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Field Evaluation of Fundamental Period of Damaged and Retrofitted Reinforced Concrete Buildings: Case Study of Sarpol-e Zahab Earthquake

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ABSTRACT: The fundamental period of a building plays a critical role in determining structural behavior during strong motions such as earthquakes and estimating building base shear in the new design of structures, as well as target displacement in seismic assessment of existing buildings. Thus, having an appropriate estimation of the fundamental period of buildings can considerably affect design and evaluation processes. In this research, to investigate the effects of damages on fundamental periods, ambient vibration tests were conducted on 22 seismically-damaged reinforced concrete (RC) buildings following the earthquake of Sarpol-e Zahab 2017. The obtained values for fundamental periods were compared with their counterparts calculated by empirical relations proposed in the first and fourth edition of the Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard No. 2800) and the first revision of Instruction for Seismic Rehabilitation of Existing Buildings (No. 360). The obtained results for damaged RC buildings with moment resisting frame show a significant difference between fundamental periods of ambient vibration tests and empirical relations such that in a building with a damage state of 4, the obtained period from ambient vibration tests was 2.32 times greater than the calculated value using empirical relations. Furthermore, in retrofitted RC buildings, fundamental periods from empirical relations were up to 1.7 times greater than values determined using ambient vibrations. Therefore, two empirical relations for determining fundamental periods of damaged RC buildings with moment resisting frames and retrofitted RC buildings by adding shear walls are proposed by fitting curves on the obtained results of ambient vibration tests.

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1- Introduction

In general, the behavior of structures during large vibrations induced by earthquakes depends on the dynamic characteristics of the structure (Fundamental period, damping, and mode shapes). Among these characteristics, the fundamental period of structure can be considered as the most critical and influential behavioral characteristic. With the aim of presenting an approximate estimation for the fundamental period of buildings, empirical relations have been proposed by design and evaluation codes, which are mainly based on the results of field and experimental tests. Using ambient vibration tests, Oliveira and Navarro, Chiauzzi et al., and Salameh et al. determined the fundamental periods of 197, 12, and 330 reinforced concrete (RC) buildings, respectively [1-3]. Goel and Chopra proposed empirical relations for fundamental period calculation of RC buildings by running the analyses on the recording vibrations of 27 and 16 RC buildings with moment-resisting frame and shear wall as a lateral load resisting system, respectively, during an earthquake in California [4-6]. These relations became the base of later-proposed empirical relations in American codes and provisions.On November 12, 2017, an earthquake with a magnitude of 7.3 (Mw) struck Sarpol-e Zahab (Iran). During the earthquake, many buildings suffered considerable damages to the extent that they needed to be retrofitted. Concerning the importance of the fundamental period of structure in the evaluation and retrofitting process, ambient vibration tests were conducted on 22 damaged and retrofitted buildings. The purpose of this study is to determine the fundamental periods of damaged and retrofitted RC buildings, investigate the effect of damage rate on changes in this characteristic, and draw a comparison between the obtained results and the empirical relations proposed in different editions of Standard No. 2800 and Instruction for Seismic Rehabilitation of Existing Buildings (No. 360) [6-8].

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2- Methodology

Ambient vibration tests are conducted on 22 RC buildings (12 damaged and 10 retrofitted buildings) whose heights range from 1 to 7 stories (i.e., 3.2 to 22.3 meters). In order to investigate the effect of damage severity on the fundamental period, buildings are classified into five damage states according to the suggested criteria in European Macroseismic Scale [9]. Damaged RC buildings were retrofitted by adding shear walls, and damaged beams and columns were locally retrofitted.Ambient vibrations of buildings were recorded using the SSR-1 data logger and Ranger Seismometer model SS-1 sensors. Sensors were located as close as possible to the story center of stiffness to measure buildings' vibrations. In cases where torsion was inevitable, in addition to the center of stiffness of each story, sensors were located at the corners of each story. In this research, records of vibrations were processed through 5 modal identification methods, including enhanced frequency domain decomposition (EFDD) and curve-fitting frequency domain decomposition (CFDD) methods in the frequency domain and stochastic subspace identification-unweighted principal component (SSI-UPC), stochastic subspace identification-principal component (SSI-PC), and stochastic subspace identification-canonical variate analysis (SSI-CVA) methods in the time domain using ARTeMIS software [10].

3- Results and Discussion

The obtained periods are compared with the results of empirical relations proposed in the Iranian Code of Practice for Seismic Resistant Design of Buildings first and fourth editions, as well as Instruction for Seismic Rehabilitation of Existing Buildings 1st edition. Results show that the calculated periods using empirical relations proposed in codes present underestimated values. This difference is such that for a building with damage state of four, the acquired fundamental period from ambient vibration tests is 2.32 times the highest value calculated by empirical relations. Due to the direct influence of the fundamental period of a building on the calculated target displacement in the evaluation process of building, this significant discrepancy in period estimation can lead to incorrect evaluation of existing structure; because, according to Instruction for Seismic Rehabilitation of Existing Buildings 1st edition, in target displacement estimation process the fundamental period of a building should be considered equal to the period that is calculated using empirical relations of code or the least value of 1.4 times of period that is calculated using empirical relations of code and analytical period that is obtained from analytical models [15]. Thus, an underestimated value of the fundamental period leads to an underestimated and contrary to certainty value for target displacement. Investigations show that fundamental periods of all buildings that were retrofitted by adding shear walls are lower than the values calculated using empirical relations of codes, and periods of those buildings that already had shear walls during the earthquake are greater than the values calculated using empirical relations of codes.

Due to the significant difference between the obtained periods for damaged RC buildings with moment-resisting frame and retrofitted RC buildings by adding shear walls and the calculated values of codes empirical relations, new empirical relations are proposed by curve-fitting on the obtained periods using ambient vibration tests. For damaged RC buildings with moment resisting frame as a lateral load resisting system, $T = 0.099H^{0.9}$ is proposed that approximately is twice the relations suggested by empirical relations of codes. Besides, for RC buildings with shear walls or masonry infill walls, $T = 0.036H^{0.75}$ is proposed that its result is less than the proposed values of codes empirical relations.

4- Conclusion

Due to the importance of buildings fundamental periods in estimating base shear of buildings in the design process and target displacement in buildings evaluation in retrofitting process, by curve-fitting on the obtained results of ambient vibration, $T = 0.099H^{0.9}$ and $T = 0.036H^{0.75}$ are proposed for RC damaged buildings with moment resisting frame as a lateral load resisting system and retrofitted (or new) buildings by adding shear walls, respectively.

The obtained results of this research demonstrate that the proposed empirical relation for calculation of the fundamental period of RC buildings with moment resisting frame in Instruction for Seismic Rehabilitation of Existing Buildings 1st edition is significantly contrary to certainty.

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