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# Relationship Between Damage Index and Performance Levels of RC Frames

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**ABSTRACT:** In recent years, in order to have a comprehensive evaluation of structural damages, quantitative methods are developed. In this regard, several research works have been done. The damage indices are based on structural drift regarding the importance and vast application of performance-based design. In this paper, the relationship between the performance levels and damage indices are studied. Several models of RC moment resisting frames were selected and analyzed using dynamic and pushover methods. Furthermore, various damage indices i.e.; Park-Ang index, stiffness index, drift index, and maximum softening and Plastic softening index for different models were estimated. Finally, the relationship between the values of these indices and the performance levels of frames is discussed in accordance with FEMA-356.

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## 1- Introduction

In recent years, the design of earthquake-resistant structures has been accompanied by a change in the attitude of resistance into performance methods. Experience of recent earthquakes has shown that in resistance-based design, although the lives of people are preserved, the structures suffered great damage and heavy economic losses. Therefore, the performance-based design has been considered as a method based on displacement and deformation (and in accordance with the expected performance level). For this purpose, instructions provide different levels of damage to the structure and provide a suitable measure for controlling the amount of loss and damage. In order to determine the amount of damage to the structure, researchers have introduced various indices.

The purpose of this study is to investigate the relationship between Park-Ang damage index [1], ultimate softening index, maximum softening index [2], proposed stiffness index [3], and lateral displacement [4, 5] with performance level set forth in FEMA-365. In the present study, for the non-linear analysis of frames, IDARC 2D software has been used which is a very powerful application in the analysis of RC structures.

## 2- Performance levels evaluated in this research

According to FEMA-356, the numerical values of the damages corresponding to each performance level are summarized in Table 1 [6].

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**Table 1. Assigning damage index to FEMA performance levels [6]**

| C | CP | LSR | LS | DC | IO | A-B | Performance levels |
|---|---|---|---|---|---|---|---|
| 1 | 0.83 | 0.67 | 0.5 | 0.33 | 0.17 | 0.0 | Damage indices |

## 3- Models Analysis

Five RC frames were designed. Details are completely expressed in reference [7]. These frames were initially designed, using Sap2000 software and the incremental loading pattern. The models were designed according to the standard spectrum of 2800 regulations. Each of frames reveals a performance level, then IDARC software is used to calculate the index values and perform nonlinear time histories analyzes.

## 4- Selection of earthquakes

In this research all selected frames are designed on a bedrock, therefore, for nonlinear dynamic analysis, 7 earthquake records on the bedding have been selected from the [1]PEER database and are scaled according to the rules of the 2800 regulations.

## 5- Investigating the relationship between damage index and performance levels

To investigate this relationship, there is a need for non-linear

1 Pacific Earthquake Engineering Research

time history models' analysis, which is done by the non-linear IDARC 2D software. In this research, the damage index values for each of the frames are calculated separately for each of the seven earthquake records presented in section 5, then, the average of these values is calculated, and given that each of the frames in this study represents a specified performance level according to FEMA, so the average values obtained for each index corresponding to that level of performance. Lastly, the results are presented in the form of Figures 1-4, and the relation between FEMA performance levels and damage indices is presented in Table 2.

**Table 2. Relationship between FEMA performance levels and damage indices**

| Performance level | A-B | IO | DC | LS | LSR |
|---|---|---|---|---|---|
| Park-Ang index | 0 | 0.08 | 0.218 | 0.4 | 0.623 |
| Stiffness index | 0 | 0.02 | 0.2 | 0.411 | 0.63 |
| Maximum softening index | 0 | 0.1714 | 0.3456 | 0.5355 | 0.73 |
| Ultimate softening index | 0 | 0.2654 | 0.4493 | 0.5917 | 0.68 |
| Lateral deformation index | 0 | 0 | 0.124 | 0.3393 | 0.616 |

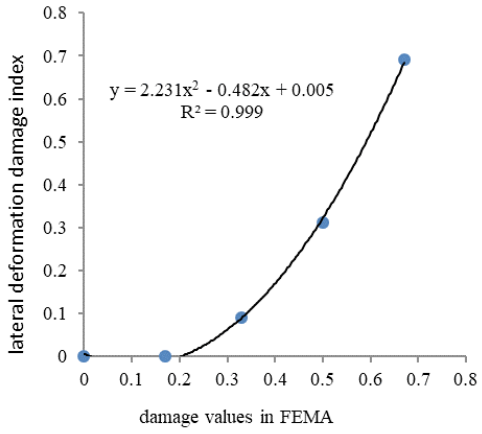


**Figure 1. Relationship between FEMA performance levels and lateral deformation damage index**

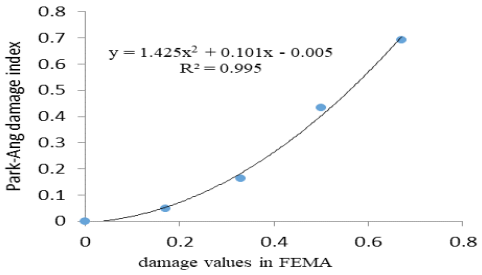


**Figure 2. Relationship between FEMA performance levels and Park-Ang damage index**

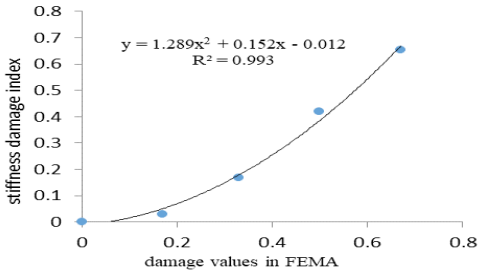


**Figure 3. Relationship between FEMA performance levels and stiffness damage index**

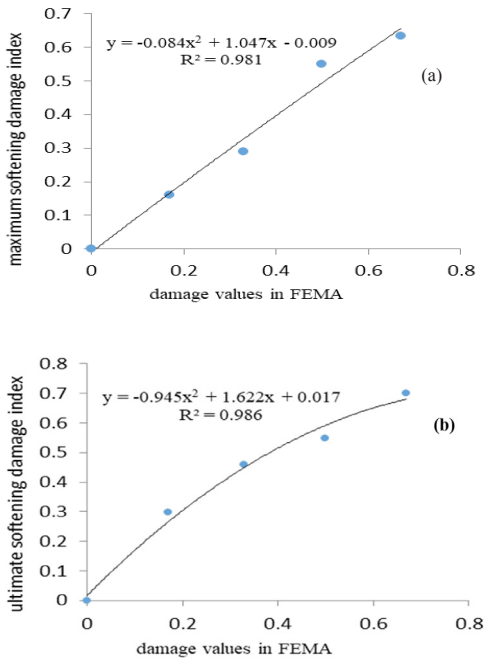


**Figure 4. Relationship between FEMA performance levels and maximum softening damage index (a) ultimate softening damage index (b)**

## 6- Conclusions

1. The value of all damage indices of concrete frames for the range A-B performance level is close to zero.
2. The values of the indices at the level of IO performance vary in the range of 0.0-0.264. Therefore, there is a large dispersion between the damage indexes at this level of performance. The value of the maximum softening index is approximately equal to the FEMA value, and the value of the lateral deformation index is zero. At the level of LS performance, the values of the indices, except the softening index, are concentrated in the range of 0.31-0.41, and less dispersion is observed, so it can be a reasonable range.
3. In general, the ultimate softening and the lateral deformation index provide unacceptable values at lower performance levels. On the other hand, the values of Park-Ang and stiffness indices are close to each other at all levels. Therefore, these two indices can provide a reliable range for examining the extent of damage at different performance levels.

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