Evaluation of Damages on Arc Frames of Reinforced Concrete by using Pushover

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Abstract: Qualification the scope of damage on structures is of the most important categories recently has been considered very much by researchers. For this purpose, different researchers by consideration of different aspects of structures have paid to presenting indexes. Depending most of these indices to nonlinear dynamic analysis performance which is very complex and time consuming has caused that using of these indices more be restricted to research project. The aim of this research is representing a simple and effective index on the basis of increasing load analysis and proportionate with operation point of structures which can represent a fair estimation of the scope of damages on structures.

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1. Introduction

However, in last earthquakes of the world, designed structures on the basis of existent seismic criteria, have performed fairly in preserve of individuals' safety, but the scope of created destructions in structures and entered economic damages has been very extended and unexpected. Nowadays, it has been specified well that designed structures on the basis of this criteria, against hard earthquakes will bear heavy damages. Thus, designing on the basis of operation as a method which is based upon acceptance of displacement and expected transformation (and according to anticipated level) was considered. From the most categories in operational designing, is having clear image of scope of damages entered on designed structure in different level of hazard. For this purpose in instructions such as FEMA and AAATC40 [1, 2] different level of damages entered on structures have been represented. Determinant criteria of structure situation in these instructions are on the basis of lateral transformation; however in some researches it has been indicated that using this standard as only standard of destruction is considerable [3].

We can investigate damage in various aspects, but generally, damaged entered on a structure is decreasing structure capacity in sustaining types of entered loads relative to safe structures before occurrence of earthquake or each another criterion which caused decreasing capacity of structure. For determining scope of entered damages on structure, researchers have introduced many indices which of them in a manner, estimate damages entered on structure. These indices can be categorized in three category: The first category are indices on the basis of most experienced transformation of structure, such as most relative displacement of stories[4] and the most ratio of transforming of stories[5]. Second category are indices on the basis of aggregate damage among it we can refer to Gobara damage index which is based on pushover analysis[6] and Chai and Fejfer damage index which is based on entered energy[7]. In third category there are indices that are combination of maximum transformation and aggregate damage, among them we can refer to damage index of Park and Ang [8] Venchzo and Banon [9]. From other damage indices introduced by researchers in recent years we can refer to Falerbo, et al research which by using of plastic energy in plastic joints they paid to representing an index for evaluation of scope of damage entered on reinforced concrete frames, of course it is necessary to mention that in this research idea of centralized plastic joint is used that in the case of reinforced concrete structures because of cracking phenomena can not to model real behavior of structure in a desired form [10]. Jang, et al. by using of method of force analogy and the combination of energy and displacement of structure (3rd category) introduced an index and paid to comparison of results from this index by using of time history analysis and combination of square root of sum of squares resulted from considering three first mode of structure for two Elcentro and Northrij earthquakes[11].

Study of literature of subject indicates that however some referred indices have suitable compatibility with observed damage on structures, but calculation of most of them needs to performance of nonlinear dynamic analysis which time consuming and complexity of this method and also uncertainty about specifications of future earthquakes has caused that these indices less be used in common designing of building frames and more delicate to activities and research projects. Nowadays, pushover analysis as a model which can model capacity of structure and in any case has not complexity of nonlinear dynamic analysis is considered very much. Now if we can define an index based on performance of this analysis and proportionate with operation point of structure which have suitable computability with real behavior of structure and also by using it we can estimate real damage rate, we can have an important pace in aspect of more practically of determining the rate of damage entered on structures in categories such as designing and strengthening. In this research, at first it is paid to investigation of lateral transformation criterion accuracy (emphasized by standard such as FEMA273 and ATC40) in evaluation of rate of damages entered on structures and in the following it is paid o effective strategies in evaluation of rate of damages entered on structures. For this purpose, by considering 7 record of earthquake, it is paid to nonlinear modeling of several arc frames and index of Park and Ang damage is calculated for them. Then by comparison of results of this modeling with results of damage indices suggested in pushover analysis, a new criterion is introduced.

2. Indices of Evaluated Damage in this Research

1-2- Index of Park and Ang Damage

In present research, this index which was suggested by Park and Ang in 1984, as index of base is used for comparison with other indices. Main advantage of this index is in its compatibility with experimental results and also its simpliness and grading proportionate with observed damage. This index is gained by relation bellow:

$$DI_{P\&G} = \frac{\theta_m - \theta_r}{\theta_u - \theta_r} + \frac{\beta E_h}{M_y \theta_u} \quad (1)$$

there, θ_m is the most created circulation in element in history of loading, θ_u is the most capacity of cross circulation, θ_r recovering circulation after loading, M_y yielding anchor, β constant of model and E_h is wasted energy in cross. In table 1 proportionate of real damage entered in structure with amounts of this index which has been by Park, is shown:

Table 1: Details of damage, proportionate to Park Index (8)

Degree of Damage	Apparent Sight	Index of damage	Situation of Building
Collapsing	Local or general collapsing of	>1	Demolition
Hard	Crushing of concrete spread, appearing of ricocheted armatures	0.4-1.0	Un-repairable
Average	Big and expanded cracks, laminating of concrete in weaker elements	0.25-0.4	Repairable
Little	Small cracks, local crushing of concrete in columns	0.1-0.25	Repairable
A few	Appearance of scattered cracks	<0.1	Repairable

2-2- Lateral Deforming Damage Index

This index is the most famous indices in classification of general indices of structre which is calculated by equation bellow:

$$DI_{Drift} = \frac{\Delta_m}{H} \quad (2)$$

there, Δ_m is maximum movement of roof (corresponding to operation point) and H is height of structure. In present research this index is calculated by using push over analyzing and is compared with results of Park and Ang damages (dynamic).

3-3 Index of Energy Damage

Using of wasted energy by structure in many researches for determining the rate of entered damages on structure most of which were on the basis of dynamic analyses. Kaeo and Akiyama considered wasted accumulated energy by hysteresis attenuation as acceptable index for estimation of structure damage [12]. Jang and et.al used entered energy and plastic energy of structure for determining the rate of damage entered on structure [11], etc. By referring to energy equilibrium of energy equation for a nonlinear system, under stimulation of an earthquake:

(3)

Or

$$\int_0^u m\ddot{u}(t)du + \int_0^u c\dot{u}(t)du + \int_0^u f_s(u,\dot{u})du = -\int_0^u m\ddot{u}_g(t)du$$

KE+DE+SE+PE=IE

There in, $KE = \int_o^u m\ddot{u}(t)\, du$ is kinetic energy, $DE = \int_0^u c\dot{u}(t)du$ is attenuation energy, $SE = \frac{f_s^{\,2}}{2k}$ is strain energy, $PE = \int_0^u f_s(u,\dot{u})du - SE$ is plastic energy and $IE = -\int_0^u m\ddot{u}_g(t)du$ is the energy entered into system.

As we consider, entrance energy to a structure is wasted by four mechanisms. In general condition, kinetic and strain Mechanisms generally undertake little share of rate of wasted energy by structure and most of energy is wasted by attenuation and yield mechanisms. In these two mechanisms, whatever structure enters into nonlinear phase, share of yield energy of attenuation energy is more which is explaining of lower speed of non-elastic systems to elastic systems. The aim of this section is representing an index on the basis of absorbed energy by structure in pushover analysis. With regard to this point that, curve of capacity resulted from pushover analyzing is structure Hysteresis ring push, then we can know low surface of this curve in operation point indicator of absorbed energy of structure in the biggest Hysteresis ring of it under a special square mostly has the large share of absorbed energy by structure. This index is calculated by relation bellow:

$E_{pp=}a_y d_p - d_y a_p$

There in,

d_p and a_p is coordinates of operation point.

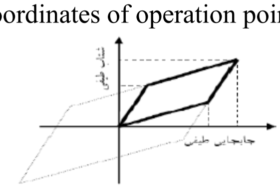


Figure 1- Hysteresis ring of structure in operation point

In definition of this index initial point which is entrance of structure to nonlinear phase and is considered beginning of structure damaging, a point of capacity curve corresponding to the first cracking of structure member has been considered and amount of damage index in this point is zero and whatever structure behavior enters into nonlinear phase, structure element is more damaged and the amount of this index is more to finally in a point final capacity of structure, the amount of this index would be reached to unit number. In purpose of determining final capacity of structure, different definitions have been brought up by researches. But in this research final capacity point of structure is considered a point of curve of structure capacity in which by little increase of lateral force, structure causes to very big sudden deformation to the previous phase and so-called in curve of capacity structure cutting occurs. Phase of calculation of E_{fp} also is similar to E_{pp}. E_{ip} is the area related to sub-curve of capacity in the point of first cracking. It should be mentioned that, this index hereinafter is called under title of index of energy damage.

3. Modeling of Frames

In this section in purpose of evaluation of introduced damage indices in last sections, the number of 14 reinforced concrete frame were considered which be concluded of large level of stories number and spans. All frames have selected from reference [13]. Four span frames have number storeys of 5, 8 and 12 and 15, 5 span frames have storeys number of 2, 4, 6, 8 and 10 and 2 span frame have storyes number of 1, 3, 5, 7 and 9. Height of all storeys is 3.2m and length of all spans also is 4m. In modeling of these frames it is assumed that all frames there are in stone bed and by average risking according to loading 2800 standard and according to ABA by-law have been designed for the region (in designing these frames all standards such as restriction of lateral transformation in 2800 by-law has been observed). Frames have loader wide of 4m and in all storeys having dead load of 760 and live load of 200 km/m^2. Importance of frames are assumed of middle type according to standard 2800. In process of analyzing and designing of these frames specified strength of concrete equal to 30 MP, elasticity module of concrete equal to 2386 MP, corresponding strain with maximum strength of concrete equal to 0.002, final strain of concrete equal to 0.003, strength of flowing steel 300 MP and steel elasticity module equal to 200000 MP have been assumed. General scheme of these frames has been indicated in figure 2 and details related to their designing are indicated in table 2.

Figure 2- General View of Under-study Frames

Table 2- General Specification of Under-study Frames

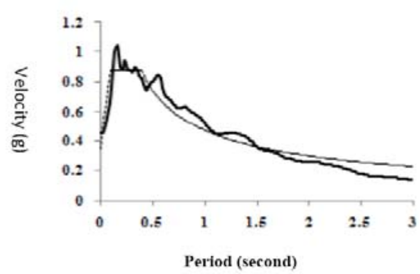
No. of Frame	S5B4	S8B4	S12B4	S15B4	S2B5	S4B5	S6B5	S8b5	S10b5	S1B2	S3B2	S5B2	S7B2	S9B2
G. Height (m)	16	25.6	38.4	48	6.4	12.8	19.2	25.6	32	3.2	9.6	16	22.4	28.8
Structure Period	0.56	0.79	1.07	1.27	0.28	0.47	0.64	0.79	0.941	0.167	0.38	0.56	0.72	0.87
Base Shear (K. Newton)	159.8	202.1	247.6	276.8	114.1	173.5	215.2	248.3	277.76	22.83	73	94.3	111.8	105.5

4. Choosing Earthquakes

For performance of nonlinear dynamic analyzing it is necessary that some velocity writer proportionate to geo-technique specification and conditions of soil of establishment of project place being chosen and these velocity writers be compatible with spectrum of designing of region. As it was mentioned, modeled frame in this project are designed on stone bed and as a result, registered records also have chosen on stone bed. In this research 7 records earthquakes from collection of existent records in FEMA440[14] registered on stone bed, in a manner have been chosen from data base PEER and according to principles of bylaw 2800 have been scaled which average spectrum resulted of them in range of 0.03 to 2.4 second which upon bylaw 2800 is an important limit for designed frames in this research (limits between 0.2T and 1.5T), have the least difference with spectrum of plan of 2800 bylaw, which specification related to these records and average spectrum resulted from them in sequence are indicated in table 3 and figure 3.

Table 3- General Specification of Earthquakes

No. of Earthquake	1	2	3	4	5	6	7
Name of Earthquake	Imperial Valley	Landers	Loma Prieta	Loma Priiea	Loma Prieta	Northridge	Northridge
Station No.	286	21081	58131	58151	58338	23590	90019
Component (degree)	135	90	270	90	45	90	180
Maximum velocity (g)	0.195	0.146	0.06	0.09	0.084	0.056	0.256



5. Numeric Study

In this secion initially we pay to comparison of Park and Ang damage indices and lateral transformation index and then we will pay to evaluation suggested index of this research. For this purpose, considered frames are modeled and pushover and nonlinear dynamic analyses is performed on model. Pushover analysis in this research by using of loading model of existent sequence in reference [1] has been performed which diagram of shear base-displacement roofs of considered frames are shown in figure 4. For performance of all analyses DARC V6.1 has been used which is the very powerful software in analyzing reinforced concrete structures [15]. For calculation of damage indices in pushover analyzing, firstly operation point of structure by capacity spectrum method determined and then amount of these indices were calculated in operation point of structure [16]. In the following for this purpose that relation between explained indices be determined in a vast level, for each of frames 5 operation point was calculated which in order are related to spectrum of average response indicated in figure 3 and spectrums which by co-efficient of 1.5, 2, 2.5 and 3 equal to first spectrum are scaled and then amounts of damage indices in these points are calculated. In the following, for calculation of damage indices in dynamic condition, existent compatible records, became compatible with scaled spectrums and it was paid to performance of nonlinear dynamic analysis. Analogous to each calculated damage in operation point in pushover analysis, by averaging of results related to 7 earthquakes being compatible with scaled spectrum, damage related to nonlinear dynamic analysis was calculated. In presented forms in this section, triangular point are related to damage correspond to average spectrum in figure 3 and are correspond to planning earthquake of 2800 bylaw; square points are analogous to 1.5fold of average spectrum in figure 3, which approximately can be analogous to hazard level of M.E. in ATC40 which indicates probability of 5% occurrence in 50 year, (however, determining of this level needs to more investigations, but by referring to reference [2], this level nearly is 1.25 to 1.5fold of designing level spectrum which with regard to this subject, for explaining relative estimation of damages in this level, the most limit of this approximation i.e. 1.5fold of average spectrum, has been selected) and other points have been specified by square points. In the following in this research these points are mentioned by their figure.

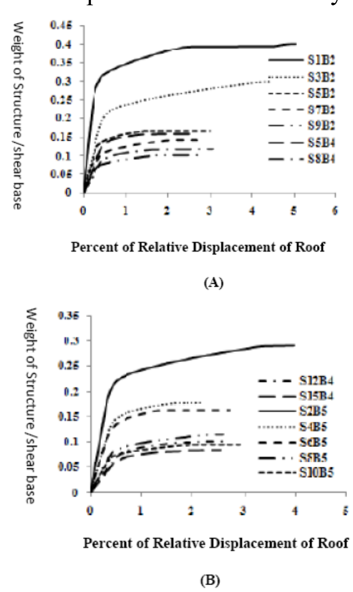


Figure 4- Base shear curve – Displacement of frames roof

6. Comparison of Park and Ang Damage Index with Index of Lateral Transformation

In this section we have paid to comparison of Park and Ang damage index in dynamic analysis and index of lateral transformation in pushover analysis results of which are shown in figure 5.

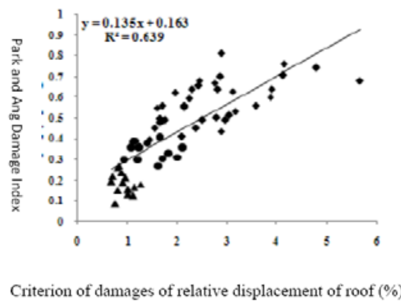


Figure 5- Comparison of Park and Ang Damage Index and Relative Displacement of Roof with Linear interpolation

As we see in figure 5, these two criteria have many scattering to each other. From this point we can result that displacement criterion cannot be suitable index for assessment of operation of structure. We can know this subject relevant to non-consideration of final capacity of structure in this index because in this criterion only in this criterion only the rate of lateral displacement of roof has been considered and general capacity of structure in bearing this displacement is not considered. In consideration of triangular points which are correspond to designing spectrum and are indicating of hazard level of 10% in 50 year, it is observed that amounts of Park damage index, changes from 0.841 to 0.27. By referring to table 1, this range of changes, is indicating without damage and a few damage situations with regard to specification of operation levels which with regard to indicated operation level specifications, can considered operation level of OP and IO. This subject is indicating suitable operation of ABA bylaw and 2800 in restriction of damaged entered on designed structures by using of standards of these bylaws and upper hand operation of them. Also by referring to circle point which are indicating of hazard level of 5% in 50 year, it is observed that range of changes of these points is from 0.27 to 0.42 which by referring to table 1, indicating of average damage level and by referring to operational level, it can be indicating of operational level of LS. This subject again indicates suitable operation of ABA bylaws and 2800. Results show that for triangular points, range of relative displacement changes from is 0.673 to 1.25 and for circle point is from 0.915 to 2.1 which with regard to specifications of operational levels, defined in reference [1] on the basis of amounts of this criterion, is indicating suitable operation of structures. Among other considerable points of these figures we can refer to this point that to relative displacement limits of %1.7, amounts of Park and Ang index is less than 0.4 which is border of repairable and un-repairable damage levels.

7. Comparison of Park and Ang damage Index and Index of Energy Damage

In this section, amounts of Park and Ang damage index in dynamic analysis, by amount of index of energy damage which is calculated in operation points, have been compared. Results from this comparison are shown in figure 6.

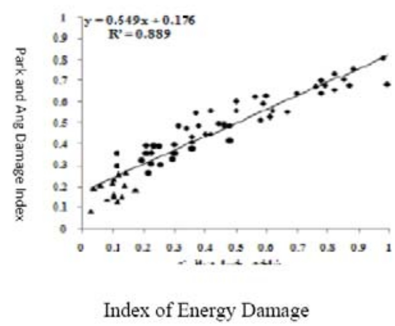


Figure 6- Comparison of Damage Indices with Linear interpolation

As it is seen in figure 6 the least amount of achieved damage is related to a point by coordinates of (0.841 and 0.027) and the most amount is related to a point by coordinates of (0.683 and 0.94) and is observable that at the first of this diagram the amounts of Park and Ang damage index are more and whatever we go to end of diagram, this difference will decrease which we can now this subject because of increasing of hysteresis energy share from wasted energy by structure, by evermore entrance of structure into nonlinear phase. Also, average amount of energy damage index is 0.4 which is very close to index of Park damage. From other considerable cases in this diagram, scope of changes of energy damage index for limit of triangular and circle point is as 0.027 to 0.176 and 0.11 to 0.36. Now if the aim is preparation a table such as provided table by Park (Table 1) but is according to lateral transformation of roof and energy damage index we can represent a table as table 4.

Table 4- Various level of damage, proportionate to amounts of damage index of transforming of plastic and relative displacement of roof.

Amounts of Relative Displacement of Roof %	D<0.67	0.67<D<1.15	1.15<D<1.8	2.1<D
Amounts of Energy Damage Index	D<0.076	0.076<D<0.165	0.165<D<0.38	0.38<D <1
Details of Damage	Without Damage: Existence of crack in few and little number	Little damage: Small crack in length of element	Average damage: Hard crack and existence of split	Hard damage: hollowi ng of concrete and appearin

Conclusion:

In this research, at first it was paid to criteria of relative displacement by using of Park and Ang damage index. Results state that using this criterion of lateral transformation of roof, as the only criterion of recognition operation of structure is not suitable. Comparison of Plastic transformation damage index in pushover analysis and index of Park and Ang damage index in dynamic analysis, is indicating of more suitable operation of transforming index to the relative displacement criterion. On the basis of resulted nearly much points that each of them is result of two analysis of damage in nonlinear dynamic and nonlinear static conditions, relations for estimation of dynamic index amount in account of static results were extracted. Evaluation of damage entered on designed structures on the basis of ABA bylaw and 2800 of Iran, showed that in earthquake of planning level of 2800 bylaw and level of hazard M.E. in ATC40 a, ABA and 2800 bylaw of Iran in limitation of damage entered on structures has a suitable operation of life safety. Represented table in this research, on the basis of suggested index, give simple and effective criteria for prediction of operation level and damage of reinforced concrete arc frames, without need to performance of complex and time consuming nonlinear dynamic analyses to designers.

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