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Multistory Buildings as Band Pass Filters for Earthquake Excitations

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***Abstract*— A case study of six-story reinforced concrete building subjected to five earthquakes with different characteristics have been analyzed using linear transient time history analysis. The study concentrate on the frequency point of view through comparing the frequency of the structure obtained from the modal analysis with frequency content of both the excitation and the resulting response extracted by Fast Fourier Transform.**

The analysis show that the multistory buildings work as band pass filters through interacting with a selective band of frequencies of the excitation "the active band", and not affected by other frequencies that laying out of this band. The severity of earthquake then to be characterized not only by its value of PGA, but as well, by the dominated frequency of the signal.

Keywords—Multistory; Frequency Domain; Time Domain; Earthquakes; Band Pass Filters

I. BUILDING DESCRIPTION

A real hospital building constructed in Baghdad-Iraq is chosen as the case study of the present work. The building has an H-shape plan of 43.2×43.2m, and height of 24.5m as shown in Fig. 1. The height is 4.5m for the ground story and 4.0m for the other five typical stories, measured from beams centers. The main horizontal span is 7.2m in both directions. All the 56 per story columns are 500×500mm in cross sections, beams of 600×300mm, and slabs of 200mm in thickness. The building modeled as fixed supported at the base and the damping ratio considered as 5%. The material properties are summarized in Table I. and the real earthquake load cases in Table II.

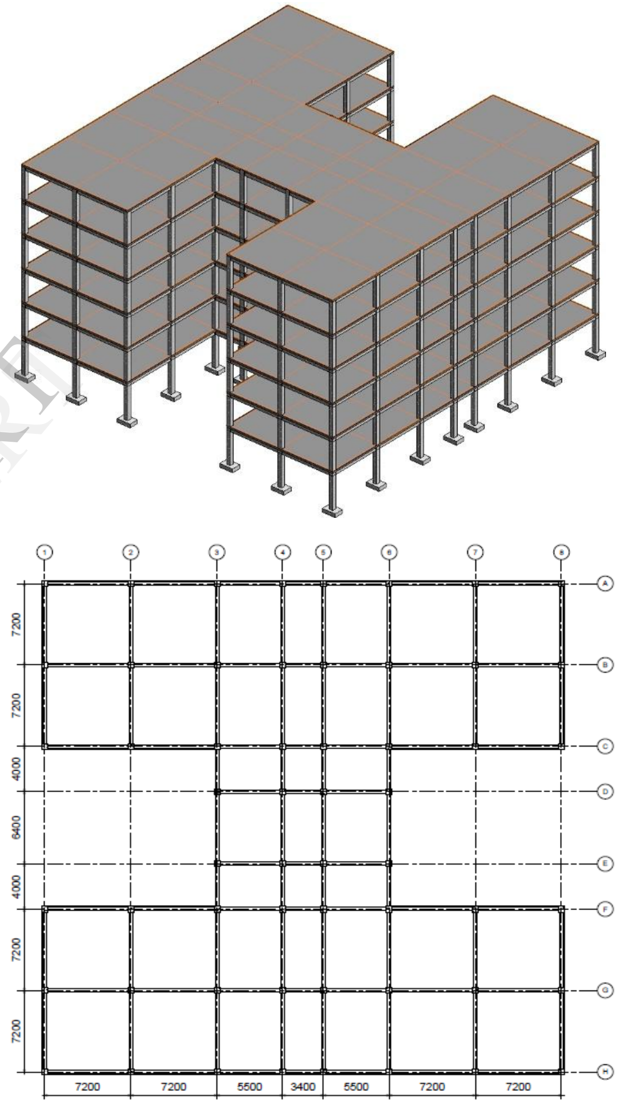

Fig. 1. The 3D and plan views of the H building

TABLE I. MATERIAL PROPERTIES OF H BUILDING IN N-MM-SEC UNITS

Material	E	Poisson Ratio	Mass/V	Grade
Concrete	24,860	0.2	2.403E-09	F'c=27.5
Steel	200,000	0.3	7.849E-09	Fy=414

TABLE II. EARTHQUAKE LOAD CASES

No.	Short Name	Description
1	El Centro	EL Centro 1940-US
2	Bn09	Badra09-Iraq
3	Bn19	Badra18-Iraq
4	Kn11	Kirkuk11-Iraq
5	Kn13	Kirkuk13-Iraq

II. MODAL ANALYSIS

The frequency of the first 15 modes of the building obtained from 3D modal analyses using three different software are shown in Table III.

TABLE III. BUILDING MODES IN SAP2000, ETABS AND ANSYS

Mode	**f (Hz)**		
	SAP2000	**ETABS**	**ANSYS**
1	0.986-Y	0.995-Y	0.958-Y
2	1.015-X	1.023-X	0.997-X
3	1.023-T	1.029-T	0.999-T
4	2.990-Y	3.018-Y	2.952-Y
5	3.067-X	3.096-X	3.060-X
6	3.101-T	3.122-T	3.079-T
7	5.081-Y	5.133-Y	5.167-Y
8	5.185-X	5.235-X	5.318-X
9	5.263-T	5.302-T	5.381-T
10	6.170-T	6.196-T	6.174-T
11	6.862-T	6.892-T	6.872-T
12	7.154-Y	7.235-Y	7.564-Y
13	7.257-X	7.333-X	7.723-X
14	7.414-T	7.478-T	7.884-T
15	8.128-T	8.173-T	8.256-T

[a] * X and Y denote to modes in the two horizontal directions and T for torsion about Z axis.

III. TRANSIENT TIME HISTORY ANALYSIS

A transient time history analyses have been carried out for H building subjected to the five earthquakes that shown in Table II. The analyses have been done using the three software of SAP2000, ETABS, and ANSYS.

Figures from (2) through (21) are showing the results of the analyses. Four figures are presented for each loading case. The first two figures are the time domain representation of the earthquake acceleration and the time history of the displacement response of the roof of the building. The second two figures are the frequency domain representations, where the first figure is for the frequency content of the ground motion and the second is the amplitude spectrum of the displacement response vibration

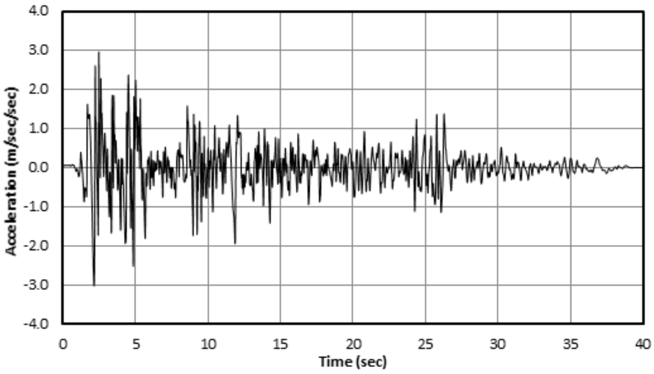

Fig. 2. Acceleration time history record of El Centro 1940 earthquake

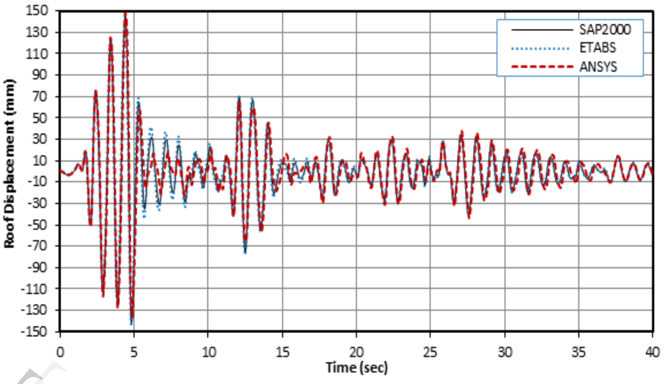

Fig. 3. Roof displacement in x-direction to El Centro, using three software

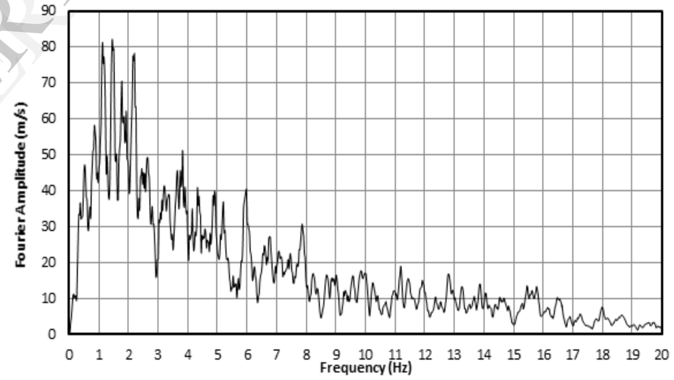

Fig. 4. Fourier amplitude spectrum of El Centro earthquake acceleration

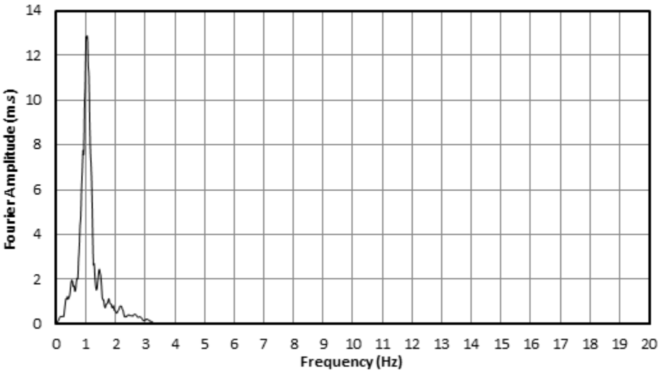

Fig. 5. Fourier amplitude spectrum of roof displacement due to El Centro

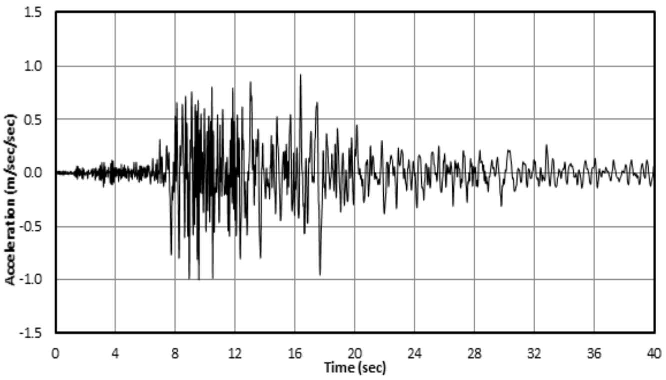

Fig. 6. Acceleration time history record of Bn09 earthquake

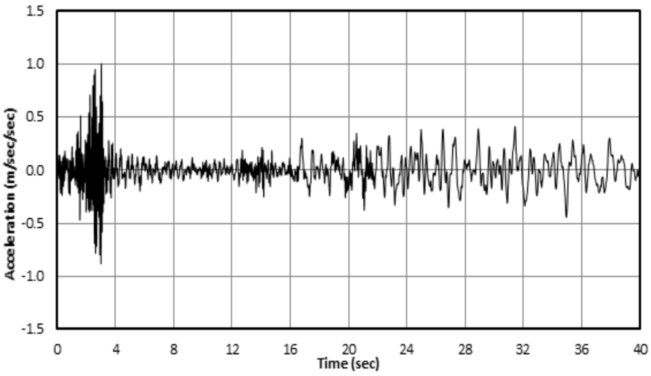

Fig. 10. Acceleration time history record of Bn18 earthquake

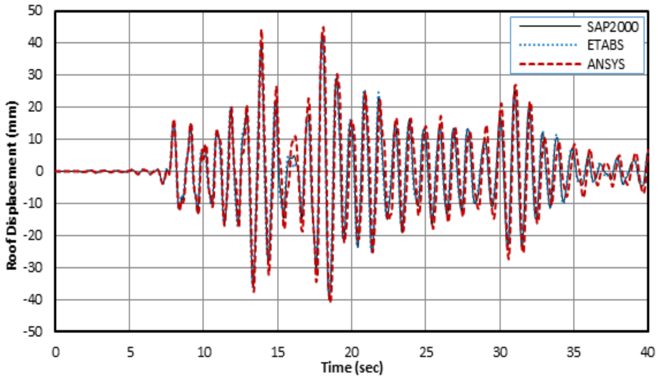

Fig. 7. Roof displacement in x-direction to Bn09, using three software

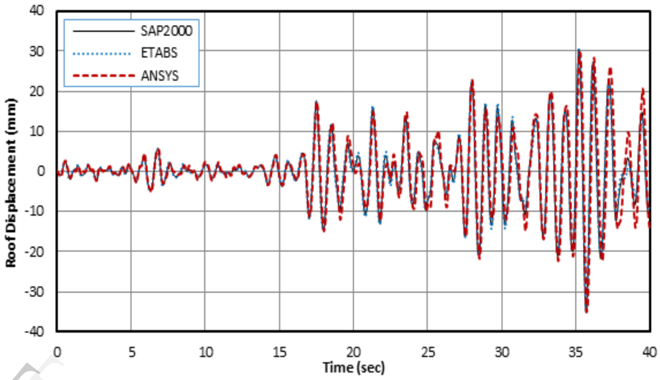

Fig. 11. Roof displacement in x-direction to Bn18, using three software

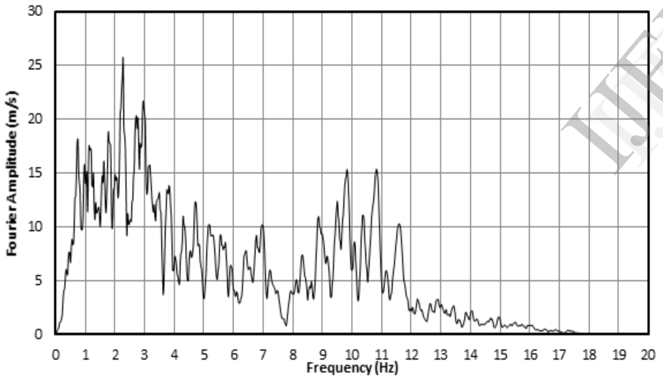

Fig. 8. Fourier amplitude spectrum of Bn09 earthquake acceleration

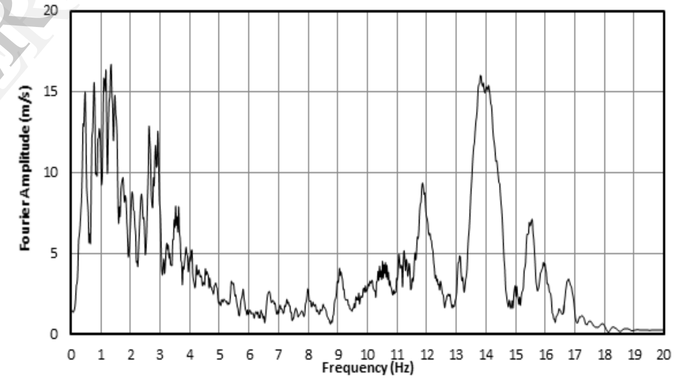

Fig. 12. Fourier amplitude spectrum of Bn18 earthquake

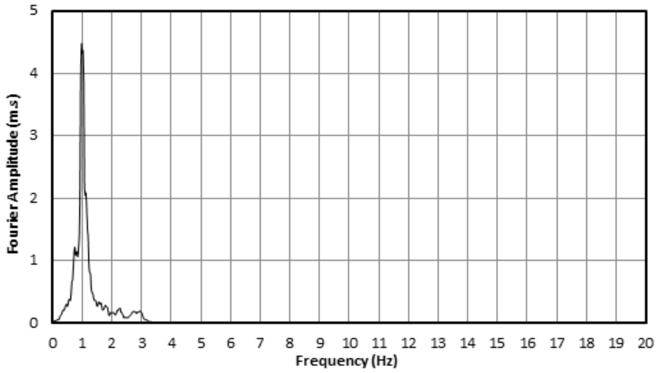

Fig. 9. Fourier amplitude spectrum of building response to Bn09

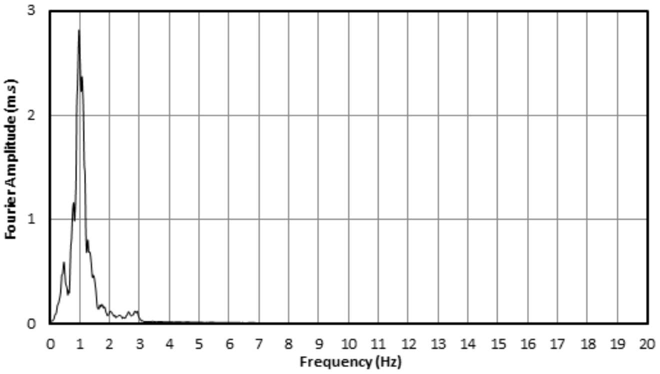

Fig. 13. Fourier amplitude spectrum of building response to the Bn18

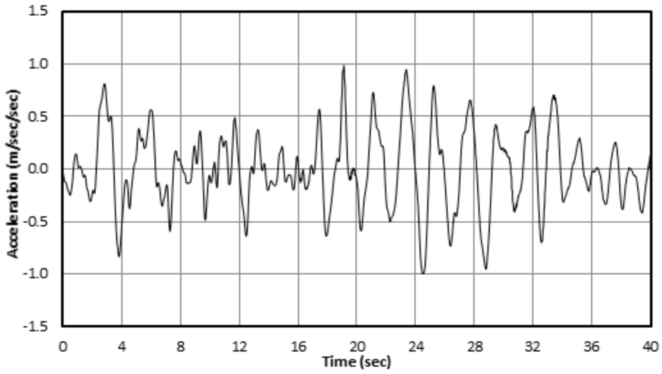

Fig. 14. Acceleration time history record of Kn11 earthquake

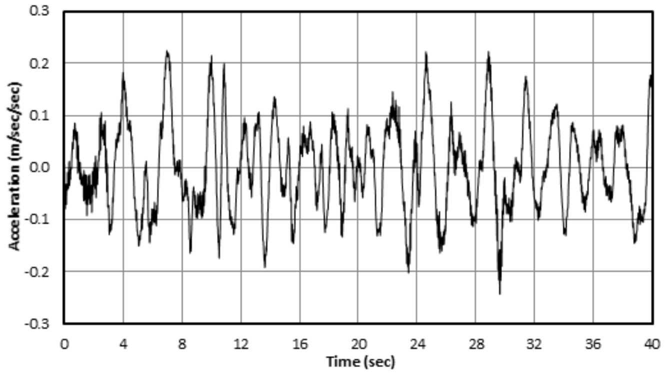

Fig. 18. Acceleration time history record of Kn13 earthquake

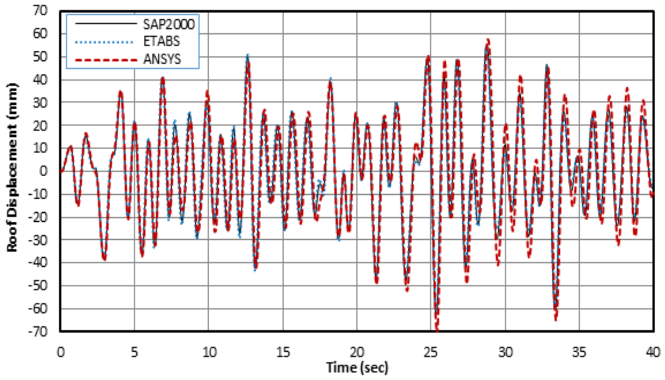

Fig. 15. Roof displacement in x-direction to Kn11, using three software

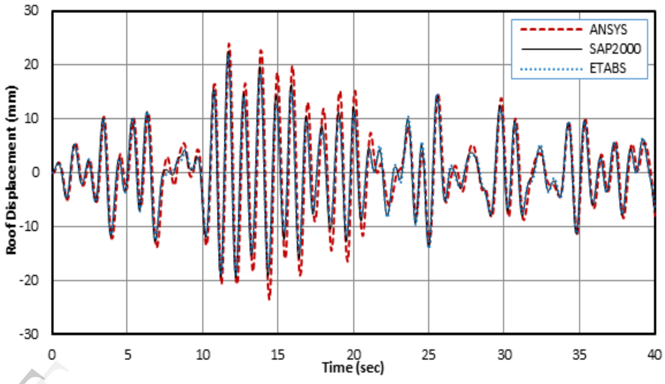

Fig. 19. Roof displacement in x-direction to Kn13, using three software

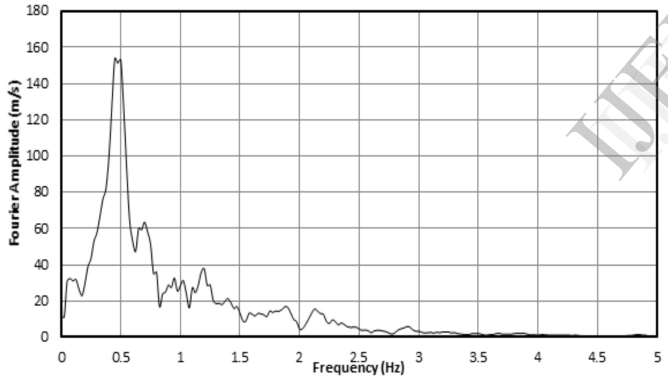

Fig. 16. Fourier amplitude spectrum of Kn11 earthquake

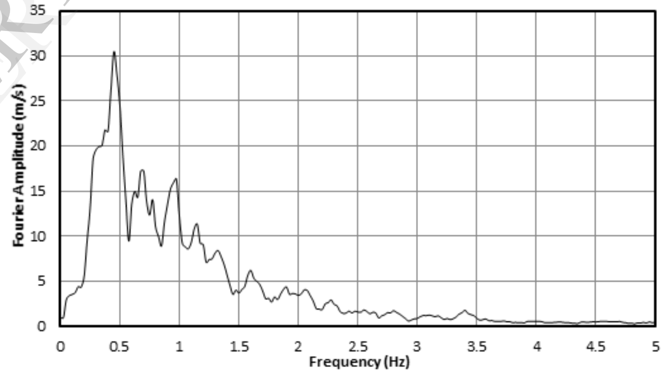

Fig. 20. Fourier amplitude spectrum of Kn13 earthquake

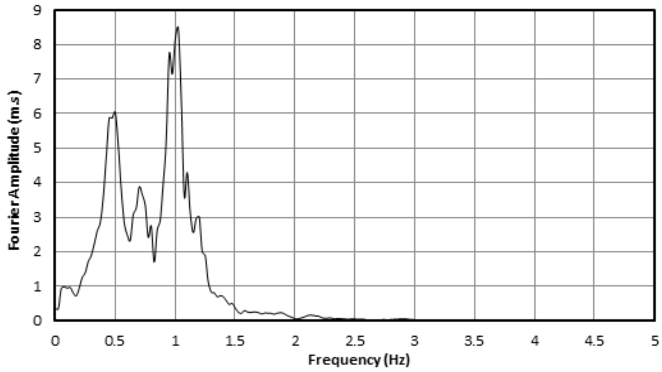

Fig. 17. Fourier amplitude spectrum of building response to Kn11

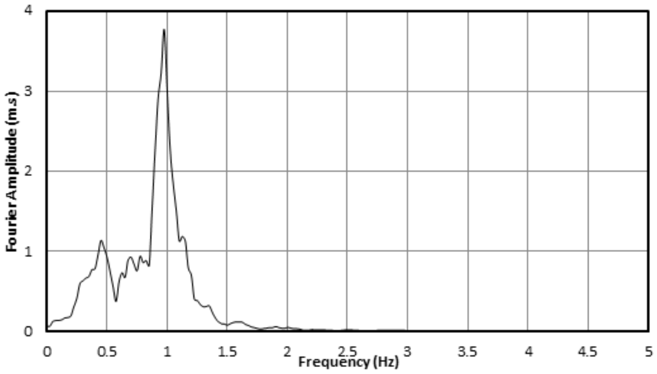

Fig. 21. Fourier amplitude spectrum of building response to Kn13

IV. DISCUSSION

The presented five earthquakes loading cases and their corresponding response of the structure have shown some specific characteristics that are discussed in following paragraphs:

A. *The El Centro and Bn09 loading cases*

These two earthquakes are typical examples for wide band frequency earthquakes as shown in Fig.4 and Fig.8. The frequency of the response, on the other hand, that are shown in Fig.5 and Fig.9 respectively, are very narrow banded and dominantly vibrate around 1.0 Hz which is approximately equal to the fundamental frequency of the building shown in Table III.

B. *The Bn18 Loading Case*

The nature of this specific earthquake and the corresponding response of the building typically emphasize on the importance of the frequency content of loading on the response of structures.

The earthquake as shown in Fig. 12 has two distinct bands of frequency reflecting two intensity of amplitudes of Fig. 10. The first 4 seconds of the record, which has relatively high amplitude is vibrating around 14Hz, that is very high and far from the fundamental frequency of the building and for this reason, the time domain representation of Fig. 11 showed no significant response to this range of excitation. On the other hand, the lower amplitudes of the record exerted after 16 seconds as shown in Fig.10 have caused considerable response in Fig. 11 because it vibrate nearly in coincides with the fundamental frequency of the structure as shown in Fig. 12.

C. *The Kn11 and Kn13 Loading Cases*

These two earthquakes are examples of low frequency excitation that are lower than the fundamental frequency of the structure. The two earthquakes are dominantly vibrating around 0.5Hz, which is about the half of the fundamental frequency of the building. This makes the effect of such earthquakes act like quasi-static loading, where the time history response seem to track the pattern of the excitation, that means both the excitation and the response are vibrating nearly in phase with no dynamic magnification for the response.

In such type of excitation, the response of the structure is more sensitive to the displacement of ground rather than to its acceleration, and hence the parameter of peak ground displacement (PGD) is more important than the (PGA) as mentioned by many authors [1].

V. CONCLUSIONS

- The pairs of frequency domain figures for each loading case have shown that the structure can feel only a specific band of frequency of the excitation in relation to its fundamental frequency. This "active band of frequency" may be suggested as (0.25-4) of the fundamental frequency of the building.
- Buildings are generally tend to vibrate dominantly around their fundamental frequency no matter how is the frequency distribution of the excitation.
- When the excitation comes with much lower frequency than the fundamental of the building, which is not a very common case, the response of the building will behave as a quasi-static response. It will be in phase with the excitation and exhibit no dynamic magnification as it can be noticed in comparing the shape of the excitation and the response of Fig. 14 and Fig. 15 for the Kn11 loading case.
- The time domain pairs of figures show that the values of the maximum response are tracking the maximum values of acceleration of the ground (PGA) with some lag in time that is required to build some sort of resonance.

REFERENCES

[1] Chopra, A. K. (2007) "Dynamics of Structures: Theory and Applications to Earthquake Engineering", Third Edition, Pearson Prentice Hall, Upper Saddle River, New Jersey, 914 pp.