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Non-Linear Analysis of Asymmetric Structures

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Abstract: The study of multi-story building behaviour always depends on strength, durability, stiffness and adequacy of the regular configuration of the structures. Understanding the seismic behaviour of asymmetric structures is a challenging task, considering the aspect of irregularity (either in the plan or elevation) is generally known as asymmetric. Various researchers had studied the behaviour of this asymmetrical building by taking into considerations of different approaches such as plan configuration, vertical irregularity, mass and stiffness, in different methods of analysis. The irregular structures are less prone to the seismic forces, hence there is a need to study and specify some improvements in codal provisions for this type of asymmetrical structures. In the present study, we have considered a plan irregular structure (which replicates the Microsoft building at Hyderabad). The overall structural behaviour of asymmetrical building is investigated under different earthquake cases, such as with El-Centro, Loma and Uttarkashi database. Analysis of structure (using software program E-TABS V-17) for various earthquake intensities and checking for multiple criteria at every level for essential practice. The non-linear methods Time History analysis is carried over to find the structural behaviour.
Keywords: multi-story building, plan irregularity, Time history analysis.

I. INTRODUCTION

In recent days, tall structures are becoming slenderer which increases the possibility of extra sway compared to prior high-rise buildings. Because of increasing urbanisation and population growth, there is a high demand for tall building construction all over the world. Because of the increase in population, the availability of land for construction has decreased. As a result, with less land available, a large number of buildings are constructed, resulting in high-rise buildings. In response to the increased demand for high-rise buildings, these structures are designed with aesthetic views in mind. As a result, building structures may have uneven mass, stiffness, and strength distributions across their height. The structural engineer's task gets more challenging when such constructions are located in a high seismic zone. As a result, the structural engineer must be well-versed in irregular structure seismic response. In today's society, many buildings have uneven elevation and plan arrangements. Earthquake forces are more likely to damage such structures. More major elements that reduce the seismic behaviour of structures are structural imperfections.

According to Indian Standard, structures are categorised as structurally regular or irregular. The plan, vertical, and lateral force resisting systems of regular structures have no substantial discontinuities. Damage can be easily caused by buildings with abnormalities. The behaviour of multi-story buildings during strong earthquakes is determined by the building's bulk, stiffness, and strength distribution in both horizontal and vertical planes. Discontinuities in stiffness, mass, or strength along the diaphragm can cause a building's weakness.

A. Types of Irregularities

According to the current code, an "irregular structure" is one that has a specific geometric shape or that has stiffness and mass discontinuities. As the demand for architecture views of buildings grows, the concept of irregularity emerges.

The configuration of a building is classified as two types of irregularities as per the code IS1893-2016.

1) *Plan Irregularity:* Any structure which has different in mass distributions or load patterning are called as irregular structure in plan.

If a building has:

a) Torsional irregularity which is due to eccentric mass in asymmetric plan
b) Common re-entrant corners
c) Excessive slab openings or cut-outs
d) Out-of-plane offset in vertical elements like columns along the perimeter
e) Non-parallel load resisting systems then such building termed as a plan irregularity as per IS1893.

Buildings with irregular plans appear to be more susceptible to large deformations and damage when subjected to strong ground motion than those with regular plans, owing to the additional torsional forces caused by the existing eccentricity between the centres of mass and the rigidity of the resisting elements.

2) *Vertical Irregularity:* The irregularity in the building may be due to irregular distributions of mass, strength and stiffness along the height of the building. As per IS1893 these are of five types,
a) Irregularity in Stiffness
b) Irregularity in Mass
c) Irregularity in Vertical Geometry
d) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force
e) Discontinuity in Capacity

B. Scope of the Project

In this topic, we will talk about the Microsoft building in Hyderabad, Telangana. This building is considered to have an irregular structure.

The goal is to identify and observe the seismic irregularity of the building in response to various earthquake data inputs.

Because of its irregularities, the irregular structure will suffer severe damage as a result of the earthquake. To investigate its effects, a high-raised irregular building is considered and analysed using the etabs software, taking into account various earthquake data.

II. METHODOLOGY

A. Salient Features

The building plan and its geometry

1) Dimensions of the Plan : 90mx50m
2) The number of storeys : 20 storey
3) Height of a typical storey : 3m
4) Height of the bottom storey : 3m
5) Height in total : 60m
6) the number of bays in the x direction : 18
7) the number of bays in the x direction : 14
8) Bay width in both the x and y directions: 5m
9) Material Properties
a) Slab beam & column - M30 N/mm^2
b) Reinforcement – Fe 550N/mm^2

10) Frame section (beam and column)
a) *1 – 9th floor*

Interior column dimensions = 380mmx750mm
Exterior column dimensions = 380mmx600mm
Beam dimensions = 380mmx450mm

b) *10th – 15th floor*

Interior column dimensions = 380mmx600mm
Exterior column dimensions = 380mmx450mm
Beam dimensions = 300mmx450mm

c) *16th – 20th floor*

Interior column dimensions = 300mmx450mm
Exterior column dimensions = 300mmx450mm
Beam dimensions = 230mmx300mm

11) slab section

Slab – 125 mm

B. Software Approach

Extended Three-Dimensional Analysis of Building System (ETABS) is an abbreviation for Extended Three-Dimensional Analysis of Building System. It is a sophisticated and appropriate special purpose analysis and design programme designed specifically for building systems. Increases the productivity of structural engineers in the building industry.

This thesis' research is based on an examination of structural models that describe asymmetric multi-story structures. The first section of this chapter defines the computational models, as well as the basic assumptions and building geometries that were investigated for this study.

The structures chosen were constructed in accordance with Indian standards. This chapter's second section provides a high-level overview of the design approach used in this study. A building's structural irregularity has a significant impact on seismic response. As a result, structural irregularity must be considered when developing seismic design approaches. In addition, seismic design code techniques are based on elastic analysis and a single degree of freedom (SDOF) system, both of which are unrealistic. First, the building models with irregularity magnitude and position under gravity loading have been described in this chapter. Second, for structural building analysis, a Non-Linear Time History Analysis approach was used.

Etabs V17 is being used to model and analyse a twenty-story reinforced concrete frame structure.

C. Method of Analysis

Working State Method and Limit State Method are two methods for dealing with gravity.

1) *Working State Method:* This was the earliest approach of design. It is based on elastic theory, with the assumption that steel and concrete are both elastic and obey Hook's law. It means that stress is proportional to strain up to the point of collapse. The materials' allowed stresses are computed using the elastic theory and the assumption that the steel-concrete bond is ideal. The allowed stresses are not exceeded anywhere in the structure when the structure is subjected to the worst combination of operating loads, according to this procedure. The ultimate strength of concrete and yield strength or 0.2 percent proof stress of steel are divided by safety parameters to obtain acceptable stresses. These safety factors take into consideration the inherent uncertainties in the production of these materials. Bending compressive stresses in concrete should have a factor of safety of 3 and yield/proof strength in steel should have a factor of safety of 1.78, according to IS 456, and yield/proof strength in steel should have a factor of safety of 1.78.
2) *Limit State Method:* This is the most logical way because it takes into account both the structure's ultimate strength and its serviceability requirements. It's a clever mix of working stress and ultimate load design techniques. Before failure, a limit state is defined as the permitted boundaries of safety and serviceability criteria. The ideas of ultimate load safety (ultimate load approach) and working load serviceability are used in this method (working stress method).
3) *Seismic Approach:* To determine the seismic resistance and behaviour of a building under applied seismic frequencies, various types of analysis are used. The analysis can be performed based on the external applied loads, structural materials used, and structure type, and it is classified as follows:

a) Linear static analysis and nonlinear static analysis are two types of static analysis.
b) Linear Dynamic Analysis and Nonlinear Dynamic Analysis are two types of dynamic analysis.

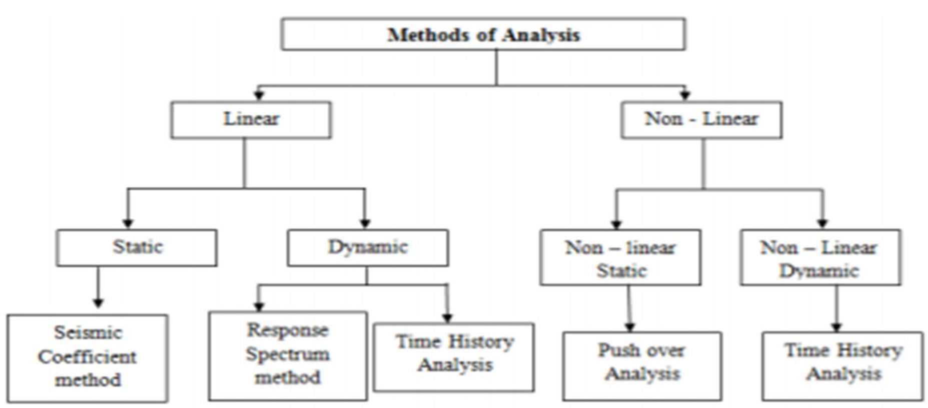

Figure 1: Method of Analysis

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D. *Analysis Using Etabs*

1) *Loading Procedure*

a) Define different loads (Dead load, live load, Earthquake load and wind load)
- Dead Load: The self-weight multiplier is set to 1 by default to calculate dead load.
- Live load
- Floor Finish Load and
- Wall Load
- Seismic load

b) Assigning the load to the structure
- *Gravity Loading*
  - Select the floor objects and provide the floor finish load as 1.0 KN/m^2
  - Select the floor objects again and provide the shell distributed load i.e., live load as 3 KN/m^2
  - Select the beam objects and provide the frame distributed load i.e., live load as $6N/m^2$
- *Seismic loading*
  - Zone factor – 0.16, for zone III
  - Response reduction factor – 3
  - Soil Type – II
  - Importance factor – 1.5
  - Number of modes to consider – 15
  - Factor of scale – Ig/2R
  - The least amount of eccentricity – 0.05
  - The Damping – 5 percent
  - The Mass source – 1DL + 0.5 LL
  - Diaphragm design – Rigid

c) *Define Load Combinations*
- The load combinations used for analysing the structure with gravity loads are as follows:
  - 1.5*(D.L + L.L)
- The load combinations used for analysing the structure with Lateral loads are as follows:
  - 1.5*(D.L + L.L + WL + FF)
  - 1.5*(D.L + L.L + WL - FF)
  - 1.2*(D.L + L.L + WL + FF + EQX)
  - 1.2*(D.L + L.L + WL + FF - EQX)
  - 1.2*(D.L + L.L + WL + FF + EQY)
  - 1.2*(D.L + L.L + WL + FF - EQY)
  - 0.9 *(D.L + L.L + WL + FF) + 1.5 * EQX
  - 0.9 *(D.L + L.L + WL + FF) - 1.5 * EQX

2) *Restraint*

a) After the complete loading of the structure, the building should be made to restraint at the bottom of the structure which shows that it is fixed at the bottom.

b) Select one story and select enter story of the plan (base floor) and assign the restraint property from the assign.

3) *Run*

a) The number of modes to be considered in this dynamic structural analysis should be at least 90% of the total seismic mass. The dynamic response of the building will be evaluated at each time interval in this analysis. This analysis could be performed using previously recorded ground movement data from earthquake databases.

b) During earthquake analysis, the slab in a building is treated as a single rigid member. To accomplish this, all slabs are chosen first and diaphragm action is used for rigid or semi-rigid conditions.
c) Define the time history function by inputting the different earthquake data i.e., El-centro data, 1989 loma data and Uttarkasi data by considering three different models.
d) Check the model for any error like overlapping of any objects.
e) Run the analysis by simply pressing the key F5.

III. RESULTS AND DISCUSSIONS

The results of different models have been compared. Storey displacement, storey drift, base shear, and time history are some of the factors. The study' findings, as well as the parameters for each model, are plotted on a graph and explained more below.
For the first time, the basic model is analysed without lateral loads, and the results of the following parameters, such as time period mode shape storey drift and displacement, are compared to the structure analysed with el-centro earthquake data, Loma earthquake data, and Uttarkasi earthquake data.

The following parameters are similar in all models, as shown in the table below.

Table 1: Modal Participating Mass Ratios (regular)

Mode	Period (sec)	UX	UY	Sum UX	Sum UY
1	2.767	0.2305	0.3348	0.2305	0.3348
2	2.445	0.003	0.2518	0.2335	0.5866
3	2.308	0.4906	0.1321	0.7242	0.7187
4	0.968	0.0548	0.0782	0.779	0.7969
5	0.878	0.0012	0.0557	0.7802	0.8525
6	0.838	0.1027	0.0281	0.8829	0.8807
7	0.534	0.0114	0.0159	0.8943	0.8965
8	0.49	0.0005	0.0122	0.8948	0.9087
9	0.469	0.0212	0.0054	0.916	0.9141
10	0.371	0.0085	0.0115	0.9245	0.9256
11	0.341	0.0003	0.0089	0.9248	0.9345
12	0.326	0.0154	0.0039	0.9402	0.9384
13	0.287	0.0047	0.0065	0.945	0.9449
14	0.266	0.0003	0.0052	0.9452	0.9502
15	0.255	0.0085	0.0023	0.9537	0.9525

The above table are the time period and the mass participating values where these values are similar to the other three models.

A. Comparison of three models

Using time history analysis of El-Centro, Loam, and uttarkasi data applied to respective models, factors such as storey displacement, time period, storey drift, and base shear were compared. The findings of the analysis, as well as the parameters associated with each model, are plotted on a graph and contrasted and discussed in the following way.

B. Comparison Between Structure with El-centro data, Loam data and Uttarkasi data Models

Given below are the comparison between structure with El-centro data, Loam data and uttarkasi data. The results will be compared in this section and will be concluded respectively.

C. Comparison of Storey Displacements

The results which are obtained for comparison of El-centro data, Loam data and uttarkasi data in X and Y direction are shown in below table below and plotted as shown in graph 17 and 18.

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Table 2: Maximum Story Displacement in x and y Dir.

Story	El-Centro		Loam		Uttarkasi	
	X	Y	X	Y	X	Y
1	7.813	6.764	7.709	7.6	5.228	4.779
2	20.704	17.68	21.297	21.522	14.334	12.859
3	33.059	28.176	36.232	37.182	24.205	21.119
4	49.188	40.076	51.366	53.304	34.058	28.636
5	64.557	52.633	66.332	69.464	43.637	35.201
6	76.049	61.944	80.962	85.477	52.797	43.26
7	81.488	66.221	95.167	101.255	61.387	51.092
8	80.414	71.068	108.946	116.817	69.246	58.498
9	76.551	74.658	122.594	132.527	76.315	65.383
10	80.945	75.599	140.046	152.615	84.162	73.27
11	89.065	74.244	159.874	175.711	91.136	80.61
12	95.262	84.245	181.09	198.632	95.379	85.508
13	99.031	90.612	202.359	220.347	97.343	87.578
14	100.388	92.698	222.066	240.422	98.54	87.184
15	105.237	90.969	239.819	258.541	97.798	93.256
16	113.758	98.845	255.526	274.628	104.426	101.573
17	119.996	113.56	266.759	286.359	113.511	108.548
18	126.805	126.105	275.849	296.043	119.679	115.225
19	134.116	135.711	282.934	303.838	123.51	120.95
20	138.791	142.087	288.03	309.776	125.602	124.872

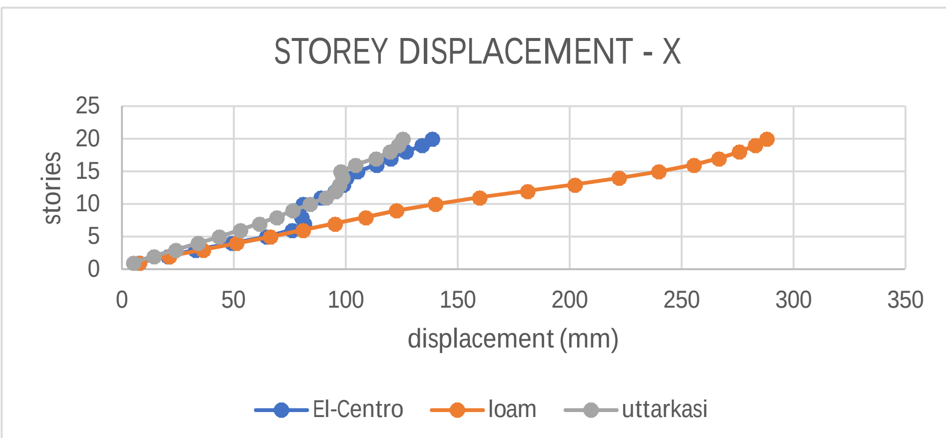

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Figure 2: Represents comparison of storey displacement in El-centro data, Loam data and uttarkasi data model in X-direction.

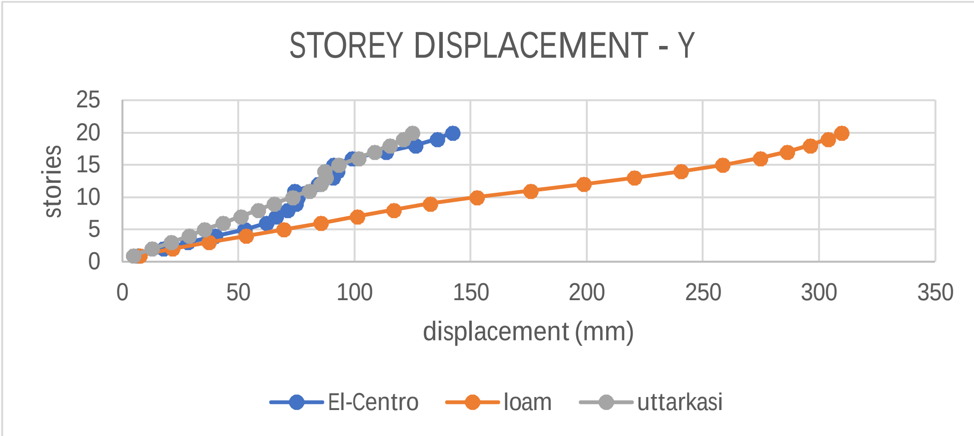

Figure 3: Represents comparison of storey displacement in El-centro data, Loam data and uttarkasi data model in Y-directions.

The above table compares the values of storey displacement. Maximum storey displacement obtained from structure in El-centro data, Loam data and uttarkasi data model is 138.791 mm 288.03 mm and 125.602mm respectively in X direction and 138.791 mm 309.776 mm and 124.872 mm respectively in Y-direction.

D. Comparison of time Period and Frequency

The values of time period (sec) and Frequency are obtained and comparison of structures El-centro data, Loam data and uttarkasi data model are noted.

Table 3: Time Period and Frequency

Mode	El-centro		Loma		Uttarkasi	
	Period	Frequency	Period	Frequency	Period	Frequency
1	2.767	0.361	2.767	0.361	2.767	0.361
2	2.445	0.409	2.445	0.409	2.445	0.409
3	2.308	0.433	2.308	0.433	2.308	0.433
4	0.968	1.034	0.968	1.034	0.968	1.034
5	0.878	1.138	0.878	1.138	0.878	1.138
6	0.838	1.193	0.838	1.193	0.838	1.193
7	0.534	1.872	0.534	1.872	0.534	1.872
8	0.49	2.041	0.49	2.041	0.49	2.041
9	0.469	2.13	0.469	2.13	0.469	2.13
10	0.371	2.696	0.371	2.696	0.371	2.696
11	0.341	2.936	0.341	2.936	0.341	2.936
12	0.326	3.067	0.326	3.067	0.326	3.067
13	0.287	3.482	0.287	3.482	0.287	3.482
14	0.266	3.762	0.266	3.762	0.266	3.762
15	0.255	3.916	0.255	3.916	0.255	3.916

When compared the three model the time period and frequency both are similar in three of the models after the modal analysis.

E. Comparison of Story Drift

The storey drift results obtained for comparing the three different model are provided in table below and plotted in below graphs.

Table 4: Maximum Story Drift in X and Y Dir.

Story	El-centro		Loma		Uttarkasi	
	X	Y	X	Y	X	Y
1	0.002615	0.003354	0.00257	0.002533	0.001743	0.001593
2	0.004556	0.005388	0.004529	0.004641	0.003036	0.002693
3	0.00493	0.006376	0.004978	0.00522	0.00329	0.002753
4	0.004765	0.007394	0.005045	0.005374	0.003284	0.002688
5	0.004284	0.008573	0.004989	0.005387	0.003193	0.002708
6	0.003616	0.007465	0.004877	0.005338	0.003053	0.002686
7	0.002851	0.005844	0.004735	0.005259	0.002863	0.00261
8	0.002633	0.005789	0.004726	0.005187	0.002681	0.002469
9	0.002646	0.005338	0.004825	0.005237	0.002564	0.002533
10	0.005777	0.006067	0.006412	0.006696	0.003559	0.00419
11	0.007498	0.004845	0.007484	0.007699	0.00417	0.005246
12	0.006672	0.002539	0.007456	0.007745	0.004453	0.005124
13	0.00626	0.002343	0.00709	0.007444	0.005262	0.004485
14	0.00648	0.002489	0.006569	0.006962	0.005656	0.004804
15	0.007757	0.003025	0.005918	0.006342	0.005483	0.004936
16	0.00851	0.003436	0.005236	0.005711	0.004788	0.00457
17	0.007484	0.003927	0.003744	0.004146	0.003028	0.003182
18	0.008126	0.004095	0.00303	0.003414	0.002323	0.002344
19	0.006987	0.003741	0.002362	0.002732	0.002033	0.002021
20	0.004249	0.00218	0.001699	0.002055	0.001396	0.001418

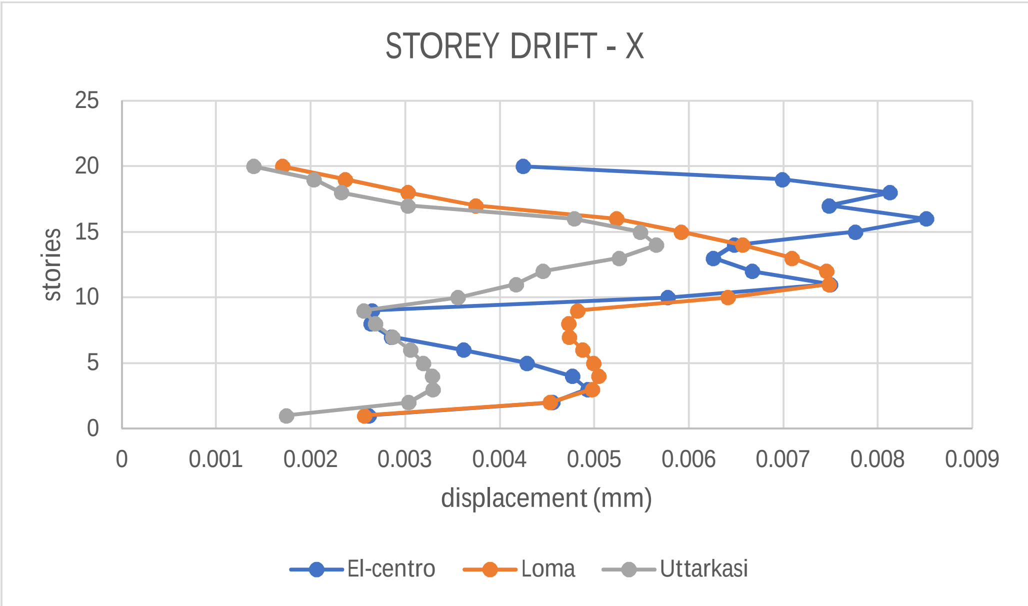

Figure 4: Represents comparison of story drift in X-direction between the structure with El-centro data, Loam data and uttarkasi data.

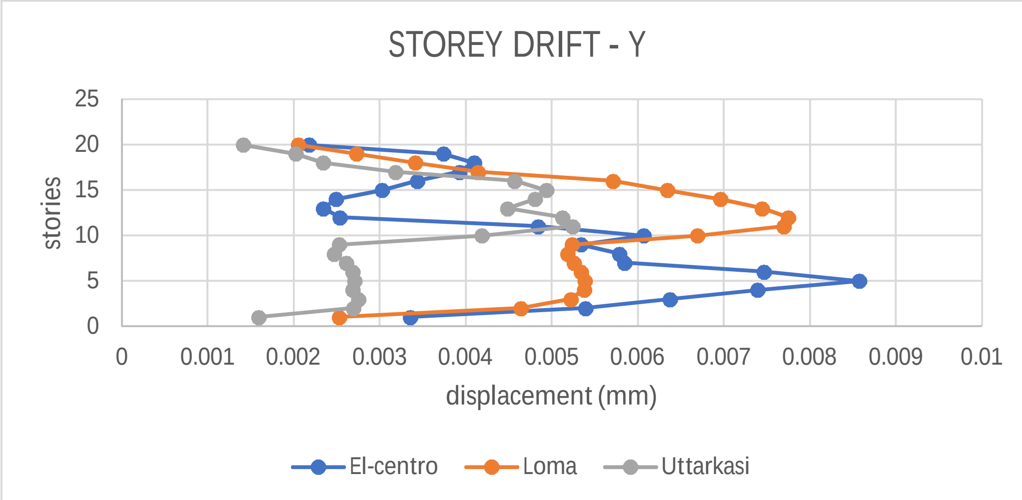

Figure 5: Represents comparison of story drift in Y-direction between structure with El-centro data, Loam data and uttarkasi data.

Maximum drift in the X and Y directions with El-Centro data model was found to be at storey 16 of 0.00851 mm and 0.008573 mm at story 5, Loma data model was found to be at storey 11 of 0.007484 mm and 0.007745 mm at story 12, Uttarkasi data model was found to be at storey 14 of 0.005656 mm and 0.005246 mm at story 11 respectively.

F. Base shear comparison

The maximum base shear in the x and y directions for three different models is compared in the table below and plotted in the graph below.

Table 5: Base Shear

El-centro		Loma		Uttarkasi	
FX (kN)	FY (kN)	FX (kN)	FY (kN)	FX (kN)	FY (kN)
14741.13	10946.677	15666.097	13104.868	15716.966	13110.459

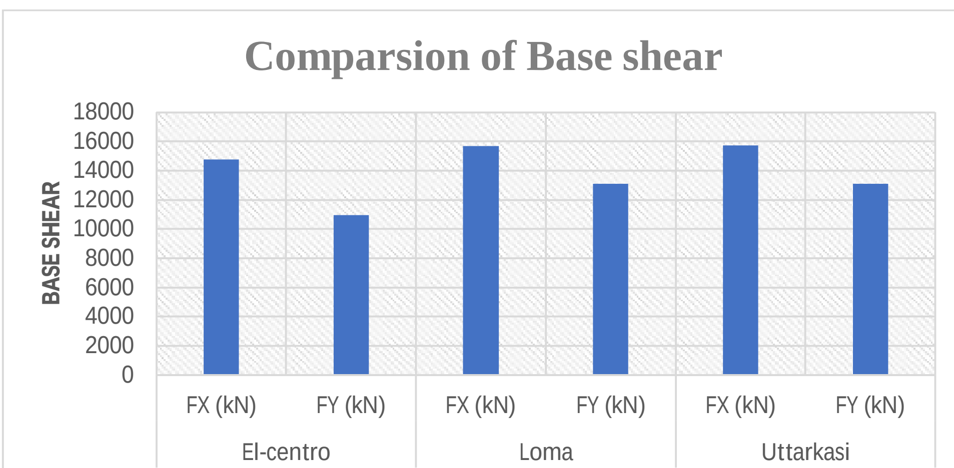

Figure 6: Represents comparison of base shear in x and y direction between the structure with El-centro data, Loam data and uttarkasi data.

According to the results, the base shear in X-direction with El-centro data model is 14741.13 kN, Loam data model is 15666.097 kN and uttarkasi data model is 15716.966 kN and the base shear in Y-direction with El-centro data model is 10946.677 kN, Loam data model is 13104.868 kN, uttarkasi data model is 13110.459 kN.

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Last but not the least this project is dedicated to my family, for without their blessings nothing would have been possible.

V. CONCLUSION

A. The storey displacement obtained for the structures under different earthquake data (El-Centro data, Loam data and Uttarkashi data) in X-direction is 138.791mm 288.03mm and 125.602mm respectively and in Y-direction is 138.791mm 309.776mm and 124.872mm respectively.

B. The percentile amount of the story displacement in X-direction when compared the Uttarkashi model with the El-Centro and Loma Model is 90% and 44% respectively.

C. The time period and frequency when compared both are similar in three of the models after the modal analysis.

D. The maximum story drift in X and Y direction with El-Centro data model was found to be at storey 16 of 0.00851 mm and 0.008573 mm at story 5, with Loma data model was found to be at storey 11 of 0.007484 mm and 0.007745 mm at story 12, and finally Uttarkashi data model was found to be at storey 14 of 0.005656 mm and 0.005246 mm at story 11.

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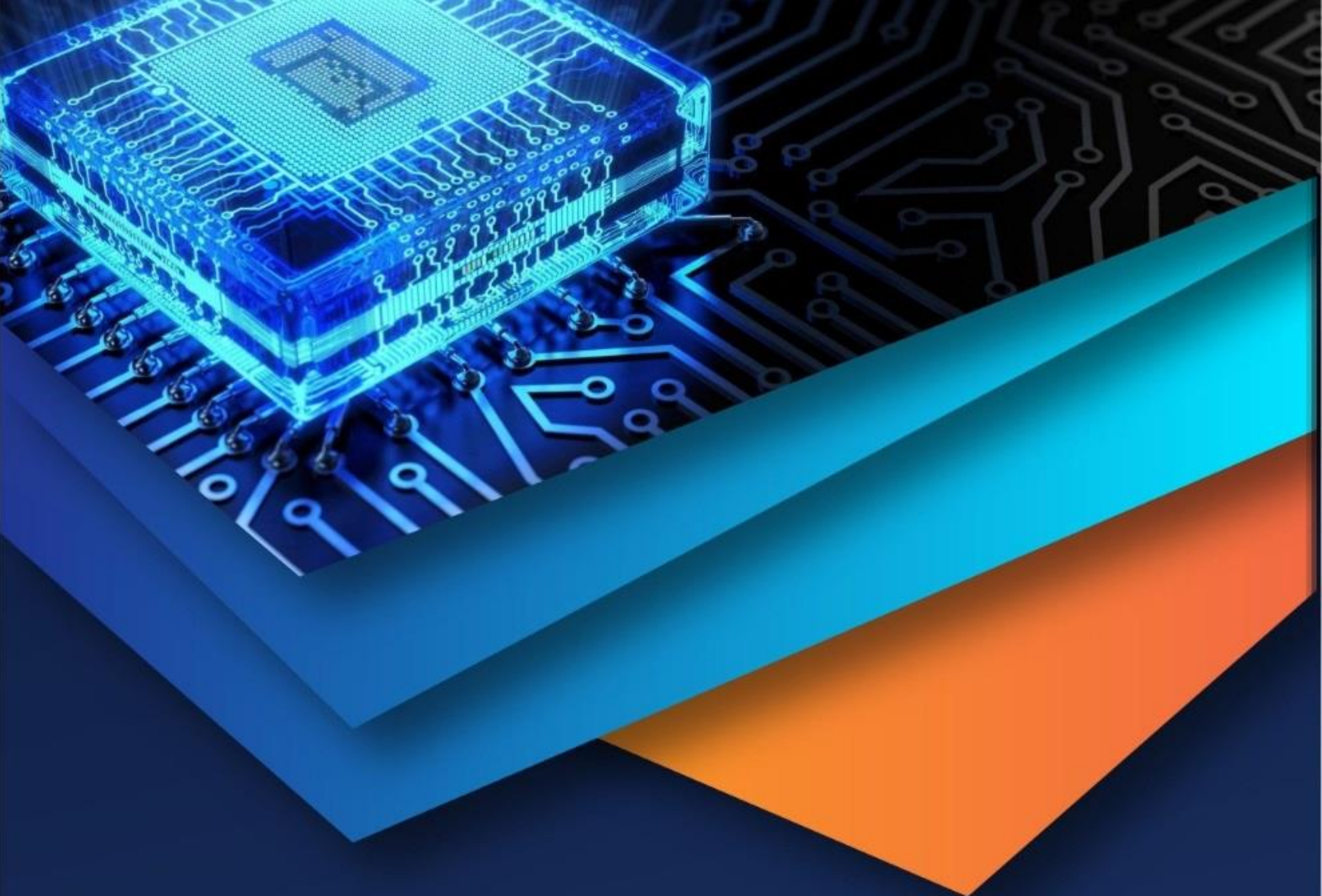
- IS 875: 2015 PART 1, 2, 3 LOADS
- IS 456: 2000 PLAIN AND REINFORCED CONCRETE STRUCTURE
- IS 1893: 2016 CRETIRIA FOR EARTHQUAKE RESISTANT DESIGN

The percentile amount of the base shear for the El Centro data model in X-direction when compared with the Loma and Uttarkashi model is 94.1% and 93.7%



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45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

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