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Seismic Assessment of Steel Frame Bridges and Comparison with Damage Indices

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ABSTRACT: Vulnerability assessment and seismic retrofit of bridges as lifelines are of great importance. In recent years, performance-based procedures in bridges are taken into consideration by researchers. In this paper after evaluation of proposed methods for seismic performance assessment of bridges, a laboratory model of box-shaped steel bridge piers was analyzed for verification and results were compared with a tested model's data. Then based on the properties of a real bridge, several bridges' models were designed for parametric studies. The mentioned bridge is continuous and consists of steel moment frames in a longitudinal direction. Further, after evaluating performance levels of the bridges, obtained results were compared with damage indices and the difference between structural specifications and mentioned indices were indicated. The nonlinear static analysis procedure was utilized to analyze the models. Energy, effective stiffness and Park-Ang damage indices were employed to evaluate damage. Independence of indices from geometric changes of structures, the high adaptation of Park- Ang index with energy index due to use of energy as a common concept and more accurate results of energy damage index in each performance level were some of the results.

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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. The philosophy of performance-based design is to estimate the structural performance objectives when a certain level of seismic hazard occurs. Along with the research on building structures, efforts have been made to define and categorize performance targets and ultimate limit states for the design and calculation of bridges. Iemura [1] proposed a performance-based seismic design flowchart. Pantelides et al. [2] investigated a reinforced concrete pier of a bridge and three separate levels of performance corresponding to the observed damage of the pier were presented. In this study, the percentage of relative displacement has been used as a criterion for the differentiation of performance levels. Ghobarah [3] introduced the failure threshold of the bridge piers at three levels of non-damaging, moderate damage and significant damage, equivalent to the relative displacement of less than 0.2 %, less than 0.4 %, and less than 5.2%. According to his findings, if a structure exceeds a relative displacement of 2.5%, severe failures will occur.

The purpose of this study is to investigate the performance levels of continuous steel bridges with frame system and a quantitative comparison of these levels with damage indices. In other words, attempts have been made to provide a quantitative interpretation for the qualitative performance levels used in codes, with the help of damage indices. A static nonlinear method has been used for investigation of the damage process and its extension in the bridge structure. Calculation of damages to the structure was performed using the effective hardness, energy, and Park-Ang damage indices.

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2- Performance-based design and structural analysis

In Pre-standard and Commentary for the Seismic Rehabilitation of Buildings (FEMA 356), structural performance levels are defined as 3 main levels and 2 intermediate levels. The main performance levels are the Immediate Occupancy (IO), life safety (LS) and Collapse Prevention (CP). The intermediate levels are defined as the limited failure and limited safety.

Although linear analysis and elastic performance evaluation provide a good view of the elastic capacity of a structure, it is incapable of predicting the structural failure mechanism, how to redistribute forces during successive yielding, and cannot deliver reliable results about the amount of plastic deformation and therefore the amount of structural damage. Thus, using a nonlinear static analysis method to investigate the behavior of the bridges in the earthquake is logical [4].

3- Damage Indices

The quantitative structural damage after the earthquake is one of the topics that many researchers have addressed and have proposed different indices to evaluate the damage. In this research, three of these indices are used including damage index based on stiffness, damage index based on energy and local Park-Ang damage index.

4- Validation of Structural Analysis Method

Susantha et al. [**] placed box-shaped pillars of a steel bridge on a seismic table exposed to cyclic loading for investigate the capacity of the bases' ductility. In order to validate the structural analysis method, the sample was modeled in SeismoStruct software [5] and the results were compared with the results of the experiment. Comparison of the capacity curves generated by computer modeling and the laboratory study confirms the accuracy of modeling and structural analysis.

5- Model Evaluation, Nonlinear Analysis and Calculation of Damage Index

In this study, six steel-frame bridges were designed based on the general specifications of the existing bridge, in order to investigate the performance levels of steel bridges and compare the results with damage indices. In order to evaluate the seismic behavior of bridges, a complete 3D analysis was used. By selecting the mass center of the bridge's deck as a control point, the pushover analysis was performed in the longitudinal direction and the capacity curve for each of the structures was plotted. After pushover analyzing and determining the performance levels, hardness, energy, and Park-Ang damage indices were calculated for each structure corresponding to the performance levels. To compare the magnitude of damage indices corresponding to performance levels, and to examine the amount of data dispersion, mean, variance, and standard error of the damage indices at each performance level have been calculated.

6- The Relationship between Damage Indices and Relative Displacement

This section attempts to investigate the relationship between the damage indices and relative displacement, which can be seen in Figures 1 to 3.

It is obvious that a certain relationship cannot be considered between the values of the damage indices and the relative displacement,

The relationship between damage indices with each other is also examined in the same way. The investigation of the graphs showed that there was a clear and meaningful relationship between energy damage index and Park-Ang, as shown in Figure 4.

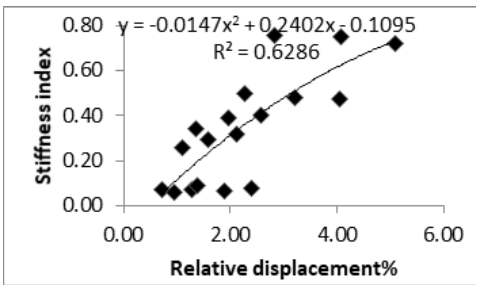

Figure 1. Relationship between stiffness index and relative displacement

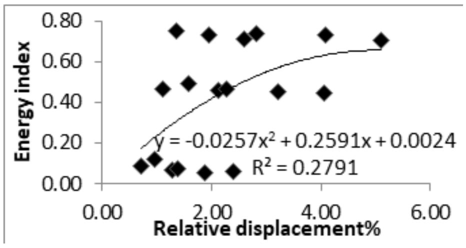

Figure 2. Relationship between energy index and relative displacement

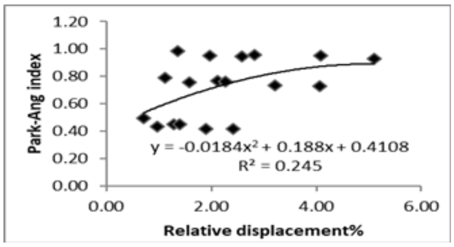

Figure 3. Relationship between Park-Ang index and relative displacement

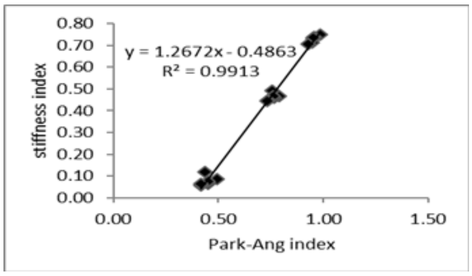

Figure 4. Relationship between the energy and Park-Ang indices

7- Conclusions

1. The study of the failure process showed that the increase in deck height, yielded to the increase of relative displacement corresponding to the performance levels. This means that on longer bridges, due to more flexibility, the structure tolerates more displacement before it reaches its failure.
2. Comparison of the damage index values for different models showed that the results of each index were closely related to each other in each of the performance levels. Despite the geometric variation of the study models, the indices had almost constant and close values.
3. The stiffness index changes occurred in a smaller range than the energy index and the Park-Ang index. Apart from the IO performance level, with two hardness and energy indices having almost identical results, the hardness index results were comparable at the two levels of LS and CP and in some cases, interference was also observed.
4. The values of the energy index and the Park-Ang index are very well adapted to each other. This seems to be due to the use of the concept of energy absorbed

by the structure in these indices.

5. Comparison of the stiffness, energy and park-Ang index values for the corresponding performance levels and the amount of data dispersion indicated that the energy index, in general, had more accurate results with less dispersion than the other indices. The average values of the energy index were 0.08, 0.46 and 0.73, respectively, corresponding to the performance levels of IO, LS, and CP.

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