ASSESSMENT OF DAMAGE INDEX OF RC FRAME AT VARIOUS PERFORMANCE LEVELS

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ABSTRACT

Damage sustained by an element is quantified by damage index that is a number in the range of zero to one. Models that define the damage of an element generally divided into three categories: the first group includes models that used the maximum deformation of an element during loading to explain the damage index. In the second place there are models that use maximum hysteresis energy dissipation of an element during cyclic loading to explain the amount of damage. In the last are models in which the definition of damage combines the two factors of maximum deformation and hysteresis energy.

This kind of model is named combined indices. This paper studies the structural damage index of RC frames that applied to them the performance levels of IO, LS and CP by method of displacement coefficient. In order to achieve this goal a fourteen story RC frame which was designed according to Iranian concrete code of practice has been selected. Then the members of this frame have been checked for three performance levels of IO, LS and CP with related acceptance criteria and with the level of knowledge equal to one. Then theses frames were subjected to record of various earthquakes and performed nonlinear dynamic analysis. After all damage indices of frames calculated and explained in the basis of various seismic acceleration parameters. Assessment of the result can cause to this conclusion that although the damage is generally explain with the basis of PGA but seismic spectral parameters are believed to be better suited for the characterization of the seismic damage potential.

Keywords: (RC Frame, damage index, Performance Level)

1. INTRODUCTION

Vulnerability is a term that generally will be used to show the extent of damage and injury, that probably caused by earthquake to the buildings, services, geographic areas and resulting to communities.

Seismic performance of structures can be quantified by determining the range of damage to the structures by the means of damage index. For a system with single Degree of freedom, appropriate damage index, is a normalized quantity that, its value for elastic- mode is zero and for potential failure state (major damage has been entered) is one.

Models that expressed the damage to a member are divided into three categories: the first group includes models that used the maximum deformation of an element during loading to explain the damage index. In the second place there are models that use maximum hysteresis energy dissipation of an element during cyclic loading to explain the amount of damage. In the last are models in which the definition of damage combines the two factors of maximum deformation and hysteresis energy.

2. PARK AND ANG DAMAGE INDEX [2]

Indices that included effects of deformation and energy absorption called combined indices. Most famous of them is Park and Ang damage index that consists of simple linear combination of normalized deformation and energy dissipation:

$$D = \frac{\delta_m}{\delta_u} + \beta_e \frac{\int dE}{F_y \delta_u} \tag{1}$$

The first term is a simple, pseudo static displacement. It makes no measure of cumulative damage, this measure is evaluated by second term that is the energy term. The advantages of these models are its simplicity and the fact that it has been calibrated against a significant amount of shear and bond failures. Park, Ang and Wen suggested $D = 0.4$ as a threshold value between repairable and irreparable damage. This paper uses the index to evaluate for structural damages.

3. STRUCTURAL MODELING

The final goal of this study is evaluation of damage index of RC frame at various performance levels under seismic loading. For this reason a 14story building with height of 43m were designed in accordance with Iran Concrete Code (ICC).

Dead load value with partitioning load is 650kg per square meter and live load value is 250kg per square meter in stories. The values for the roof of structure are 550 and 150 respectively. Characteristic strength of concrete and yield stress of reinforcements have been set at 210Mpa and 400Mpa.Culomn dimensions from the first to forth story is $80 \times 80\text{cm}^2$, in fifth to ninth stories is $60 \times 60\text{cm}^2$ and from tenth to fourteenth story is $40 \times 40\text{cm}^2$. Beams in first to seventh stories are $40 \times 50\text{cm}^2$ and in eighth to fourteenth stories are $30 \times 45\text{cm}^2$ rectangular. Plan of the building has shown in Fig.1.

Then frame of axis 2 on the plan was selected and nonlinear incremental static (push over) analysis with the conditions of controlling displacement and limitations of 500 steps for the monotonic analysis and 0.5 for the coefficient of lateral force to stop the process was performed by the IDARC 2D(a program for the inelastic damage analysis of building). In this study we considered the structural performance levels of IO(Immediate Occupancy), LS(Life Safety) and CP(Collapse Prevention) at hazard leve1 i.e. probabilities of exceedance greater than 10%/50years.

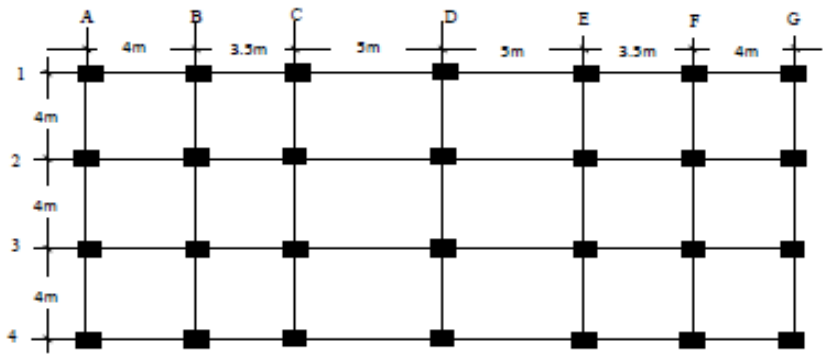

Figure 1: Structural plan.

4. STRONG GROUND MOTION

In this study the records are normalized by a set of multipliers of g by which a record changing into series of records that have different PGA but have similar frequency content and duration. By this method the effect of two parameters of frequency content and duration can be eliminated from the procedure. We have used the records of El Centro , Tabas[1] and Naghan[2] earthquake for the study.

PGA multipliers are 0.1g, 0.2g, 0.3g, 0.4g, 0.5g, 0.6g, 0.7g, 0.8g, 0.9g and various parameters of the records calculated by SEISMOSIGNAL software. Because of the using of three records with different PGA and also Because of the frames have three performance levels, for the easiness of the nominations we used an abbreviation method that uses the FIO, FLS and FCP for the performance levels and EL, TA and NA for the earthquakes with using the numbers of 1 to 9 for the suffices that indicate to PGA of the records. For instance FIOEL3 indicating the frame with designing of IO level undergoing the El Centro earthquake with PGA equals to 0.3g and it continues in the same way for FLSNA3,FCPTA3 ,… and so on.

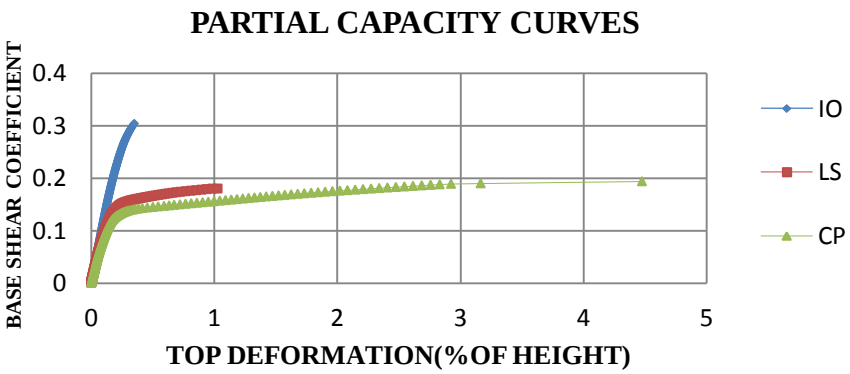

Figure 2: Pushover capacity curves.

It is noteworthy to say that spectral characteristics of the records such as Sa(spectral acceleration) calculated at period of first mode.

[1] A city in the East of IRAN

[2] A city in the South West of IRAN

5. DATA PROCESSING OF THE RESULTS

The response of the structures can be assesses after applying nonlinear dynamic analyses to the structures and calculating output for 0.005 time steps.

As stated before we use the Park and Ang damage index to evaluating the structural damage. After modeling and applying nonlinear dynamic analyses to the structures by IDRAC v4 and calculating the global damage index for all frames we should show results in graphs. Figs 3 to 5 shows the global damage index that calculate and integrate throughout the all elements of frames after earthquake versus peak ground acceleration of records in form of percentage of g.

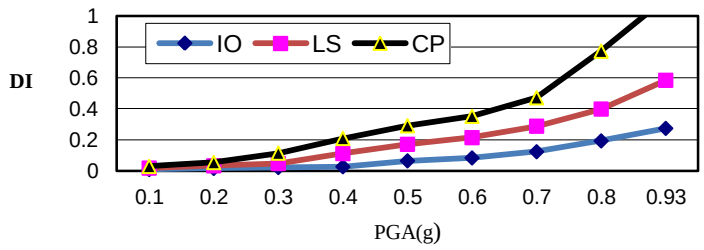

Figure 3: Damage indices in frames vs. PGA (TABAS EQ) .

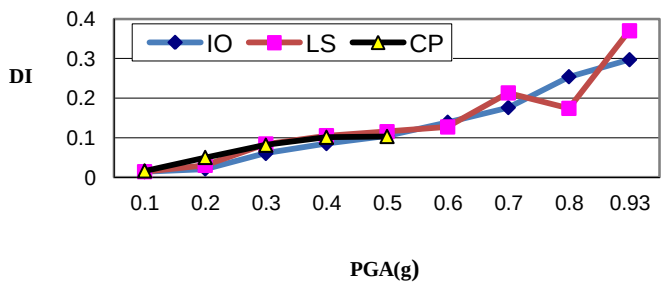

Figure 4: Damage indices in frames vs. PGA (EL CENTRO EQ) .

On can observe that in almost all horizontal values (PGA) calculated damage indices in CP frame higher than LS and in LS frame is higher than IO. This happens because of two reasons: first, difference between ability of the frames to absorb the energy of the records during the hysteretic cyclic loading and the other is related to the ductility and sustainability under the high displacements. As seen in the figures there is no difference between damage indices at low PGAs and only when the level of PGA exceed a bond level the indices are far from each other in vertical direction in curves. If the indices are drawn versus the spectral acceleration (Sa) then the figures 13 to 15 are obtained. Period of the first mode that SA calculated on the basis of which are 1.1, 1 and 0.9 for CP , LS and IO frame respectively.

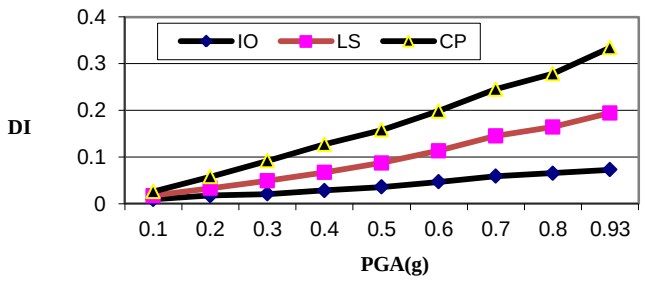

Figure 5: Damage indices in frames vs. PGA (NAGHAN EQ) .

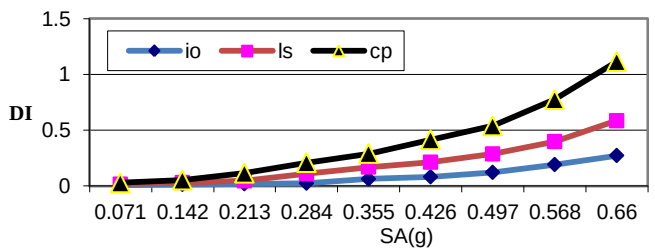

Figure 6: Damage indices in frames vs. SA (TABAS EQ) .

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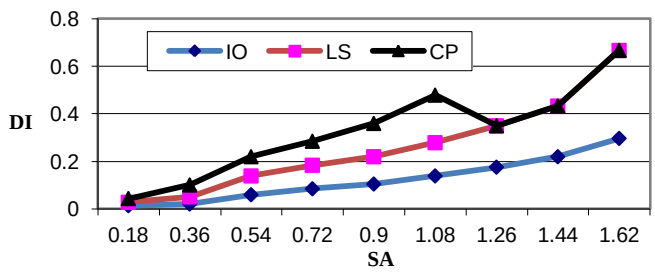

Figure 7: Damage indices in frames vs. SA (EL CENTRO EQ) .

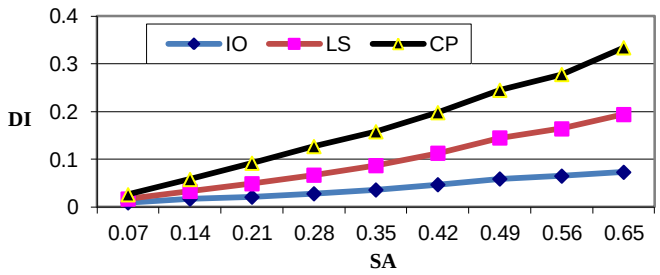

Figure 8: Damage indices in frames vs. SA (NAGHAN EQ) .

Calculating the period of the first mode and therefore the spectral accelerations in previous session were in the basis that the state of the element sections are non cracking and thus undamaged. We can obtain these data at the end of the nonlinear dynamic analyses and by using those data (damaged and cracked section) the graphs can be drawn. Also this time we see that the damage observed in CP frame higher than LS and in the LS frame greater than IO frame in turn generally.

Reasonably it is always be expected that under an specified earthquake or at a constant seismic hazard level the damage index observed in a frame with CP performance level must be greater than a frame with LS performance and in frame with LS performance greater than IO frame (albeit with similarity in static loading , site conditions , geometry ,…). This is not happening when damage index is presented by the PGA as the strong ground motion parameter and in some points this pattern disordered as shown in the figures 10 to 12. But when the indices are presented by SA in all studied cases the level of damage in CP is higher than LS an in LS in is higher than IO performance level. This can be justified by this fact that increasing in PGA necessarily doesn't mean increasing in input energy and displacements because PGA in a record is one point or one temporary pulse of earthquake. Additionally vibrational specifications of the structure also important in the ability of the structure to absorb energy so it seems that PGA can't be fully suitable earthquake parameter to mention the damage index. Maybe it'll be better that presented by the spectral parameters such as SA and SV that included both vibrational specification of structure and effects of all parts of the record. Tables 8 to 10 calculate the correlation between damage and SA and PGA by using the Pearson correlation coefficient.

Table 1: Pearson coefficient for DI and PGA and SA.

	EQ	TABAS		EL CENTRO			NAGHAN		
STRUCTURE	IO	LS	CP	IO	LS	CP	IO	LS	CP
PGA	0.824	0.763	0.746	0.827	0.831	0.786	0.934	0.942	0.927
SA	0.932	0.97	0.953	0.978	0.912	0.956	0.994	0.994	0.998

As seen in table in all cases the coefficient for SA is higher than PGA. The coefficient for Tabas and El centro earthquake is 0.95023 in average for SA and 0.79633 for PGA and this values for the naghan earthquake are 0.9955 and 0.9343 respectively

6. CONCLUSIONS

A 14-story RC frame with height of 43m from the base level was designed for three performance levels of IO , LS and CP for 10%/50years hazard level. Then structural damage index under three records of earthquake was calculated by IDARC program. Damages are correlated with two parameters PGA and SA of earthquakes and after that Pearson Correlation Coefficient for two cases calculated. We observed that damage values have better correlation with SA than PGA. In this regard we can do more supplement studies to take into account other structural aspects such as variations in height or non regular plan or using large variety of records and correlating damages other strong motion parameters for example SV , SD , time history , stress drop in fault , magnitude ,… .

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