Seismic analysis of vertically geometric irregular structures

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***Abstract*—Due to the advancement in construction, materials and non-availability of land there is a demand of constructing multi storey structures in the society. In multistory structures different types of loads are acting in that more dangerous is earthquake which shakes the surface of ground and releases the energy in the form of seismic waves. The forces caused by the earthquakes are very high and also they are random in nature so we cannot predict them, hence proper care should be taken in the design of multistory structures so that the lateral load resisting system should be well enough to withstand the forces coming due to the earthquakes. In this study the vertical geometric irregular RC buildings of 15 storey are studied for seismic performance. Here five buildings, one regular and four irregular buildings are considered with geometric irregularity by considering the IS 1893 codal provisions and analysis is done by ETBAS 2016 version using three different seismic analysis methods (linear static, response spectrum and time history method) The analysis is done. Bhuj time history is used for time history method. The analysis is done according IS 1893-2016(part 1). Results shows that linear static method gives higher results in terms of storey displacement, base shear, story drift compared to response spectrum. This study also shows that the stiffness is important parameter in seismic analysis in response spectrum and time history method. It is concluded that geometric irregular buildings are more vulnerable to earthquakes and proper care should be taken in design of these buildings.**

***Keywords* — Geometric irregularity, response spectrum, time history, stiffness**

I. INTRODUCTION

Due to the advancement in construction, materials and non-availability of land there is a demand of constructing multi storey structures in the society. In multistory structures different types of loads are acting in that more dangerous is earthquake which shakes the surface of ground and releases the energy in the form of seismic waves. Earthquakes are devastating in nature and has the ability to cause severe damage to the RC buildings. Earthquakes are classified based on the magnitude of ground motion i.e. light, moderate, strong, great earthquake, earthquakes are also classified based on effect of earthquakes on structures. In the world some of the parts are more prone to seismic effect, in that some parts of India like north east states, Gujarat, parts of Jammu Kashmir and Uttarakhand are earthquake prone areas compared to other parts where in other parts of India (more than 50%) are also subjected to seismic effect. The seismic zone map of India is divided into four zone namely, II III IV V based on risk of earthquakes at particular place and occurred earthquakes at that place. These zoning are assigned based on the peak ground acceleration, also called as design ground acceleration.

The regular buildings in plan and elevation perform well in earthquakes due to the proper distribution of forces along buildings. In different types of irregularities the vertical irregularity is dangerous because of its variation in stiffness, mass and strength the irregularities in buildings are 1) Horizontal irregularity 2) Vertical irregularity.

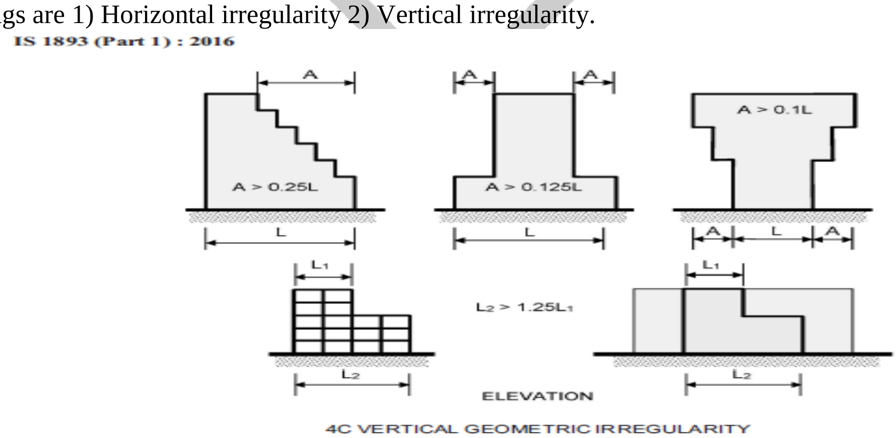


Fig. 1 IS 1893 specification for geometric irregularity

II. Literature review

Different studies have been carried out for the seismic analysis of RC structures some of them are

S.Chandrashekaran et al- conducted a detailed dynamic analysis of 10 story RC frame building using response spectrum method based on Indian codal provisions and different seismic parameters like base shear, story shear, and story drifts are computed [7]. **Alok Madan et al**-An analytical evaluation of 14 story RC building frame is analyzed by using the nonlinear dynamic time history analysis and nonlinear static analysis. Here in this paper effect of masonry infill walls in building during seismic performance are analyzed by using masonry infill RC frame and other models by eliminating the infill walls at various floors like ground floor [1]. **N. R. Chandak –**in this paper the parametric study on RC structural walls and moment resisting frames buildings of structural types using response spectrum method is carried out.in this 6 different buildings models considered with three structural types namely symmetric, monosymmetric, unsymmetrical are considered and analysis is being done [6]. **S Patil et al** have conducted the nonlinear dynamic analysis (time history) of ten storied RC frame with and without soft storey by considering the different seismic intensities are carried and responses of such building are studied. Results shows that the seismic parameters like base shear, displacement, story drifts are found to be varied in similar pattern with increased intensities. **Mahmood Hosseini et al** have conducted the seismic analysis on how good the IBC 2009 and ACI 318-2014 provide LS PL (life safety performance level) of particular building in Tehran for this they have taken buildings with different storey like 4,7,9,13,16 and analysis is being done for RC special moment resisting frame by taking highest seismic zone [4].

From the above studies it shows various studies are done to find the performance of various RC buildings with different irregularities like horizontal irregularity(torsion irregularity, reentrant corner,) and vertical irregularity (mass ,stiffness and strength irregularity) so in this project geometric irregularity at upper stories by keeping mass same for irregular buildings is studied.

III. OBJECTIVES

1) To study seismic parameters (base shear, storey displacement, storey drift, time period) of the vertical geometric irregular RC structures by linear static method, response spectrum method.
2) To study RC building response when the geometric irregular structures are subjected to ground motion data (BHUJ time history) by time history method.

IV. ANALYSIS METHODS

Linear static method (Equivalent static method)

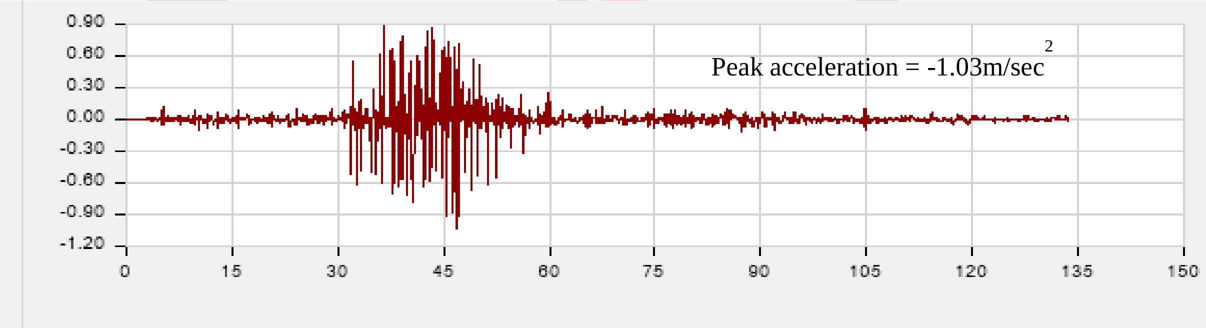
It is a method where the earthquake (dynamic) load is applied as a static load i.e. lateral force to the buildings. This method computation is easy because of periods and higher mode shapes of buildings of particular earthquake load are not considered.

Response spectrum analysis

This is a linear dynamic analysis where the multiple mode response shapes of building are considered for the analysis. In this method the variability of mass and stiffness is taken into account for the calculation of seismic parameters. This method is suitable for irregular buildings in plan and elevation where in the effect of higher modes are dominant.

Time history analysis

It is the nonlinear type seismic (dynamic) analysis which involves step by step analysis of building model in time domain of multi-degree of system with the time history of any earthquake as data applied at base of the building model. This method gives time dependent response (dynamic) of building in which the solution is direct function (numerical integration) of input earthquake ground motion.



Graph 1 showing time history of BHUJ vs acceleration

The analysis is done using the above three methods and since seismic response parameters for linear static method gives higher values, and the values obtained from dynamic analysis are obtained in normalized form hence according to IS 1893 all the response parameters of dynamic analysis (response spectrum and time history) are scaled using scale factor(Ig/2R).

V. MODELLING AND ANALYSIS

In this study different models of G+14 storey of regular and irregular configuration is chosen i.e. one regular structure and five irregular structures with vertical geometric irregularity provided at different sides of building are considered for structures. For model 1 regularity is provided to all the floors and for irregular buildings the bottom 5 storey the setback is not provided only the upper stories are provided with setbacks at different floors.

Description of each model

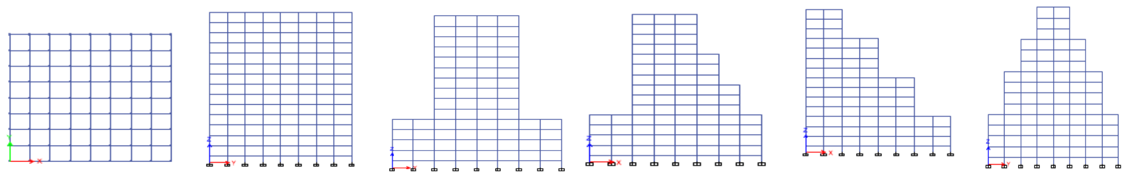
Regular: there is no irregularity provided.

Irregular 1: Setback is provided at 5th storey by sudden reduction in mass and stiffness.

Irregular 2: One side sudden reduction is provided whereas gradually reduced in other side.
Irregular 3: There is no reduction on one side where as gradual reduction on other side.
Irregular 4: Gradual reduction of mass and stiffness on both sides

Models considered for flat ground

- Buildings are of 8 X 8 bay of span 5 m in both direction with a storey height of 3 m



Plan regular irregular 1 irregular 2 irregular 3 irregular 4

Table 1 Different models and their A/L ratio

Models	A/L ratio	IS code limit
Irregular 1	0.25	0.125
Irregular 2	0.375	0.25
Irregular 3	0.75	0.25
Irregular 4	0.375	0.10

Table 2 Different parameters used in the analysis

Parameters	**Description of RC building**
Structure Type	RCC frame structure
Number of Stories	G+14
Storey Height	3m
Bay Width in both direction	5m
Beam Size	300*300,400*400, 500*500 (mm)
Column Size	400*400,500*500, 600*600(mm)
Slab	200,175 (mm)
Grade of Concrete(f_{ck})	Beam M25 Column M30
Grade of steel(Fy)	Fe 415
Live Load(LL)	3 kN /m^2
SIDL (230 mm wall)	12 kN/m
Floor finish load (FF)	1 kN /m^2
Seismic Zone (Z)	V
Importance Factor(I)	1.5
Response Reduction Factor(R)	5
Soil Type	Medium
Type of structure	Special moment resisting frame
Damping	5%
Time history used	Bhuj earthquake

VI. RESULTS AND DISCUSSIONS

The models are analyzed by keeping same mass for irregular buildings except model 1 for all other models same mass is used for analysis.

The analysis is done using the above three methods and since seismic response parameters for linear static method gives higher values, and the values obtained from dynamic analysis are obtained in normalized form hence according to IS 1893 all the response parameters of dynamic analysis (response spectrum and time history) are scaled using scale factor(Ig/2R). Comparison is done between all the methods.

Mass: Regular building has higher mass whereas irregular buildings of same mass is used for structures. Mass of all models are provided in table 3.

Stiffness: Among the buildings regular has more stiffness and among irregular buildings irregular 3 has maximum stiffness compared to other buildings. Stiffness of all models are provided in table 3.

Center of mass (COM) and center of rigidity (COR): since geometric irregular buildings are studied, these buildings center of mass and center of rigidity will not coincide hence causing the building to twist by certain radians.

Displacement:

The regular building shows less top storey displacement values than irregular buildings because of its uniform distribution mass and stiffness along the height and it has more stiffness at higher stories. Linear static gives higher displacement values than response spectrum method because it considers only the fundamental mode. Among irregular buildings since the mass is same based on stiffness the variation of displacement takes place due to this irregular 2 and irregular 3 shows higher displacement. Due to its symmetry irregular 1 shows lesser displacement. The displacement values depends on mass in linear static and for response spectrum it depends on mass and stiffness at higher storey. Lateral Displacement of all models are provided in table 4.

The maximum displacement values from time history gives at 42 to 46 seconds for various models based on acceleration values of bhuj time history.

Base shear: base shear depends on mass and stiffness of buildings hence irregular 1 gives higher base shear. Among irregular buildings since the mass is same the stiffness of irregular 3 and model 4 are more hence base shear of those are more.

Story drifts: story drift depends on displacement of storey roof and floor, lateral displacement depends on stiffness of particular storey. Irregular 3 and model 4 has least stiffness hence they show more drift values. The LSM and RSM gives similar values but the former shows higher values due to its analysis procedure. Except regular, for other models the stiffness at higher storey is less hence maximum storey drift is obtained at higher storey. The obtained drifts values well within the limit (0.004h) provided in IS 1893-2016. The maximum drift seen in the direction of setback irregularity like x direction.

Torsion: torsion arises due to the difference between center of rigidity and center of mass of a building this is more often case in irregular buildings. Here irregular structures are subjected to torsion than regular structures. Regular shows lesser angular acceleration values. Irregular 3 gives maximum angular acceleration among all the models. the graph 6 shows the angular acceleration values.

Table 3 Results of all models

Models	Regular	Irregular 1	Irregular 2	Irregular 3	Irregular 4
Mass(kg)	28589769	19939609	19938557	19938412	19938717
Stiffness(kN/m)	17157771	14596559	14579291	15865158	15176378
Time period (sec)	2.667	2.46	2.294	2.245	2.025

Table 4 Seismic parameters of all models

Parameter	method	Regular		Irregular 1		Irregular 2		Irregular 3		Irregular 4	
		X	Y	X	Y	X	Y	X	Y	X	Y
Displacement (mm)	LSM	81	81	95	93	102	102	102	101	100	95
	RSM	61	62	62.5	63	64	65	69	67	69	65
Base shear (kN)	LSM	5518	5517	4121	4264	4398	4392	4904	4473	4945	5028
	RSM	5512	5512	4095	4239	4390	4392	4873	4466	4909	5012
Maximum Storey drift(10^{-3})	LSM	3.028	3.034	4.155	3.295	3.878	3.867	4.371	3.607	4.23	3.639
	RSM	2.685	2.969	2.929	3.211	3.973	4.019	5.129	4.278	5.048	4.335

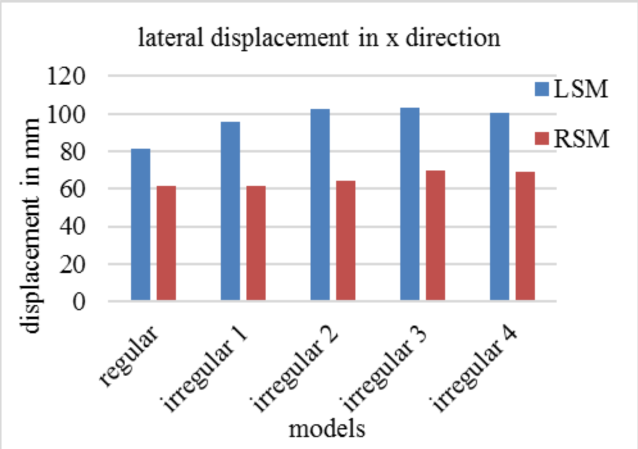
Comparison of parameters from linear static and response spectrum method

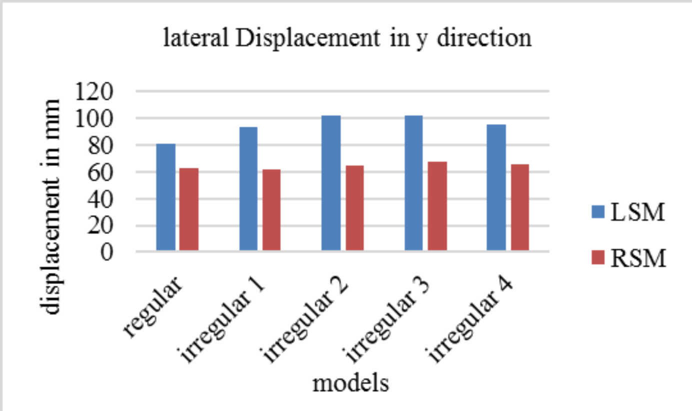
Table 5 Base shear comparison

Models	**EQ X (kN)**	**EQ Y (kN)**	**SPEC X (kN)**	**SPEC Y (kN)**	**% Variation in x**	**% Variation in y**
Regular	5518	5517	4410	4409	25.12	25.13
Irregular 1	4121	4264	3827	3623	7.68	17.69
Irregular 2	4398	4392	3752	3458	17.21	27
Irregular 3	4904	4473	3865	3946	26.81	13.35
Irregular 4	4945	5028	3752	3458	31.79	45.4

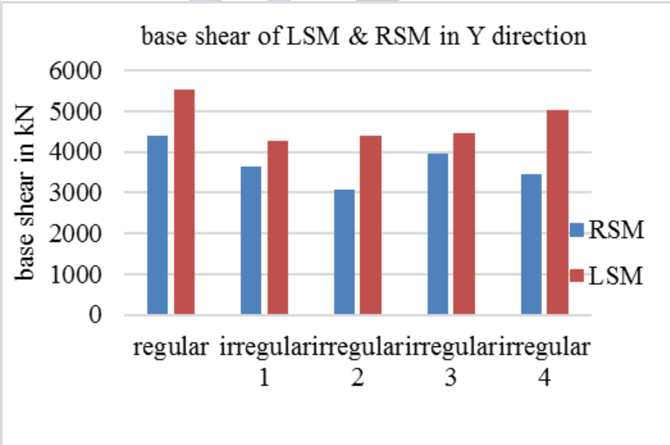
Table 6 Top story Displacement comparison

Models	EQ X (mm)	EQ Y (mm)	SPEC X (mm)	SPEC Y (mm)	% Variation in x	% Variation in y
Regular	81.28	81.42	61.737	62.558	31.6	30.16
Irregular 1	95.93	93.829	61.863	62.29	55.02	50.61
Irregular 2	102.263	102.306	64.243	64.421	59.18	58.80
Irregular 3	102.988	101.772	69.954	67.796	47.10	49.77
Irregular 4	100.768	95.205	69.358	65.555	45.29	45.34

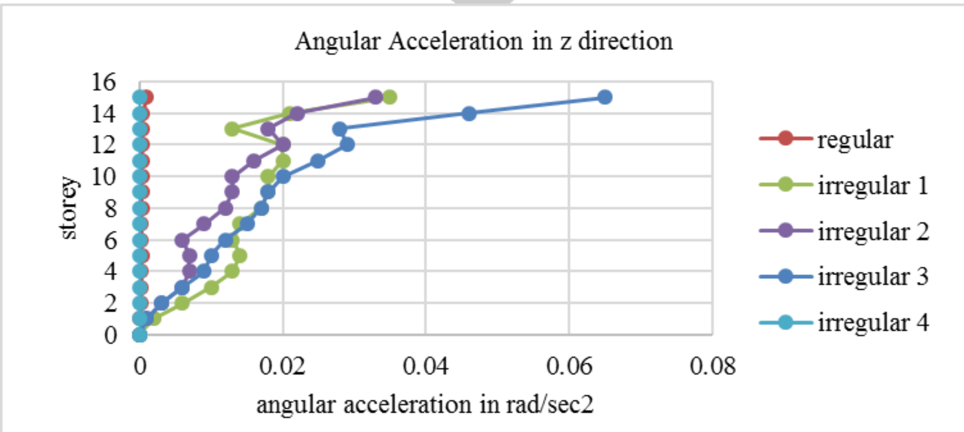




Graph 2 and 3 showing lateral displacement in x and y direction

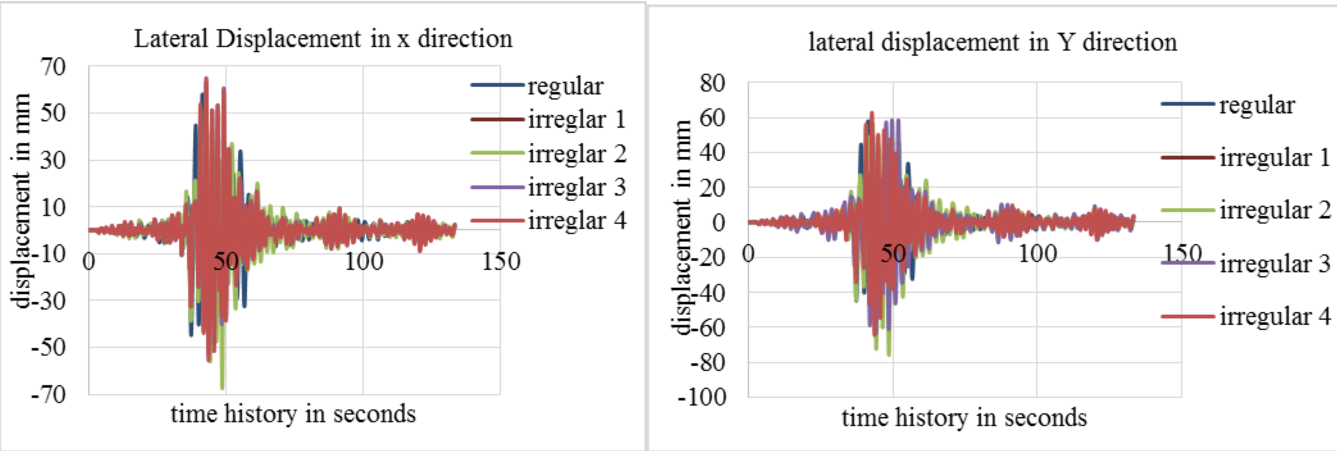


Graph 4 and 5 showing lateral displacement in x and y direction

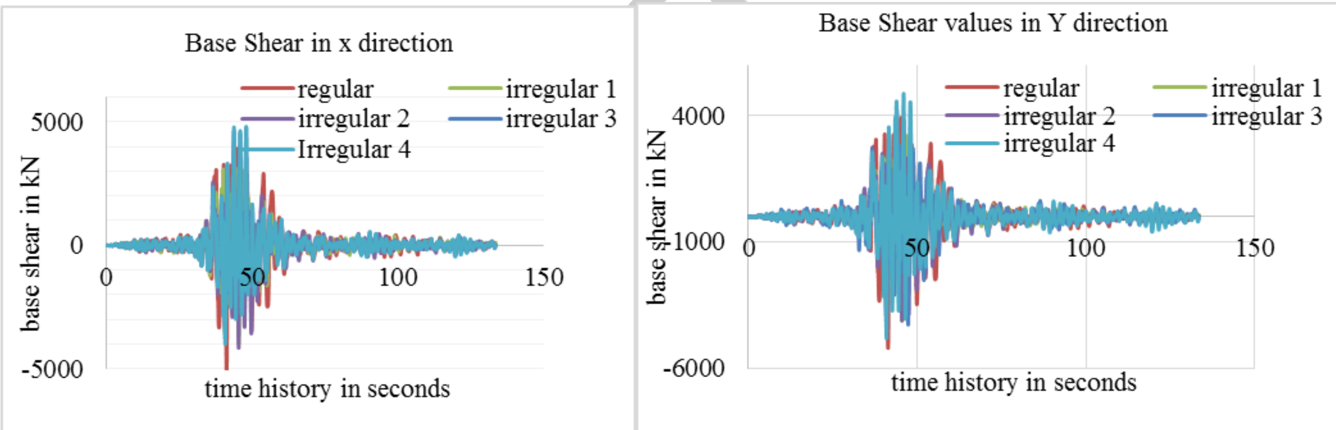


Graph 6 angular acceleration in z direction

Time history results



Graph 7 and 8 showing lateral displacement vs. time history



Graph 8 and 9 showing base shear vs. time history

VII. CONCLUSIONS

The analysis is done by three method namely linear static, response spectrum, and time history method for the structures. The comparative analysis is also done among the models. The following are the conclusion are drawn from this study.

1. Regular building gives lesser values of storey displacement, base shear, storey drift, torsion than geometric irregular buildings.
2. Irregular 1 with geometric irregularity and symmetric to both the axis perform as decent as regular buildings.
3. Among the irregular models geometric irregular buildings where setback provided on both sides (irregular 4) is vulnerable to earthquakes compared to other setback buildings.
4. When the same mass is used for different irregular buildings the stiffness plays important role in seismic performance.
5. Linear static method over estimates the values of seismic parameters (storey displacement, base shear, storey drift) compared to response spectrum method.
6. Compared to regular structures, Irregular structures are subjected to twisting force i.e. torsion.
7. Time history method predicts the correct response of the structure compared to other methods of analysis since it uses real time data.
8. Seeing the storey drift values by all the methods they lie wee within the prescribed limit of IS 1893-2002, linear static gives higher results compared to response spectrum method.

VIII. ACKNOWLEDGMENT

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