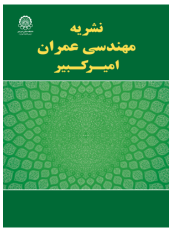

Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(3) (2021) 251-254
DOI: 10.22060/ceej.2020.16781.6342

Seismic Reliability Cable-Stayed Bridge with Latin Hypercube Sampling Methods

A. Rashid, H. Rahman Shokergozar * , M. Mohebbi

Earthquake Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran.

ABSTRACT: Cable bridges are one of the essential structures that are sensitive to vibrations. Therefore, it is necessary to investigate the seismic behavior of them. The uncertainty in structural members and earthquake excitation should be considered due to the undetectability and indeterminably them. In this paper, the reliability of the cable-stayed bridge with a 640-meter length span in two states with linear and nonlinear behavior for materials is investigated. The uncertainty in member parameters of pylons, girders, and cables, which includes the elasticity modules, cross-section, material yield strength, is considered, and the efficiency of each one is simulated by the sampling method. Linear and nonlinear time history dynamic analyses are performed by artificial earthquakes produced at four different seismic hazard levels. The sensitivity analysis shows that the cable parameters have the highest sensitivity. The reliability analysis also indicates that the failure probability in the pylon is more than cable, and the failure probability in the nonlinear model is higher than the linear model.

Review History:

Received: Jul. 17, 2019
Revised: Apr. 22, 2020
Accepted: May. 13, 2020
Available Online: Aug. 21, 2020

Keywords:

Reliability
Cable-stayed bridge
Artificial earthquake
Uncertainty
Latin hypercube sampling

1. Introduction

Cable-stayed bridges are one of the most common infrastructures with long spans, and recently they are constructed with more than 1000 meters span lengths. Operating loads, car accidents, and natural disasters are important causes of the failure at bridges. Therefore, an accurate assessment of them under natural hazards and service conditions is an essential issue [1]. The seismic behavior evaluation of such structures is a significant concern of engineers in high-seismic zones, and appropriate estimation of the seismic response could ultimately lead to structural damages and also economic losses [2]. Modeling parameters are usually considered definitive in analysis, but in reality, they are uncertain. These uncertainties are due to the member's geometry, material mechanical properties, the distribution and amount of loads, and so on. The deterministic analysis could not indicate the complete behavior of structures, and probability analyses are used to compensate for this defect. Cheng & Xiao (2005) estimated the serviceability reliability of cable-stayed bridges using a combination of the response surface method (RSM), finite element method (FEM), first-order reliability method (FORM), and the importance sampling updating method [3]. Cheng and Liu (2012) are investigated the effect of soil-pile interaction on the assessment of the reliability of cable-stayed bridges using the combination method proposed by Cheng & Xiao (2005) [4]. Truong & Kim (2017) proposed the improved Latin Hypercube (IHS) and an effective importance sampling (EIS) method for reliability analysis of steel cable-stayed bridges. They considered uncertainty at structural members, dead and live loads. In this paper, the seismic reliability of a cable-stayed bridge modeled at two different conditions (linear model and nonlinear model) is evaluated using artificial ground motion records. The ultimate (failure of cables, girders, and Pylon members) and serviceability (exceeding allowable drift) are considered as limit states functions. Latin Hypercube methods are used for sampling and simulation analyses. This method is a statistical method for generating a near-random sample of parameter values from a multidimensional distribution.

2. Methodology

The William H. Harsha Bridge is considered in this study (Fig. 1). This bridge is a cable-stayed bridge that connects Maysville, Kentucky, and Aberdeen, Ohio, over the Ohio River. The bridge has a total span of 2,100 feet (640 m) and the main span of 1050 feet (320 meters). The finite element modeling of William H. Harsha Bridge is developed using OPENSEES software. Two different models are made, one model with an assumption of linear behavior at the geometry and material properties, and the second one is considered geometric and material nonlinearity at all members. The linear and nonlinear time history analyses are performed for both models. Twenty-four artificial earthquakes are constructed for this purpose. The artificial earthquakes are developed according to four different properties (probability of being exceeded in 50 years of 20, 10, 5, and 2 percent).

*Corresponding author's email: h_rshokrgozar@uma.ac.ir

Fig. 1. William H. Harsha Bridge [6].

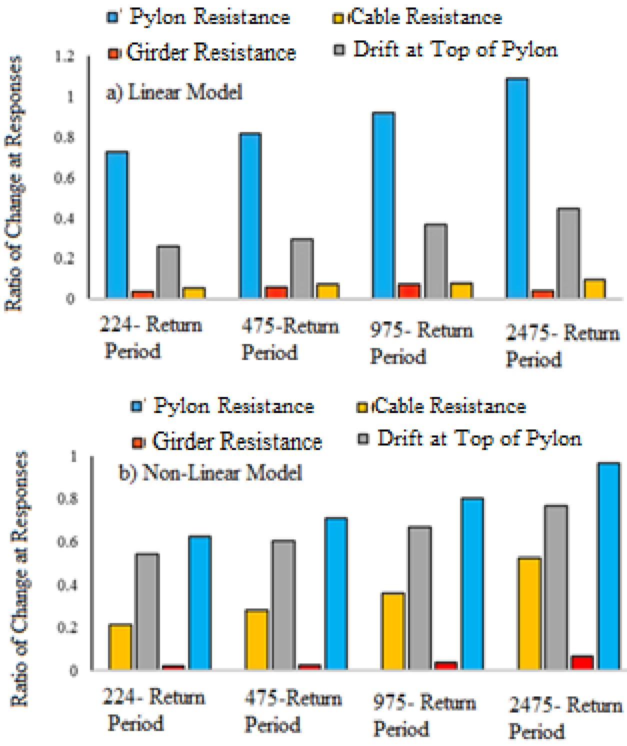

Fig. 2. The ratio of change at responses for various seismic levels.

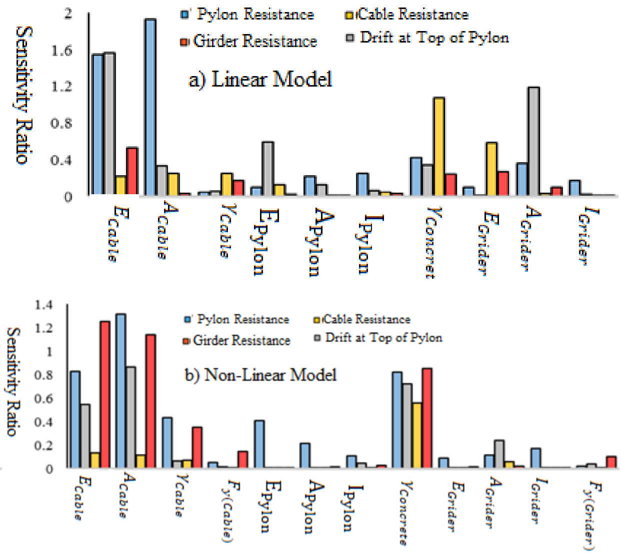

Fig. 3. Sensitivity ratios of girder, cable, pylon to input parameters

One of the essential steps in reliability analysis is sensitivity analysis, which is used to reduce the number of variables. This ratio is equal to the percentage of changes in the output response (probability of failure), divided by the percentage change of a special input variable with the assumption to be constant other parameters, which is shown as follow:

$$RS = \frac{\left(\frac{Y_2 - Y_1}{Y_1}\right)\times 100\%}{\left(\frac{X_2 - X_1}{X_1}\right)\times 100\%} \tag{1}$$

Where X1 is the initial value of the input, X2 is the changed value of one of the parameters, and Y1 is the initial output, Y2 is the output change relative to the change in one of the parameters. This equation is equivalent to the normal partial derivative. Variables with the highest sensitivity ratios have the most significant effect on the limit state function or the failure probability [7].

3. Results and Discussion

The average percentage of changes in the dynamic response of the pylon, girder, cable resistance, and drift at the top of the pylon, compared to the static responses are shown in Fig. 2 for linear and nonlinear models in the four different seismic levels. According to this figure, in the linear model, the pylon resistance and drift responses are raised by increasing the seismic return period. This result is due to the rising seismic demand of the bridge. However, in the girder and cable resistance, there is not a significant percentage of changes. This result is due to the lower stiffness of these members than the pylon. As shown in Fig. 2 in the nonlinear model, the percentage of changes in the drift at the top of the pylon as well as the pylon resistance increases with increasing return period. Unlike the linear model, the cable resistance is increased at higher performance levels. By increasing the return period, the pylon resistance in the linear model has a higher percentage change than the nonlinear model, but cable and girder resistances, and the drift at the top of the pylon changed significantly at the nonlinear model.

The results of sensitivity analysis and sensitivity ratio of different parameters in linear and nonlinear models are presented in Fig. 3. As can be seen in the linear model, the elasticity modulus and cross-sectional area of cables are more sensitive than other parameters, and the girder inertia moment and pylon cross-sectional area are less sensitive than other parameters. In the nonlinear model, the cross-sectional cable area and elasticity modulus, and density of concrete slabs have a higher sensitivity ratio. The girder elasticity modulus, pylon inertia moment, and yield stress of girder have a meager sensitivity ratio; in other words, these parameters are among the low significant parameters of structure. The reliability of the cable-stayed bridge in linear and nonlinear models has

Table 1. Failure Probability and dispersion coefficient for ultimate and service limit state at linear and nonlinear models.

		Pylon	Cable	Girder	Drift
Linear Model	F. P.	0.26	0.175	0.047	0.36
	D. C.	0.0034	0.066	0.136	0.0029
Nonlinear Model	F. P.	0.302	0.164	0.06	0.382
	D. C.	0.0025	0.12	0.147	0.0026

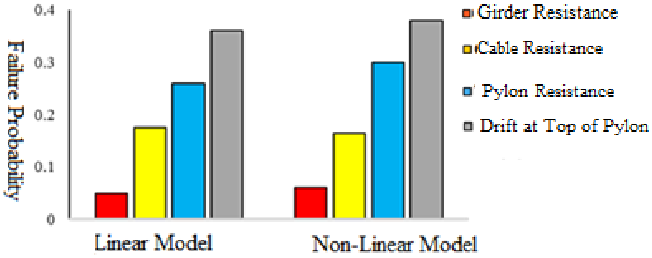

Fig. 4. Failure probability of cable-stayed bridge at linear and nonlinear models.

been evaluated using the Latin Hypercube simulation. The failure probability and the dispersion coefficient, Table 1, for the ultimate and service limit states are estimated. According to Table 1, it is observed that between the criteria that are considered for the ultimate limit state, the pylon resistance has the highest failure probability and also has the lowest dispersion coefficient, while the girder resistance has the lowest failure probability and also the highest dispersion coefficient. According to Fig. 4, by comparing the result of two linear and nonlinear models, it can be concluded that the probability of failure in different limit states is almost the same, but the failure probability in the nonlinear model is higher than the linear model. It can also be concluded that the failure probability in the service limit state is higher than the ultimate limit states.

4. Conclusions

In this study, the seismic reliability of a cable-stayed bridge has been investigated, and two linear and nonlinear models have been developed using Opensees software. Some uncertainty parameters in the cable, girder, and pylon members were also considered in analyzes. To assumption, the uncertainty at the seismic loads, artificial earthquakes at four different levels was used. Fifty samples of variables have also been generated using the Latin Hypercube sampling method to assess the structural reliability. Modal, static, linear, and nonlinear time history analyzes were used to obtain structural responses. The results of sensitivity analysis, as well as estimating the failure probability of the cable-stayed bridge can be summarized as follows:

- The average percentage change of dynamic responses indicates that the bridge pylon is the vulnerable member of the cable-stayed bridge during the earthquake.
- The bridge pylon has a high failure probability compared to the cable and girder elements.
- The failure probability in the nonlinear model is higher than the linear model.
- In cable-stayed bridges, cable elasticity modulus and cross-section are high impact parameters.

References

[1] Ren, W. X., & Peng, X. L. (2005). Baseline finite element modeling of a large span cable-stayed bridge through field ambient vibration tests. Computers & structures, 83(8-9), 536-550.

[2] Cunha, M. A., Guerreiro, L., & Virtuoso F. (2012). Influence of the Plastic Hinges Nonlinear Behavior on Bridges Seismic Response. In 15th World Conference on Earthquake Engineering, Lisbon, Portugal.

[3] Cheng, J., & Xiao, R. C. (2005). Serviceability reliability analysis of cable-stayed bridges. Structural Engineering and Mechanics, 20(6), 609-630.

[4] Cheng, J., & Liu, X. L. (2012). Reliability analysis of steel cable-stayed bridges including soil-pile interaction. Steel and Composite Structures, 13(2), 109-122.

[5] Truong, V. H., & Kim, S. E. (2017). An efficient method of system reliability analysis of steel cable- stayed bridges. Advances in Engineering Software, 114, 295-311.

[6] Nazmy, A. S., & Abdel-Ghaffar, A. M. (1990). Three-dimensional nonlinear static analysis of cable-stayed bridges. Computers & structures, 34(2), 257-271.

[7] Mahmoodian, M., Li, C. Q. 2012. Sensitivity analysis in structural reliability of buried pipelines. 6th International ASRANet Conference, Integrating Structural Analysis, Risk & Reliability, London, UK.

Please cite this article using:

M. A. Rashid, H. Rahman Shokergozar, M. Mohebbi, Seismic Reliability Cable-Stayed Bridge with Latin Hypercube Sampling Methods, Amirkabir J. Civil Eng., 53(3) (2021): 251-254.

DOI: 10.22060/ceej.2020.16781.6342