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EFFECT OF USING HIGH STRENGTH CONCRETE COLUMNS ON THE STRUCTURAL BEHAVIOUR OF R.C BUILDINGS

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ABSTRACT

Strength, durability and stability are the main criteria for material selection and design in the construction industry. Consequently, development and enhancement of construction materials is always an active and attractive field for engineers and researchers. Elevated temperature (fire) is a potential threat for any structural buildings that can cause a major damage. Response of construction materials exposed to elevated temperature or fire requires a full study and analysis with lessons learned from previous cases. High strength concrete (HSC) has been used in the lower story columns of high rise buildings owing to its qualities over normal strength concrete (NSC) in many countries. But, the full structural qualities of the HSC were unable to be used because of insufficient information regarding the structural behaviour of the material and its properties. Columns moment- curvature curves were developed and maximum inter story drifts were obtained for the different frame models with variation in columns concrete strength. The study shows that frames with HSC columns have got lower stiffness and performed well in satisfying ductility demand. The maximum inter storey drifts are slightly higher for frames with HSC columns, but the contribution of the concrete strength in resisting the lateral deformations was significant. Economic comparisons were also made and it was found that the most economical frame corresponds to frame with the highest columns concrete strength.

KEYWORDS: High strength concrete (HSC), Normal strength concrete (NSC), strength.

INTRODUCTION

In developing countries, the increasing reliance of employment on economic and social considerations is one of the reasons that lead to increasing rural-to-urban migration which in turn lead to increased demand on land use in large cities like Addis Ababa. Following this, more high rise structures are being constructed now than in the past. On the other hand, for the developed countries, the engineering challenge where by the two targets of boasting the longest bridge and the highest building have become serious considerations in the conceptual design of landmark projects is another stimulus for construction of high rise buildings. Thus, the need for higher buildings naturally leads to the conclusion that high strength construction materials will be increasingly used in the future. The following three performance criteria lend weight to the argument for the use of high strength concrete (HSC) for such high rise buildings.

OBJECTIVE OF STUDY

The objective of this project is to investigate the structural behavior of medium to high rise frame building with reinforced HSC columns subjected to seismic lateral load in addition to gravity loads. In light of this, the variation of the different structural responses due to change in columns concrete strength for regular moment resisting building frames will be studied. This will provide data which determines the need for using HSC columns over NSC for medium to high rise buildings and the HSC will be given attention by structural designers. The obtained data which is related to structural responses will act as a supportive document for possible decision to be made on the need for awareness creation in using HSC column and increase confidence that it can be used economically for high rise building frames.

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SCOPE OF THE STUDY

- Only RC buildings are considered.
- Only vertical irregularity was studied.
- Linear elastic analysis was done on the structures.
- Column was modeled as fixed to the base.
- The contribution of infill wall to the stiffness was not considered. Loading due to infill wall was taken into account.
- The effect of soil structure interaction is ignored.

Structural Design consideration of HSC

High-strength concretes have some characteristics and engineering properties that are different from those of normal strength concretes. The use of higher-strength concretes permits more efficient structural designs, allowing members to span longer distances, be smaller in cross section, and carry larger loads. The HSC members design are more likely to be controlled by serviceability and other practical design considerations instead of strength. As a result, special considerations may be required in the design of high-strength concrete structural members.

Structural details:

Concrete grades F_{cs} (MPA)	Equivalent cylindrical strength of concrete F_c (MPA)	Modulus of elasticity E_c (MPA)	Modulus of rupture Fr (MPA)
30	24	23,164.6	4.605
50	40	27,897.5	5.945
70	56	31,744.6	7.034
90	75	35,652.043	8.141
100	83.33	37,207.254	8.581

Transmission of column loads through floor system of HSC column

It has been proposed in this study that beam/slab concrete strength to be used is NSC of C30 and kept constant for all models while columns concrete strength vary from C30 to C90. Based on the ratios of columns concrete strength to that of beam/slab concrete strength, the load transmission of the frame system could be affected.

i) Concrete of strength specified for the column shall be placed in the floor at the column location. Top surface of the column concrete shall extend 0.6m into the slab from face of column. Column concrete shall be well integrated with floor concrete. It requires the placing of two different concrete mixtures in the floor system. The lower strength mixture should be placed while the higher-strength concrete is still plastic and should be adequately vibrated to ensure the concretes are well integrated. This requires careful coordination of the concrete deliveries and the possible use of retarders. In some cases, additional inspection services will be required when this procedure is used. It is important that the higher-strength concrete in the floor in the region of the column be placed before the lower-strength concrete in the remainder of the floor to prevent accidental placing of the low-strength concrete in the column area. It is the responsibility of the licensed design professional to indicate on the drawings where the high- and low-strength concretes are to be placed.

ii) Strength of a column through a floor system shall be based on the lower value of concrete strength with vertical dowels and spirals as required.

iii) For columns laterally supported on four sides by beams of approximately equal depth or by slabs, it shall be permitted to base strength of the column on an assumed concrete strength in the column joint equal to 75 percent of column concrete strength.

METHODS AND ANALYSIS

Seismic analysis:

Seismic analysis is a major tool in earthquake engineering which is used to understand the response of buildings due to seismic excitations in a simpler manner. In the past the buildings were designed just for gravity loads and seismic analysis is a recent development. It is a part of structural analysis and a part of structural design where earthquake is prevalent. There are different types of earthquake analysis methods. Some of them used in the project are-

- Equivalent Static Analysis
- Response Spectrum Analysis
- Time History Analysis

Equivalent static analysis:

The equivalent static analysis procedure consists of the following steps:

1. Estimate the first mode response period of the building from the design response spectra.
2. Use the specific design response spectra to determine that the lateral base shear of the complete building is consistent with the level of post-elastic (ductility) response assumed.
3. Distribute the base shear between the various lumped mass levels usually based on an inverted triangular shear distribution of 90% of the base shear commonly, with 10% of the base shear being imposed at the top level to allow for higher mode effects.

Response spectrum analysis:

In this the magnitude of forces in all directions is calculated and then effects on the building is observed. Following are the types of combination methods:

- absolute - peak values are added together
- square root of the sum of the squares (SRSS)
- complete quadratic combination (CQC) - a method that is an improvement on SRSS for closely spaced modes

The result of a RSM analysis from the response spectrum of a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, because information of the phase is lost in the process of generating the response spectrum.In cases of structures with large irregularity, too tall or of significance to a community in disaster response, the response spectrum approach is no longer appropriate, and more complex analysis is often required, such as non-linear static or dynamic analysis.

Time history analysis:

Time history analysis techniques involve the stepwise solution in the time domain of the multi degree-of-freedom equations of motion which represent the actual response of a building. It is the most sophisticated analysis method available to a structural engineer. Its solution is a direct function of the earthquake ground motion selected as an input parameter for a specific building. This analysis technique is usually limited to checking the suitability of assumptions made during the design of important structures rather than a method of assigning lateral forces themselves.

STRUCTURAL MODELLING:

S.No.	**Type of loads**	**Loads**
1	Live Load	3kN/m^2
2	Density of RCC considered:	25kN/m^3
3	Thickness of slab	150mm
4	Depth of beam	400mm
5	Width of beam	350mm
6	Dimension of column	400x400mm
7	Density of infill	20kN/m^3
8	Thickness of outside wall	20mm
9	Thickness of inner partition wall	15mm
10	Height of each floor	3.5m
11	Earthquake Zone	IV
12	Damping Ratio	5%
13	Importance factor	1
14	Type of Soil	Rocky
15	Type of structure	Special Moment Resisting Frame
16	Response reduction Factor	5

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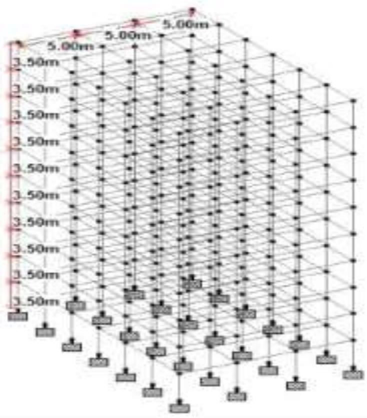
Modelling Regular 10 storied



Plan of regular structure (10 storeys) *3D view of regular structure (10 storeys)*

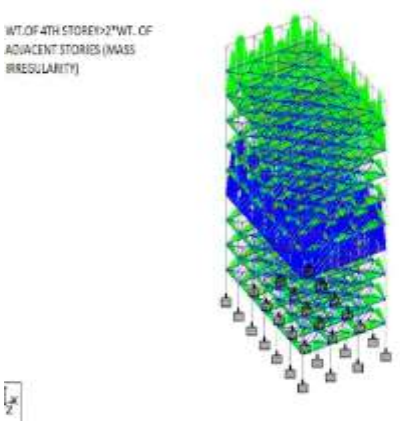
Mass Irregular Structure(10 storeys): The structure is modeled as same as that of regular structure except the loading due to swimming pool is provide in the fourth and eighth floor. Height of swimming pool considered-1.8m. Loading due to swimming pool-18kN/m^2 3D view of mass regular structure (10 storeys) with swimming pools on 4th and 8th storeys.

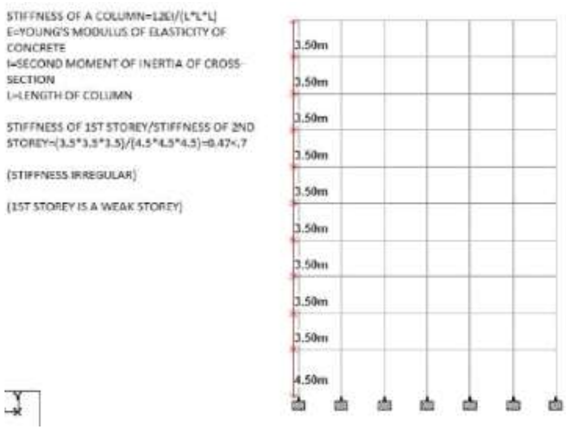
Stiffness Irregular Structure (Soft Storey): The structure is same as that of regular structure but the ground storey has a height of 4.5 m and doesn‘t have brick infill. Stiffness of each column= 12EI/L^3

Stiffness of ground floor/stiffness of other floors= $(3.5/4.5)^3$

=0.47<0.7

Hence as per IS 1893 part 1 the structure is stiffness irregular.





stiffness irregular structure (10 storeys)

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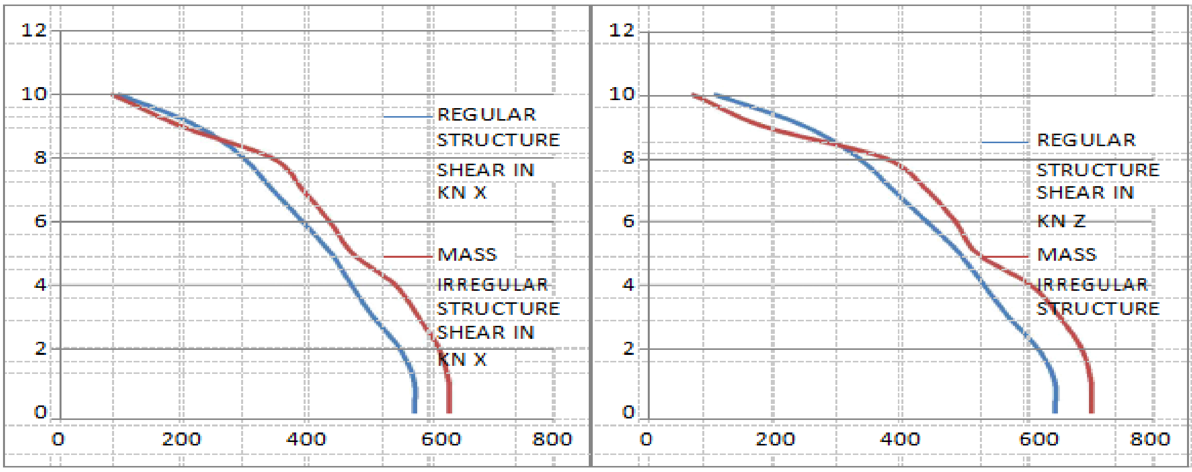
Comparison of Peak storey shear forces of Regular structure and MassIrregular structure

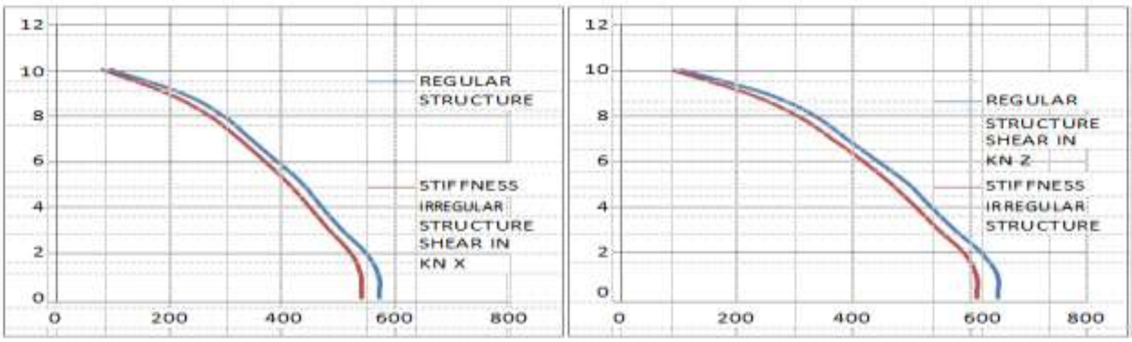


Comparison of Peak storey shear forces of regular and mass irregular structure.

The storey shear force is maximum in ground storey and it decreases as we move up in the structure. Mass irregular storey shear force is more in lower storeys as compared to regular structure. The graph closes in as we move up the structure and the mass irregular storey shear force becomes less than that in regular structure above 8th storey.

Comparison of Peak storey shear forces of Regular structure and Stiffness Irregular structure

The Stiffness Irregular structure has a ground storey height of 4.5m(more than height of the above storeys). This makes the building less stiff than regular structure. Hence the inter storey drift is observe to be more in stiffness irregular structure. And hence, the storey shear force is more in regular structure as compared to stiffness irregular structure.



Comparison of Peak story shear forces of regular and stiffness irregular structure.

TIME HISTORY ANALYSIS:

Introduction to is code ground motion used: Regular and various types of irregular buildings were analyzed using THA and the response of each irregular structure was compared with that of regular structure for IS code Ground motion. The IS code ground motion used for the analysis had PGA of 0.2g and duration of 40 seconds.

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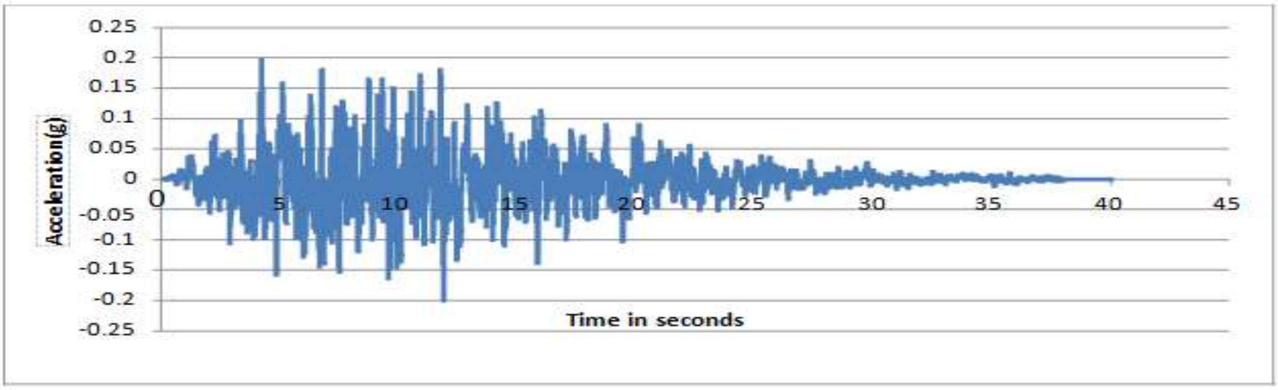
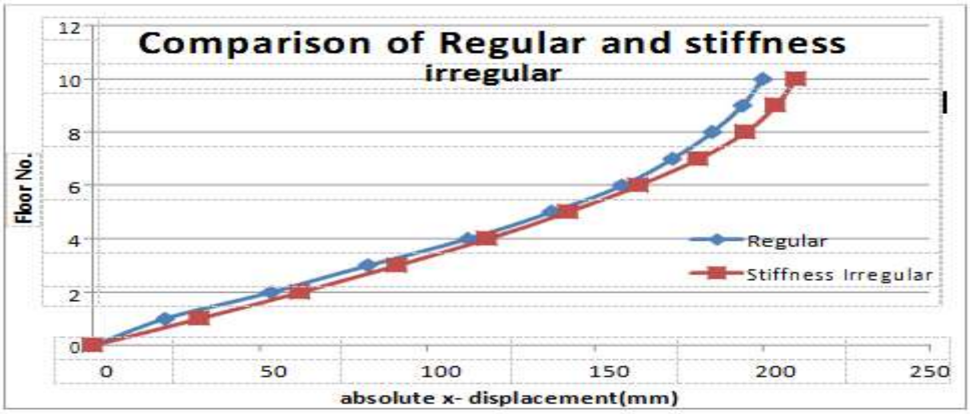


IS code ground motion with PGA scaled to 0.2g and duration equal to 40 seconds

RESULTS AND DISCUSSIONS

Regular structure

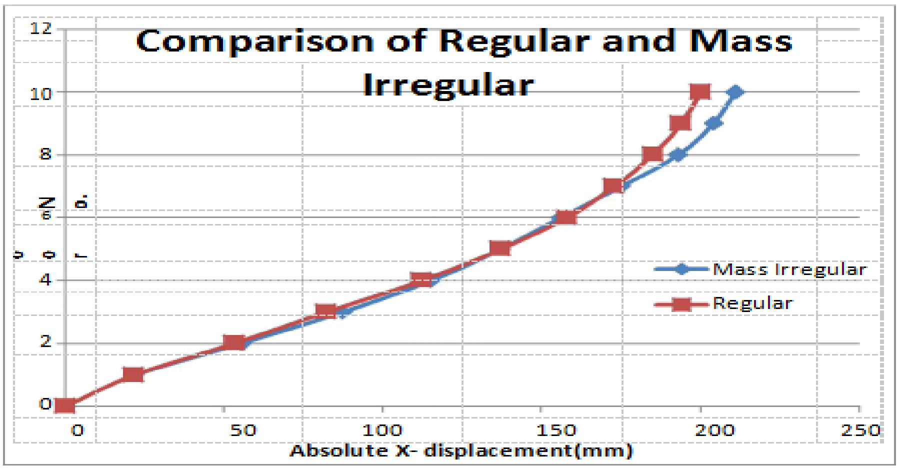
Comparison of Time history displacements of different floors ofRegular structure and Stiffness Irregular structure



Comparison of displacements along x-direction of regular and stiffness irregular structure

Due to less stiff ground storey the inter storey drift is found to be more in stiffness irregular structure. Hence, the floor displacement is more in stiffness irregular structure than regular structure.

Comparison of Time history displacements of different floors of Regularstructure and Mass Irregular structure



Comparison of displacements along x-direction of regular and mass irregular structure

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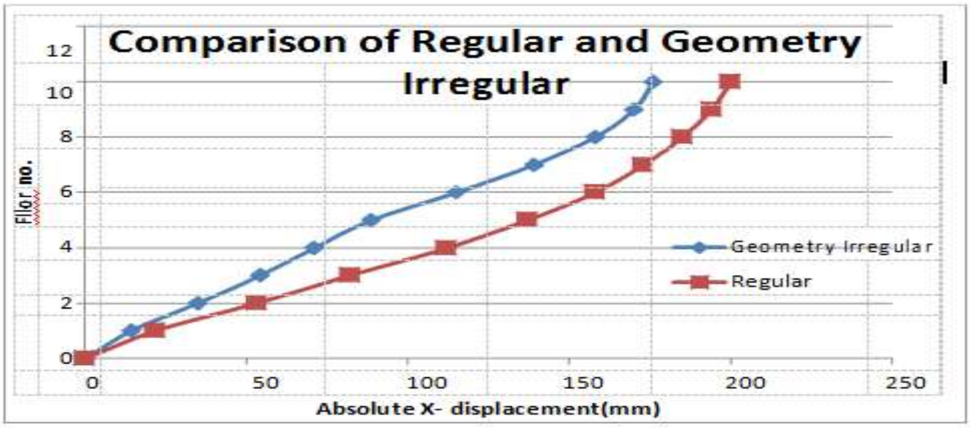
Mass irregular structure has swimming pool in 4^{th} and 8^{th} floor hence the 4th storey displacement is more in mass irregular structure. The effect of extra mass is found to be more in 8^{th} storey where higher inter storey drift is observed. Higher the position of extra mass the moment of the inertial force is more leading to larger displacement.

Comparison of Time history displacements of different floors of Regularstructure and Geometry Irregular structure



Comparison of displacements along x-direction of regular and geometry irregular structure

In geometry irregular structure the stiffness up to 5^{th} storey is far more than that of regular structure. So the displacement in lower storeys of geometry irregular structure is very less as compared to regular structure. But at 5^{th} storey due to setback there is a sudden increase in the displacement and hence there is decrease in slope of the graph.

DUCTILITY BASED DESIGN:

Specifications:

S.No.	Type of loads	Load values
1	Live Load	$3kN/m^2$
2	Density of RCC considered:	$25kN/m^3$
3	Thickness of slab	150mm
4	Depth of beam	450mm
5	Width of beam	350mm
6	Dimension of column	450x450mm
7	Density of infill	$20kN/m^3$
8	Thickness of outside wall	20mm
9	Thickness of inside wall	15mm
10	Height of each floor	3.5m
11	Total height of the structure	35m
	Force Amplitude factor	9.81

CONCLUSIONS

Columns moment- curvature curves were developed to look into the ductility levels of the different concrete strength columns. It was found that frames with HSC columns have got lower stiffness and performed well in the level of columns ductility. The maximum stories displacement and inter storey drifts have been obtained from the analysis output and ggraphical comparison were made between the frames with varied columns concrete strength. The result showed that the maximum inter storey drifts are within the limit and slightly higher for frames with HSC columns, but the contribution of the concrete strength in resisting the lateral deformation was obtained to be substantial. Economic comparisons were also made and it was found that the most economical frame corresponds to the highest available columns concrete strength which uses small but sufficient amount of longitudinal reinforcement.Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered .All three kinds of irregular RC building frames had plan symmetry. Response spectrum analysis (RSA) was conducted for each type of irregularity and the storey shear forces obtained were compared with that of a regular structure. Three types of ground motion with varying frequency content, i.e., low (imperial), intermediate (IS code),high (San Francisco) frequency were considered. Time history analysis (THA) was conducted for each type of irregularity corresponding to the above mentioned ground motions and and nodal displacements were compared. Finally, design of above mentioned irregular building frames was carried out using IS 13920 corresponding to Equivalent static analysis (ESA) and Time history analysis(THA) and the results were compared. Our results can be summarized as follows

- According to results of RSA, the storey shear force was found to be maximum for the first storey and it decreased to a minimum in the top storey in all cases.
- According to results of RSA, it was found that mass irregular building frames experience larger base shear than similar regular building frames.
- According to results of RSM, the stiffness irregular building experienced lesser base shear and has larger inter storey drifts.
- The absolute displacements obtained from time history analysis of geometry irregular building at respective nodes were found to be greater than that in case of regular building for upper stories but gradually as we move to lower stories displacements in both structures tended to converge. This is because in a geometry irregular structure upper stories have lower stiffness (due to L-shape) than the lower stories. Lower stiffness results in higher displacements of upper stories.
- In case of a mass irregular structure, Time history analysis yielded slightly higher displacement for upper stories than that in regular building, whereas as we move down, lower stories showed higher displacements as compared to that in regular structures.
- When time history analysis was done for regular as well as stiffness irregular building (soft storey), it was found that displacements of upper stories did not vary much from each other but as we moved down to lower stories the absolute displacement in case of soft storey were higher compared to respective stories in regular building.
- Tall structures have low natural frequency hence their response was found to be maximum in a low frequency earthquake.

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