International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:9, No:6, 2015

Effects of Ground Motion Characteristics on Damage of RC Buildings: A Detailed Investigation

M. Elassaly

Abstract**—**Damage status of RC buildings is greatly influenced by the characteristics of the imposed ground motion. Peak Ground Acceleration and frequency contents are considered the main two factors that affect ground motion characteristics; hence, affecting the seismic response of RC structures and consequently their damage state. A detailed investigation on the combined effects of these two factors on damage assessment of RC buildings is carried out. Twenty one earthquake records are analyzed and arranged into three groups, according to their frequency contents. These records are used in an investigation to define the expected damage state that would be attained by RC buildings, if subjected to varying ground motion characteristics. The damage assessment is conducted through examining drift ratios and damage indices of the overall structure and the significant structural components of RC building. Base and story shear of RC building model, are also investigated, for cases when the model is subjected to the chosen twenty one earthquake records. Nonlinear dynamic analyses are performed on a 2-dimensional model of a 12-story RC building.

Keywords**—**Damage, frequency content, ground motion, PGA, RC building, seismic.

I. INTRODUCTION

CONTINUOUS effort has been aimed towards increasing the recognition of the potential seismic hazard of earthquakes and the resulting liability of constructions, in general and RC buildings, in particular. Seismic performance of RC structures under earthquake motion are directly associated with the level of structural damage attained. Research work has been conducted to properly estimate, predict and mitigate the risk and damage encountered in RC buildings [1]-[3]. Factors, that affect the seismic performance and damage state of a structure, include the dynamic characteristics of the structure, regarding its stiffness and mass coefficients, structural irregularity [4], [5], site effects, local soil conditions, location of building with respect to fault zone, soil-structure interaction effects [6], presence of infill walls [7], [8], ground motion characteristics regarding Peak Ground Acceleration, frequency content, duration, angle of incident, ... etc., [9], [10].

The present research focuses on evaluating the mutual effects of PGA and frequency contents of ground motions on the damage state of RC buildings. Other factors related to ground motion characteristics, such as duration and angle of incident are not accounted for. Twenty one ground motion records have been employed in the current study. The study investigates the correlation between PGA and frequency content of the chosen group of ground motions; hence, their effects on damage state of RC buildings are investigated. The structural seismic response is assessed for the natural original values of PGA of the chosen ground motions, as well as for two hypothetical cases where PGA has been scaled up and down to simulate relatively low and high values of PGA. The utilized earthquake record is classified into Low, Medium and High record, according to their frequency contents. The frequency content of a ground motion, by a quantitative factor A/V following the classification method according to [11]; where A represents PGA in terms of g, while V represents the PGV of the ground motion. Correlation between the significant two factors PGA and A/V has been established. Damage assessment procedure, of RC building, is proposed; where two damage indicators are calculated. The following damage indicators are employed: damage indices, according to the Park and Ang model, 1985, and the inter-story drift limits, according to [12]. These two indicators are used to quantitatively express damage and performance of RC building. Results of the study, explicitly define the expected damage state of RC building if subjected to varying ground motion characteristics. Nonlinear time history analyses of model building are performed using the computer program IDARC2D V.6.1. [13].

II. INVESTIGATED RC BUILDING MODEL

The assumed RC model has 12 story height, with regular 3 meter floor height, for all stories. This height resembles mid-height RC buildings. Regular plans, with 5 equal bays and a spacing of 5 meter in the longitudinal and transverse directions, are proposed. Base columns are assumed to be fixed to the foundation. The proposed model is designed according to the [14] ECCS-201, 2008. The configurations of the selected model are presented in Fig. 1, where the intermediate column C1 has a cross section of (75x75 cm) and reinforcing high grade steel of 26 bars size 16mm; the comparable values for edge column C2 are (50x50 cm) and 12 bars size 16mm. The connecting beam B is assumed to be (25x75 cm) for its cross section, with 5 bars 16 mm for top and bottom reinforcement. These configurations of columns and beams are kept constants for all stories of investigated model. The above model, with regular configuration, in both plan and elevation, is meant in order to be able to draw objective and neutral conclusions, regarding the effects of earthquake characteristics on seismic damage assessment of this type of RC buildings.

M. Elassaly is with Civil Engineering Department, Fayoum university, Fayoum City, Egypt, (phone: +201001434326; fax: +2025216788; e-mail: Mohamed.elassaly@ gmail.com).

III. DAMAGE EVALUATION

The damage evaluation process generally requires estimating the structural capacity and the expected demand. The difference between these two quantities is evaluated using seismic performance indicator to reflect the state of the structural damage. The Park-Ang index has been thoroughly employed as a damage indicator [15], [13]. The Park-Ang damage index expresses the structural seismic deformation as a linear combination of two terms: the first term represents the damage caused by excessive deformation and the second term reflects cumulative damage caused by repeated cyclic response. It is expressed mathematically as: [16]

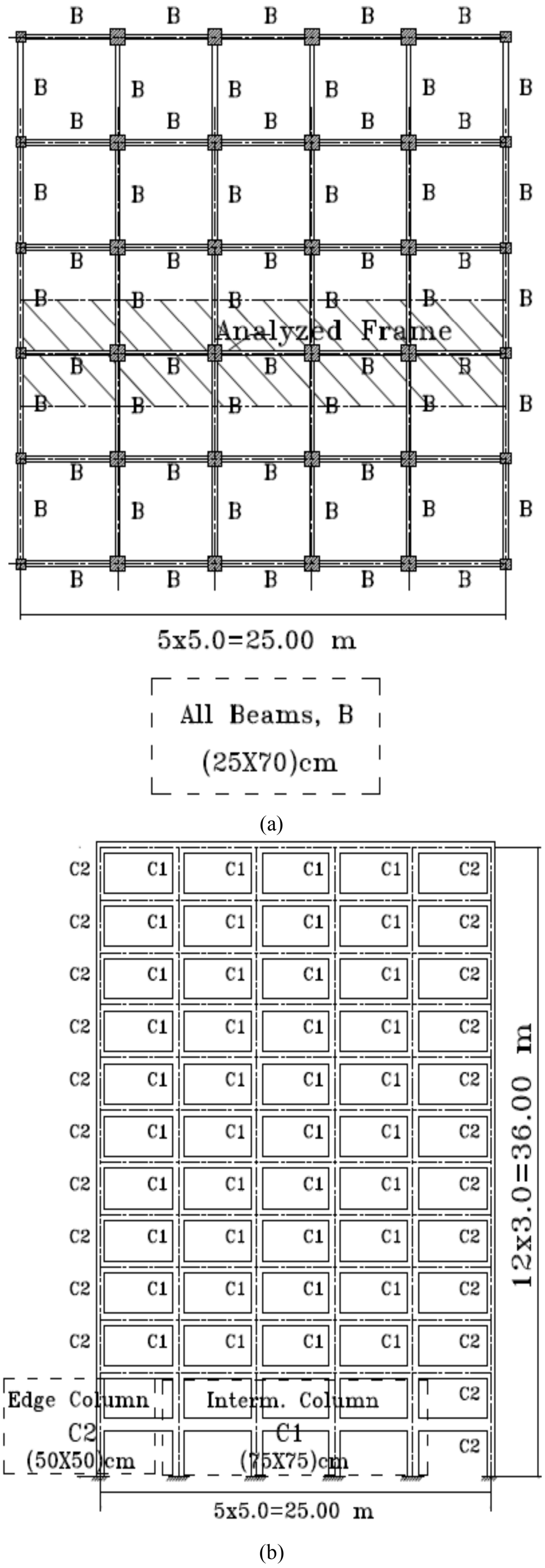
$$DI=\frac{\delta_m}{\delta_u}+\frac{\beta}{\delta_u P_y}\int dE_h \qquad (1)$$

in which δ_m is the maximum deformation of element, δ_u is the ultimate deformation and β is a dimensional constant parameter with average experimental value of 0.15 for concrete structures. $\int dE_h$ is the hysteretic energy absorbed by element during the earthquake, and P_y is the yield strength of element. For both terms of the index, the numerator expresses the demand, while the denominator represents the capacity. Higher demand to capacity ratio reflects higher degree of structural damage. Moreover, global damage index for part or all of a structure is the average of the relevant local indices, weighted by the corresponding local energy absorptions.

$$\mathrm{DI}_{\mathrm{STORY}}=\sum(\Lambda_I)_{component}(\mathrm{DI}_I)_{component};\quad (\Lambda_I)_{component}=\left(\frac{E_I}{\sum E_I}\right)_{component}$$
$$\mathrm{DI}_{\mathrm{OVERALL}}=\sum(\Lambda_I)_{\mathrm{STORY}}(\mathrm{DI}_I)_{\mathrm{STORY}};\qquad (\Lambda_I)_{\mathrm{STORY}}=\left(\frac{E_I}{\sum E_I}\right)_{\mathrm{STORY}} \qquad (2)$$

where λ_I is energy weighting factors and E_i is total absorbed energy by component or story "i". Correlation between damage index limit states, according to [16], and damage status of building, is presented in Table I. Five damage states of building are defined: none, slight, minor, moderate and severe.

On the other hand, [12] introduced other seismic performance indicator; that is through the expected maximum inter-story drift ratios. Table II presents the proposed limits by [12]. Three distinct limit states are defined: Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP).



(a)

(b)

Fig. 1 Configuration of proposed model; plan (a), elevation (b)

IV. GROUND MOTION

For the present study, 21 earthquake records are used in the analysis; data of these records are presented in Table III. These earthquakes represent wide range of intensities and frequency contents of seismic waves [17]. These records are subdivided into three groups: LFC, MFC and HFC for Low, Medium and High Frequency Content record, respectively. The classifications of these groups are based upon the quantitative factor A/V of each earthquake, where A equals PGA, in terms of g, and V equals the PGV, in terms of m/s. The spectral acceleration of these three groups of earthquakes, HFC, MFC and LFC records, are depicted in Fig. 2. The average spectral acceleration of each group is also depicted to emphasize the differences between the significant features of each group. The LFC group, shown in Fig. 2 (a), has the largest average spectral acceleration in the low frequency range (high period; T>1.5~1.8s); whereas the MFC (Fig. 2 (b)) is considered the dominant group in the range (0.8<T <1.5~1.8s). For the high frequency range (low period; T<0.45s.), the HFC group has the largest spectral acceleration (Fig. 2 (c)). Therefore, each group of ground motion is expected to be the prevailing group that affects different set of buildings, according to their fundamental frequencies. For the present study, the fundamental frequency of the proposed model of RC building equals 1.46s; thus, it is expected to be affected mostly with MFC and LFC earthquake groups.

Fig. 3 depicts a correlation between PGA of the selected group of earthquake record with their corresponding values of A/V ratio. Limits of A/V defining different zones of frequency content are depicted in the Fig. 3 high frequency content zone, defined with A/V>1.2, PGA may reach as high as 1.779g. Thus, it could be concluded that low frequency earthquakes, are associated with relatively low values of PGA; whereas, high frequency earthquakes would have relatively high values of PGA. Trend line of variation, depicted in Fig. 3, confirms the above mentioned conclusion. Low frequency zone is defined for regions of A/V < 0.8; where PGA varies from a minimum value of 0.348g to a maximum value of 0.843g.

TABLE I
DAMAGE INDEX AND CORRESPONDING DAMAGE STATE [16]

Descriptions		Damage Index	Damage State of Building
Slight	Sporadic occurrence of cracking	< 0.1	No Damage
Minor	Minor cracks; partial crushing of concrete in columns	0.1-0.25	Minor Damage
Moderate	Extensive large cracks; spalling of concrete in weaker elements	0.25-0.4	Repairable
Severe	Extensive crashing of concrete; disclosure of buckled reinforcement	0.4-1.0	Beyond Repair
Collapse	Partial or total collapse of building	>1.0	Loss of Building

TABLE II
INTER-STORY DRIFT LIMIT STATES [12]

Structural performance levels	Drift (%)
Immediate Occupancy (IO)	1
Life Safety (LS)	2
Collapse Prevention (CP)	4

TABLE III
CHARACTERISTICS OF DIFFERENT CLASSES OF NATURAL GROUND MOTIONS [17]

class	ID	Earthquake/ Component	Date	M	Soil Type*	PGA (g)	PGV (m/s)	a/v ratio
Low frequency contents (LFC)	P0030	Parkfield / PARKF/C02065	28/06/1966	6.1	A	0.476	75.1	0.63
	P0809	Cape Mendocino / CAPEMEND/PET090	25/04/1992	7.1	A	0.662	89.7	0.74
	P0927	Northridge / NORTHR/NWH090	17/01/1994	6.7	A	0.583	75.5	0.77
	P0927	Northridge / NORTHR/NWH360	17/01/1994	6.7	A	0.59	97.2	0.61
	P0934	Northridge / NORTHR/SYL360	17/01/1994	6.7	A	0.843	129.6	0.65
	P0993	Northridge / NORTHR/STC180	17/01/1994	6.7	A	0.477	61.5	0.78
	P1540	Duzce, Turkey / DUZCE/DZC180	12/11/1999	7.1	A	0.348	60	0.58
Medium frequency contents (MFC)	P0082	San Fernando / SFERN/PCD164	09/02/1971	6.6	B	1.226	112.5	1.09
	P0127	Gazli, USSR / GAZLI/GAZ090	17/05/1976	6.8	C	0.718	71.6	1.00
	P0806	Cape Mendocino / CAPEMEND/CPM000	25/04/1992	7.1	C	1.497	127.4	1.18
	P0890	Northridge / NORTHR/MUL279	17/01/1994	6.7	D	0.516	62.8	0.82
	P0998	Northridge / NORTHR/PAR--L	17/01/1994	6.7	Unknown	0.657	75.2	0.87
	P1056	Kobe / KOBE/TAZ000	16/01/1995	6.9	E	0.693	68.3	1.01
	P1056	Kobe / KOBE/TAZ090	16/01/1995	6.9	E	0.694	85.3	0.81
High frequency contents (HFC)	P0409	Coalinga /COALINGA/D-OLC270	22/07/1983	5.8	B	0.866	42.2	2.05
	P0449	Morgan Hill / MORGAN/CYC285	24/04/1984	6.2	C	1.298	80.8	1.61
	P0729	Superstitn Hills(B) / SUPERST/B-SUP135	24/11/1987	6.7	C	0.894	42.2	2.12
	P0810	CAPEMEND/RIO360	25/04/1992	7.1	D	0.99	42.1	2.35
	P0935	Northridge / NORTHR/TAR090	17/01/1994	6.7	B	1.779	113.6	1.57
	P1021	Northridge / NORTHR/KAT000	17/01/1994	6.7	B	0.877	40.9	2.14
	P1551	Duzce, Turkey /DUZCE/375-N	12/11/1999	7.1	B	0.97	36.5	2.66

* A: Deep broad, B: Sallow stiff, C: Rock, D: Deep narrow, E: Soft deep

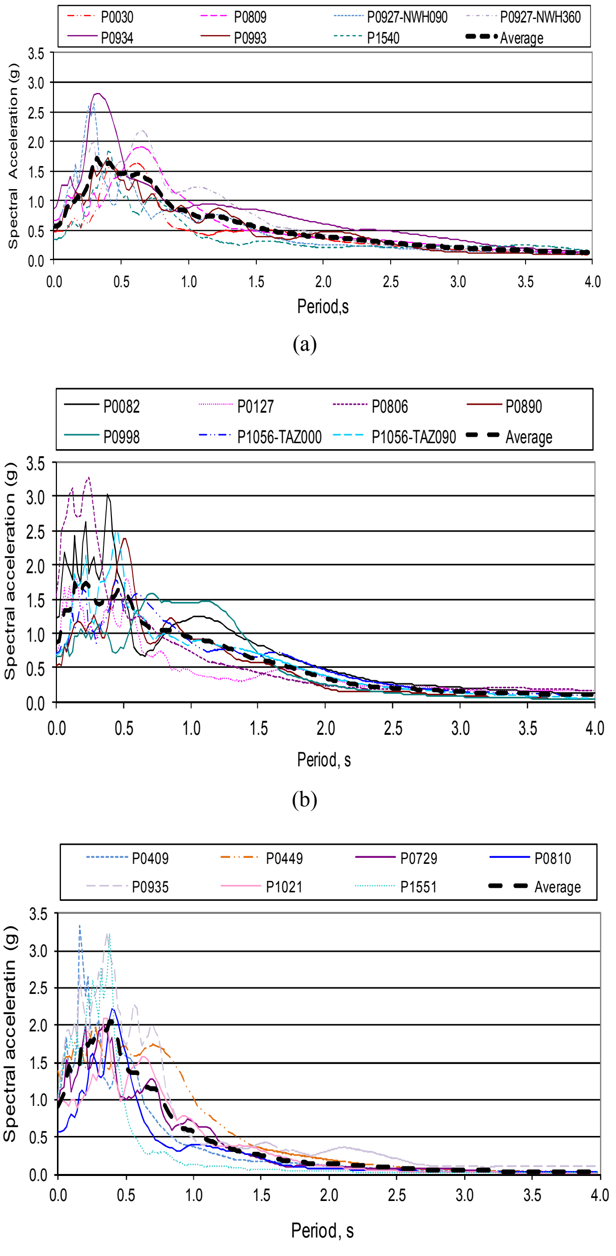
V. NONLINEAR TIME HISTORY ANALYSIS

A model representing two-dimensional idealization of interior frame of sample building is investigated. Torsion effects are ignored since the investigated model is assumed to have regular plan configurations. Effects of infill walls on the overall stiffness of model are not accounted for. Nonlinear time history analyses are performed to assess damage state of RC buildings when subjected to varying ground motion characteristics. A time step of 0.001s and a 5% Rayleigh proportional damping are selected. The computer program IDARC2D [13], is employed. This computer program has been used extensively and successfully in damage analysis of structures [18], [19]. The analysis takes into consideration the P-delta effects. A smooth hysteretic model is used to simulate the elastic-yield transition and the shape of unloading; it incorporates stiffness degradation, strength deterioration, non-symmetric response, slip-lock and a tri-linear monotonic envelope. Significant structural features are assessed, such as damage indices for the overall structure as well as for the significant columns and beams, located at particular locations of the building. In addition, inter-story drift ratios and shear distribution, along the height of RC building, are calculated for each investigated case.

VI. RESULTS AND DISCUSSION

Figs. 4-8 summarize the outcomes of the present study. Fig. 4 depicts the variation of the overall damage indices of RC building, subjected to different earthquakes, having various frequency contents, whereas their peak ground accelerations are scaled to 0.5g (part a), 1.0g (part b) and original PGA (part c), respectively. Figs. 4 (a) and (b) show that for a RC building subjected to earthquakes having the same PGA, the ones with low frequency content, would generally result in higher values of overall damage indices when compared to other frequency content categories. According to the correlation between the overall damage index and the damage state of RC buildings (Table I), the followings could be stated:

- For the relatively low values of PGA (i.e. PGA=0.5g, Fig. 4 (a)), RC buildings would experience moderate damage state, if subjected to a LFC earthquake; whereas a minor damage state is expected if the building is subjected to MFC ground motion. If a HFC record is applied, a case of slight or no damage state is expected for the RC building.
- For the relatively high values of PGA (i.e. PGA=1.0g, Fig. 4 (b)), RC buildings is expected to suffer severe damage state, if subjected to a LFC earthquake; whereas a moderate damage state is likely to occur, if the building is subjected to MFC ground motion. Minor damage state, for the RC building, is expected if a HFC record is applied.
- For the original natural values of PGA (Fig. 4 (c)), a moderate damage state is expected if RC building is subjected to either LFC or MFC earthquake; minor damage is expected for the case of HFC record.



(a)

(b)

(c)

Fig. 2 Spectral acceleration of the different categories of earthquakes used in the study; Spectral acceleration of Low Frequency Content EQ (a), Spectral acceleration of Medium Frequency Content EQ (b), Spectral acceleration of High Frequency Content EQ (c)

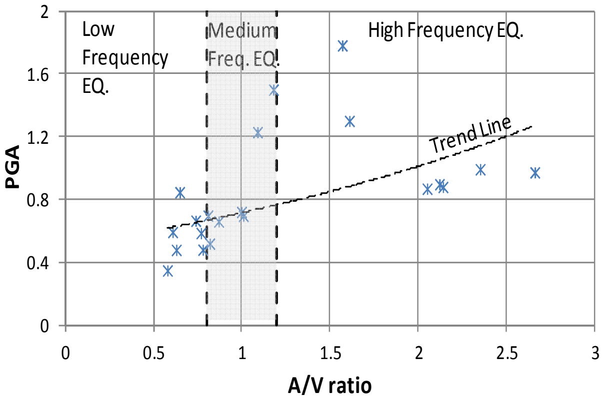


Fig. 3 Correlation between PGA and A/V ratio for various earthquakes

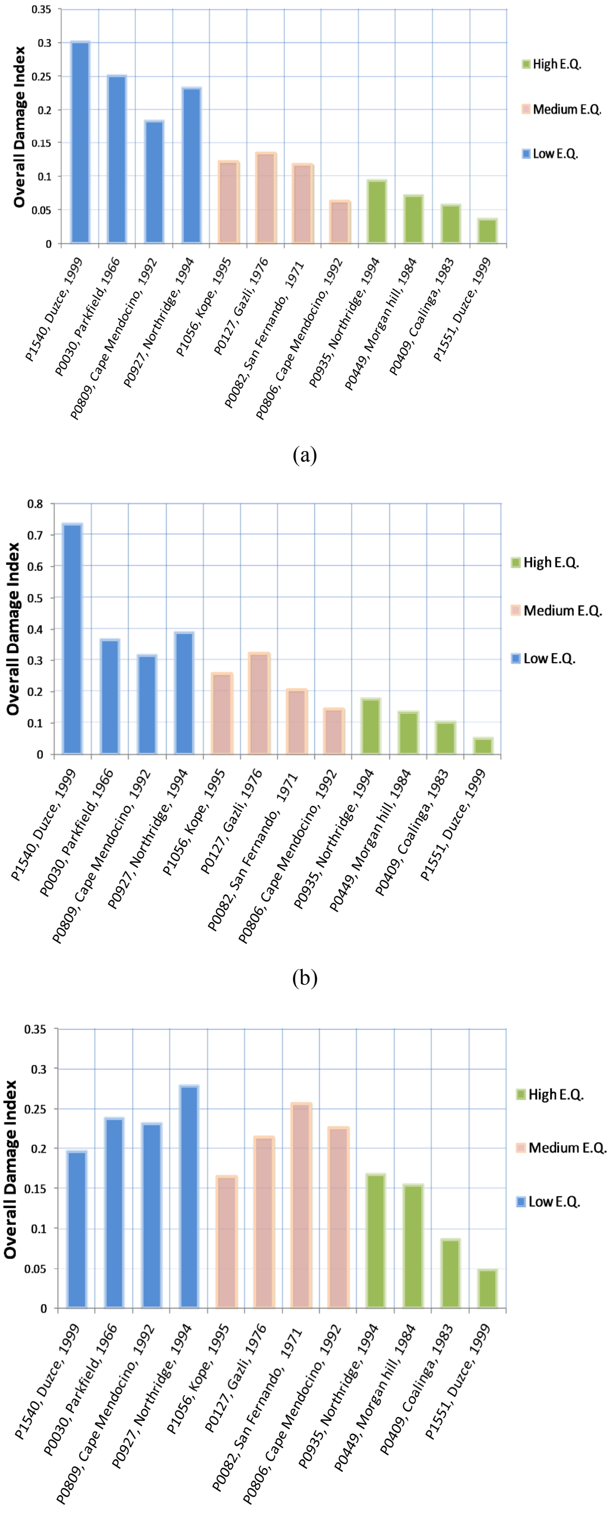
- For the structural configuration considered and for all investigated cases of PGA, the LFC earthquake group results in the highest overall damage indices when compared to those resulting from other groups of frequency content.

Figs. 5 (a)-(c) depict the variation of maximum inter-story drift ratios along the height of RC building, when subjected to different earthquakes having peak ground accelerations scaled to 0.5g, 1.0g and original PGA, respectively. Fig. 5 (a) shows that the LFC earthquakes result in maximum inter-story drift ratios of almost 2 to 3 %, which resembles the highest values attained for a ground motion with PGA in range of 0.5g. The HFC records, would lead to a maximum value of almost 1% for the drift ratio, for same value of PGA.

Based on these results, it can be concluded that no RC building is expected to reach Collapse Prevention CP limit state (Table II, FEMA-356, 2000), if subjected to this range of PGA.

For the high value of PGA of 1.0g, shown in Fig. 5 (b), the corresponding values of drift ratios may reach as high as 2% and 18%, for the HFC and LFC records, respectively; thus, the drift ratios is expected to increase by 2 to 6 times, if the PGA is doubled. Moreover, Fig. 5 (b) shows that only those records with LFC, would lead a RC building to surpass the CP limit state. It should be noted that this very high inter-story drift ratio range for the LFC record, would certainly involve formation of plastic hinges in many joints of the building. Inspecting the damage mechanism (not shown) reveals the formation of plastic hinges at both column heads and bases for most of building stories, as well as cracking and yielding of reinforcing steel.

When applying the earthquakes, with their original PGA, to the RC building (Fig. 5 (c)), no RC building is expected to surpass the CP limit state. Moreover, among the highest four values of maximum drift ratios attained, three cases occur due to LFC records, whereas one case is due to HFC record (P0935, Northridge, 1994, H).



(a)

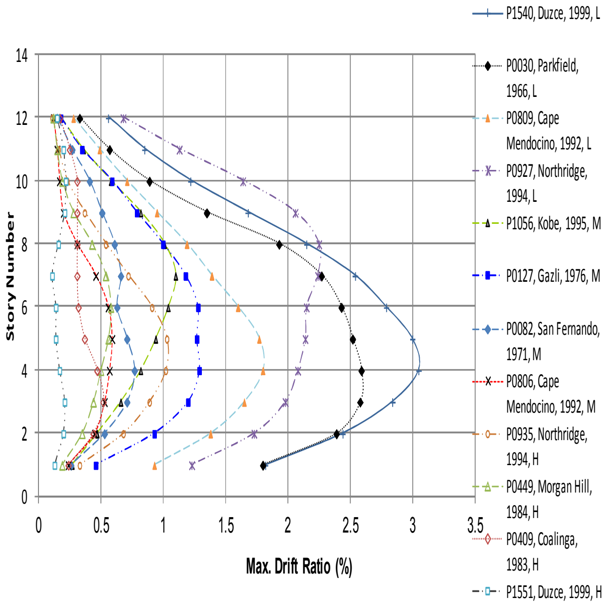
(b)

(c)

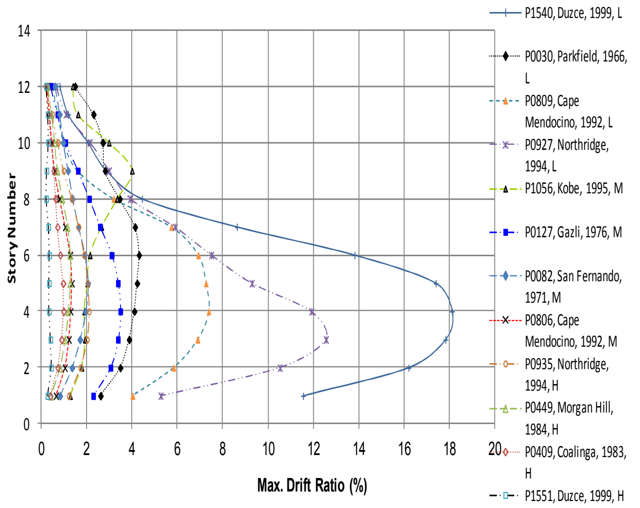
Fig. 4 Overall damage indices of RC building, for EQ having various PGA and frequency contents; Earthquakes are scaled to have PGA=0.5g (a), Earthquakes are scaled to have PGA=1.0g (b), Earthquakes have their original PGA (c)

For this particular case of HFC record, the PGA was 1.779g which represents the highest PGA among the investigated cases. Finally, the MFC records result in intermediate results among those of LFC and HFC records, for all investigated cases of ground motions and for the considered configuration of RC buildings.

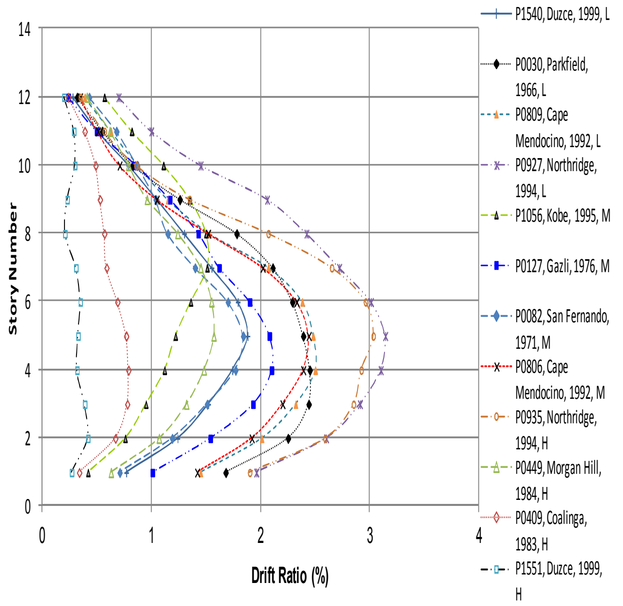
Fig. 6 demonstrates the variation of most significant two seismic features of RC building, with the factor A/V for various values of PGA; these features represent the overall damage index and the maximum base shear. Due to the wide scattering of the output results, trend lines of expected behavior are plotted to emphasize the objective conclusions. Marginal zones of Low, Medium and High frequency contents earthquakes, are highlighted. Figs. 6 (a), (c) and (e) show that the overall damage index of RC building is greatly affected with A/V factor for the investigated values of PGA as well as for the original values of PGA; the overall damage index significantly decrease with the increase in A/V ratio. The percentages of decrease, for the inspected range, are 85, 90 and 80% for the PGA of 0.5g, 1.0g and original values, respectively. For the variation of maximum base shear, Figs. 6 (b) and (d) show somehow similar behavior, where a slight decrease in the maximum base shear is expected for the increase in A/V, for the investigated values of PGA. The ratio of decrease varies between 1.75 to 1 and 1.5 to 1 for the PGA of 0.5g and 1.0g, respectively. Contrary to this behavior, Fig. 6 (e) shows no profound correlation for the variation of base shear of RC building with A/V, for the original values of PGA of earthquakes.



(a)

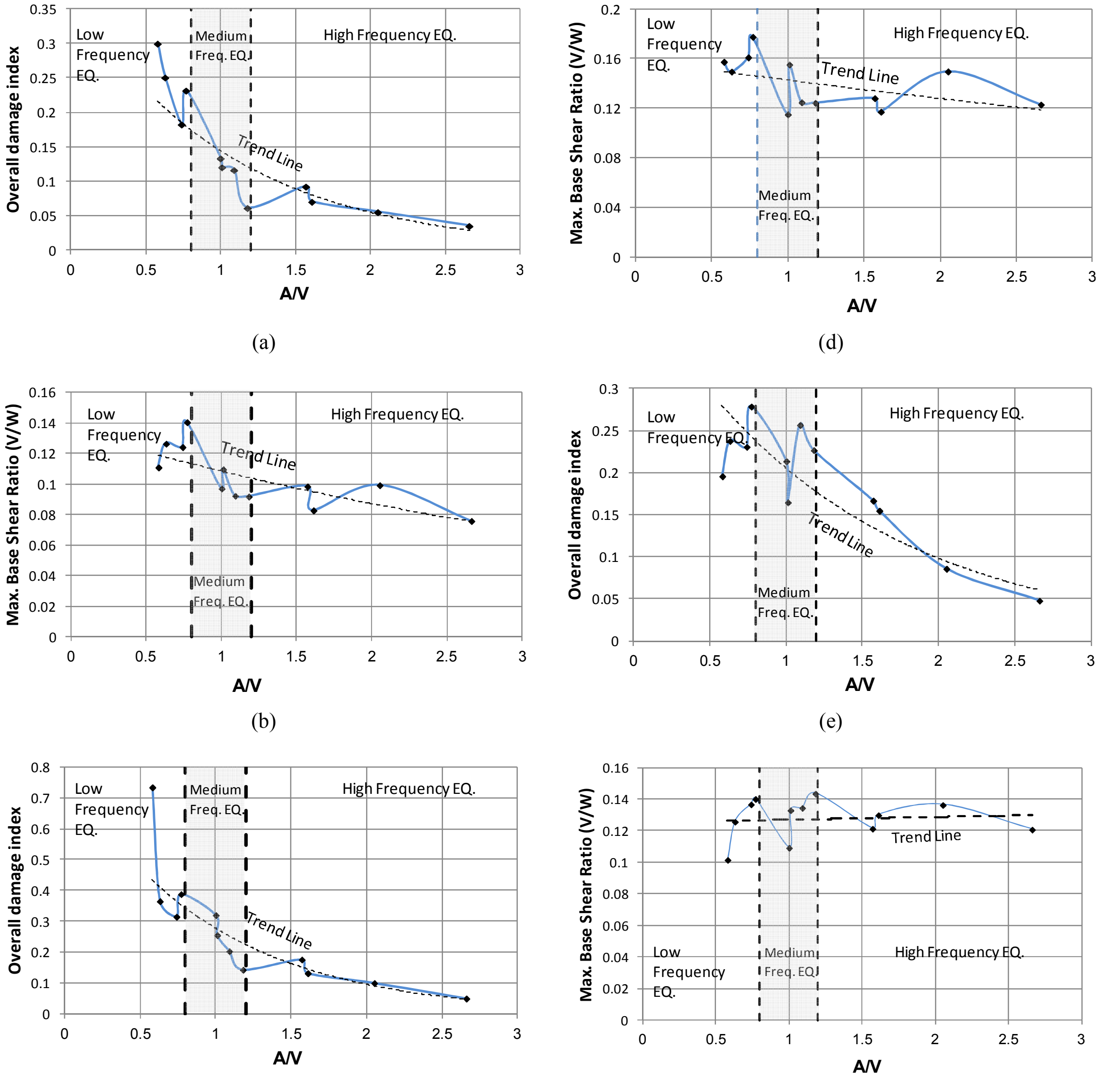


(b)



(c)

Fig. 5 Maximum drift ratios of RC building, for EQ having various PGA and frequency contents; Earthquakes are scaled to have PGA=0.5g (a), Earthquakes are scaled to have PGA=1.0g (b), Earthquakes have their original PGA (c)



(a) (d)

(b) (e)

(c) (f)

Fig. 6 Variation of overall structural damage index and maximum base shear with factor A/V, for various PGA; Earthquakes with PGA=0.5g (a), Earthquakes with PGA=0.5g (b), Earthquakes with PGA=1.0g (c), Earthquakes with PGA=1.0g (d), Earthquakes with Original PGA (e), Earthquakes with Original PGA (f)

Fig. 7 depicts the variation of maximum inter-story drift ratio of RC building with A/V factor; it should be noted that the drift ratio is represented along the y-axis by log scale. In general, Fig. 7 shows that the drift ratios decrease significantly with the increase of A/V factor. The percentages of decrease, for the inspected range, are 93, 97 and 86% for the PGA of 0.5g, 1.0g and original values, respectively.

Fig. 8 presents the variation of damage indices of particular story columns and connecting beams, with A/V, for various values of PGA; the particular story locations are at the base, mid-height and top story, respectively. Figs. 8 (a), (c) and (e) show that damage indices of base columns are most affected with the variation of A/V; damage indices are greatly reduced with the increase of A/V. Columns, located at mid-height and top stories, are hardly affected with the variation of A/V; exception may occur for the case of relatively high values of PGA (PGA=1.0g, Fig. 8 (c)), where damage indices of columns located at mid-height are significantly reduced with increase of A/V. Figs. 8 (b), (d) and (f) show that damage indices of beams, located at mid-height stories, are greatly reduced with the increase of A/V.

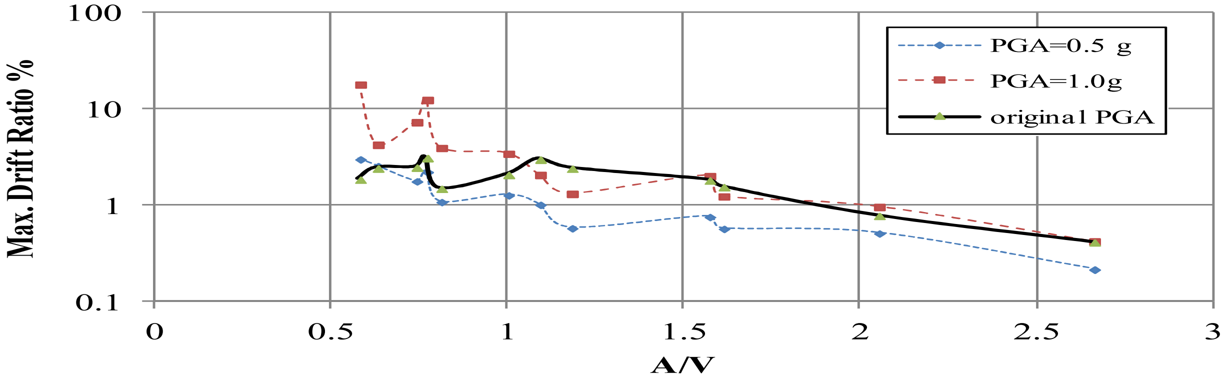
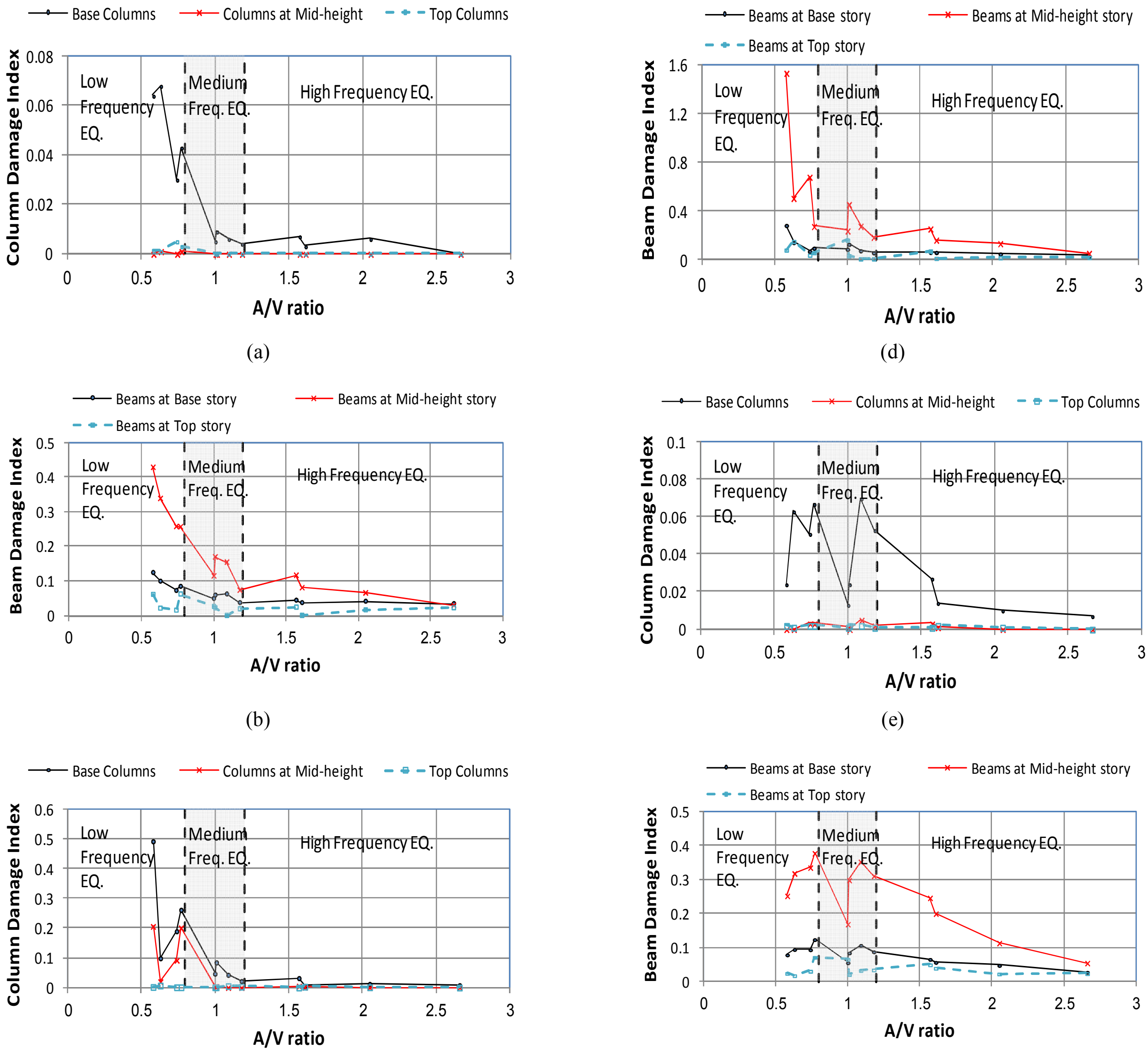


Fig. 7 Variation of maximum inter-story drift ratio with factor A/V, for various PGA



(a)

(d)

(b)

(e)

(c)

(f)

Fig. 8 Variation of story column and beam damage indices with factor A/V, for various PGA; Earthquakes with PGA=0.5g (a), Earthquakes with PGA=0.5g (b), Earthquakes with PGA=1.0g (c), Earthquakes with PGA=1.0g (d), Earthquakes with Original PGA (e), Earthquakes with Original PGA (f)

VII. CONCLUSIONS

The current research work represents a comprehensive study on the combined effects of PGA and frequency contents of earthquakes on damage assessment of RC buildings. 21 earthquake records, with varying configurations, have been employed in the analysis. The study is limited to investigating the seismic performance of 12 story R.C. buildings, with regular configurations. The following conclusions are drawn:

- Low frequency earthquakes, are generally associated with relatively low values of PGA; whereas, high frequency content earthquakes would generally have relatively high values of PGA.
- If RC building is subjected to earthquake with relatively low values of PGA, in range of 0.5g, Moderate, Minor or No damage states are expected: for LFC, MFC and HFC records, respectively. The inter-story drift ratios are not expected to reach CP limit state. The maximum expected drift ratios are within 3%.
- If RC building is subjected to earthquake with relatively high values of PGA, in range of 1.0g, the following damage states are expected: Severe, Moderate and Minor damage state for LFC, MFC and HFC records, respectively. In addition, the inter-story drift ratios are expected to surpass the CP limit state, only for the case of LFC records.
- If RC building is subjected to LFC or MFC earthquake with its original PGA, a Moderate damage state is expected; whereas a Minor damage state is expected for HFC earthquake. Regarding the inter-story drift limits, no RC building is expected to surpass the CP limit state.
- In general, LFC earthquake group results in the highest overall damage indices when compared to those resulting from other groups of frequency content.
- If PGA of an earthquake is increased from 0.5g to 1.0g (i.e. doubled), inter-story drift ratios are expected to increase by 2 to 6 times due to the expected non-linear behavior of building; whereas, the base shear is expected to increase by 30% to 60 %.
- With the increase in A/V ratio of an earthquake, both the overall damage index and the inter-story drift limits, of RC building, significantly decrease.
- The earthquake record that leads to the highest base shear may not be the one that leads to the highest inter-story drift ratio.
- Damage indices of base columns and beams located around mid-height of RC building, are the most affected structural component, with the variation of A/V ratio of an earthquake.

REFERENCES

[1] A. S. Elnashai, “A very brief history of earthquake engineering with emphasis on developments in and from the British Isles,” *Chaos, Solitons & Fractals*, Volume 13, Issue 5, April 2002, Pages 967-972.

[2] A. S. Elnashai, “Assessment of seismic vulnerability of structures,” *Journal of Constructional Steel Research*, Volume 62, Issue 11, November 2006, Pages 1134-1147.

[3] S. El-Kholy, M. El-assaly, and M. Maher, “Seismic vulnerability assessment of existing muti-story reinforced concrete buildings in Egypt,” *Arab J Sci Eng, 2012, 37:341–355.*

[4] M. El-assaly, M. Maher, and S. ElKholy, “Seismic damage assessment of vertical irregular RC buildings: case study of setback buildings*, 10th International Conference RASD*, 12-14 July, Southhampton, U.K., 2010.

[5] M. El-assaly, “Seismic Performance Assessment of vertical Irregular R.C. Buildings, for Various Ground Motion Characteristics,” *CSCE 2012, 3rd International Structural Specialty Conference,* Edmonton, Alberta, Canada, 2012.

[6] O. Kwon, and A. S. Elnashai, “Probabilistic Seismic Assessment of Structure, Foundation, and Soil Interacting Systems,” *Mid-America Earthquake Center, 2007.*

[7] A. Madan, and A. Hashmi, “Analytical prediction of the seismic performance of masonry infilled reinforced concrete frames subjected to near-field earthquakes,” *J. Struct. Engrg.*, 2008, 134 (9), 1569 – 81.

[8] M. Dolsek, and P. Fajfar, “The effect of masonry infills on the seismic response of a four storey reinforced concrete frame-a probabilistic assessment,” *Engineering Structures*, 2008, 30, 1991–2001.

[9] M. El-assaly, “Effects of Frequency Content of Ground Motion on Seismic Response of Multistory Buildings,” *CSCE 2005, 33rd Annual General Conference of the Canadian Society for Civil Engineering*, Toronto, Ontario, Canada, 2005.

[10] M. Maher, S. ElKholy, and M. El-assaly, “The effects of ground motion characteristics on the seismic fragility curves of R/C buildings, *CSCE 2009 Annual General Conference,* St. John’s, Newfoundland and Labrador, Canada, 2009.

[11] T. Sawada, K. Hirao, H. Yamamoto, and O. Tsujihara, “Relation between maximum amplitude ratio and spectral parameters of earthquake ground motion,” *Proceedings of 10th World Conference on Earthquake Engineering*, Madrid, Spain, 1992, 2:617-622.

[12] FEMA-356, Pre-standard and commentary for the seismic rehabilitation of buildings, *Federal Emergency Management Agency*, Washington (DC), 2000.

[13] IDARC2D, A Computer Program for Seismic Inelastic Structural Analysis, *Department of Civil, Structural and Environmental Engineering*, University at Buffalo, New York, http://www.civil.eng.buffalo.edu/ idarc2d50/, 2006.

[14] ECCS-201, Egyptian Code for Design and Construction of Concrete Structures, *Ministry of Housing*, Utilities and Urban Communities, Cairo, Egypt, 2008.

[15] Y. J. Park, and H-S. Ang, “Mechanistic Seismic Damage model for Reinforced Concrete,” *Journal of Structural Engineering, ASCE*, 1985, 111(4), 722-739.

[16] Y. J. Park, H-S. Ang, and Y.K. Wen, “Damage-Limiting A seismic Design of Buildings,” *Earthquake Spectra*, 1987, 3(1), pp. 1–25.

[17] PEER. Strong Motion Database, the Pacific Earthquake Engineering Research Center and the University of California, Web site: http://www.peer.berkeley.edu/smcat/, 2000.

[18] S. K. Kunnath, A. M. Reinhorn, and R. F. Lobo, , IDARC Version 3.0, “A Program for the Inelastic Damage Analysis of Reinforced Concrete Structures,” *Technical Report NCEER 92-0022, NCEER, State University of New York at Buffalo*, 1992.

[19] M. R. Tabeshpour, A. Bakhshi, and A. A. Golafshani, “Seismic vulnerability, performance and damage analysis of special structures,” *13th World Conference on Earthquake* Engineering, Canada, 2004.