Seismic performance evaluation of RC bridge piers designed with direct displacement-based design

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ABSTRACT

In Direct Displacement-Based Design (DDBD), the performance objective is to achieve the design displacement (target displacement) and the stiffness and strength of the structure is determined in such a way that the maximum displacement of the structure in an earthquake reaches this displacement. For this purpose, the design base shear is determined based on 3 key parameters of equivalent damping, damping modification factor and P-Delta effect. Due to the variation of relationships for each of these parameters, in this study the influence of using different relations on achieving performance objectives is investigated. In this study, 8 bridge piers with 2 different heights, 2 different span lengths and 2 seismic hazard levels were selected. In order to design the piers, the displacement design spectra were extracted from AASHTO acceleration design spectra. Then, each of these piers was designed for 27 different design paths resulting from 3 distinct relationships for each of the 3 key parameters and a total of 216 bridge piers were designed by DDBD approach. Then, to evaluate the seismic performance of the piers, each of the 216 piers was modeled in OpenSees software and subjected to 14 far-field earthquake records scaled on the design spectrum. After determining the maximum displacement of each pier, the proximity of this displacement to the target displacement was studied as a performance objective indicator. The results of analysis show that the use of different design relations has a significant effect on the maximum displacement of piers and their construction cost. So that for the most designed bridge piers, the use of different relationships causes a 20% decrease or increase in the maximum displacement compared to the target displacement and up to 40% changes in the construction cost. Among 27 design paths, using the Priestley relationship for equivalent damping, the Japanese regulation formula for the damping modification factor, and the Pettinga and Priestley formula for the P-Delta effect, provides a more suitable performance for all bridge piers designed with different heights, different span lengths and different seismic hazard levels.

KEYWORDS

Direct displacement-based design method, RC bridge pier, Equivalent viscous damping, P-Δ effect, nonlinear dynamic analysis.

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1. Introduction

In traditional design methods, force was a criterion for determining the demand of the structure during an earthquake. But after the Lomaprieta earthquake in 1989, extensive research was done by researchers who developed seismic design criteria for bridges based on performance, and in many of them, displacement instead of force was used as the demand criterion [1-5].

Several design methods based on (DBD) have been presented, one of which is Direct Displacement-Based Design (DDBD), which was proposed by Priestley [1]. In DDBD, the design base shear is calculated based on the substitute structure method [6]. In this method, the non-linear structure is replaced by a linear single degree of freedom system, which is defined based on the secant stiffness and equivalent damping. Therefore, equivalent damping is one of the most important and influential parameters in the design process. In the following years, relatively extensive research was done to determine the equivalent damping relationship for all types of hysteresis behavior and various relationships were presented [7-11].

Despite the significant difference in the presented design relationships, a wide and comprehensive research to investigate the effect of using different design relationships is not observed in the literature review. Therefore, in this research, by studying a large number of bridge piers that are designed using various relationships; The impact of using different relationships for achieving to performance objectives has been investigated. In addition, the cost of building the piers has also been compared in different cases. As a result, it is possible to determine the best combination of relationships for the design of concrete bridge piers based on the seismic performance of the designed piers and their construction cost.

2. Methodology

In order to select the relationships for each of the three equivalent damping parameters, the damping correction factor and the p-delta effect, first all the relationships that were suitable for the design of concrete bridge piers were collected. Then, for each design parameter, the graph obtained from different graph relationships was drawn and compared. Further, equations that led to similar graphs were eliminated and other equations were selected for evaluation.

three equations were considered for all three variables, their combination results in 27 design paths. Since the purpose of this study was to evaluate bridge piers designed by DDBD, the design of all piers was done by the authors. But for the bridge deck, the specifications of the deck provided in reference [12] have been used. The cross-section of the desired deck, which is related to a two-lane road, is shown in Figure 1. Two heights of 5 and 10 meters have been used for the height of the piers.

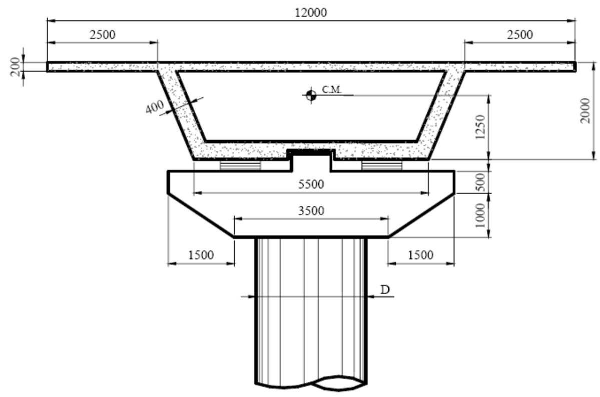

Figure 1: Cross-section of the deck and used piers (dimensions in millimeters) [12]

In this research, OpenSees software was used for modeling and nonlinear time history analysis. A single degree of freedom system was used to model the piers, which was used to define the cross sections of fiber and circular shape. Also, to consider the nonlinear effect, the dispBeamColumn element has been used for the member elements. for the modeling of the concrete used in the bridge piers, concrete02 materials were used. For the modeling of longitudinal rebars, steel02 material is used, which uses the deterioration behavior model of Filippo et al [13].

3. Results and Discussion

In order to obtain the accuracy of the design in estimating the target displacement, the bias function statistical index has been used, this index shows how close the results are to the design objective.

the results related to the bias or deviation shows that the amount of deviation from the change of the design displacement is largely affected by the selected relations. the average displacement has a deviation of about 20% compared to the target displacement. the design basis path, which is the same path presented by Priestley, has an acceptable accuracy with a deviation of 0.98. Also, design routes 9, 11, 20 and 21, which have deviations of 0.985, 0.97, 0.957 and 1.01, respectively, have a high accuracy in estimating target displacement.

Therefore, these routes can be considered as the best routes from the point of view of deviation of the results. Although In terms of construction cost, while the amount of construction cost changes in different paths related to pier 4 is around 40%, but it fluctuates up to 80% in pier 6.

4. Conclusion

In DBD, the goal is to achieve the target displacement during the earthquake. For this purpose, the key parameters were considered as: (1) equivalent damping, (2) damping correction factor and (3) parameters due to p-delta effect. Since the relationships presented for each of these parameters have a significant variety, which leads to different design results. In this study, the effect of using different relationships on seismic performance of piers has been evaluated.

For this purpose, for each of the mentioned key parameters, three different relationships were selected based on reputation and dissimilarity, and from the combination of these relationships, a total of 27 design paths were created.

The results of these analyzes show that the use of different design relationships has a significant effect on the seismic performance of the structure and the cost of building piers. In general, design with different relationships for many designed piers, the maximum displacement of the pier is about 20% on average compared to the target displacement and the construction cost is changed by about 40%.

Based on the evaluation of 27 selected design paths for 8 designed piers, design path 9 is suggested as the best design path. This design path also shows a reasonable construction cost compared to other paths. Among other design paths, some design paths lead to good results only in some piers.

5. References

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