Calculation of bridge seismic dynamic reliability based on seismic vulnerability

Wenyu Xu[1], Yanqun Zhou[2*]

[1]Nanjing University of Science and Technology Zijin College, Nanjing, 210023, China

[2]Hunan City University, Yiyang 413000, China

Keywords: Seismic vulnerability; Bridge; Seismic; Reliability

Abstract: In order to evaluate and calculate the seismic dynamic reliability of bridge structures, a calculation method of seismic dynamic reliability of Bridges Based on three-dimensional seismic vulnerability is proposed in this paper. Based on the theory of bridge seismic vulnerability, the damage condition of pier column and bearing components is described by the three-dimensional failure surface of components, and the damage judgment standard containing multiple single damage indexes is used as the evaluation index of three-dimensional seismic vulnerability; Secondly, based on the analysis of the bending failure of existing piers, the damage state judgment equation of pier bending and shear failure is established; Based on the relevant literature, the adaptive damage comparison table is made, and various damage degrees are quantified. On this basis, combined with the seismic design criteria and seismic related theories of bridges at home and abroad, the seismic dynamic reliability is calculated and analyzed. The simple test of seismic vulnerability shows that this method can be applied to the seismic performance analysis of bridge structures.

1. Introduction

China is one of the largest earthquake stricken areas in the world. The earthquake has a great harm and has a great impact on the national economy [1]. In China's rail transit system, as a bridge with great role, it plays an important role in seismic research [2]. In view of the profound impact of earthquake disaster experience, many experts began to pay attention to the seismic problem of bridges and conducted a lot of discussion. On China's urban roads, the damage of bridges will not only affect people's daily activities, but also affect the disaster relief work after the earthquake. Therefore, to calculate the seismic reliability of the structure of the bridge in the transportation system and find its weakness is the key to ensure the safety, quickness and efficiency of the bridge [3]. Because there are a large number of focal faults in Western China, the seismic requirements of railway and expressway bridges in this area are significantly different from those in other areas [4]. In addition, because there are many mountains, valleys and gullies in the west, the bridge in this area is a typical non-standard bridge type, and its response shows significant characteristics in the near field [5]. With the continuous development of China's economy and society, the seismic evaluation and calculation of Sichuan Tibet line, Sichuan Qingdao line, Chengdu Lanzhou line, Lixiang line, Yaxi Expressway and Tibet expressway has become an important topic in the field of bridge engineering.

In order to meet the needs of performance-based seismic design of bridge structures, improve the efficiency of seismic dynamic reliability analysis and calculation of bridges, and meet the requirements of seismic capacity reliability calculation of bridges, this paper proposes to describe the failure status of pier columns and bearing components by three-dimensional failure surface of components, and studies it based on the damage state equation containing multiple single failure indexes. Based on the analysis of the bending and shear failure of existing piers, the bending and shear failure model of piers is established. According to the seismic capacity of the supporting structure, the failure form of the supporting structure is put forward; On this basis, the three-dimensional seismic failure criteria of pier column and bearing components are established, and various damage conditions are quantitatively calculated. According to the seismic design

  DOI: 10.25236/icceme.2022.011

criteria of bridges at home and abroad and the reliability principle of engineering, this paper calculates and analyzes the three-dimensional seismic vulnerability, which provides a new idea for the seismic dynamic reliability analysis and calculation of complex structures [6].

2. Theory and method of seismic vulnerability analysis

2.1. Basic ideas of analysis

In the urban rail transit system, bridge is an essential link. In recent years, many earthquakes have occurred in many places in China, resulting in serious traffic accidents. It is of great significance to evaluate the seismic disaster risk of the current road traffic system. The seismic capacity analysis of the bridge can provide a basis for the maintenance, reinforcement, disaster relief activities, direct economic loss estimation and seismic performance evaluation of the road system after the earthquake [7]. It is widely used in evaluating the damage degree of highway bridges (slight damage, medium damage, serious damage and collapse). In the structural reliability theory, the function function is used to express the anti-interference ability of structural components under different actions, that is, it is necessary to determine the relationship between their needs and functions. Depending on the value of the function, the reliability depends on its value below 0. In earthquake, the "failure" of bridge structure can be defined as the occurrence of specific slight, medium, serious and collapsed earthquake damage [8]. In other words, from the point of view of engineering structure reliability, it is possible that the structural state equation of the bridge is lower than 0 to a certain extent under the action of specific seismic load. The seismic performance and seismic requirements of the bridge structure are expressed by C、D respectively, and z is the state variable; Then, when the probability density function of $z<0$ is $f(z)=z$, the damage probability in structural earthquake is: $z=C-D$.

$$P_f = P(z<0) = \int_{-\infty}^{0} f_z(z)dz \tag{1}$$

The results show that there is a certain correlation between the reliability and failure probability of the structure. In other words, when the variance of the mean value and standard deviation of the structural damage equation under N earthquakes is determined, the seismic failure probability of the structure can be obtained. It can be seen from this point that on the premise of three-dimensional seismic performance evaluation, the state equation that can accurately reflect the damage status of structural members is established, and it is combined with the damage index threshold associated with various damage status, so as to judge the damage degree.

2.2. Bridge damage index and discrimination

The main seismic damage of bridge structure is the damage of pier and bearing. Therefore, based on the damage state equation of pile foundation and pile foundation, the three-dimensional seismic vulnerability analysis is carried out. Based on the research on the mechanism of seismic bending shear failure, the seismic vulnerability of bridge structure is analyzed. According to the code for seismic design of highway bridges JTG / T 2231-01-2020 and the relevant regulations of Caltrans, this paper introduces the failure yield surface of pier under eccentric load proposed by Bresler, and establishes the bending failure index and its criterion of pile body under three-dimensional earthquake; In this paper, the shear axial stress failure yield surface proposed by Vecchio et al. Is introduced. Combined with the support sliding criterion proposed by jangid, the failure index and criterion of pier structure under three-dimensional earthquake are established [9]. For the bending damage index of the pier, the damage limit is determined under the given load. If it exceeds the limit, it is determined that the structure is bent. Then, according to the research results of Priestley et al., the uniaxial shear failure criterion of pier column is shown in Table 1.

Table 1 Uniaxial shear failure criteria for pier columns

Damage state	Describe	Index
Undamaged	Micro crack	0<V<Qs
Slight	Crack increase	Qs<V<Qm
Medium	Complete oblique crack	Qm<V<Qse
Serious	Wide complete oblique crack	Qse<V<Qc
Complete	The stirrup breaks and the protective layer falls off	V<Q

Different indexes represent different degrees, and QS ~ Q represents the slight to complete damage of the bridge. For the deformation damage of the bearing, the damage degree is directly related to the relative deformation between the upper and lower base plates. Therefore, in the three-dimensional seismic vulnerability analysis of the bearing, the damage index still adopts the relative displacement of the bearing, but it should be able to characterize the relationship between the relative displacement between the upper and lower base plates in any direction and the seismic damage degree of the bearing. The damage state equation is composed of multiple damage indexes. According to the different distribution characteristics of each damage index and based on the relevant theory of engineering structure reliability, the damage probability of bridge construction under three-dimensional earthquake can be calculated.

3. Calculation of bridge seismic dynamic reliability

3.1. Introduction and significance of seismic dynamic reliability calculation

Most of the external disturbances suffered by the bridge change with the passage of time and are very random. With the understanding of random disturbances, we gradually realize that random disturbances can be represented by a random method, and these random disturbances can be classified. For example, in civil engineering, the random impulse wind pressure model acting on the surface of buildings through impulse wind speed, the random process model of earthquake acting on the foundation of buildings, the random process model of uneven road surface acting on automobile chassis, the random process model of wave force acting on the surface of buildings, and the random process model of wave force acting on the surface of buildings. This theory of dynamic random disturbance promotes the emergence, application and development of structural theory to a certain extent. The mathematical model of random disturbance of structures and the response and reliability of linear and nonlinear systems. It can be said that the ultimate goal of random vibration analysis of structures is to quantitatively evaluate them, that is, to quantitatively evaluate them from the perspective of probability. Structural dynamic reliability theory is an important part of structural system and a new interdisciplinary subject [10]. In addition to its own static load, whether it is rare earthquake action or a large number of vehicle loads that often occur, it belongs to a random dynamic disturbance, so the research on its dynamic reliability has important practical value. Especially when the random load is large, the dynamic reliability analysis of the structure must be carried out. The structural design (including earthquake) is based on the theory of possibility reliability, from the existing approximation to the complete possibility level. Therefore, the calculation method of structural dynamic reliability has great practical value in improving, perfecting and developing and improving the seismic performance of bridge structures.

3.2. Calculation method of seismic dynamic reliability

With the increasing maturity of structural reliability theory, probabilistic limit state design method based on reliability has become the general development trend of all kinds of engineering structure design. As the future development direction of structural seismic design, it should be performance-based structural seismic design based on structural reliability theory. Fema-273 points out that "the theoretical framework of performance-based structural seismic design should be reliability theory". Seismic reliability is a quantitative index to measure the seismic reliability of structures. Seismic motion, seismic demand and seismic capacity are the three cornerstones of seismic engineering. Therefore, the factors affecting the seismic reliability of the structure can be summarized into two comprehensive variables: seismic demand D and seismic capacity C. The failure probability can be calculated by using the relationship between seismic demand D and seismic ground motion parameter Sa:

$$P_f = \sum P[C \le D \mid PGA = x] P(PGA = x) = \int F_R(x) \mid dH(x) \mid \tag{2}$$

Where: $F_R(x)$ is the seismic vulnerability function; $H(x)$ is the risk function. In order to facilitate the reliability calculation, firstly, the seismic random excitation process needs to be discretized into a series of random variables according to the time axis, and the linear filter impulse response method is adopted. The linear filter impulse response method is not only efficient, but also has practical physical significance, and can be better applied to the discretization of seismic random process. Considering the non stationarity of seismic excitation, the non stationarity of seismic excitation is simulated by modulation function, and the sum is accumulated according to the number of linear filters. Figure 1 shows the iterative process of reliability calculation.

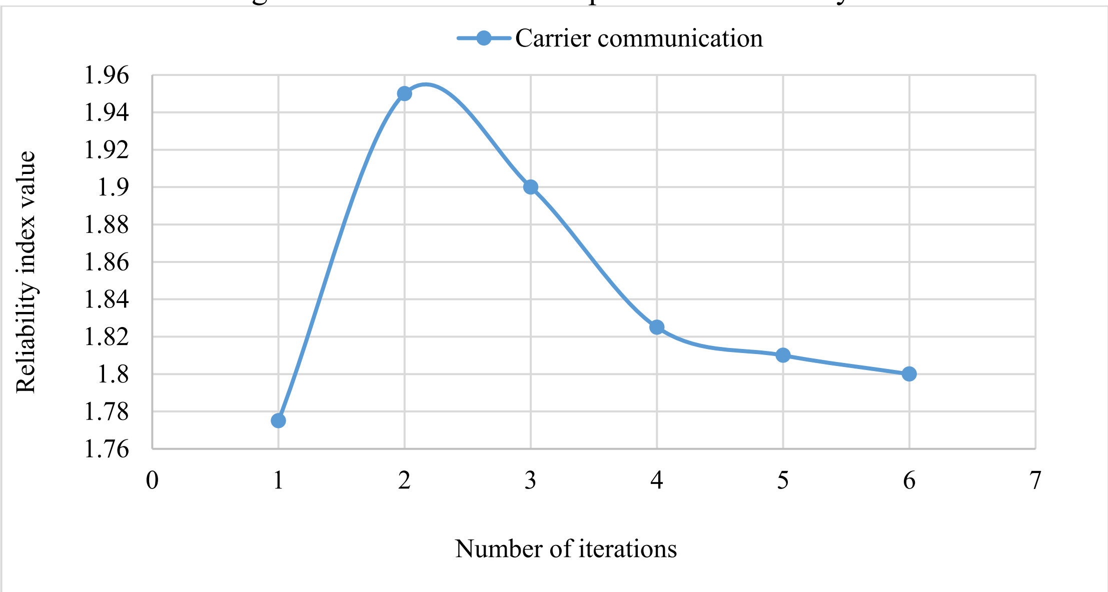

Figure 1 Iterative process of reliability calculation

Taking a long-span suspension bridge as the engineering background, the longitudinal layout of the bridge is 70m + 132M + 328m + 132M + 70m, the rise span ratio of mid span and side span is 1 / 5.1 / 12.4 respectively, the transverse width is 35m, the stiffening beam is flat closed steel box girder, single box 3 rooms, and the whole bridge adopts the form of parallel double main cables. The seismic dynamic reliability of the key parts of the bridge tower column is analyzed by using the method mentioned above. The seismic excitation is simulated according to the fortification degree VII, and the horizontal and vertical excitation are considered at the same time. It is assumed that the vertical excitation is half of the horizontal direction, and the random excitation is discretized by the linear filter impulse response method described above. The filter parameters and modulation function parameters are the same. The dynamic failure mode of the tower column only considers the failure type of the first crossing of the bearing capacity, That is, when the internal force of the tower column crosses the ultimate bearing capacity for the first time, it is regarded as damaged. A total of 39 iterations are carried out during convergence, and a total of 219 bridge time-domain dynamic analysis are required. The final reliability index is high. The calculation results in this paper are compared with other methods. Compared with other methods listed, the accuracy of the method proposed in this paper is high. In conclusion, the method in this paper can be effectively used to calculate and analyze the seismic dynamic reliability of long-span complex bridges under random seismic excitation.

4. Conclusions

Bridge is a structure used to cross natural or artificial obstacles, and it is also under the action of strong ground movement.

Components that are relatively easy to break. A large number of bridges in China are located in earthquake areas, and the earthquake will cause great damage to bridges.

Damage, resulting in traffic interruption or endangering traffic safety. The research on the calculation of bridge seismic reliability based on seismic vulnerability can provide the necessary basis for the reliability analysis of transportation system, loss evaluation, priority evaluation of bridge reinforcement and earthquake emergency decision-making. There is an urgent need to improve the research on bridge seismic vulnerability and reliability in China. Based on the seismic vulnerability theory and taking the basic definition of seismic vulnerability as the starting point, this paper establishes the three-dimensional seismic vulnerability analysis method of bridge components. The research conclusions are as follows: (1) the basic concept and analysis method of seismic vulnerability are studied, and the bridge damage identification comparison is described. (2) for the three-dimensional seismic failure probability of bridge components, the damage state of the structure is characterized by the damage state equation of components, The damage state equations of pier column and bearing are constructed, and the failure criteria under different damage states are given (3) Combined with an example, it is proved that the method in this paper can provide effective reliability calculation.

Acknowledgements

The Scientific Research Project of Hunan Provincial Department of Education 21C0680 Nonlinear finite element analysis of mechanical properties of partially filled circular concrete filled steel tubular piers with ribs

References

[1] Li Lifeng, Li Huihui, Xu Kaiduo, et al. Seismic vulnerability analysis of bridges considering the correlation of random variables [J]. Journal of Hunan University (Natural Science Edition), 2017, 07(v.44;No.283):123 -132.

[2] Wu Wenpeng, Li Lifeng, Hu Sicong, et al. Research review and prospect of seismic vulnerability analysis of highway bridges [J]. Earthquake Engineering and Engineering Vibration, 2017, 37(4):12.

[3] Zhang Zhi, Li Xiaojun, Lan Riqing, Song Chenning. Seismic vulnerability analysis of piers of skewed continuous rigid frame bridges [J]. Chinese Journal of Earthquake Engineering, 2020, v.42(06):49-59.

[4] Wu Wenpeng, Li Lifeng. Research on seismic vulnerability analysis method of bridge structure system [J]. Vibration and Shock, 2018, 037(021):273-280.

[5] Wan Huaping, Wei Zhicheng, Su Lei, et al. Optimal design of bridge isolation bearings based on system seismic vulnerability [J]. Earthquake Engineering and Engineering Vibration, 2021, 41(5):10.

[6] Liu Chunguang, Ren Wenjing. Seismic Vulnerability Analysis of Offshore Isolated Bridges Based on Monte Carlo Sampling [J]. Journal of Natural Hazards, 2017, 26(1):10.

[7] Li Huihui, Li Lifeng. Time-varying seismic vulnerability of bridges considering variable correlation [J]. Vibration and Shock, 2019, 38(9):11.

[8] Shan Deshan, Zhou Xiaohang, Yang Jingchao, et al. Bridge seismic damage identification

combined with seismic vulnerability analysis [J]. Vibration and Shock, 2017, 36(16):7.

[9] Wu Wenpeng[1,2,3], Liang Peng[1]. Analysis of Influence Law of Uncertainty Parameters in Bridge Seismic Vulnerability Function [J]. Journal of Xiangtan University: Natural Science Edition, 2018, 40(5):8.

[10] Li Huihui, Li Lifeng. Time-varying seismic vulnerability of bridges considering variable correlation [J]. Vibration and Shock, 2019, 038(009):173-183.