Evaluation of near-fault ground motions on seismic behavior of the movable folding bridges

Mohamad Hossein Taghavi Parsa [a*], Ali Ahani [b]

[a1] Ph.D. Graduate of Structural Engineering, University of Qom
[b] M.Sc. Graduate of Structural engineering, University of Tabriz

ABSTRACT

Bridges are structures with great importance, and any interruption could cause financial damage and even life-endangering people's life. Based on the type of structure, bridges can be divided into conventional, cable, and movable bridges. Space limitations in urban areas and the establishment of the cities around the rivers attracted designers and engineers to these types of bridges. Considering the importance of the foldable bridges, seismic behavior of the bridge under subjection to near-fault ground motions has been investigated in this paper. Inheriting impulse effects in near-field contents is the main difference with far-field records. The total length of the bridge is 40 meters and consists of three movable spans, which are 3.65, 2.7 and 3.65 meters long. To study the seismic behavior of the bridge, at first modal analysis has been performed in ABAQUS built model and then under subjection to near-fault ground motions, which has been matched according to issue No.463 seismic time history analysis performed. The acceleration response, base shear, and vertical deflection of the bridge induced by perpendicular horizontal excitations were calculated and extracted. The destructive effect of the Varzeghan earthquake is more than other earthquakes, and the numerical value of acceleration response, vertical displacement, base shear, and tower drift is considerably higher than other earthquakes. The connection zone of the tower to the deck is vulnerable to seismic loads, and plastic hinges have been formed.

KEYWORDS

Time History Analysis, Movable Folding Bridge, Near Field Ground Motion, Response Spectrum

[*] Corresponding author : Email : mh.taghavi@stu.qom.ac.ir

1. Introduction

Bridges are predominant structures that play a crucial role in connecting and reducing the distance between two points. Movable bridges are also of great importance and part of complex structures that are usually built on rivers. The dynamic characteristics of bridges are of paramount importance. For this reason, these properties have been studied by researchers and designers. Moving bridges have been built in many forms, including but not limited to the swing bridge, Bascule Bridge, and the folding bridge in recent years. Hörn bridge is one example of a foldable bridge which is located in Kiel city in Germany country. To this purpose time history analysis of the Hörn bridge has been carried out in this study.

While most of the researchers were focused on the seismic response of the bridges, some tried to be more specific and investigated the effect of the near-fault ground motions [1-5]. Investigation of the seismic behavior of the foldable bridge is missing in the literature, even though many studies concerning bridges' seismic behavior have been carried out. This paper aims to evaluate the seismic performance of the Hörn three-span folding bridge.

2. Methodology

The bridge is consists of three segmented folding spans, which are 3.65,2.7 and 3.65 meters long, respectively and the total length of the bridge is 40 meters. The deck is composed of five longitudinal and two transversal beams at each foldable segment.

Because of the complexity of the bridge and the inefficiency of traditional methods for evaluating the bridge under lateral and seismic loads, numerical analysis has been carried out. To achieve this goal model of the bridge was prepared in commercial FEM software (ABAQUS) due to the ability of the software for nonlinear analysis as well as Time-History analysis.

For performing time-history analysis, selected ground motions must be matched according to Issue No. 463 [6], while the criteria are almost the same in the AASHTO Recommended LRFD Guidelines for the Seismic Design of Highway Bridge [7]. According to Issue No. 463, an envelope of response spectrum for selected ground motions must be calculated, and then with standard design spectrum must be compared. According to the 4th edition of 2800 seismic code [8], in a designated interval of 0.2T and 1.5T. In which T stands for a natural period of the bridge, the envelope of the response spectrum should not be less than the standard design spectrum.

In Figure 1 developed model in ABAQUS commercial software has been displayed.

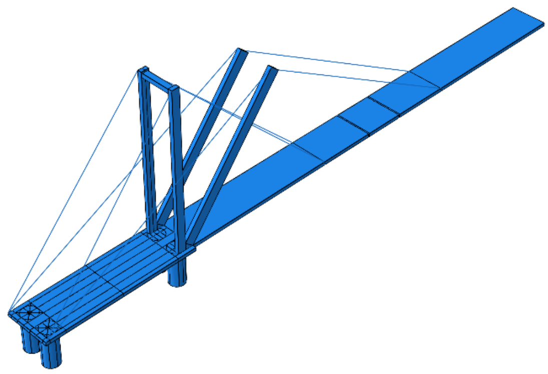
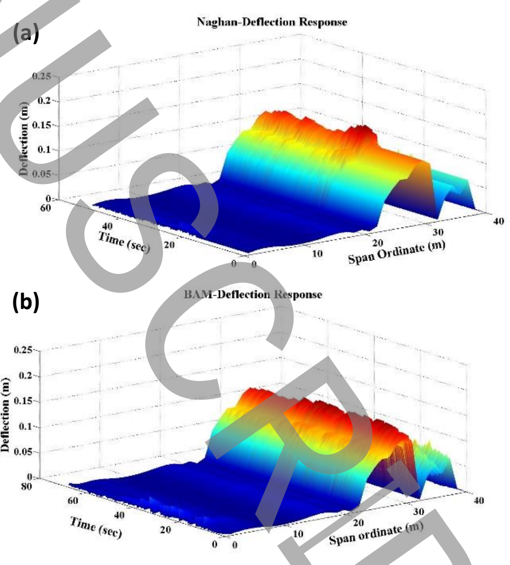


Figure 1. Developed Model

3. Results and Discussion

At the first step, modal analysis of the bridge for obtaining mode shapes and the corresponding period has been performed. The six consecutive mode shapes of the bridge were symmetrical vertical, lateral, tower sway, longitudinal, asymmetrical vertical, and torsional, respectively. The modal participation factor for the first and second modes is 76.33 %, 6.74 %, respectively. This significant drop in value for the second mode indicates that the behavior of the bridge is highly affected by the first vibration mode.

Three-dimensional surface of the span ordinate, time, and deflection of the span extracted after completion of the analysis. Mentioned surface for the five ground motions has been shown in Figure 2.



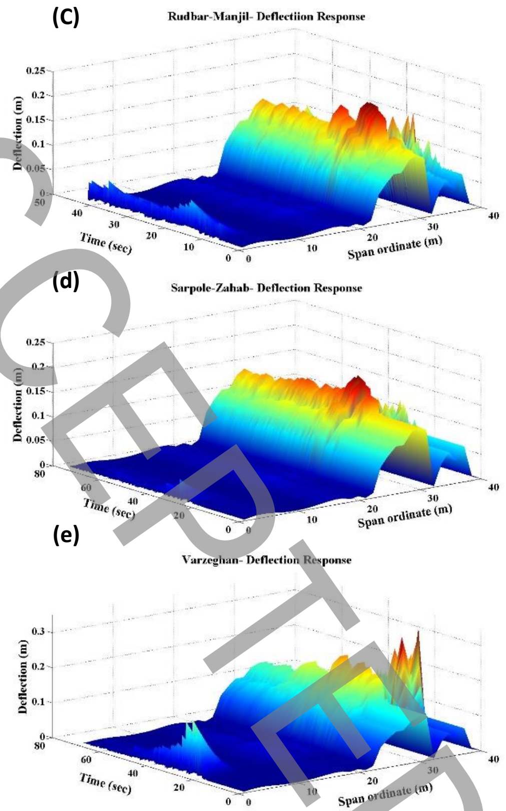


Figure 2: Vertical Deflection Response of the Bridge Span (a) Bam Excitation - (b) Naghan Excitation - (c) Rudbar-Manjil Excitation - (d) Sarpole-Zahab Excitation - (e) Varzeghan Excitation

As graphs indicate, there is considerable pressure at the end of the deck towards the pier. Displacement caused by Varzeghan ground motion has higher values in comparison to other ground motions. It seems that due to the closeness of the predominant period of the Varzeghan record to the bridge period, phenomena of the resonance have occurred in the bridge, while this effect has minimal effect in the Naghan record.

Stress contours for the bridge have been obtained and illustrated in Figure 3. Contours show there is plastic hinge formation in the connection zone of the towers to the deck and top beam, which connects the first towers' columns.

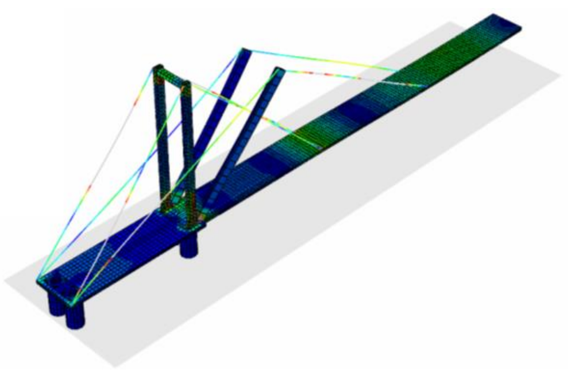


Figure 3: Stress Contour at Varzeghan record

4. Conclusions

In this paper, a Time-History analysis of the Hörn folding bridge has been performed, and seismic behavior of the bridge subjected to near-fault ground motions has been evaluated from different aspects. To this purpose, at first modal analysis for matching the selected near-fault ground motions was performed. The first vibration mode of the bridge was dominant in the seismic behavior and response of the bridge. This phenomenon was observed in the resonance effect that occurred at the Varzeghan record, which has a predominant period value close to the first period of the structure. The landmark outcomes of the study are presenting as follows:

- The acceleration response for different ground motions after matching has been achieved, even though that PGAs for all of them are equal to 1, the Hörn bridge response was different for each of them.
- Results also indicate that the horizontal excitation causes vertical deflections in the bridge structure. There is considerable displacement in the deck, which causes pressure force towards the pile.
- Plastic hinges have been formed in the connection zone of the towers to the deck, which was indicative of more vulnerability to seismic damage than other elements.

5. References

[1] G. Antonellis, M. Panagiotou, Seismic response of bridges with rocking foundations compared to fixed-base bridges at a near-fault site, Journal of Bridge Engineering, 19(5) (2014) 04014007.
[2] H. Choi, M.S. Saiidi, P. Somerville, S. El-Azazy, Experimental study of reinforced concrete bridge columns subjected to near-fault ground motions, ACI Structural Journal, 107(1) (2010).
[3] V. Phan, M.S. Saiidi, J. Anderson, H. Ghasemi, Near-fault ground motion effects on reinforced concrete bridge columns, Journal of structural engineering, 133(7) (2007) 982-989.
[4] A. Sengupta, L. Quadery, S. Sarkar, R. Roy, Influence of bidirectional near-fault excitations on RC bridge piers, Journal of Bridge Engineering, 21(7) (2016) 04016034.
[5] V. Van Cao, Characterization of near-fault effects on potential cumulative damage of reinforced concrete bridge piers, International Journal of Civil Engineering, 17(10) (2019) 1603-1618.
[6] M.o.R.a. Transportation, Iranian Road and Railway Bridges Seismic Resistant Design Code, in, Building and Housing Research Center, Tehran, 1387 (2008) (In Persian).
[7] T.O.S.o. Bridges, AASHTO Guide Specifications for LRFD Seismic Bridge Design, AASHTO, 2011.
[8] B.a.H.R.C. (BHRC), Iranian code of practice for seismic resistance design of buildings, Standard No. 2800, fourth edition, in, Building & Housing Research Center, Tehran, Iran, Tehran, 1394 (2015) (In Persian).