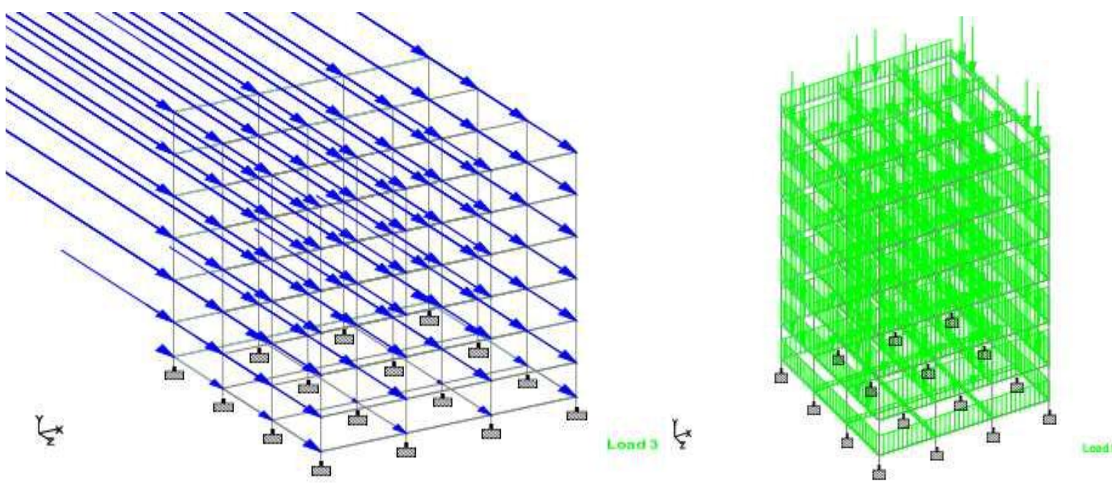

Fig 2.14: Earthquake & Vertical Loads (B Suresh Et Al., 2012)

Kai Hu et al. (2012) did comparative study of high rise RCC structure with oblique column in China using ETABS, SAAP 2000, MIDAS and SATWE. Structure was 29 stories with 3 underground. Response spectrum result was similar in all software's, however ETABS couldn't analyze the oblique columns. ETABS gave better time history result than all.

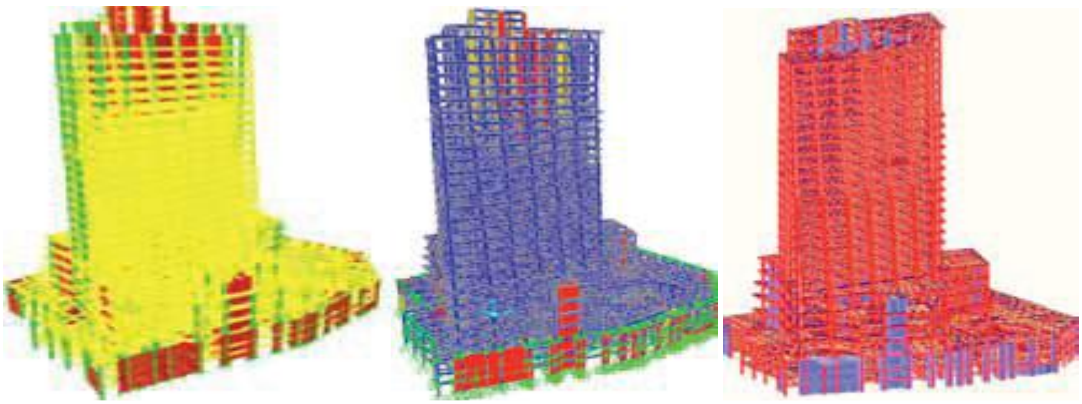

Fig 2.15: Model Etabs, Sap 2000, Midas (Kai Hu Et Al. 2012)

Mehmet Metin Kose (2009) studied the parameters affecting the fundamental period of RCC buildings with infill walls using ANN. Result obtained was that storey height/ no of floors have primary affect over period of vibration. Percentage of shear wall had second most importance.

CHAPTER 3
SCOPE, FUTURE & OBJECTIVE OF STUDY

3.1 Scope & future of Study

In this project "linear and no linear analysis of leaning towers" various analysis like P-Delta analysis, time history analysis, push over analysis, response spectrum analysis are done on a leaned structure with and without shear core and the results are compared and the best suited structure is taken into consideration for practical implementation. The results of the analysis can be used in future for leaned structures design & analysis.

3.2 Objective of Study

- To study the concrete design of structure for two different arrangement of structures(with and without shear core)
- To locate the center of gravity of the structures for two different arrangement of structures(with and without shear core)
- To find out the storey drift using P-Delta analysis for two different arrangement of structures(with and without shear core)
- To find out the frequencies of the structure using time history analysis for two different arrangement of structures(with and without shear core)
- To find out the most economical and safe structure amongst the two different arrangement of structural scheme.
- To find out the minimum no. of mode shapes required for the analysis of the structure using ETABS.

CHAPTER 4

EXPERIMENTAL PROGRAMMES

4.1 General

Using SOFTWARES like STAAD. Pro V8i, ETABS, the various analysis of a 30 storey RCC leaned building is done. The base floor plan is 40m*40m the top floor plan is 47.053*40m. Height of each storey taken is 4 meters and the dimension of the vertical columns is taken to be 600mm*600mm. The primary beams have dimension of 400*300mm for the inner portion and 300*300mm for the outstanding slab part.

Number of stories inclined is top ten stories and the reference is taken from the eleventh storey from the top. Inclination provided is of 10degrees. Depth of the foundation provided is taken as 20 meters and the soil is taken to be hard. The compressive strength of concrete is 25MPa and steel reinforcement is taken Fe415.

The structural detail of the building is given in Table:-

Table 4.1: Structural Detail

S.NO.	PARTICULARS	SPECIFICATIONS
1	Base Floor Plan	40*40 m
2	Storey Height	4m
3	Vertical Columns	0.6*0.6m
4	Primary Beams	0.4*0.3m ,0.3*0.3m
5	Number Of Storeys Inclined	Top 10 stories with 10degree inclination from 30^{th} storey
6	Depth Of Foundation	20m
7	Type Of Soil	Hard
8	Type Of Concrete	M 25
9	Reinforcing Steel	Fe 415

Various analyses to be done are concrete design and comparison amongst shear core provided structure and the structure without shear core. This would give the amount of concrete required for the construction work and also help in the cost analysis of the structure. Next analysis to be done is locating the center of gravity in both the cases and would help in determining the effect of the shear core on the structures stability. The P-Delta analysis of the structure would help in finding the lateral drift of the storey hence the lateral loads effect can be easily found out. The time history analysis would give the response of the structure under the influence of the realistic earthquake data obtained from the United States Geological Survey website and hence would help in understanding the linear and non linear behavior of the structure. Response spectrum analysis is a linear analysis and it helps in finding the steady state response of the structure under different oscillations when a single shock or vibration is applied. Push over analysis is the non linear analysis which helps in understanding up to which limit the structure would be able to withstand the lateral loads before undergoing overturning.

Table 4.2: Various Linear and Non Linear Analyses

LINEAR ANALYSIS	NON LINEAR ANALYSIS
Response spectrum analysis	-
Time history analysis	Time history analysis
-	P-Delta analysis

The various analysis and design to be taken out in this research are given in table:-

Table 4.3: Various Design & Analyses

S.NO.	WITHOUT SHEARWALL	WITH SHEARWALL
1	Concrete Design	Concrete Design & Shear Core Design
2	Locating The C.G.	Locating The C.G.
3	P-Delta Analysis	P-Delta Analysis
4	Time History Analysis	Time History Analysis
5	Response Spectrum Analysis	Response Spectrum Analysis

- Concrete design of the structure is done as per the IS 456 recommendations.
- Centre of gravity of the leaned tower is automatically located and determined by STAAD. Pro V8i.
- For the P-Delta analysis the no. of iterations taken is 10. The analysis will determine the deflection in columns and hence the max. Lateral deflection/ drift can be found out.
- Time history analysis is carried out to determine the seismic response of the structure under the real time data of the earthquake happened in past time.
- The data of time v/s acceleration is taken out from the UNITED STATES GEOLOGICAL SURVEY website.
- Response spectrum analysis is a linear analysis and is done with the help of same vibration or shocks.
- With the help of the various analysis results obtained the safer structure is to be determined.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Concrete & Shear Core Design

Quantity of concrete and the amount of reinforcement is determined using STAAD. Pro software. Also the design of shear wall is performed on STAAD. Pro V8i.

The quantity of concrete and reinforcing steel along with the bar dia. is obtained. The quantity of steel required for design of slabs is not included in the result however the detailed steel reinforcement design result can be obtained from the STAAD output file .The total volume of concrete required for the construction of structure without shear wall is 8143.5 meter cube and the detail of the reinforcement to be provided is give below in table.

Table 5.1: Reinforcement Detail

BAR DIAMETER(mm)	WEIGHT (NEWTON)	
	WITHOUT SHEAR CORE	WITH SHEAR CORE
8	1402604	1421167
10	357118	419814
12	2008366	2239126
16	2348758	1880853
20	2898976	2896659
25	1137714	917502
32	103073	83251
40	4645	-
Total	**10261253**	**9858372**

Now the concrete quantity and reinforcement quantity required for the construction of the leaning tower with shear wall is obtained , however it can be noted that the quantity of concrete for shear core is not included in the below result . The total volume of the concrete required for construction is 8208.3 meter cube and the detail of the reinforcement is given below.

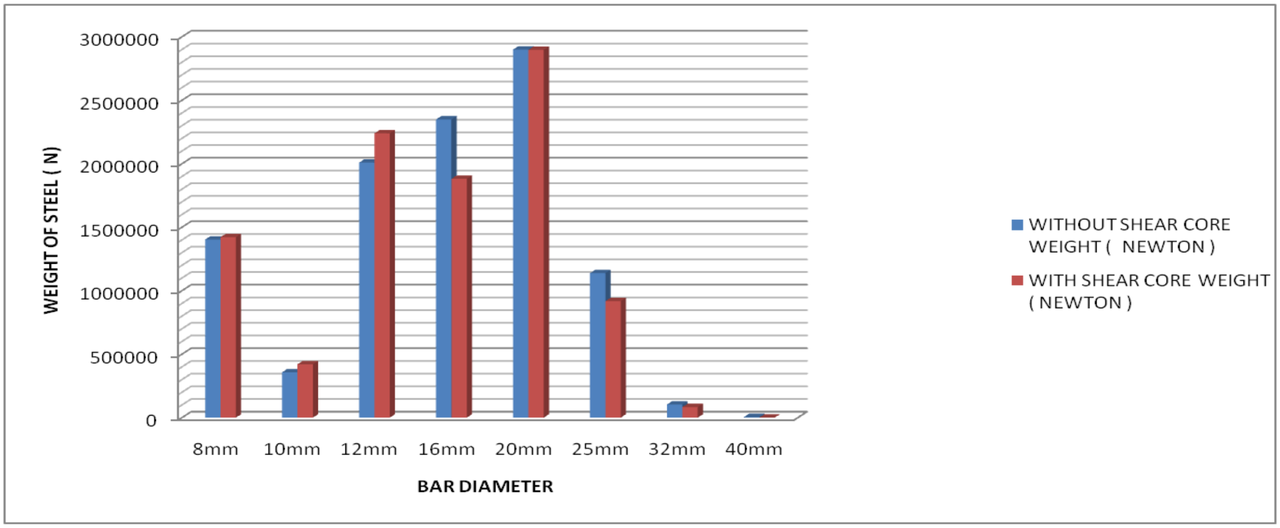

Fig. 5.1: Quantity of Steel

Clearly it can be seen that the quantity of steel reinforcement required for design using shear core is less than that is required in without shear core design. The steel reinforcement required in case of shear core is 3.9% lesser than the standard structure.
The max. Dia. of bar included in the shear core structure is 32 mm however the max. dia. of bar in case of normal structure is 40mm which is quite high and not accepted as the allowable dia. to be used at site is 32mm depending upon the bar availability.

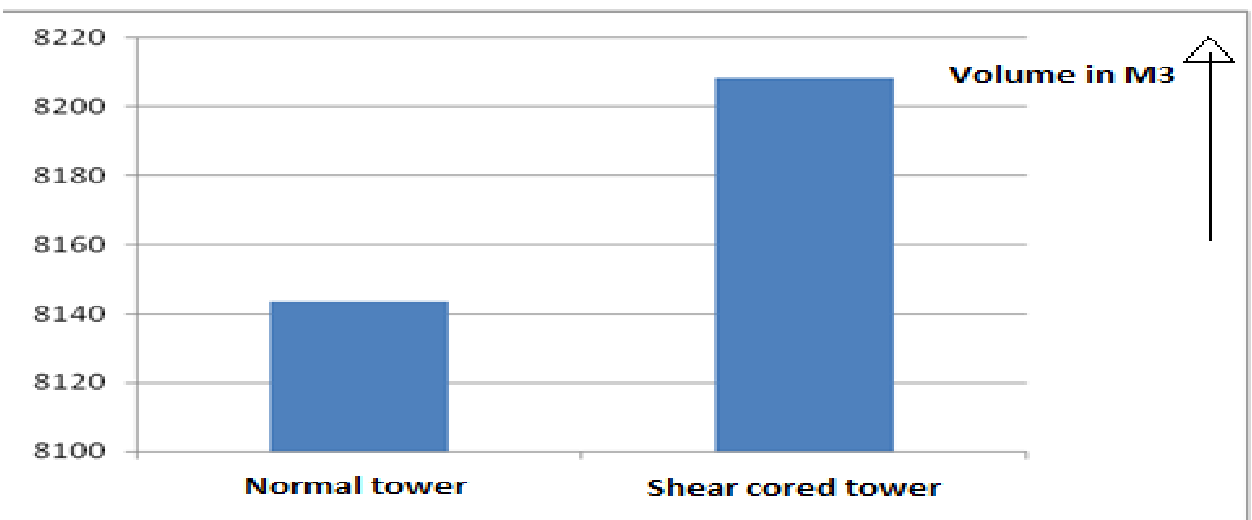

Fig 5.2: Volume of Concrete

The amount of concrete required in case of shear cored structure is 0.789% greater than the normal structure. Reason behind this increase is the presence of shear core which is an RCC panel structure hence greater quantity of concrete is needed.

5.2 Locating the C.G.

With the help of the staad pro the centre of gravity of the structure can be easily found out.

The location of the C.G. for structure without shear core is give below in table below,

Table 5.2: Location of C.G.

AXIS	DISTANCE(M)	
	WITHOUT CORE	**WITH CORE**
X	19.3137	20.0149
Y	62.6289	62.4936
Z	19.9981	19.9147
SELF WEIGHT	**343904.2188 (KN)**	**357665.9062 (KN)**

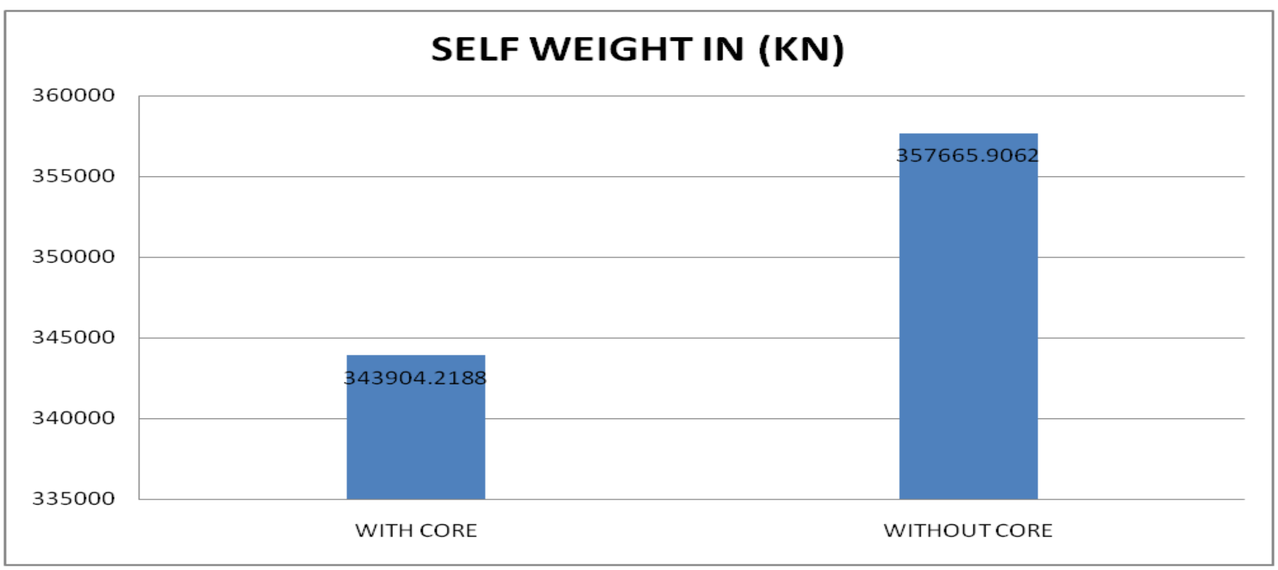

Fig 5.3 Self Weight

It can be seen that the self-weight of the structure is 3.84% less in case of the shear cored structure, hence the structure in case of shear core is lighter that that without shear core.

Clearly it can be seen that the centre of gravity of the structure is get shifted slightly towards the centre of the structure in case of shear core, also the C.G. is shifted downward.

Hence it can be concluded that the shear core helps in maintaining the C.G. of the structure.

It can be seen that the self-weight of the structure is get increased in case of the shear cored structure hence the stability of the structure is obtained greatly in case of the cored structure.

5.3 P-Delta Analysis Result

The values of p-delta analysis is most critical in the case of seismic loading , values for the displacement , moment and reactions are given in the table below,

Table 5.3: P-Delta Result For Without Shear Core

DIRECTION	MAX. LOAD (TOTAL)	MAX. REACTION	MAX. DISPLACEMENT	NODE NO.	MOMENT AT ORIGIN
X	183.40 KN	-183.4 KN	7.01664E-01	3762	-
Y	0.00 KN	0.00KN	4.24379E-02	3878	-
Z	0.00 KN	0.00KN	4.32009E-05	3432	-
MX	-	-	-	-	0.00 KN.m
MY	-	-	-	-	3667.96 KN.m
MZ	-	-	-	-	16904 KN.m

Now the p-delta result for tower with shear core in the case of seismic loading is given below,

Table 5.4: P-Delta Result with Shear Core

DIRECTION	MAX LOAD (TOTAL)	MAX. REACTION	MAX. DISPLACEMENT	NODE NO.	MOMENT AT ORIGIN
X	190.64 KN	-190.64KN	6.61455E-01	3762	-
Y	0.00	0.00KN	4.45621E-02	3876	-
Z	0.00	0.00KN	7.09283E-03	4145	-
MX	-	-	-	-	0.00 KN.m
MY	-	-	-	-	3799.22 KN.m
MZ	-	-	-	-	-17557 KN.m

Now the comparison for maximum displacement in both the cases is given below in the Table,

Table 5.5: Max. Displacement

DIRECTION	MAX. DISPLACEMENT	
	WITHOUT SHEAR CORE	WITH SHEAR CORE
X	7.01664E-01	6.61455E-01
Y	4.24379E-02	4.45621E-02
Z	4.32009E-05	7.09283E-03

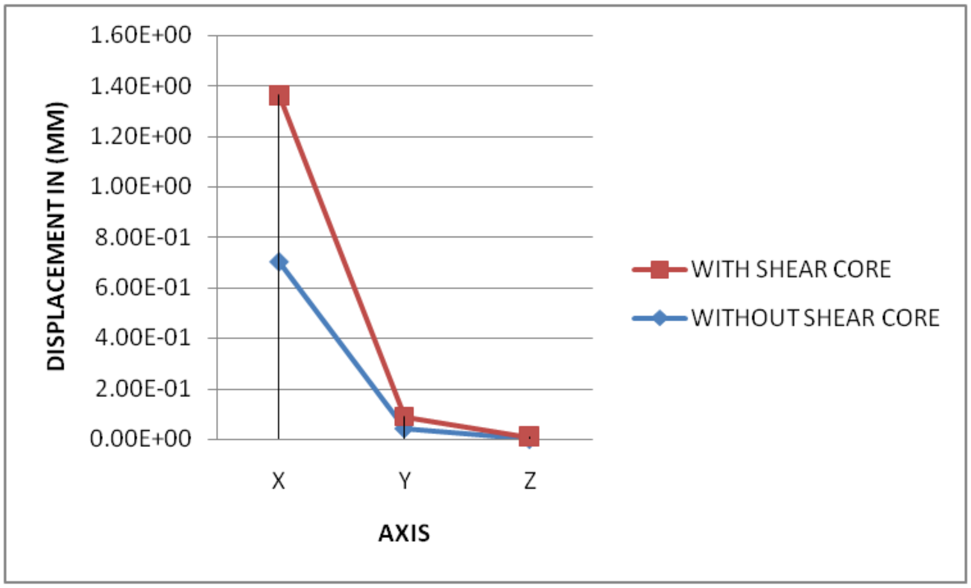

Fig 5.4: Deflection Comparison

Clearly it can be seen from the above graph that the deflection in case of shear cored structure is lesser than the other one , the reason behind this difference is the presence of shear core which resists the storey shift hence allowing the structure to withstand lateral loads easily. It can be seen that the deflection in case of shear cored structure is 5.7% lesser than the structure without core.

5.4 Time History Analysis

The result for time history analysis in case of without shear wall is given in table below,

Table 5.6: Time History Result

MODE	FREQUENCY(CYCLE/SEC)		PERIOD(SEC)
	WITHOUT CORE	WITH SHEAR CORE	
1	2.62	2.630	0.38174
2	2.909	2.915	0.34378
3	2.951	3.018	0.33888
4	3.18	3.19	0.31444
5	3.341	3.34	0.29930
6	3.35	3.42	0.29851

The number of mode shapes taken was equal to 6, this result shows that at the earlier stage the frequency was high and it decreases with increase in time.

From the result obtained from shear core tower it can be seen that the frequency at earlier stage is higher in comparison to later stages. However it can be known that as compared to regular leaning tower the tower with shear core has average1.0977% higher frequency .This may be due to the decrease in self-weight of structure with shear core.

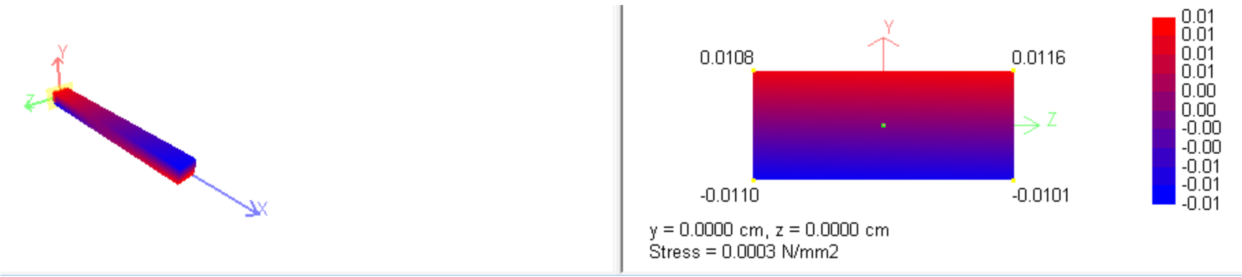

Fig 5.5: Beams Stress Diagram

The maximum base shear and the minimum base shear is given below in the table below,

Table 5.7: Base Shear Comparison

VALUE	WITHOUT SHEAR CORE(KN)	WITH SHEAR CORE(KN)
MAXIMUM	203.256	125.069
MINIMUM	-204.62	-82.864

The above values shows that the shear force in case of normal structure without shear core has 38.46% greater force than shear cored structure and hence may undergo shear deformation early.

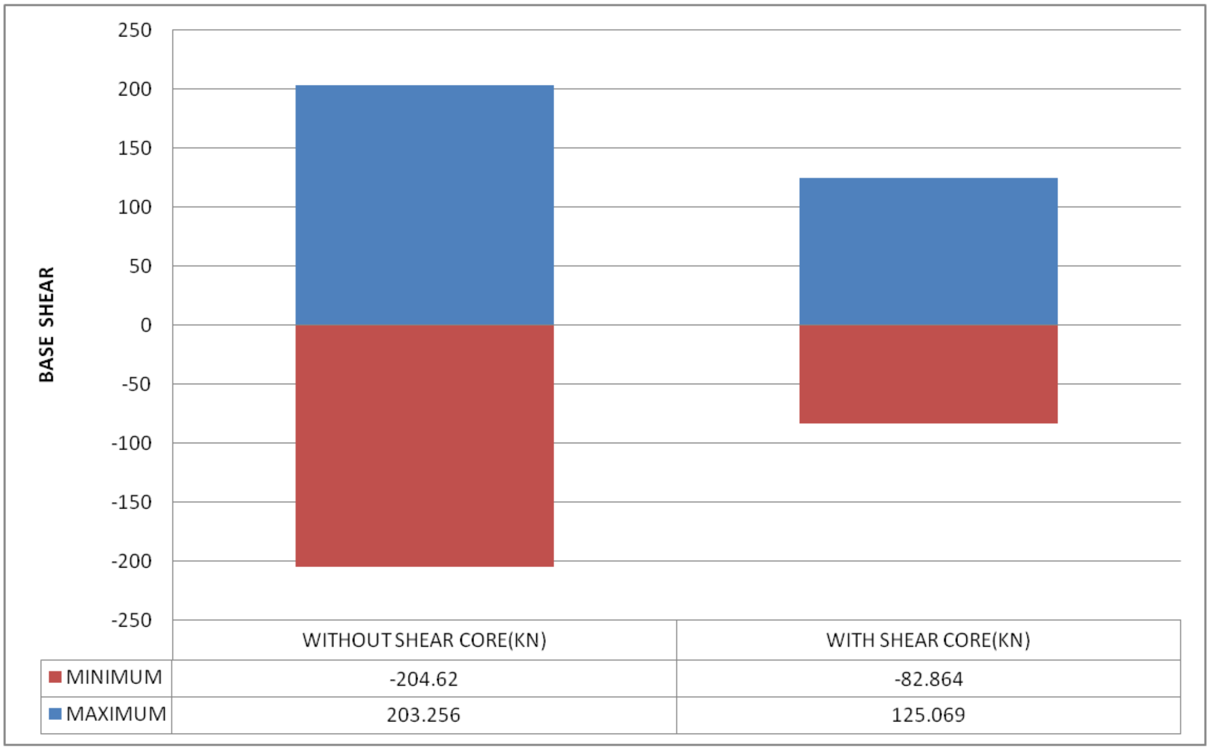

Fig 5.6: Max. Base Shear Comparison

The result for various max. & min. values are also give below in the figure for normal leaning tower,

Beam End Force Summary

The signs of the forces at end B of each beam have been reversed. For example: this means that the Min Fx entry gives the largest tension value for an beam.

				Axial	Shear		Torsion	Bending	
	Beam	Node	L/C	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	3451	1706	26:GENERATE	**8.88E+3**	-155.436	0.000	0.000	-0.000	-624.286
Min Fx	303	3	5:WL Z	**-1.81E+3**	-4.911	-108.529	-1.048	438.241	-19.114
Max Fy	3482	1737	27:GENERATE	5.61E+3	**203.256**	0.000	-0.000	-0.000	423.082
Min Fy	959	370	23:GENERATE	5.08E+3	**-204.620**	3.378	0.017	-6.396	-434.499
Max Fz	1584	706	28:GENERATE	5.96E+3	5.610	**218.981**	3.246	-461.580	9.972
Min Fz	5364	2752	29:GENERATE	5.96E+3	5.610	**-218.981**	-3.246	461.580	9.973
Max Mx	10418	3901	9:GENERATEI	21.582	-29.782	0.957	**37.399**	-0.765	-33.792
Min Mx	7580	672	9:GENERATEI	21.581	62.356	-0.957	**-37.394**	1.149	61.374
Max My	4082	2048	29:GENERATE	6.29E+3	1.638	-201.123	-1.696	**718.233**	4.297
Min My	2822	1366	28:GENERATE	6.29E+3	1.638	201.123	1.696	**-718.233**	4.297
Max Mz	3460	1715	27:GENERATE	5.99E+3	189.673	0.000	-0.000	-0.000	**670.614**
Min Mz	3455	1710	26:GENERATE	5.9E+3	-188.852	0.000	0.000	-0.000	**-674.157**

Fig 5.7: Data for Shear, Torsion and Bending and Axial Force

From the above result it can be seen that the max base shear occurs at the base floor with column no. 3482. Also, the minimum shear force is produced in the inner column no. 959 at the base floor.

The result for various max. & min. values are given below in the figure for tower with shear core.

Beam End Force Summary

The signs of the forces at end B of each beam have been reversed. For example: this means that the Min Fx entry gives the largest tension value for an beam.

				Axial	Shear		Torsion	Bending	
	Beam	Node	L/C	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	3452	1707	4:GENERATEI	**7.64E+3**	-1.729	-0.115	-0.018	0.402	-6.377
Min Fx	15065	1408	4:GENERATEI	**-78.263**	20.482	0.001	0.004	0.451	15.801
Max Fy	10237	2377	4:GENERATEI	-2.587	**125.069**	0.084	-0.569	-0.086	169.690
Min Fy	8238	1693	4:GENERATEI	0.154	**-82.864**	0.103	-0.389	0.202	126.670
Max Fz	4409	2375	4:GENERATEI	181.551	33.877	**77.535**	0.061	-129.070	58.239
Min Fz	2519	1352	4:GENERATEI	180.107	32.842	**-72.104**	-0.344	120.020	56.448
Max Mx	10242	320	4:GENERATEI	-19.801	68.482	1.038	**29.100**	-0.989	94.760
Min Mx	10252	3730	4:GENERATEI	-19.793	68.647	-1.036	**-29.458**	0.988	95.240
Max My	4409	2386	4:GENERATEI	130.658	33.877	77.535	0.061	**181.069**	-77.269
Min My	2519	1363	4:GENERATEI	129.214	32.842	-72.104	-0.344	**-168.394**	-74.918
Max Mz	10238	2718	4:GENERATEI	-2.636	125.033	0.270	-1.440	-0.270	**169.764**
Min Mz	5030	2718	4:GENERATEI	336.184	99.337	-7.523	-0.271	-18.236	**-242.919**

Fig 5.8: Data for Shear, Torsion and Bending and Axial Force

Clearly it can be seen that the max base shear is obtained for base floor column no. 10237. However, the min. shear is found in the beam 8238 of shear core, this may be due to the shear core presence.

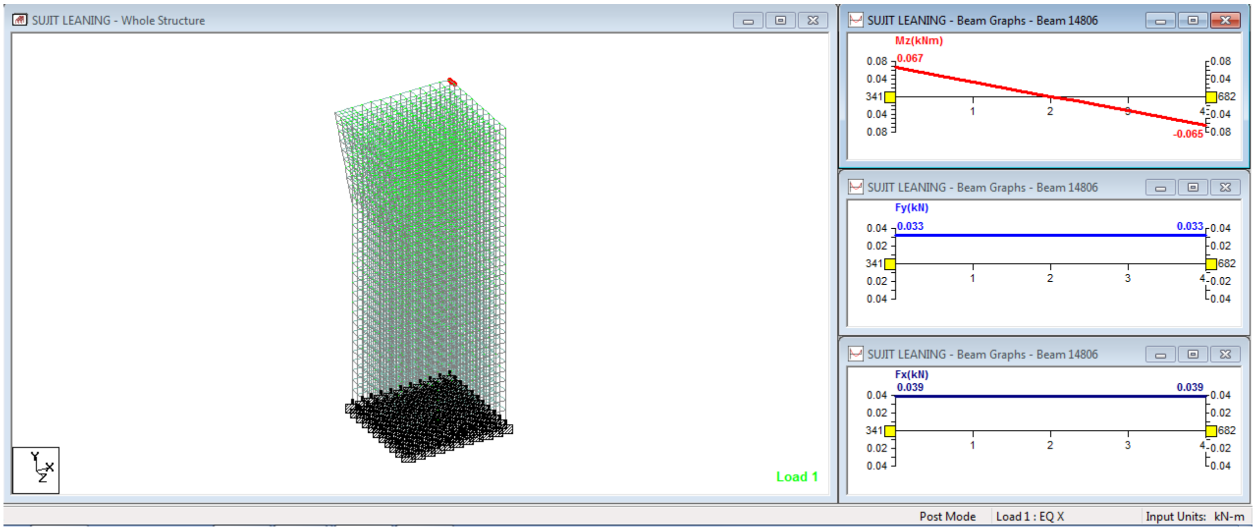

Fig 5.9: SF & BM Diagram for a Beam Member

5.5 Response Spectrum Analysis

The Modal Participation Factor Result for the RSA of the structure obtained from ETABS is given below in the table,

Table 5.8: Base Shear Comparison

	BASE SHEAR(KN)	
CASE	**WITH CORE**	**WITHOUT CORE**
EQ	-815432.6	-756452.6
RS	785642.32	696487.7

It Can Be Seen From The Above Result That The Ratio of EQ & RS Base Shear In Case Of Without Shear Core Is 0.92079 And That In Case Of With Shera Core Is 0.963467 Which Is The Required Percentage Of Minimum 85%, Hence The Base Shear Obtained Is Correct.

The story displacement of the structure is shown below in the figure,

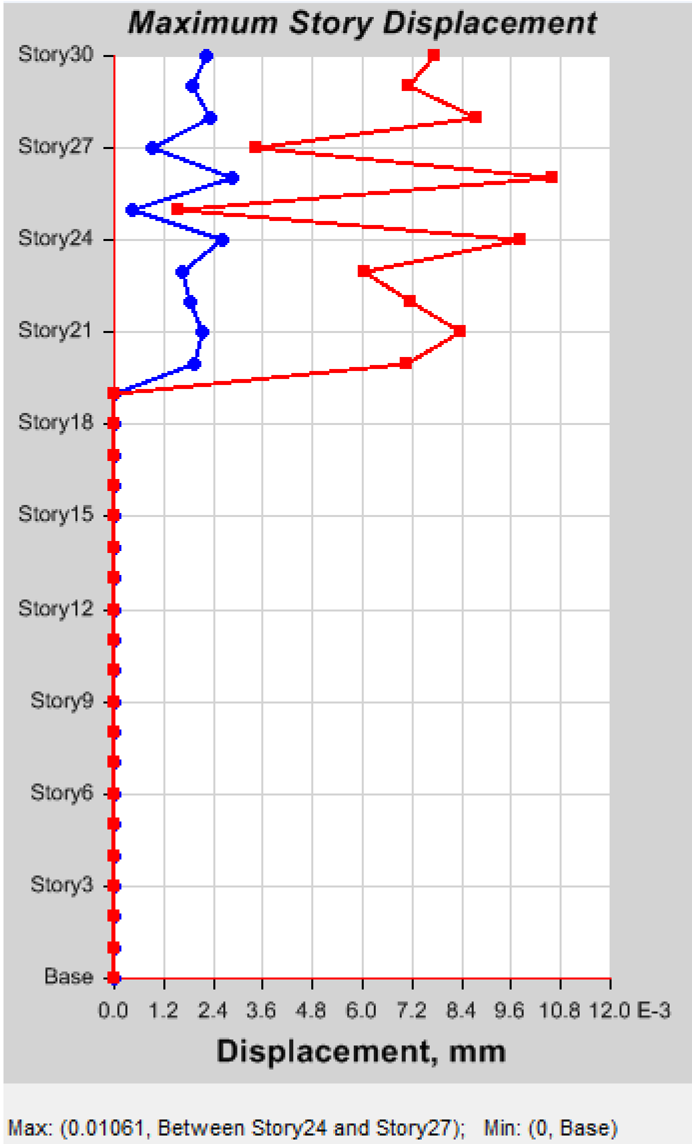

Fig. 5.10: Story Displacement

The modal participation mass ratio specified by IS Code is minimum of 90%. This mass ratio is obtained in the 81st mode hence the minimum number of modes required for the analysis of the structure is 81. It can be seen from the above figure that the max. Displacement in the structure is below H/60-H/100 as specified by the IS code.

CHAPTER 6
CONCLUSIONS

Following conclusions can be derived from the analytical results obtained:-

1- From the concrete design obtained, it can be seen that the quantity of reinforcement & concrete required for shear cored tower is higher than the normal leaned tower by 0.789%.
2- The C.G. is get shifted towards the centre of the structure and also to downwards as compared to conventional one. Hence greater stability will be acquired by providing shear core.
3- The base shear is maximum at the base of the building in both cases of with and without shear core.
4- The base shear in case of normal structure in 38.46% more than the shear cored structure.
5- From the time history analysis it's seen that at the initial phase of vibration the frequency was high, however it gets decreased at later ages.
6- Frequency in case of shear cored structure is 1.097% greater than the without cored structure.
7- Because of heavy weight of shear cored tower the frequency of structure is higher at all ages.
8- The p-delta analysis of the columns showed that the structures storey drift is 5.75% lesser in case of shear cored structure.
9- The various analysis showed that the shear cored leaning tower is much stable and safer than the other tower without shear core.
10- From the Response spectrum analysis it's clear that the minimum number of mode shapes required is 81.
11- From the various analysis performed it's found that the structure with shear core is safer than the structure without core.

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THANK YOU