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Assesment of interdependency between Near – Field seismic acceleration parameters and overall structural damage index in the concrete buildings

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Abstract

This paper investigates the correlation between near –field seismic parameters and damage index in concrete buildings and then compares obtained results with those observed in related to far – field seismic parameters. The excitations such as PGA, PGV, PGD, Arias Intensity and SED are extracted from near and far field seismic records for characterizing the seismic excitation. On the other side, structural damage index is expressed by the modified Park /Ang overall structural damage index (OSDI). After the evaluation of seismic parameters, Nonlinear Dynamic Analysis on the three concrete frames reinforced by shearwall and three moment resisting frames (MRF) are carried out to observe response parameters. The degree of the interrelationship between mentioned seismic parameters and strucural damages are determined by correlation coefficients. Finally as a result with observing these coefficients, those parameters play significant role to predict structural damages, are known. In related to near – field records, Results indicate there is high correlation between PGV and SED and damage index. Also it is revealed that degree of correlation is increased with increasement of height and period of structure. Findings show that about tall concrete buildings which are subjected near – field ground motions, PGV and SED especially PGV can be used as parameters to predict structural damages.

Keywords: Near- Field Ground Motion, Damage Index, Seismic parameters, shearwall

Introduction

Near – field ground motions contain distinct large amplitude pulses in both velocity and displacement. These pulses can cause high level of interstory drift ratio and damage in structural systems (Tothong and Cornell, 2006). Recent concern about the damage potential of near – field ground motions has led to considerable interst in the nature of these motions and their impact on structural performance. more detailed description about these ground motions have been presented in the section 3. moreover all of near – field and far – field ground motions are characterized by parameters called seismic parameters. Infact, inherent information of earthquakes accelerograms can be classified in the three categories (Elenas and Meskouris,2001):

1 : peak parameters (e.g. peak ground acceleration(PGA), peak ground velocity (PGV), peak ground displacement (PGD))

2 : spectral parameters (e.g. response-, energy-,Fourier-spectra)

3: energy parameters (e.g. Arias Intensity, Husid Diagram, strong motion duration(smd) after Trifunance / brady, power $p_{0.9}$, SED).

The definitions of these parameters have been completely presented in the literature (Jennings,1982, Arias, 1970, Trifunac and Brady, 1975, Meskouris, 2000, Naeim and Anderson, 1993, Trifunac and Novikova,1995)

It should be point out that in present study only PGA, PGV, PGD, Arias Intensity and SED as selected parameters are considered. Studies of vulnerability of structures during the last destructive earthquakes have shown more or less marked interdependency between the above-mentioned parameters and structural responses (Elenas et al, 1995, Elenas and Liolios, 1995, Elenas, 1997, Elenas, 1998)

On the other side, recently researchers found fundamental differences between structural behaviour of structures subjected to near – field earthquakes in compare with far – field earthquakes (Ghobarah, 2004). Hence in present paper, it has been tried that the vulnerability of structures subjected to these earthquakes and its relation with seismic parameters would be considered. For this purpose First by computer Analysis of accelerograms by Seismosignal software, some of parameters such as PGA, PGV, PGD, Arias Intensity and SED are extracted and then nonlinear dynamic analyses for extracting response parameters and applied damages on the three concrete frames reinforced by shearwall and three moment resisting frames (MRF), each time under a given seismic excitation, by IDARC software (Reinhorn et al, 1996) are carried out. After that, correlation coefficients are used to investigate degree of interdependency between seismic parameters and damage indices. Finally it will be revealed which of parameters provide high correlation with damage indices and which of them can be used to predict damages of structures during future near – field earthquakes.

2. Seismic Acceleration parameters

The acceleration records used in this study are based on near – ground motions. Also the parameters utilized in present paper contain : peak ground acceleration(PGA), peak ground velocity(PGV), peak ground displacement(PGD), seismic energy density(SED) and Arias intensity. As mentioned in the previous section, The definitions of each parameter have been presented in the literature (Jennings,1982, Arias, 1970, Trifunac and Brady, 1975, Meskouris, 2000, Naeim and Anderson, 1993, Trifunac and Novikova,1995). For this reason it will not be repeat again here. Tables 1 and 2 show respectively the near and far field seismic excitations which have been provided for using in present analysis. The seismic events have been chosen from worldwide well known sites with strong seismic activity.

In this section of the paper a brief overview of the fundamental concepts of near- field ground motions is given. The near – field of an earthquake can be defined as the area in the close vicinity of the fault rupture surface. Besides strong shaking, the characteristics of near – field ground motions are depended to the fault geometry and the orientation of the traveling seismic waves (Bray and Rodríguez, 2004). Pulse-like near-fault ground motions resulting from directivity effects are a special class of ground motions that are particularly challenging to characterize for seismic performance assessment. These motions as shown in figure1, contain a 'pulse' in the velocity time history of the motion, ideally in the direction perpendicular to the fault rupture, and generally occurring at locations near the fault where the earthquake rupture has propagated towards the site. Despite our growing understanding of these ground motions, it is still difficult to identify this effect and account for it in ground motion prediction (attenuation) models (Alavi and Krawinkler, 2001, Boore et al, 2007, Fu,and Menun, 2004, Iervolino and Cornell, 2007)

Table 1. near - field seismic parameter

Event	Year	PGA(g)	PGV(m/s)	PGD(m)	ARIAS(m^2/s^2)	SED
n.palmspring	1986	0.331	0.294	0.057	1.197	0.055
superstitnhill	1987	0.377	0.439	0.153	1.702	0.28
morgan hill	1984	0.423	0.253	0.046	0.683	0.032
koyote lake	1995	0.434	0.492	0.077	0.775	0.076
pulmspring	1986	0.492	0.347	0.064	1.767	0.052
lomaprita	1989	0.605	0.509	0.115	3.087	0.285
n.palmspring	1986	0.612	0.315	0.046	2.137	0.043
superstitnhill	1987	0.63	0.3	0.043	3.16	0.086
landers	1992	0.785	0.319	0.164	6.58	0.124
landers	1992	0.818	0.46	0.222	8.226	0.168
kobe	1995	0.73	0.723	0.157	6.633	0.6
coalinga	1983	0.866	0.421	0.061	3.543	0.085
superstitn hill	1987	0.894	0.422	0.073	6.027	0.205
duzce	1999	0.97	0.365	0.055	9.972	0.172
nahanni	1985	0.9	0.423	0.09	3.764	0.113
capemendecino	1992	1.039	0.413	0.126	2.39	0.18
coalinga	1983	1.083	0.397	0.054	1.675	0.072
nahanni	1985	1.098	0.462	0.147	3.85	0.201
sanfernando	1971	0.8	0.373	0.081	3.767	0.127
sanfernando	1971	1.05	0.963	0.304	6.525	0.663
northridge	1994	1	0.397	0.108	2.872	0.067
morgan hill	1984	1.1	0.685	0.083	2.763	0.178
northridge	1994	1.15	0.4	0.04	4.6	0.108
northridge	1994	0.9	0.726	0.166	4.212	0.222
northridge	1994	1	0.61	0.18	7.16	0.241
northridge	1994	0.55	0.429	0.175	5.151	0.251

Table 2, far – field seismic parameters

Event	Year	PGA(g)	PGV(m/s^2)	PGD(m)	ARIAS(m^2/s^3)	SED
whittiernarrow	1987	0.186	0.046	0.002	0.261	0.001
santabarbara	1978	0.203	0.164	0.03	0.229	0.017
n.palmspring	1986	0.239	0.092	0.012	0.352	0.008
livermore	1980	0.301	0.191	0.028	0.251	0.018
chi chi	1999	0.302	0.204	0.086	1.27	0.071
kobe	1995	0.345	0.277	0.096	1.687	0.163
morganhill	1984	0.348	0.174	0.03	0.771	0.043
westmorland	1981	0.368	0.487	0.106	1.756	0.175
northridge	1994	0.41	0.43	0.118	1.913	0.18
chichi	1999	0.388	0.269	0.161	0.821	0.106
lomaprita	1989	0.411	0.315	0.065	1.055	0.033
lomaprita	1989	0.473	0.338	0.081	1.68	0.064
northridge	1984	0.482	0.45	0.126	1.975	0.151
kobe	1995	0.503	0.366	0.113	2.269	0.185
kobe	1995	0.509	0.373	0.095	3.352	0.198
chichi	1999	0.512	0.391	0.143	1.177	0.137
lomaprita	1989	0.512	0.411	0.163	1.452	0.204
capemendocino	1992	0.5	0.38	0.174	2.062	0.108
victoria	1980	0.6	0.198	0.095	1.061	0.072
victoria	1980	0.621	0.317	0.136	1.967	0.152
chichi	1999	0.639	0.396	0.113	3.637	0.164
chichi	1999	0.712	0.492	0.195	2.435	0.121
duzce	1999	0.728	0.564	0.231	3.723	0.39
whittiernarrow	1987	0.186	0.046	0.002	0.261	0.001
santabarbara	1978	0.203	0.164	0.03	0.229	0.017
n.palmspring	1986	0.239	0.092	0.012	0.352	0.008

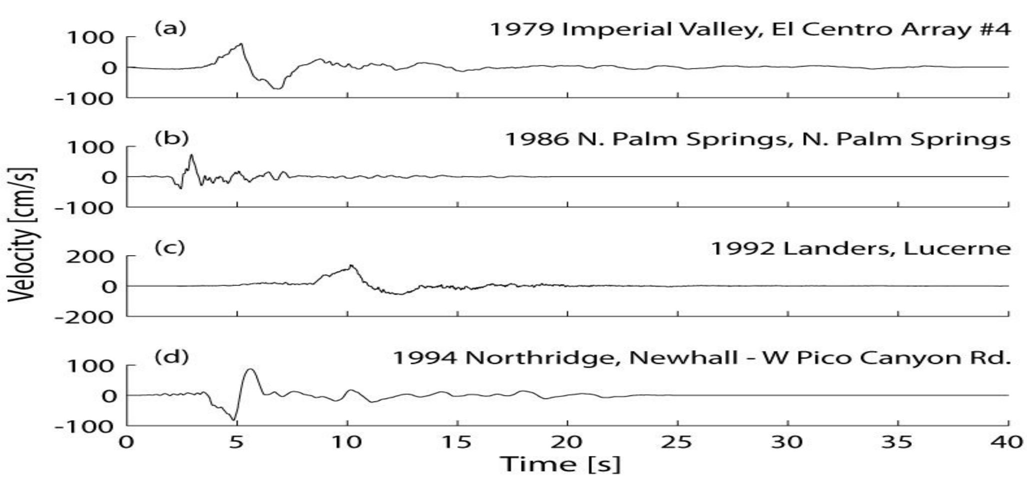

Figure 1. Four example pulse-like near-fault ground motions (Bray and Rodríguez, 2004)

3. Analytical Models

Three concrete frames reinforced by shearwall of 5, 8 and 12 story and also three moment resisting frames of 4, 6 and 8 story were designed to current iran seismic building design code by Etabs V.9 program. The buildings were assumed to be located in the Tabriz city on irans north - west. All the frames shown in figures 1 and 2 were subjected to the same dead , live, seismic and wind loads.

The distance between frames in the three dimensional model in both structural systems has been assumed to be 3 meter. also according to iran seismic design code, the building has been considered as a important class 3 with subsoil of type 2 and regional seismicity of category 4. spans of each frame in shearwall systems are 5, 3 and 6 m and in MRF system are equel to 5 meter. dead load of roof, live load of roof, dead load of storyes and live load of storyes are 585,175,570 and 200 kg / m^2 respectively. It should be pointed out The frames were designed to ensure that the columns are sronger than the beam while first plastic hinges are created in the columns and then in beams.

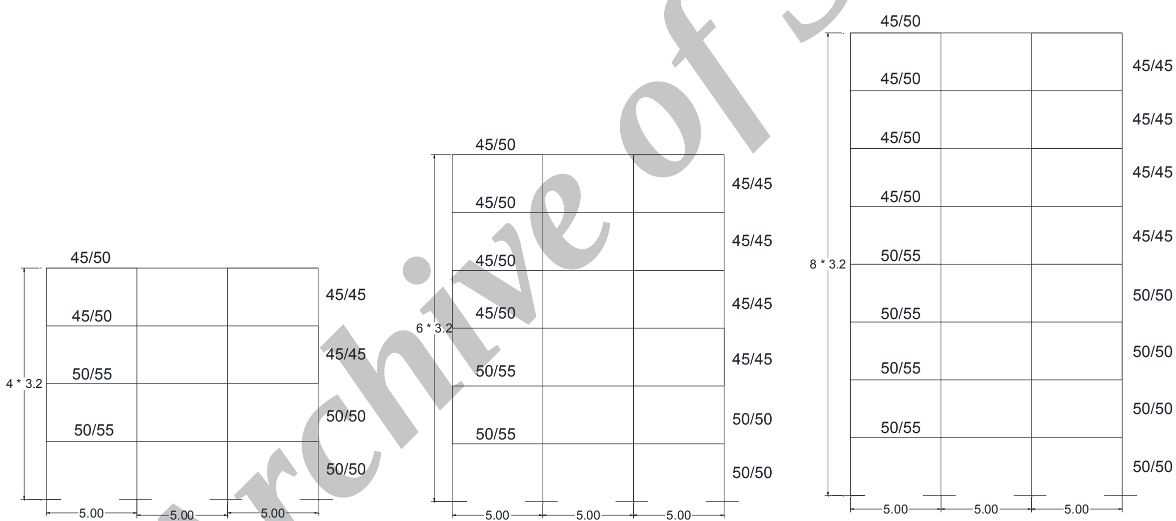

Figure 2 . Moment Resisting Frames

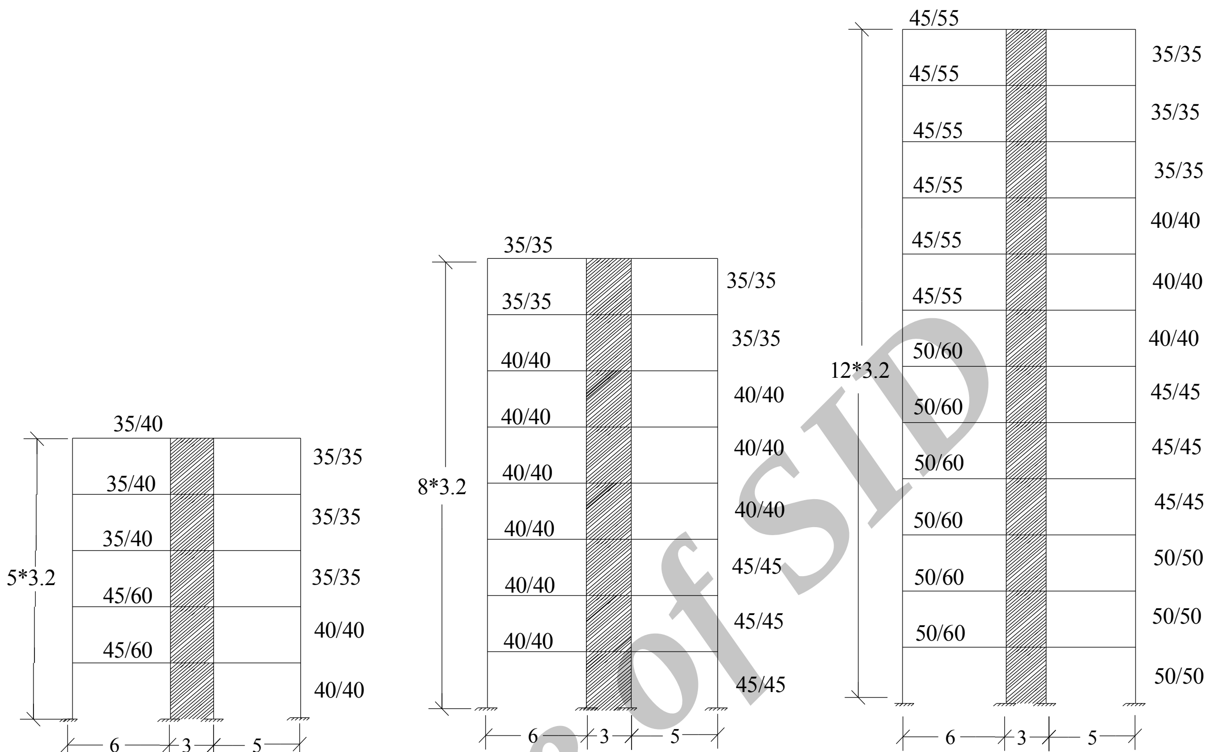

Figure 3. concrete frames reinforced by shearwall

4. Nonlinear Dynamic Analysis of Models

After designing the frames, for the observation of the structural damages and responses, a nolinear dynamic analysis by the computer program IDARCV.7 (Reinhorn and et al, 1996) are carried out. To ensure of correct modeling in the two software (Idarc and Etabs), in the Tables 3 and 4, periods of first mode of all of the frames are compared. As it can be seen, values of periods are equal nearly.

Table 3. Compare of first mode period in two softwares for shearwall system

	5 story frame	8 story frame	12 story frame
Period in Etabs (sec)	0.5	0.98	1.25
Period in Idarc(sec)	0.52	1.01	1.29

Table 4 . Compare of first mode period in two softwares for MRF system

	4 story frame	6 story frame	8 story frame
Period in Etabs(sec)	0.41	0.65	0.9
Period in Idarc(sec)	0.43	0.68	0.87

To apply Nonlinear behaviuor of structural members, a three parameters park hysteresis model which specifies the hysteresis behaviuor of members at their ends, is used. Above model incorporates stiffness degradation, strength deterioration, slip-lock and a trilinear monotic envelope. To obtain above degrading parameters, experimental results of cyclic force – deformation on the structural elements is done and then this values are extracted (Elenas, 1998). Whreas present study uses the severe parameters for stiffness degradation and strength deterioration. Finally over of 300 time – historic nonlinear dynamic analyses at time intervals of 0.005 second for six frames each time under a known near and far field acceleration record are carried out and after that response parameters are obtained. It should be remembered, among these extracted parameters the attention is focused on the overall structural damage index (OSDI) and interstory Drift.

5. Damage Index

All of the Damage indices proposed in published literatures quantify local and global structural damage of buildings, subject to base excitations, on a scale ranging from zero to unity; where zero score represents undamaged state and unity represents collapse damage state of the building. This quantification helps in assessing seismic performance of the building through analytical methods and helps in several applications such as selecting retrofitting options.

These parameters which quantify the structural damage can be qualified into ductility based (Rodriguez and Akmak, 1990) modal (DiPasquale and Akmak 1989) and energy based (Garstka et al,1991) damage indices. here focus is on the OSDI . this is due to the fact that this damage index summarizes all the damages on the structural members such as beams and columns in a single value which can be adequetly correlated to single value seismic acceleration parameters. For this purpose the overall structural damage index (OSDI) after Park /Ang ($DI_{L,PA}$) (Park and Ang, 1985) has been used to represent the structural damage. First the local damage index according to Park / Ang is calculated by the following equation :

$$DI_{L,PA}=\frac{\theta m-\theta r}{\theta u-\theta r}+\frac{\beta}{My*\theta u}E_T \quad (1)$$

Where θm is the maximum rotation during the load history, θu is ultimate rotation capacity of the section, θr is the recoverable at unloading, θr is a constant parameter (0.1 -0.15), M_y is the yielding moment of the section and E_T is the dissipated hysteresis energy. The global damage index after Park / Ang is calculated based on a weighted average of the local ones at the ends of each structural element with the dissipated energy as the weighting function. Hence the global structural damage index after Park / Ang ($DI_{G,PA}$) is defined by the following equation :

$$DI_{G,PA}=\frac{\sum_{i=1}^{n} DIL*Ei}{\sum_{i=1}^{n} Ei} \quad (2)$$

Where E_i is energy dissipated at location i and n is the number of locations at which the local damage is computed.

6. Correlation coefficient

The correlation coefficient of two variables in a data sample is their covariance divided by the product of their individual standard deviations. It is a normalized measurement of how the two groups of data are linearly related. If the correlation coefficient is close to 1, it would indicates that the variables are positively linearly related and the scatter plot falls almost along a straight line with positive slope. For -1, it indicates that the variables are negatively linearly related and the scatter plot almost falls along a straight line with negative slope. And for zero, it would indicates a weak linear relationship between the variables. So far various types of correlation coefficient have been defined by researchers but in present study To determinate the grade of correlation between seismic acceleration parameters and OSDI and Drift, correlation coefficient after pearson (Spiegel MR, 1992) will be utilized. pearson correlation coefficient between two variables x and y is given by the following equation:

$$\rho_{pearson}=\frac{\sum_{i=1}^{N}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i-\bar{X})^2\sum_{i=1}^{N}(Y_i-\bar{Y})^2}} \qquad (3)$$

Where $\bar{X}$ and $\bar{Y}$ are the mean values of X_i and Y_i data respectively and N is the number of pairs of values (X_i , Y_i) in the data. Tables 5, 6, 7 and 8 present the pearson correlation coefficient between all seismic parameters and OSDI and Drift.
Through the this coefficients it can be seen that the OSDI and Drift in most cases have the same grade of interrelation to the seismic parameters. Both of them have the maximum correlation to PGV and SED. Especially mentioned correlations in relation with near – field earthquakes in compared with far – field earthquakes appreciably are greater. This fact can be related to existing long period pulses in the velocity record of these ground motions. Also according to following tables it can be obviously recognized that the height and first mode period of frames in both of structural systems play signficant role in the increasment of interdependency between the most of seismic parameters especially PGV and SED with OSDI and Drift. Parameters PGA and PGD exhibit poor and occasionally fair correlation to OSDI and Drift but about Arias Intensity can be said that thai parameter provide stronger correlation to OSDI and Drift.
In continue in the figures 4, 5, 6 and 7 correlation diagrams between PGV and OSDI for all of the studied frames have been presented. Meanwhile pearson correlation coefficient by R^2 sign has been shown. Effects of near fault, period and height in the increasment of correlation are clearly considerable.Table9 shows the correlation coefficient after pearson between OSDI and Drift for frames with shearwall.

Table 5. Correlation coefficients of MRF system subjected to near – field earthquakes

	OSDI 4 STORY FRAME	OSDI 6 STORY FRAME	OSDI 8 STORY FRAME	Drift 4 STORY FRAME	Drift 6 STORY FRAME	Drift 8 STORY FRAME
PGA	0.524	0.421	0.35	0.634	0.521	0.500
PGV	0.725	0.807	0.861	0.793	0.825	0.851
PGD	0.563	0.706	0.764	0.542	0.612	0.695
ARIAS INTENSITY	0.579	0.632	0.584	0.708	0.511	0.615
SED	0.581	0.784	0.85	0.538	0.597	0.686

Table 6. Correlation coefficients of MRF system subjected to far – field earthquakes

	OSDI 4 STORY FRAME	OSDI 6 STORY FRAME	OSDI 8 STORY FRAME	Drift 4 STORY FRAME	Drift 6 STORY FRAME	Drift 8 STORY FRAME
PGA	0.510	0.470	0.434	0.552	0.525	0.512
PGV	0.595	0.664	0.774	0.612	0.689	0.811
PGD	0.402	0.430	0.554	0.291	0.351	0.536
ARIAS INTENSITY	0.695	0.550	0.700	0.529	0.470	0.671
SED	0.610	0.701	0.813	0.536	0.619	0.745

Table 7. Correlation coefficients of shearwall system subjected to near – field earthquakes

	OSDI 5 STORY FRAME	OSDI 8 STORY FRAME	OSDI 12 STORY FRAME	Drift 5 STORY FRAME	Drift 8 STORY FRAME	Drift 12STORY FRAME
PGA	0.25	0.30	0.25	0.32	0.38	0.36
PGV	0.63	0.83	0.90	0.72	0.87	0.83
PGD	0.30	0.56	0.63	0.20	0.55	0.56
ARIAS INTENSITY	0.30	0.35	0.53	0.30	0.26	0.48
SED	0.67	0.83	0.87	0.57	0.73	0.77

Table 8. Correlation coefficients of shearwall system subjected to far – field earthquakes

	OSDI 5 STORY FRAME	OSDI 8 STORY FRAME	OSDI 12 STORY FRAME	Drift 5 STORY FRAME	Drift 8 STORY FRAME	Drift 12STORY FRAME
PGA	0.53	0.47	0.52	0.73	0.53	0.65
PGV	0.50	0.66	0.81	0.66	0.64	0.82
PGD	0.50	0.54	0.60	0.60	0.64	0.64
ARIAS INTENSITY	0.70	0.34	0.76	0.57	0.41	0.84
SED	0.67	0.57	0.80	0.55	0.61	0.76

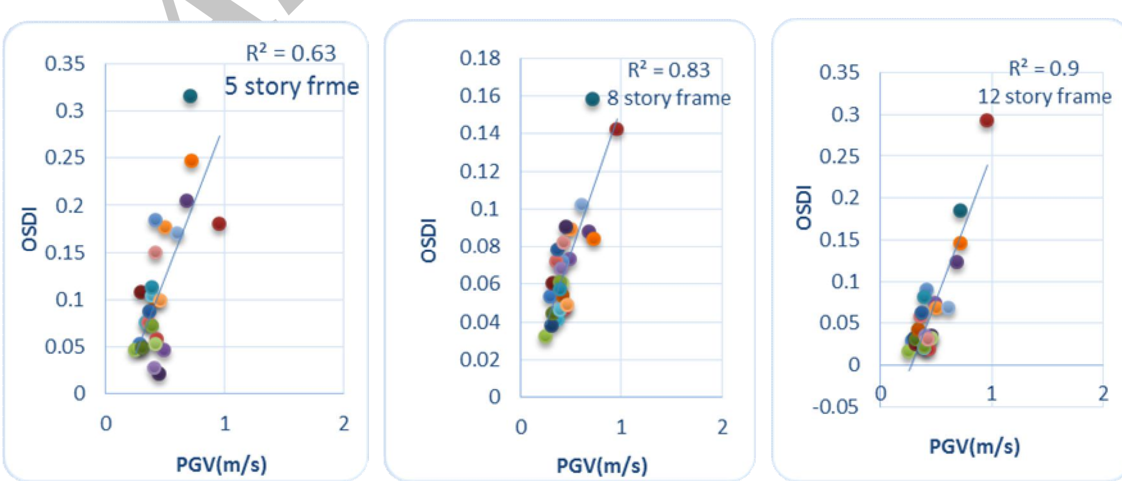

Figure 4. correlation diagrams between PGVand OSDI for shearwall frames subjected to near field records

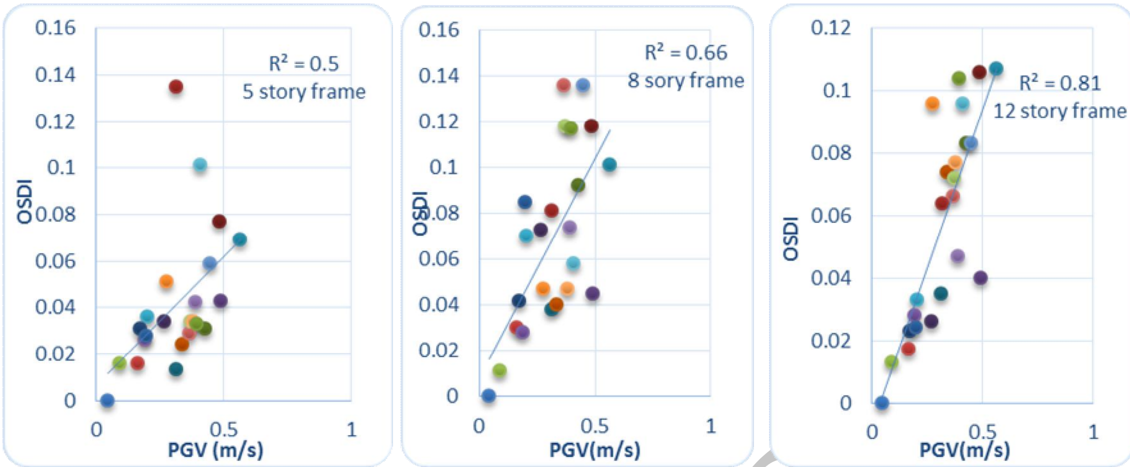

Figure 5. correlation diagrams between PGV and OSDI for shearwall frames subjected to far – field records

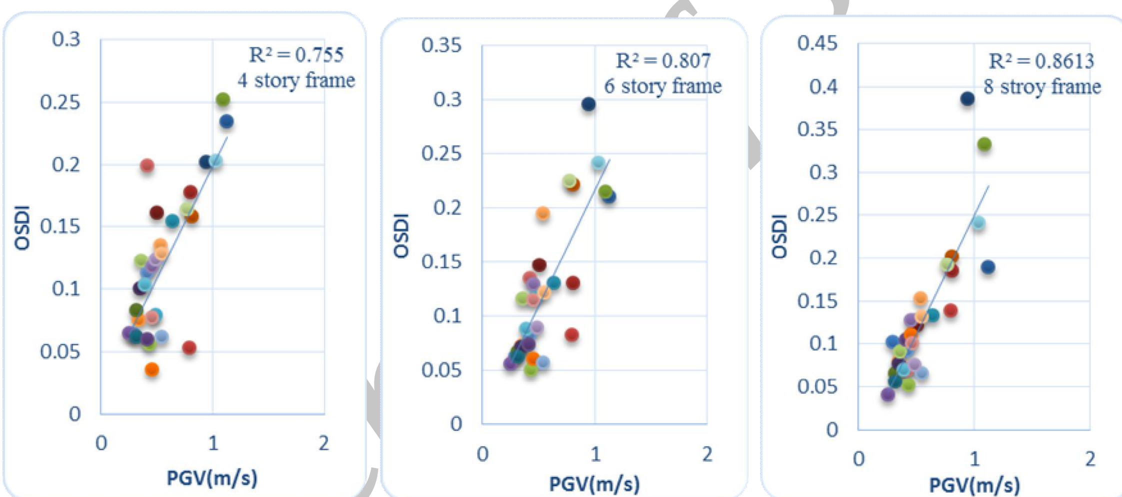

Figure 6. correlation diagrams between PGV and OSDI for MRF frames subjected to near – field records

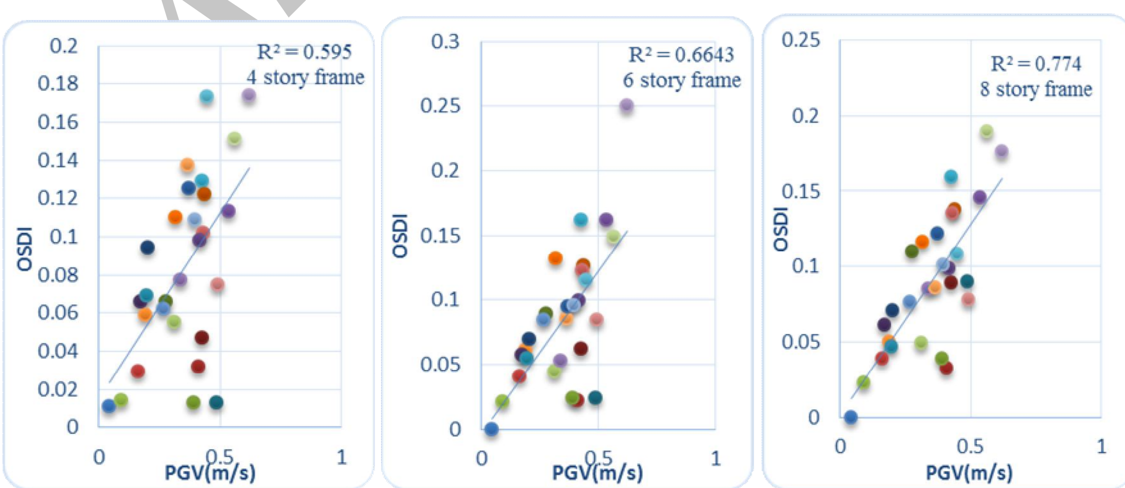

Figure 7. correlation diagrams between PGV and OSDI for MRF frames subjected to far – field records

As can be seen, correlation in all the cases is high and this means that Drift as a effective damage indicator parameter when OSDI is not available, can be used with high reliability margin to evaluate structural damages.

Table 9. Correlation coefficient between OSDI and Drift in the frames with shearwall

Frame **Sort of ground motion**	**5 story** **Near field**	**8 story** **Near field**	**12 story** **Near field**	**5 story** **Far field**	**8 story** **Far field**	**12 story** **Far field**
Correlation coefficient Between OSDI - Drift	0.91	0.94	0.92	0.90	0.96	0.91

7. Conclusion

Interrelationship between expected seismic damages and properties of near fault earthquakes has received significant interests from researchers and engineers in recent years. Hence this project was undertaken to study behaviuor of the near fault earthquakes and evaluate relations of this sort of gound motions and applied damages on the structures.

Structural damages have been expressed by the modified Park / Ang overall structural damage index (OSDI) and the degree of the interrelationship has been expressed by the pearson correlation coefficient. Based this coefficient it was revealed that some of seismic parameters such as PGV and SED provide strong correlation with the structural damages and interstory Drift. As the statistical results have shown, PGA, PGD and Arias intensity provide poor or fair correlation with the OSDI & Drift in both far and near fault earthquakes while PGV and SED especially PGV provide high correlation and also this correlation in the near field records in compared far field records for each one of six frames is clearly stronger. It was seen the degree of the interrelationship of PGV and SED with OSDI and Drift with increasement of period and height of structure in both Shearwall and MRF systems is increased.on the other hand it can be seen that degree of correlation with height and period have a direct relationship. This finding was unexpected and it is suggested that more detailed researchs about effect of height and period on the correlation with considering taller frames .

it was also shown that correlation between OSDI and Drift is strong and Drift as a adequate alternative for OSDI to assessment of applied damages on the structures can be used. Finally it can be said that the most obvious finding to emerge from this study is that in related to tall concrete buildings (MRF or Shearwall Systems with high period or high height) especially those are subjected to near fault effects, PGV can be used to predict expected damages on the structures during future earthquakes.

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