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# COLLAPSE VULNERABILITY AND FRAGILITY ANALYSIS OF RC BRIDGES REHABILITATED WITH FRP LAYERS

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Earthquake is one the most important natural phenomena that may sometimes cause economic loss in structures and human casualties in many countries. The road bridges, considered as the main and vital structures constructed on the essential municipal artery, can deliver adverse consequences during the seismic events. Undoubtedly, collapse of a bridge may risk the pedestrians and vehicles in the vicinity with severe dangers, thus necessitating the rehabilitation in the aftermath of an earthquake (Naseri et al., 2017).

Owing to the high prominence of bridges, the estimation of their damage state prior to incidence of a ground motion is critical. The seismic fragility curves are then convenient tools in the probabilistic seismic vulnerability assessment of structures through determining the probability of exceeding a specific damage state with respect to structure's seismic parameters (DesRoches et al., 2011).

Several studies have so far been carried out in the development of seismic fragility curves of both existing straight and strengthened bridges (Nielson, 2005; Padgett, 2007). According to these studies, columns are the most vulnerable locations for damage in bridges. In the process of vulnerability evaluation, the difference between design assumptions and the existing state parameters may significantly alter the estimation of capacity and demand in bridges.

Fridley and Ma (2009) produced fragility curves of a bridge specimen having columns strengthened with steel and composite jackets.

Pahlavan et al. (2015) evaluated the seismic vulnerability of four-span RC curved bridges with regular column height by means of probabilistic approach. Developing fragility curves, they carried out different probabilistic methods of bridge retrofitting. The result revealed the significant influence of various retrofitting methods on the seismic performance of bridge. Alim and Zisan (2013) studied a class of bridges strengthened with FRP. The fragility curves were then presented for both strengthened and unstrengthened cases. It was concluded that the strengthened case was less damaged.

Few investigations have already been conducted on the vulnerability assessment and fragility curves regarding the vertical component of the earthquake. Such studies have only examined the performance of bridges subjected to a limited number of records thru a deterministic evaluation of seismic damage to bridges.

In this paper, the probabilistic evaluation of bridge damage is investigated by making use of fragility curves, where identifying such an issue is of high practical importance in subsequent decisions for rehabilitation and strengthening purposes. In addition, strengthening with FRP layers is applied on the bridge piers and the results are compared with the unstrengthened specimens.

In order to gain more precise control of bridge behavior in the course of the earthquake, the OpenSEES (McKenna et al., 2010) finite element program is used in the present study. In addition, a horizontally RC box-girder highway bridge located in the north of Iran is investigated. The bridge comprises three spans of 24.5 m (total of 73.5 m), where a girder deck of 11.9 m width is supported by two piers each encompassing three circular concrete columns of 9.52 m (Figure 1).

By comparing the results of model strengthened with FRP with the initial unstrengthened model, it is perceived that the median fragility increased by 10.84, 12.9, 15.5 and 20.5 % respectively in the four damage states of slight, moderate, extensive and complete, expressing the (positive) effect of strengthening in this case.

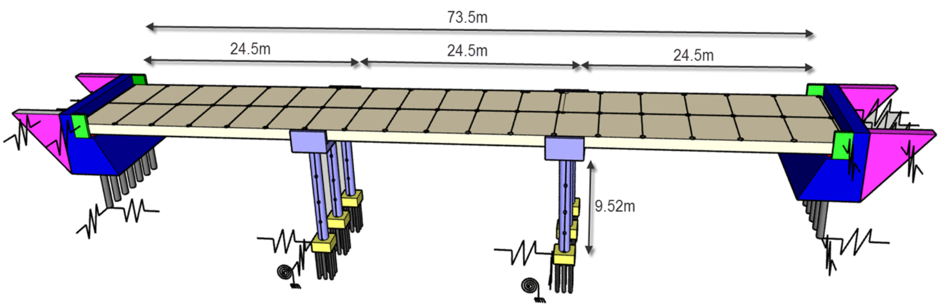


*Figure 1. Configuration details of bridge model.*

*Table 1. Modeling specifications.*

| Model Number | |
|---|---|
| 1 | With the effect of soil interaction and abutment |
| 2 | Strengthened with FRP layers with the effect of soil interaction and abutment |
| 3 | With the effect of soil interaction and abutment and vertical component of earthquake |
| 4 | Strengthened with FRP layers with the effect of soil interaction and abutment and vertical component of earthquake |

The median fragility is reduced by an average of 8.5%, 11.8%, respectively in the unstrengthened model with considering the vertical component of the earthquake, in the strengthened model with FRP. In general, considering the vertical component of the earthquake causes an average reduction of 10% in the median fragility and increases the vulnerability of the bridges in the course of an earthquake.

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