Evaluating Quality Seismic Damage Index for Urban Residential Buildings

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Abstract: By identifying the damage index of a structure, in addition to a correct understanding from real behavior of the structure, the required criterion for strengthening would be given. Researchers have given many relations for determination of damage index but such relations have been based upon laboratory methods which challenge their usage in a broad term. In this paper two new methods are given for calculation of damage index. Surveying the first crack limit and total structure failure is based upon the formation of plastic joints in the first column and basic floor columns. To give a qualitative simple and functional damage index, the functional method was given in the form of a qualitative method with statistical analysis and collection of different views. Using this method is very simple and meantime offers suitable accuracy. With a numerical study on three models it was made clear that the difference of new method with amended method of Papadopolos in approximate 3%. This shows that given qualitative method is suitable to be used in a broad terms.

Keywords: Quality Damage Index, Earthquake, Urban Building, Reformed Method

1- Introduction:

Iran is among the top ten countries of disaster-prone and in this term it suffers many casualties annually. Statistics support this finding that in average one severe earthquake higher than 7 in Richter scale would happen in this country per 10 years. Heterogeneous texture, non-familiarity of the earthquake, incorrect protection of buildings along with nonstandard planning and execution with the earthquakes which occur sometimes, had led to irretrievable life and material losses. The earthquake December 26, 2003 in Bam is one of such happenings. In this earthquake more than 80 percentage of the Bam city, itself, with surrounding villages were severely destroyed and more than 40000 persons lost their life. Giving an index for failure is a subject which has attracted researchers attention for more than three decades. For this purpose and knowing the failure indices of a structure we may understand the structure behavior in a correct way and apply to regulate its risky margins. On the other hand to control the current condition of a structure the knowledge of its failure method would be necessary for giving an improvement plan. In other words, finding a damage index in a structure make it clear that to what level the given structure would resist against side forces like earthquake. This would be more important when we try to prepare an improvement plan for an area. In such a case, the manager of strengthening program will provide programs with a lower risk. Background of activities taken place for determination of damage index goes back to the early years of 70s. In 1972, Vitman showed that using the ground movement intensity and damages of buildings upon the ratio of expenses and repair, we may determine an index for failure. In 1979 and upon two qualitative criterion, final deformation and coefficients of effects, another method was given by Okava et al [4].

In 1985, Park and Al1g gave a newer method upon maximum possible deformation of a member and final deformation with their combination with the maximum absorbed energy [5]. This method was completed with the addition of end turning effect [6]. In 2000, Mikami and Imora showed damage index should be considered before structure analysis and during the application of structural limitations. They gave a new relation based on Park and Ang relation (1985) and the level of doctility [7]. In 2001, Honglin et al., gave a modern method based on the collected datafrom GIS system [8]. This method was an innovation upon which the damage index was evaluated in an area in a qualitative manner. In the same year, Bozorgnia and Bartarvar gave two separate indices of structure failure for structures. Such relations have been clearly compiled with the performance-based design [9]. In 2003 Rinoren and Walse defined a damage index upon which the fatigue is directly incorporated in calculations [IO]. In 2004, Papadopolos et al., with a simple and accurate method introduced an exact method for calculation of damage index which is quicker and simpler than prior methods [1 I]. In 2005, Kolombo and Negro gave a method for calculation of damage index, which has been used independently from material [I2].

So it is an innovation in this field. In the same year, Jong and Shai, introduced three dimensional (3D) damage index for the first time. This method, in addition to consideration of side variation includes vertical displacement simultaneously. In other word, analysis of sensitivity would be possible [I3].

2- Calculation of damage index:

Colombo and Negro relation:

In 2005, Colombo and Negro gave the most advanced and complete relation for calculation of damage index [12]. This method is based upon material fracture theory. So it is independent from the material used in the structure. Colombo and Negro relation in general form would be as equ.I: in equ.I, DI stands for damage index, Mac in the amount of attracted force at the time of fracture and Myo stands for the attracted force for flow. To calculate the Mac we should use many relations which include many sub relations.

Using this relation would undoubtedly require accuracy and making laboratory models and numerical methods. So while we have no doubt about the high accuracy of this method, it is hard and expensive for the engineers and researchers to use it. For this reason Papadoplos and his colleagues recommended other relations which are simple and have a high precision and speed.

Papadopolos and his colleagues relation (2003):

Compared with other methods and in addition to accurate calculations, it is quick and easy to use relation. So it is introduced as an effective method in calculation of damage index. The basis for obtaining the damage index, using Papadopolos method has three folds:

a) Calculation of maximum displacement of structure using static, dynamic or spectral analysis.

b) Calculation of displacement equal to the first plastic joint in one of the column.

Table 1: The reformed coefficient for considering Seismic Geotactic [6]

Soil Type	Intensification Coefficient
I	1.0
II	2.0
III	3.0
IV	4.0

c) Calculation of displacement equal to the first plastic joint in the first level column. In other words, finding the maximum displacement while the failure has taken place. Papadopolos recommended equ.2 for calculation of damage index [11].

In equ.2, GDP is the damage index (or in other words, damage index based upon plastic joint)11 Global Damage Plastic

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Dr is the maximum displacement of the structure upon static, dynamic or spectral analysis, dy is the maximum displacement equal to the first plastic joint in one of the column and df is the maximum displacement equal to the plastic joint formed in the first level column of the structure.

3- A new method for correction of Papa'dopolos and his colleagues relation:

Papadopolos and his colleagues relation, while being simple has been proposed by them as an experimental-numerical method. So suing this relation would challenge the engineers and researchers. Then for changing this relation into a simple numerical, static analytical and nonlinear relation, it was used by the authors of this paper. In this analysis, dr is the maximum displacement equal to the first plastic joint formed in one of the columns and df is the maximum displacement equal to the first plastic joint formed in the first level column of the structure. So equ.2 is changed into a numerical relation.

From other point of view, Polos did no based geo-technique seismic effects in his research. So with the broad studies taken place by the authors of this paper,relation2 is corrected as relation3.

In equ.3, r (reformed factor) is the correction coefficient showing the geo-technique seismic effects. With exact calculations upon classification of given soil in Code 2800 and standard 82-80-1756, Queen- Sindro, the r coefficient would be given as table 1.

Upon calculated index from the aforesaid method, in case the calculated GDP value would be lower than 0/2, the related structure may need to be repaired or strengthened, GDP of more than 0.2 and lower than 0.4 means that the structure needs improvement. If the calculated value is more than 0.4 and less than 0.8, the improvement is obligatory while economic considerations should as well be noted and GDP of more than 0.8 means the structure destruction.

4- Supply of qualitative-quantitative damage index for residential buildings

As noted, there are many methods for calculation of damage index in buildings and there is no doubt that all such relations are important and reliable. But the major problem is that using such relations to determine the risk of occurrence in an urban area is a hard and expensive task. Heterogeneous texture of buildings may be counted as the major reasons for this justification. So we should use other methods to obtain a risk interval in an area so as having a precise result as the basis for decision making, we may obtain suitable speed.

On this basis, we should study the effective factors in structure failure in the prior earthquake again and determine and weigh the effective factors. In this case determination of damage index in terms of quality for improving the decision making process for renovation of buildings in a given area would be a practical and functional method. Study of prior earthquakes in Iran shows that the effective factors in structural failure are: foundation problems and subsoil, architectural problems, structure problems, connections and non-structural elements.

To give a new method for calculation of damage index we should first process the views of scientists and researchers in this field upon Delphi statistical method. By the information obtained from different earthquakes and processed data, required data for calculation of failure and values from case studies in item 6 is given in Table 2.

5- Studies performed upon damage index given by the corrected relation of Papadopolos et al.

To do a case study we should use a building which has been designed in a real conditions. So three buildings are considered in one of Tehran districts with the plan shown in fig. 1 (a, band c plans).

Upon divisions of building design resistant against earthquake, they should be constructed on II type soil. As the site of samples is located in a high-relative risk area the acceleration value (A) is considered to be as 0.35.

Framework of all models is metal made. Columns are of double type and beams are of double, single or castellated beam. Foundation is of single type with normal footing beam. Other specifications are given in table 3.

5-1 Static analysis of models

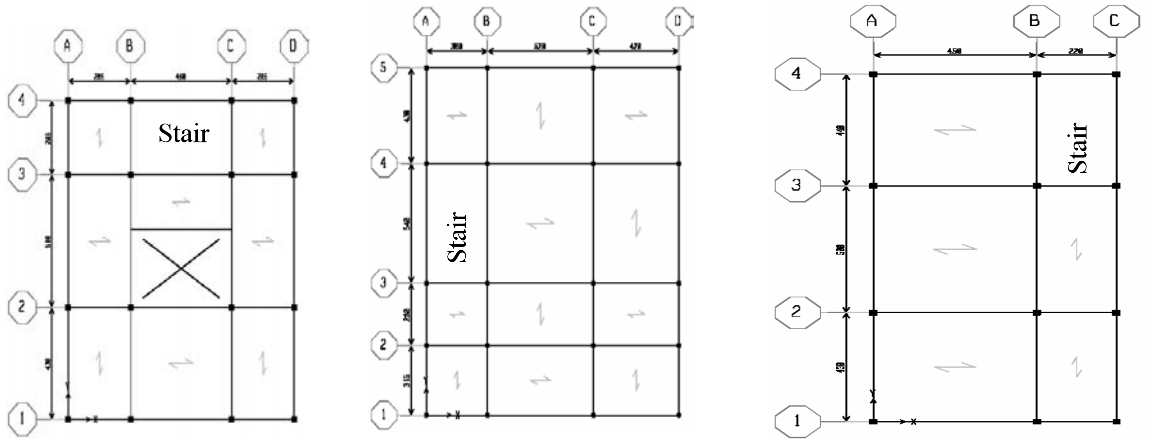
Upon performed static analysis for models following the 2 version of Building design codes against earthquake, it made clear that the maximum displacement (dy) in roof level for samples would be as per given in table 4.

5-2 Non-linear static analysis - Extra load method

Upon FEMA-273 Instructions, which is a reference in non-linear static analysis of structure, non-linear joints are defined as the curve for force displacement. Although those curves loaded to computer analysis program in this form should be the results from different tests on different structures. In

Table 2: Quality Damage Index

Dependent Coefficient	***Damage Range***	**Status**	**Weight**	**Effective present**	Inspection Kind	***Percent Dependent***	**Inspection occasion**
	0 - 0.01	Suitable	0.06	30	Design	20	**Foundation and under soil**
	0.01-0.04	Mediocre					
	0.04-0.06	Unsuitable					
	0 - 0.02	Suitable	0.10	50	Implementation		
	0.02-0.05	Mediocre					
	0.05-0.10	Unsuitable					
	0 - 0.01	Suitable	0.04	20	Column Arising		
	0.01-0.02	Mediocre					
	0.02-0.04	Unsuitable					
	0 - 0.02	Suitable	0.085	50	Lateral Porter System	17	**Structure & Diaphragm**
	0.02-0.04	Mediocre					
	0.04-0.085	Unsuitable					
	0 - 0.01	Suitable	0.034	20	Vertical Porter System		
	0.01-0.02	Mediocre					
	0.02-0.034	Unsuitable					
	0 - 0.015	Suitable	0.051	30	Ceiling		
	0.015-0.03	Mediocre					
	0.03-0.051	Unsuitable					
	0 - 0.01	Suitable	0.034	12.5	Regular in Plan	25	**Architecture**
	0.01-0.015	Mediocre					
	0.015-0.034	Unsuitable					
	0 - 0.01	Suitable	0.06	25	Soft Story		
	0.01-0.025	Mediocre					
	0.025-0.06	Unsuitable					
	0 - 0.01	Suitable	0.075	30	Short Column		
	0.01-0.02	Mediocre					
	0.02-0.075	Unsuitable					
	0 - 0.01	Suitable	0.031	12.5	Regular in Height		
	0.01-0.015	Mediocre					
	0.015-0.031	Unsuitable					
	0 - 0.01	Suitable	0.025	10	Mass Distribution In Height		
	0.01-0.015	Mediocre					
	0.015-0.025	Unsuitable					
	0 - 0.005	Suitable	0.025	10	Earthquake Joint		
	0.005-0.01	Mediocre					
	0.01-0.025	Unsuitable					
	0 - 0.01	Suitable	0.099	30	Design	33	**Connection**
	0.01-0.03	Mediocre					
	0.03-0.099	Unsuitable					
	0 - 0.01	Suitable	0.231	70	Implementation		
	0.01-0.08	Mediocre					
	0.08-0.0231	Unsuitable					
	0 - 0.01	Suitable	0.03	100		3	**Meddle Frame**
	0.01-0.02	Mediocre					
	0.02-0.03	Unsuitable					
	0 - 0.001	Suitable	0.002	20	Design	1	**Hue**
	0.001-0.003	Unsuitable					
	0 - 0.002	Suitable	0.008	80	Implementation		
	0.002-0.008	Unsuitable					
	0 - 0.005	Suitable	0.01	100	Bracing	1	**Installation**
	0.005-0.01	Unsuitable					
			1.000 $\sum=$			$\sum=$ %100	



Sample a Sample b Sample c

Figure 1: Carried out Case study

Table 3: Sample Specification

			( )	( )	( )			
Simple	Moment Resistance	5	15.04	3.06	2.8	Residential	Brick	Sample a
Simple	Moment Resistance	6	17	2.92	2.40	Residential	Hollow Brick	Sample b
Simple	Moment Resistance	4	11.20	3.00	2.20	Residential	Shared Brick	Sample c

Table 4- Computed Value d_y

Title	d_y (mm)
Sample A	116.5
Sample B	137.4
Sample C	95.2

Point	Moment/SF	Rotation/SF
E-	-0.4	-1
D-	-0.4	-1
C-	-1.15	-1
B-	-1	0.
A	0.	0.
B	1.	0.
C	1.15	1.
D	0.4	1.
E	0.4	1.

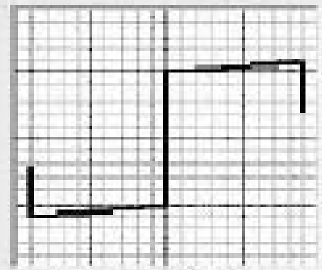


Figure 2-A: Nonlinear Plastic Hinge Moment

Point	Force/SF	Disp/SF
E-	-0.8	-7
D-	-0.8	-7
C-	-1.5	-7
B-	-1	0.
A	0.	0.
B	1.	0.
C	1.5	7.
D	0.8	7.
E	0.8	7.

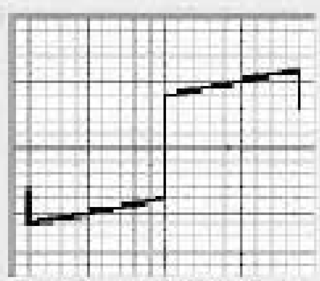


Figure 2-B: Nonlinear plastic Hinge Shear

Table 5: Computed Value d_f , d_r

Title	d_f (mm)	d_r (mm)
Model A	316.3	234.8
Model B	295.1	203.4
Model C	253.4	144.8

Table 6: Calculating GDP, GDP_r

Title	GDP	GDP_r
Model A	0.592	0.710
Model B	0.419	0.503
Model c	0.314	0.377

construction materials like steel, in most of the cases, the rupture from sectional and general buckling would occur before the rupture from final limit of strain, for this reason using the force displacement curves with a rupture point extracted upon sectional buckling would be reasonable. In FEMA-273 Instructions, specifications for standard non-linear joints are given. Figures 2-A and 2-B shows the joints used in this study for moment and shear, upon the aforesaid code.

Assigning such joints to beams, columns and wind tights and doing nonlinear static analysis, we find that the maximum displacement equal to the first plastic joint in one of the columns (dr) and the value for maximum displacement equal to the first plastic joint in the first level column (d) (which means the structure failure for samples) would be as given in table 5.

5-3 Calculation of damage index by corrected method of Papadopolos and his colleagues upon obtained values

Considering the obtained values for dy, dr and d find upon relations 2 and 3 of the structure damage index, the GDP and GDPr value are given in table 6.

6- Comparison of results obtained from damage index given by corrected Papadopolos relation and damage index (table 2)

Completing table 2 for models under study we find that qualitative damage index for samples a, b and c are respectively equal to 0.691, 0.518 and 0.391 So the results from table 2 have a high precision. Then the two given methods are in agreement in the building conditions for strengthening. In other words both methods show that their intervals are in the same row.

7-Results

- Papadopolos method is a relatively functional method against other methods, in calculation of structural damage index but this is based on the experimental-numerical method.

- Papadopolos method, like many other methods is not complete since it does not include the seismic geo-technique effects.

- Given method in this paper is changed into a simple method of suitable accuracy by correction and completion of prior method.
- In the given way, this method is changed into a numerical method.

- By statistical analysis and collecting relative professor's views, a functional method is given for the first time in this paper in the form of a qualitative method with suitable accuracy.

- Doing case studies we found that the difference between Papadopolos method (corrected by the authors of this paper) with given qualitative method for sample models would be %2.6, %2.9 and %3.6 for a, b and c models respectively.

- Considering the results from numerical study we found that a new solution has been given for estimation of structural condition to see of we need strengthening.

- In case of using the results from current study, many decisions which are based upon engineer justification would be changed into scientific and reasonable decisions.

Reference:

[1]. M.Sebt & M.Sadighi " Management and Investigation in Necessary of interim Habitancy after Earthquake for one of Tehran Region , Master of Science Theses, AmirKabir University of Technology, 2005.

[2]. Report of Reforming & building f bam city, April 2005

[3]. Vassiliou, G., (1975), "Behaviour of Repaired RC Elements" , Ph. D. Thesis NTU, Athens.

[4]. Bertero, V. and Brokken, S., (1983), "Infills in Seismic Resistant Buildings" , Journal of Struct. Eng., ASCE, 109 (6), 1337 – 61.

[5]. Park, Y. – J., and Ang, A. H. (1985). "Seismic damage analysis of reinforced Concrete buildings. "J. Struct. Eng., III(4) , 740 – 757.

[6]. A.R. Rahai, H.RashdiZadeh "Concrete Structures Seismic Retrofitting and Optimization against Earthquake", Master of Science Theses, Amirkabir University of Technology, 2003

[7]. Iemura, H. (2000), "Demand Spectra of yieldstrength and ductility factor to satisfy the required seismic performance objectives. " proceeding of International workshop on Annual commemoration of chi-chi Earthquake, Volume II – Technology Aspect, PP. 501 –508.

[8]. Honglin, HE, "Damage and seismic intensity of the 1996 Lijiang Earthquake, china: AGIS analysis", Ph. D. dissertation, Institute of Geology, China seismological Burean. (in Chenese)

[9]. Bozorgnia, Y. and Bertero, V., "Improved Shaking and damage Parameters for Post-Earthquake applications. "Proceedigns of the SMIP01 Seminar of Utiliration of Strong-Motlion Data, Los Angeles, California, September 12, 2001, PP. 1-22.

[10]. Reinhorn, A. M., Valles, R. E., and Lysiak, M., (2003), "Simplified Inelastic Response Evaluation Using Composite Spectra," Earthquake Spectra, in review.

[11]. Papadopolos, P. and Mitsopulou, A. and Athanatapulou, A. "Failure Indices for RLC Building Structures" , published by Elsevier Science Ltd. 12th European Conference on Earthquake Engineering. Paper Reference 616.

[12]. Colombo, A. and Negro, P. "A daage index of generalized applicalbility" , Eng. Strct. 27 (2005) – 1164 –1174.

[13]. Jeong, S, Elanashai, S, "Fragility Analysis Using A New 3 D Damage Index" , Published by Elsevier Science Ltd – 2005.