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Effect of Frequency Content of Earthquake Ground Motions on Structures with Varying Dimension

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Abstract

An earthquake is a catastrophe which is always a topic of concern for structural designers and civil technocrats. Not only it causes physical damage to the structures but also successful to impart psychological disorder in human minds for long-run. In order to mitigate the devastating effects of earthquake on society, it is eminent to study the dynamic characteristics in detailed manner i.e. to examine how the structure responds owing to the seismic characteristics. The various ground motion characteristic includes time-duration and velocity, frequency content and amplitude, displacement, incremental velocity and incremental displacement, peak ground accelerations (PGAs), etc. Out of these, effect of frequency content and maximum amplitude value of earthquake ground motions on the seismic response of structures is often underestimated. This paper investigates the effect of frequency content and maximum amplitude value on the seismic response of structures which is dominant of all characteristics. The study proceeds with recording time-history of acceleration obtained from conventional unidirectional harmonic shake table. Further, FFT (Fast Fourier Transform) analysis of applied time-history is done and the effect of frequency content and the maximum amplitude value of applied time-history on the seismic responses of structures is investigated and studied. For this, structures with varying dimensions (height, length, and width) are modelled and time-history analysis of structural models has been carried out in SAP2000v19. Seismic responses of analysed structures are represented in the form of fundamental natural frequency, storey displacement, and base shear. It is reported that out of many earthquake indices, frequency content and amplitude of earthquake ground motions are the most dominating. It is reported that the resonance phenomena occurs for the less height structure and thus it shows maximum displacement and base shear responses. Also, as height, length, and width of structure increases; displacement, base shear, and fundamental time-period of structureincreases.

Keywords: FFT analysis, frequency content of earthquake ground motions, resonance, and Time-history analysis.

1. Introduction

The frequency content of earthquake ground motion is often not considered while assessing the seismic response of structures, although it is assumed to be mostly governed by the magnitude of the earthquake event and its peak ground acceleration (PGA) component. However, research and studies conducted progressively stated that the seismic damage is also governed by the dynamic characteristics of earthquakes along with its magnitude and PGA. It was also observed that the seismic response of structures were more influenced by various ground motion characteristics such as its time-duration and velocity, frequency content and amplitude, displacement, incremental velocity and incremental displacement rather than the PGAs [1, 2, 3, and 4]. Further research studies have been performed and it was reported that the frequency content and the highest amplitude values were the key parameters in the earthquake resistant design of structures [5 and 6]. Studies have been performed on various structures such as liquid storagetanks, long-span bridges, stone masonry structures, multi-storied building, experimental models, etc. to check the influence of frequency characteristics and maximum amplitude value of the various earthquake events. Similar conclusions can be extracted claiming the dominance of frequency content on the seismic response of structures [7, 8, 9, 10, 11, 12, and 13]. When the dominating frequency of earthquake ground motions matches the natural frequency of structure, the seismic response of structure is greatly influenced and causes severe damage. This phenomenon is called Resonance [14].

This paper studies the effect of frequency on the seismic response of structures having varying dimensions. In first phase, time-history of acceleration is recorded for frequency ranging from 0-25 Hz obtained from the installed horizontal shake table, and FFT analysis of recorded time-history is carried out where the dominating frequency content is examined. In second phase, to study the effect of the varyingdimensions on the seismic response the structures, three single storey space frame structures with varying height, length, and width are modelled in SAP2000v19. Further, seismic responses of structure with varying dimensions arerecorded, and results are checked for the influence of frequency content and maximum amplitude value of earthquake ground motions.

2. Recorded Acceleration Time-History Data

Recorded acceleration time-history data is applied to the

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structures (Table 3) in SAP2000v19. The applied acceleration time-history data is recorded by placing an accelerometer at the platform of an unidirectional harmonic shake table as shown in Fig. 1 and with the help of data acquisition software. Unidirectional harmonic shake table is installed in the structural dynamics laboratory of AISSMS COE. The input time-history data is generated using unidirectional harmonic shake table, where frequency can be set from 0-25 Hz. Recorded acceleration time-history data is presented in Fig. 2, which is at interval of 0.005 seconds as recorded by accelerometer, for a total time of 434.50 seconds. Table 1 presented the specifications of unidirectional harmonic shake table.

Table-1. Specifications of a unidirectional harmonic shake table

Property	Specification	
Maximum payload (Kg)	30	
Sliding dimension (mm)	Length 400	Width 360
Circular mounting plate dimension (mm)	Diameter 390	
Motor	1 HP variable speed DC	
Frequency range (Hz)	0-25	
Frequency control (%)	3	

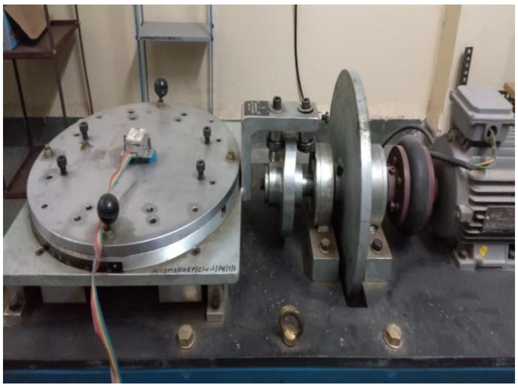


Fig. 1. Cylindrical cam type unidirectional horizontal shake table having accelerometer mounted on platform

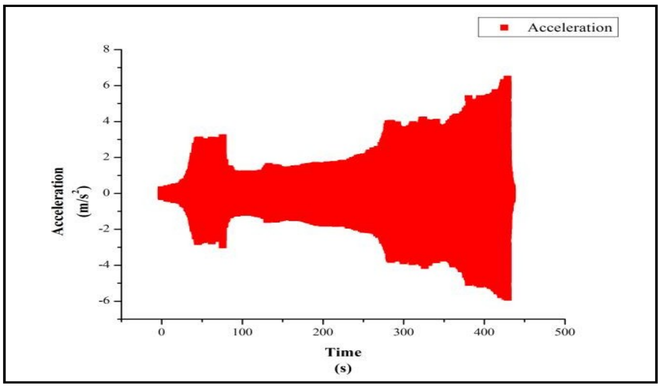


Fig. 2. Graph of recorded acceleration time-history data obtained from shake table

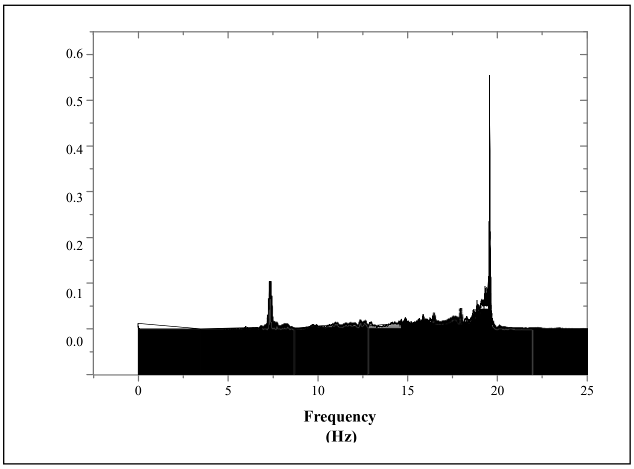


Fig. 3. Frequency v/s Amplitude response

3. Characteristics of Recorded Acceleration Time-history Data

For the present study, acceleration time-history recorded on installed shake table shown in Fig. 2 is considered. Fast Fourier transform (FFT) is performed, to convert the time domain data to a frequency domain data. The characteristics of these time domain data viz. frequency v/s amplitude is shown in Fig. 3.

Amplitude is the point which shows maximum displacement on a sine wave which is measured from the equilibrium position. In another words, it can be defined as the vertical distance of a peak of frequency from the equilibrium position i.e. it can either be positive or negative.

In the frequency domain representation, at least two frequency components, located at 07 and 19.52 Hz are clearly seen in Fig. 3. However, the highest value of fundamental frequency among all structures used for analysis in this paper is approximately equal to 07 Hz (Table 3). Hence, frequency component of 07 Hz is dominating as per as this study is concerned.

4. Structural Models for Time-History Data

Three single story space frame structural models of varying dimension i.e. height, length, and width each are modeled in SAP2000v19 for time-history analysis. These three single storey space frame structures is idealized as single-degree-of -freedom (SDOF) structures having mass lumped at the top, as shown in Fig. 4. The top and bottom plates and four corner columns are made of common material (steel). Top and bottom plates are 10 mm thick each and columns are rectangular strip of 25 mm wide and 3 mm thick. Details of material along with their properties are presented in Table 2

Table-2. Material properties of structures used for time-history analysis in SAP2000v19

		Material Properties	
Part	Material	Mass density (kg/m^3)	Modulus of Elasticity (N/m^2)
Column	Steel	7800	02x10^{11}
Plate	Steel	7800	02x10^{11}

Table 3 presented the detailed dimensions, mass, and stiffness of structures with varying height, length, and width. Varying dimension i.e. height or length or width of structures is presented in bold numbers in Table 3. Fig. 5, Fig. 6, and Fig. 7 show structures with varying height, length, and width configuration modeled in SAP2000v19 for time-history analysis, respectively.

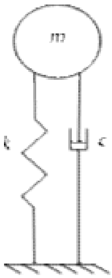
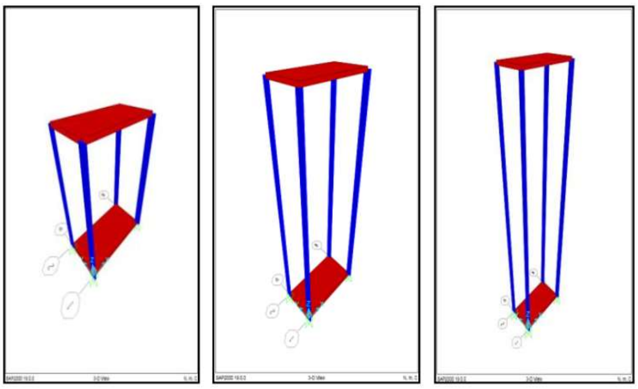


Fig. 4 Single storey space frame structure idealized as lumped mass SDOF structure

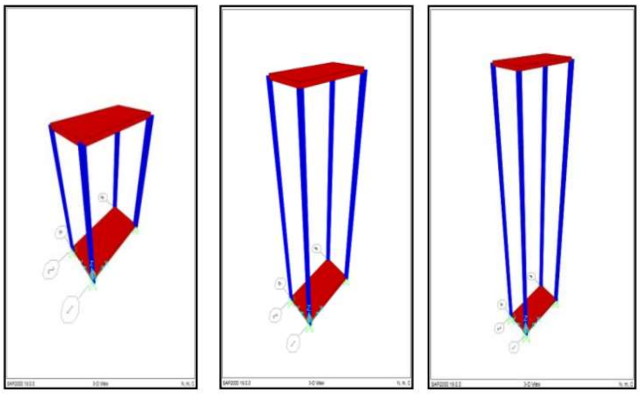
Table-3. Mass, stiffness, and dimension of structures used for time-history analysis in SAP2000v19

	Mass (kg)	Stiffness (N/mm)	Length (mm)	Width (mm)	Height (mm) (mm)
Structure 01	7.96	14.32	300	150	400
		Varying Height			
Structure 02	8.89	1.82	300	150	**800**
Structure 03	9.83	1.36	300	150	**1200**
		Varying Length			
Structure 04	14.98	14.16	**600**	150	400
Structure 05	21.99	14.16	**900**	150	400
		Varying Width			
Structure 06	14.98	14.19	300	**300**	400
Structure 07	21.99	14.19	300	**450**	400



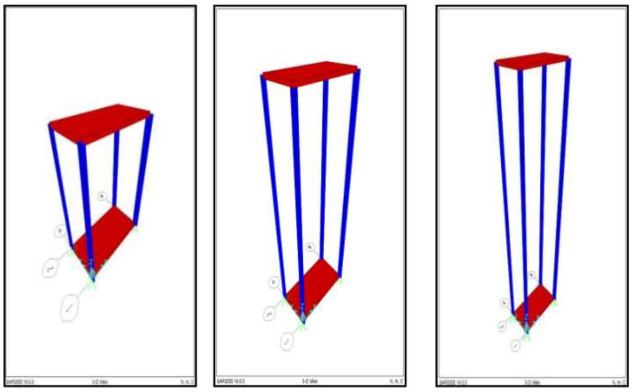
Structure 01 Structure 02 Structure 03

Fig. 5. Structures with varying height configuration modelled in SAP2000v19



Structure 01 Structure 04 Structure 05

Fig. 6. Structures with varying length configuration modelled in SAP2000v19



Structure 01 Structure 05 Structure 06

Fig. 7. Structures with varying width configuration modelled in SAP2000v19

5. Results of Time-historyAnalysis

The analysis results of Structure 01-Structure 07 with varying dimensions (Table 3) are presented in Table 4 due to the applied time-history data to the structures in SAP2000v19.

Fig. 8, Fig. 9 and Fig. 10 shows time v/s displacement response for structures with varying height, varying length, and varying width, respectively.

Table-4. Seismic responses of Structure 01-Structure 07

Structure	Fundamental natural frequency (Hz)	Storey displacement (mm)	Base shear (N)
01	6.754	7.65	18.96
	Varying Height		
02	2.278	2.05	11.36
03	1.874	4.43	12.49
	Varying Length		
04	4.895	2.35	18.84
05	4.039	1.87	28.14
	Varying Width		
06	4.900	2.40	18.84
07	4.039	1.87	28.14

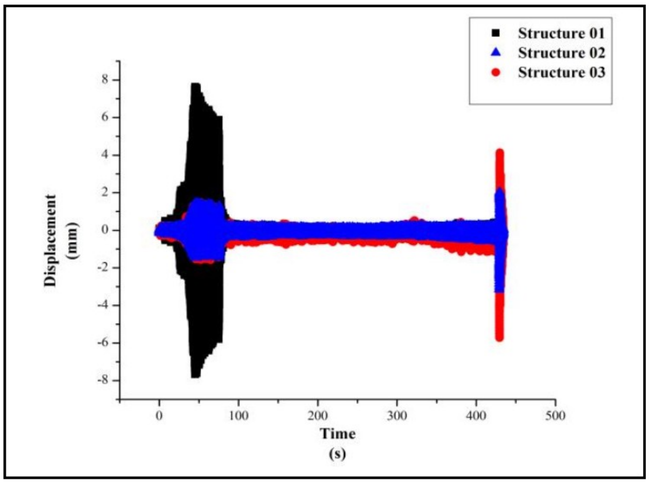


Fig. 8. Time v/s Displacement response for structures with varying height

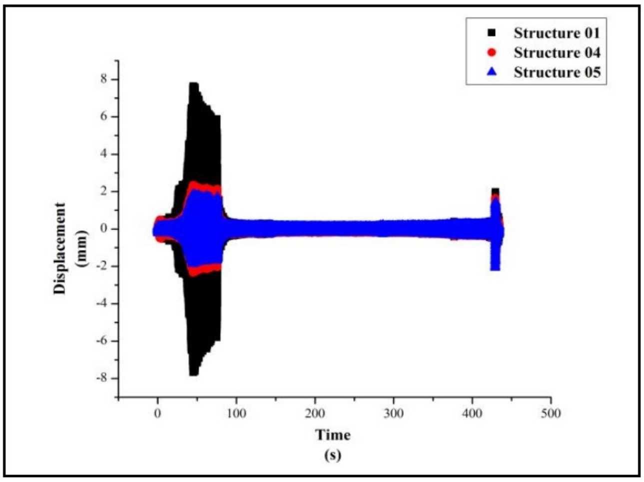


Fig. 9. Time v/s Displacement response for structures with varying length

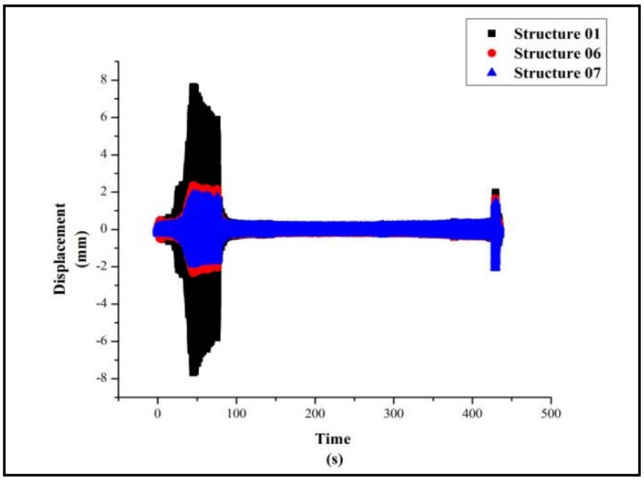


Fig. 10. Time v/s Displacement response for structures with varying width

Fig. 11 and Fig. 12 show Structure 01-Structure 07 v/s fundamental natural frequency response and Structure 01-Structure 07 v/s base shear response for structures with varying height, varying length, and varying width, respectively.

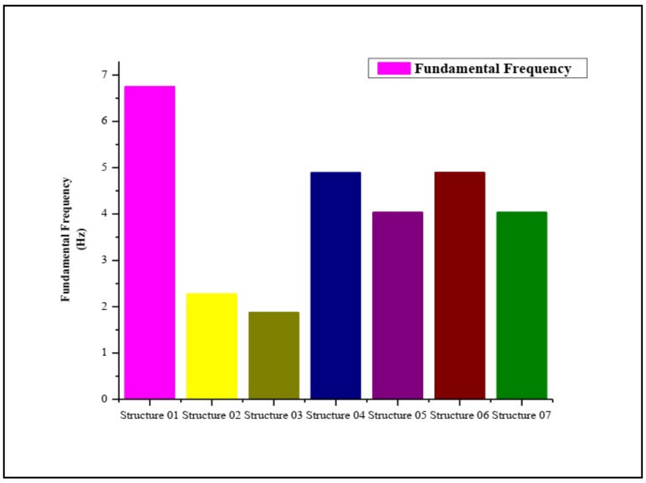


Fig 11. Structures v/s Fundamental natural frequency response

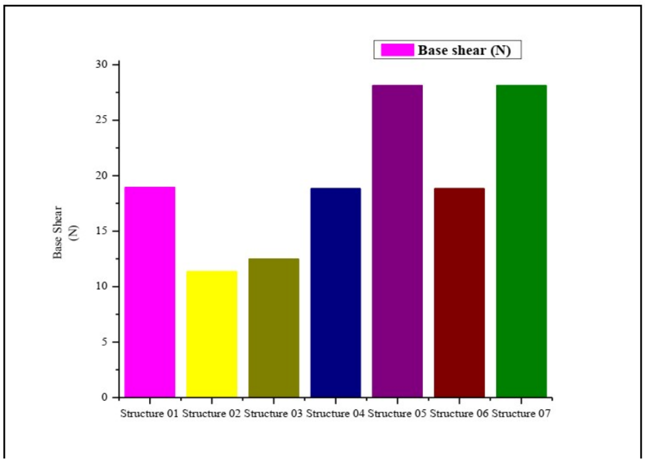


Fig 12. Structures v/s Base shear response

6.Discussions

6.1Fundamental natural frequency Results

From Table 4, it is observed that as height of the structure increases, stiffness decreases with marginal increase in mass, causing a considerable decrease in fundamental natural frequency. Hence, fundamental natural frequency of Structure 01 is more as compared to Structure 02 and Structure 03.As length and width of the structure increases, mass of the structure increases and fundamental natural frequency decreases. Mass of Structure 04 and Structure 06 is two times more than that of Structure 01 due to whichfundamental natural frequency of Structure 04 and Structure 05 is decreased by 27%. Similarly, mass of Structure 05 and Structure 07 is three times more than that of Structure 01 due to which fundamental natural frequency of Structure 05 and Structure 07 is decreased by 40%. Further, it is seen that stiffness of Structure 01, Structure 04, Structure 05, Structure 06, and Structure 07 is same.

6.2Storey Displacement Results

Generally, it is said that the structure with more stiffness show less displacement; Structure 01 has the maximum stiffness. However, it is observed that in spite of higher stiffness (Table 3), displacement of Structure 01 is maximum than all other structures as presented in Table 4. This result is due to the matching of the natural frequency of Structure 01 (6.754 Hz) with the dominating frequency (07 Hz) of applied time-history as shown in Fig. 4 (resonance has occurred). Thus, an important role is played by the dominating frequency of earthquake ground motions in dominating the displacement response of structure.From Table 4, it is observed that storey displacement of Structure 03 is more than that of Structure02. This is due to the fact that as height increases, stiffness decreases, leading to more displacement response. Stiffness of Structure 03 is less than that of Structure 02.Further, the displacement response depends on the mass of the structure. As mass increases, displacement decreases. From Table 4, is observed that Structure 05 and Structure 07 show 51% less displacement as compared to Structure 04 and Structure 06, respectively. This is mainly because mass of Structure 04 and Structure 06 is less than that of Structure 05 and Structure 07 by 47%, respectively as presented in Table 3; however, the stiffness of the mentioned structures is same.

6.3Base Shear Results

Base shear depends on the weight and stiffness of structure. From Table 4, it is observed that base shear of Structure 01 is more as compared to Structure 02 and Structure 03. This is because the excitation frequency (07 Hz) is very close to the fundamental natural frequency of Structure 01, and thus resonance has occurred resulting in maximum vibrations, and maximum base shear. Here, also frequency of earthquake ground motions dominates the base shear response.However in case of Structure 04-Structure 05 and Structure 06-Structure 07, base shear response is more as compared to Structure 01. The reason behind these is the increase in seismic weight of above structures leading to the decrement in the fundamental natural frequency. Rise in seismic weight is due to the increase in the length dimension of Structure 04-Structure 05 and the width dimension of Structure 06-Structure 07.

For structures with varying height, it is observed that base shear of Structure 03 is more as compared to Structure 02. This is mainly because stiffness of Structure 03 is less as compared to Structure 02 as presented in Table

3. This causes Structure 03 to displace more and thus more shear force is required at the base.As seen from Table 4, for structures with varying length and width, base shear increases with increase in mass. Structure 05 and Structure 06 show 50% more base shear as compared to Structure 04 and Structure 06, respectively; this is mainly due to increase in mass of structure by 50%.

From results presented in Table 4, it is observed that Structure 04 and Structure 06 whereas Structure 05 and Structure 07 have similar response quantities (fundamental natural frequency, storey displacement, and base shear) respectively. The above mentioned structures in this case have one dimension in common i.e. height; variations is seen in length and width dimensions. Even tough the dimensional variations, Structure 04 and Structure 06 have equal area participation that affects the seismic response of structures. Similar is in the case of Structure 05 and Structure 07. Hence, the response quantities of Structure 04-Structure 06 and Structure 05-Structure 07 are quite identical.

7. Conclusions

Following conclusions are drawn from the work performed in this paper.

1. Apart from other characteristics, frequency content is also important for seismic responses of structure under earthquake events.
2. Due to resonance phenomenon, it is seen that structure with less height shows higher displacement and base shear response than structure with more height.
3. As height, length, and width of structure increases; displacement, base shear, and fundamental time-period of structure increases.

Disclosures

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