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Effect of Frequency Content of Ground Motion in Low-rise Reinforced Concrete Buildings

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Abstract*— Ground motion parameters are essential for quantitatively describing strong ground motion characteristics in a compact form. For engineering purposes amplitude, frequency content and duration are of primary significance. The response of the building depends on the ratio of natural frequency of the building to the exiting frequency of the load. This paper focuses on studying the effect of varying frequency content on ground motion in low-rise reinforced concrete buildings keeping the other ground motion parameter such as peak ground acceleration and duration constant. Seven ground motions having different predominant frequency are selected, then are transformed to frequency domain using Fast Fourier Transform. The so obtained Fourier spectra are shifted preserving its other characteristics. The shifted ground motions in frequency domain are transformed to time domain using Inverse Fast Fourier Transform to obtain new time history. Linear time history analysis is carried out in finite element software, ETABS, on two to five storey regular building with obtained time history as an input. The response of buildings are found in terms of maximum storey displacement and base shear. The results show that response of the building increases with increase in frequency content of the ground motion to a certain point and then decreases and the sensitivity of the frequency content increases with increase in number of story.

***Index Terms*— Base Shear, Fast Fourier Transform and Inverse Fast Fourier Transform, Frequency Content, Ground Motion, Linear Time History Analysis, Storey Displacement.**

I. INTRODUCTION

The earth vibrates continuously at periods ranging from milliseconds to days with amplitude ranging from nanometers to meters. Most of these vibrations are so weak that they cannot be felt. The motion that has the sufficient strength to affect the people and their environment is strong ground motion. The information on earthquake ground motion can be expressed precisely with the help of time history records in all the translational direction that makes it rather cumbersome. However, for engineering purpose, strong ground motion can also be described by three characteristics of primary significance: the amplitude, frequency content and duration of the motion [1].

Earthquakes generate complicated loading of motion components covering a wide range of frequencies. The frequency content describes how the amplitude of the ground motion is distributed among different frequencies.

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The response of any structure depends on the ratio between the natural frequency of the structure and the frequency of excitation of the load, so that the characterization of the motion cannot be complete without taking into account its frequency content [2].

Only few researches have been done to study the effect of frequency content on the seismic behavior of structure [3, 4, 5, and 6]. Cakir [3] studied the evaluation of the effect of earthquake frequency content on seismic behavior of cantilever retaining wall involving soil-structure interaction using five ground motions and found that the dynamic response of cantilever wall is highly susceptible to frequency characteristics of the ground motion. To observe the dynamic behavior of tank liquid-submerged block system, Nayak & Biswal [4] studied seismic behavior of partially filled rigid rectangular tank with bottom-installed submerged block utilizing six ground motions of different frequency content. The researcher concluded that the frequency content has noticeable impact on the convective response. However, the researcher also concluded that impulsive response is almost not dependent on frequency content.

Youldash [5] studied seismic behavior of reinforced concrete buildings under varying frequency content by performing linear time history analysis of two, six and twenty storey regular and irregular building utilizing six ground motions of low, intermediate and high frequency content. The researcher concluded that ground motions of low frequency content have significant effect on the response of the building and ground motions of high frequency content have very little effect on the response of both regular and irregular building. Gound & Padhya [6] studied the effect of earthquake frequency content on the seismic behavior of regular R.C.C. buildings by performing linear time history analysis of three and six storey regular reinforced concrete building utilizing six ground motion of low, intermediate and high frequency content having equal duration and peak ground acceleration. The response of the building were found on terms of base shear and storey displacement and it was concluded that the ground motions with low and intermediate frequency have significant effect on the response of building, however ground motions having high frequency content have very less effect on the response of building.

Every earthquake has its own peculiarity governed by its amplitude, frequency content and duration. The differences in the result due to different ground motion depends on both the characteristics of ground motion as well as of the structure

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[7]. Results of the past works were concluded from the result of single ground motion having frequency content different from that of other ground motion. For the result to be based on average rather than maximum, ATC-40 [8] recommends using a set of seven or more ground motions.

In this paper, seven ground motions having different predominant frequency are selected, then the ground motion are shifted to the higher and lower frequencies to obtain new time history. Linear time history analysis of two to five storey low-rise building is carried out in finite element software, ETABS, utilizing the selected and shifted ground motions. The mean of the response due to the ground motion having same frequency content is taken and is used to study the effect on reinforced concrete buildings.

II. RESEARCH OBJEVTIVE

The general objective of carrying out this research is to investigate the effect of frequency content of ground motion for reinforced concrete buildings in terms of storey displacement and base shear performing linear time history analysis. Specific objectives of the thesis are:

1) To determine the effect of the frequency content of ground motion in the response of a building.
2) To determine the sensitivity of the building to the frequency content of ground motion with the increase in number of storey.

III. METHODOLOGY

In this study, four fictitious buildings are selected and modeled using finite element software. Seven ground motions are selected on the basis of their predominant frequency. The frequency content of the ground motions are shifted preserving its other character as Fourier amplitude and bandwidth. The so shifted ground motions are back transformed to time domain to obtain new time history. These time histories are scaled to a same PGA of 0.16g which are used as an input to perform linear time history analysis. After that, the influence of frequency content on reinforced concrete building is analyzed.

A. Ground Motions

Table 1. Ground Motions Selected [9]

Ground motions	Station	Predominant frequency (Hz)
Gorkha, 2015	THM-CH2	0.24414
Kocaeli, 1999	YARIMCA (KOERI330)	0.29297
Loma Prieta, 1989	090 CDMG STATION 47381	0.51270
Kobe, 1995	KAKOGAWA (CUE90)	0.58594
Northridge, 1994	090 CDMG STATION 24278	1.22070
Imperial Valley, 1979	USGS STATION 5115	1.90430
Trinidad, 1983	090 CDMG STATION 1498	2.75879

Predominant frequency can be a useful tool to represent frequency content of a ground motion. Predominant frequency is the frequency of the ground motion corresponding to the maximum Fourier amplitude [1].

For time history analysis, at least three ground motions should be selected. However, ATC-40 [8] recommends using a set or seven or more pairs of time history for results to be based on the average rather than the maximum value. A set of seven earthquakes having different predominant frequency are selected. All the data are obtained from PEER NGA-2 west data base [9]. Details of the selected ground motions are shown in Table 1.

B. Shifting of Frequency Content

The set of seven ground motions, in the time domain, selected having its own predominant frequency were transformed to frequency domain using Fast Fourier Transform. Then the shifting of ground motions were done in such a way that the ground motion would be shifted to predominant frequency of other ground motions also preserving its other characteristics as Fourier amplitude and bandwidth. The shifted ground motion motions were then transferred back to time domain using Inverse Fast Fourier Transform to obtain new time history of the same earthquake having a different predominant frequency. Similar processes are repeated for other ground motions, making a total of forty nine ground motions. All the ground motions are scaled to a PGA of 0.16g which are used as an input for carrying out linear time history analysis.

C. Building Parameters and Material Properties

Two to five storey regular bare frame buildings with staircase cover have been considered for this study. The stiffness due to infill wall has not been considered for the analysis. Every model has same plan in all floors except for the top floor which has only staircase cover. There are two bays in X-direction and three bays in Y-direction. Span length in X-direction is 4.2672m and that in Y-direction is 3.6576m.

The size of the slab is taken to be 125mm and the size of the beam is fixed to 230mm × 350mm. The size of the columns differ according to the number of storey in the building model. However, the size of the column in a particular model is same.

The building parameters and material properties used for the development of the models are listed in Table 2 and the size of columns adopted are listed in Table 3.

D. Design and Model of the Buildings

The frame buildings were designed using response spectrum method taking in reference design codes IS 456:2000 and IS 1893: 2016. Finite element software, ETABS Ultimate V 18.1.0, was used for design and modeling of the building.

Dead loads and live loads are assigned as per IS 875 (part 1) and IS 875 (part 2) respectively. Dead load of 1.3kN/m^2 is applied as floor finish, live load of the roof is taken as

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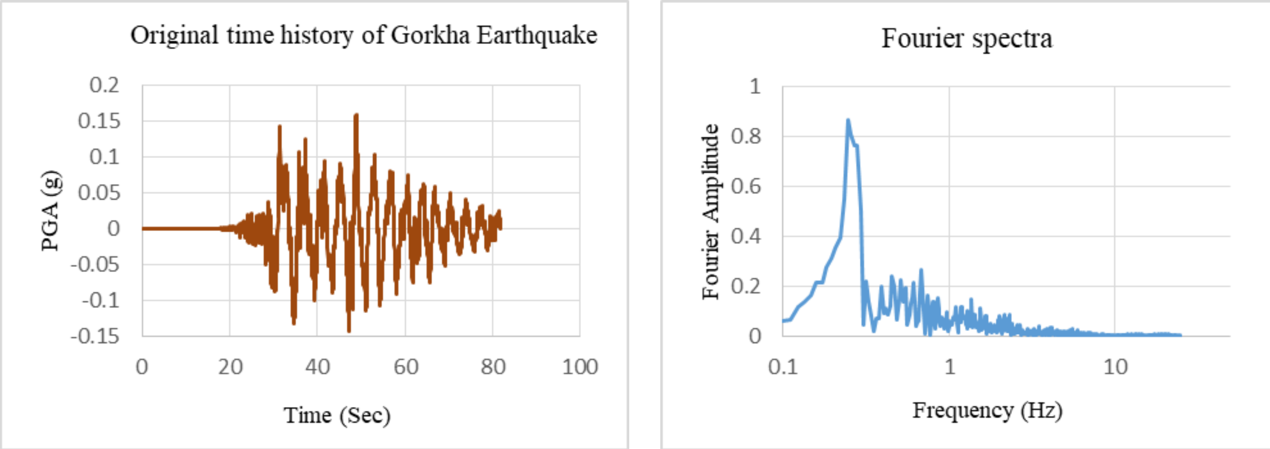

Fig. 1. Time history and Fourier spectra of Gorkha earthquake, predominant frequency 0.24414 Hz

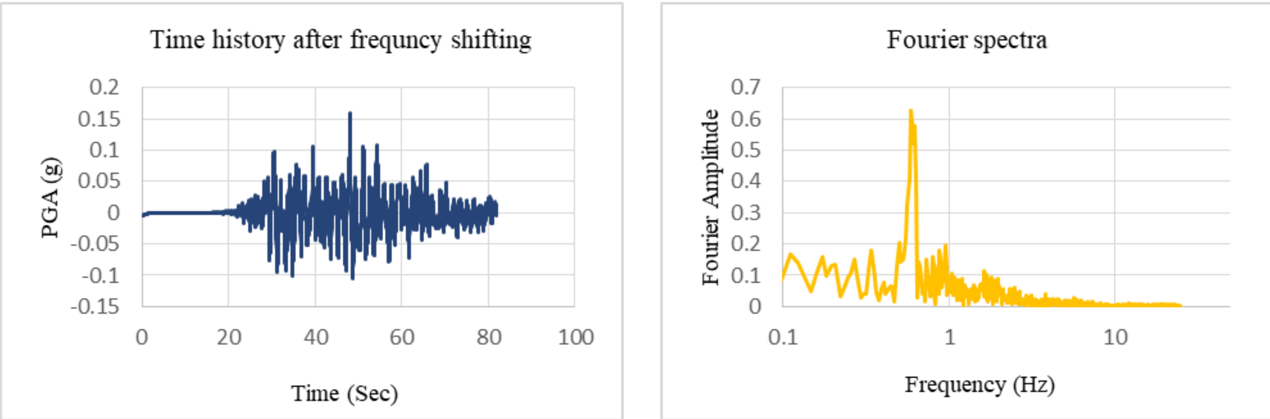

Fig. 2. Time history and Fourier spectra of Gorkha earthquake after frequency shifting, predominant frequency 0.58594 Hz

1.5kN/m^2, live load for staircase and lobby is taken to be 3kN/m^2 and for others, live load of 2kN/m^2 is applied. The thickness of the outer walls is considered to be 230mm with an opening of 30% and the thickness of the inner walls is 115mm.

The specific weight of the brick wall is taken as 19.2kN/m^3. For the seismic weight of the building total dead load of the structure and 25% of the live load on the structure is taken as per the seismic code, IS 1893: 2016. The design load combination was taken as given in the seismic code. The building models are considers as special moment resisting frame and are designed for seismic zone V, and for importance factor 1.

All floors were assumed to be rigid in its own plane by assigning rigid floor diaphragm. Soil structure interactions were not considered and hence, the foundations were modeled as rigid. Secondary effects such as temperature, shrinkage or creep were not considered.

Table 2. Building Parameters and Material Properties

Concrete grade	M20
Unit weight of concrete	25 kN/m^3
Modulus of elasticity of concrete	22360 MPa
Poisson's ratio of concrete	0.2
Steel grade	Fe 500
Unit weight of steel	7850 kg/m^3
Modulus of elasticity of steel	200 GPa
Poisson's ratio of steel	0.3
Storey height	2.8448 m

Table 3. Column Size Adopted for Different Buildings

Number of storeys	Column size
2	300 mm X 300 mm
3	350 mm X 350 mm
4	350 mm X 350 mm
5	400 mm X 400 mm

IV. RESULTS AND DISCUSSION

Based upon linear time history analysis of buildings carried out using selected ground motions and the ground motions obtained after shifting of frequencies, base shear and storey response were found. The mean value of maximum storey displacement and base shear of building due to seven ground

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motion with different characteristics but at a particular predominant frequency are plotted for every storey and is shown in the Fig. 3 and Fig. 5.

In Fig. 3, it is seen that the maximum storey displacement of the building increases as the frequency content of the ground motion increases to a certain extent, i.e. the fundamental natural frequency of the building, and then decreases. Table 4 shows the fundamental natural frequencies obtained from ETABS. Similar phenomenons are also seen for two, three and five storey building with staircase cover. A graph is plotted between maximum storey displacement and predominant frequency of the ground motions and is shown in Fig. 4.

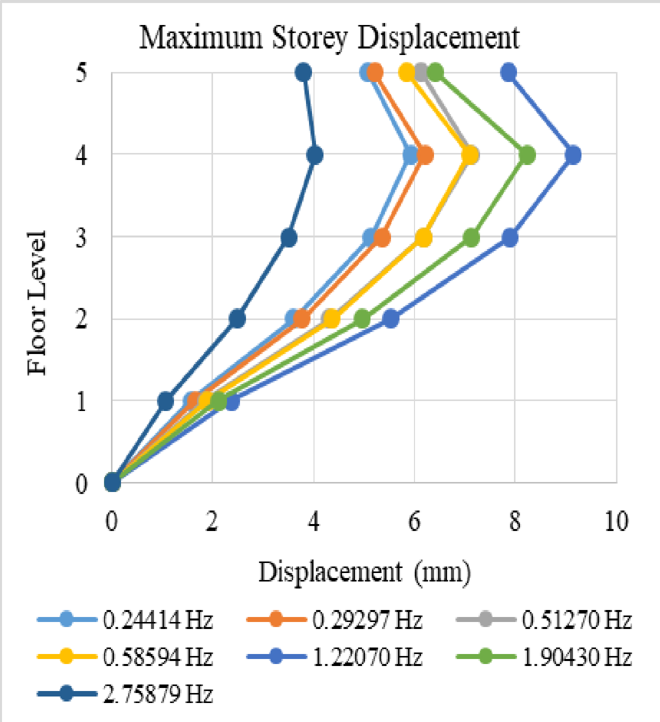

Fig. 3. Maximum storey displacement of four storey building with staircase cover due to ground motion of different predominant frequency

Table 4: Fundamental Model Frequency obtained from ETABS

No. of Storey	Fundamental Natural Frequency (Hz)
2	2.83
3	2.23
4	1.575
5	1.335

In Fig. 4, two storey building is yet to reach a peak as its fundamental natural frequency is 2.83 Hz, but for all other storey, the response has dropped after the fundamental natural frequency of the building. The sharp increase in the response near fundamental natural frequency of the building is due to the resonance phenomenon. Also, the slope of the graph increases as the number of storey increases indicating higher number of storey are more sensitive to varying frequency.

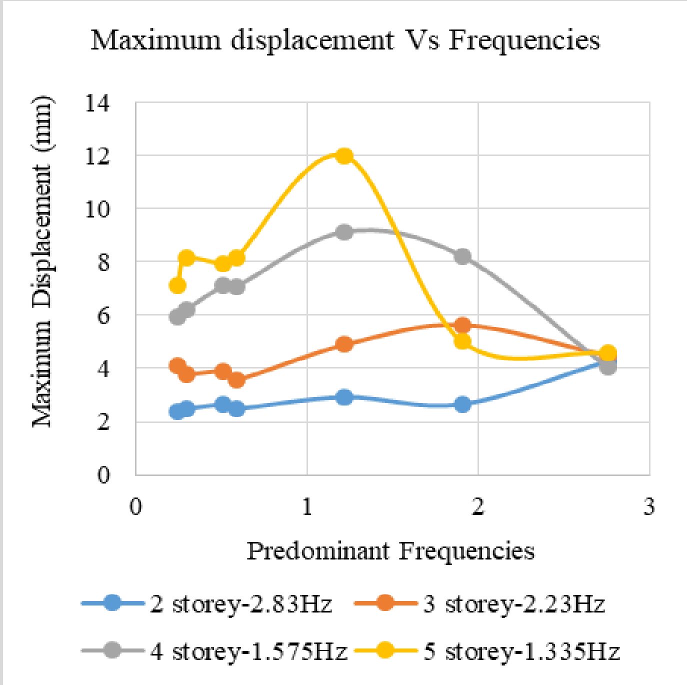

Fig. 4. Maximum displacement vs. predominant frequencies

In Fig. 5, the plot between base shear of buildings with varying predominant frequency of ground motions shows that base shear of buildings increases near its fundamental natural frequency. To determine how base shear changes with varying frequency content regression analysis is done and shown in Fig. 6. Third degree polynomial shows reasonable fit to the data. Fig. 6 shows that base shear of the building increases with increase in frequency content of the ground motion, reaches maximum near its natural frequency and then decreases.

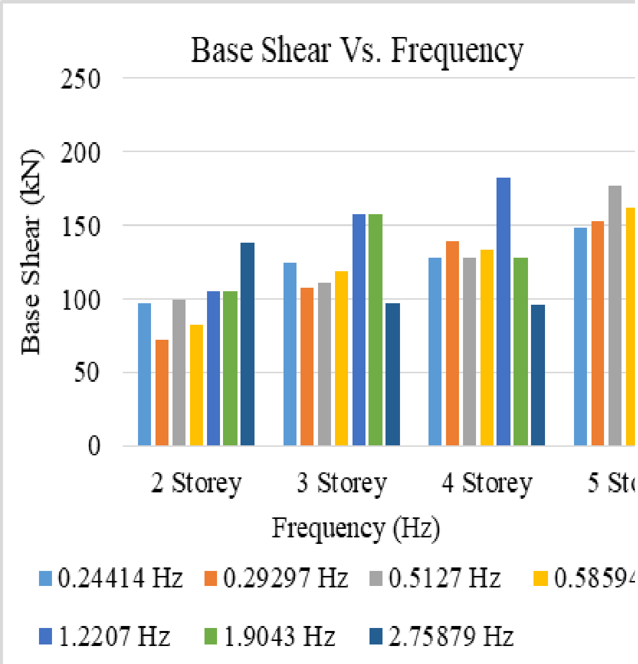

Fig.5. Base shear of buildings with varying predominant frequency of ground motion

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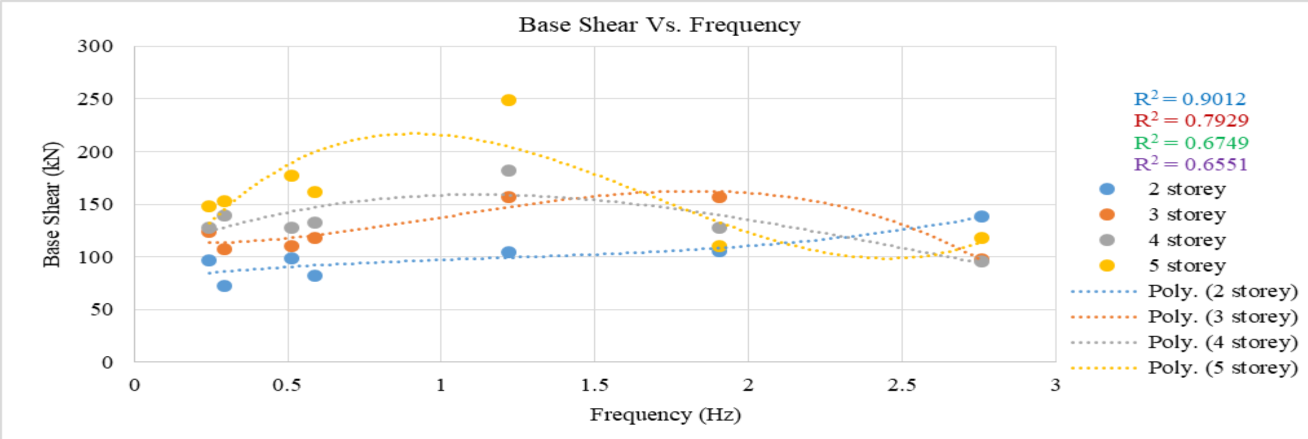

Fig. 6. Base shear of buildings with varying predominant frequency of ground motion

Youldash [5] in his thesis concluded that ground motion having low frequency content has dominant effect on reinforced concrete building and that high frequency content has very less effect on the response of the building. Intermediate frequency content ground motion has less effect than low-frequency content ground motion and more effect than high-frequency content ground motion on the RC buildings. Gound & Padhya [6] concluded that that the ground motions with low and intermediate frequency have significant effect on the response of building, however ground motions having high frequency content have very less effect on the response of building. The result obtained in this paper agrees to the conclusion found by Youldash [5] and Gound & Padhya [6], in addition to their conclusion, continuous result on how the response changes with increasing frequency content and sensitivity of the building to the frequency content of ground motion with the increase in number of storey is studied and shown in Fig. 4 and Fig. 6.

V. CONCLUSION

In this paper, seven ground motions and forty two frequency shifted ground motions with same peak ground acceleration of 0.16g and duration are applied to examine the effect of frequency content of two to five storey low-rise reinforced concrete buildings, the following conclusions can be drawn:

1) Storey response, i.e. storey displacement and base shear, increases as the frequency content of the ground motion increases to a certain frequency i.e. the fundamental natural frequency of the building and then decreases with the increase in frequency content.
2) The sensitivity of the building to the frequency content increases with the increase in number of storey.

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