Influence of Performance Degradation of Seismic Isolation Bearings on Seismic Response of Existing Bridges

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Abstract. In order to study the effect of degradation of isolation bearing performance on the seismic response of in-service bridges, a continuous girder bridge is combined to analyse the effect of degradation of isolation bearing performance on the horizontal displacement of the bearing, the vertical reaction force, the bridge self-oscillation period and the response of internal force. The results show that: with the increase of bearing degradation, continuous beam bridge stiffness decreases, the self-oscillation period increases; bearing in the longitudinal and transverse seismic horizontal displacement and vertical reaction force increases as a whole; longitudinal seismic, the transition pier and the second pier pier bottom bending moment and the transition pier pier pier bottom and top shear increases as a whole, the main pier pier pier bottom bending moment, the transition pier, the secondary pier and the main pier pier pier top bending moment and the secondary pier and the main pier pier pier top and the pier bottom and pier shear decreases as a whole; transverse seismic, the transition pier pier bottom bending moment, the transition pier bottom and the main pier top shear decreases as a whole. Under the seismic, the transition pier bottom and pier top bending moment and shear overall increase, the secondary main pier and the main pier bottom and pier top bending moment, the secondary main pier bottom and pier top and the main pier bottom shear overall decrease, the main pier top shear first increase and then decrease.

Keywords: existing bridge; seismic isolation bearings; performance degradation; seismic response.

1 Introduction

Bridge structure plays an important role in the development of regional economy and seismic relief, but at the same time, it is very easy to structural damage under the action

F. Ding et al. (eds.), *Proceedings of the 2024 International Conference on Civil Engineering Structures and Concrete Materials (CESCM 2024)*, Advances in Engineering Research 247,
https://doi.org/10.2991/978-94-6463-564-5_7

of the seismic, and may even collapse, if the bridge structure under the action of the seismic damage caused by the failure of normal use, will have a serious impact on the regional economy, the safety of the people, and the ability to carry out seismic relief work in a timely manner. At present, the bridge structure is usually used to arrange the isolation bearing to reduce the seismic response of the bridge structure under the action of the seismic, thus ensuring the safe use of the bridge. Vibration isolation bearings mainly include lead-core rubber bearings, laminated rubber bearings, hyperbolic spherical steel bearings, friction pendulum bearings, and tension cable vibration isolation bearings[1][2][3]. During the daily operation of the bridge, the performance degradation of the isolation bearings due to traffic and environmental effects will occur, which will change the seismic response of the bridge structure, thus affecting the operational safety of the bridge structure. Therefore, the effect of performance degradation of isolation bearings on the seismic response of bridge structures should be considered.

Qiu Can-xing[4] investigated the effect of gap length of gap type shape memory alloy bearing and its yield force on seismic isolation effect. Yu Xiao-qing[5] analysed the effect of different sliding friction coefficients of plate rubber bearings on the seismic response of simply supported girder bridges and continuous girder bridges. Li Jun[6] analysed the effects of ordinary plate rubber bearings and friction pendulum bearings on the seismic performance of bridge piers and pile foundations. Wang Wei-dong[7] studied the seismic performance of full-life basin-type spherical steel bearings under seismic action for different bridge structural forms and different site types. Xu Hao-tian[8] analysed the difference between friction pendulum bearings and ordinary bearings, and studied the seismic characteristics of friction pendulum bearings for rigid-continuous beam bridges. Zheng Guo-hua[9] analysed the dynamic characteristics and seismic response of bridges using high damping rubber bearings, and investigated their seismic isolation performance on bridge structures. Ma Zhen-xiao[10] studied the seismic response of bearing internal force and displacement under different working conditions with rubber bearing arrangement and friction pendulum bearing arrangement. Zhang Jing-yue[11] comparatively analysed the influence of the wear degree of friction pendulum bearing on the seismic performance of long-link large-span continuous girder bridges. Luo Le-gen[12] comparatively analysed the effect of the degree of wear of basin bearing slip plates on the seismic response of multi-tower cable-stayed bridges. Yang Ran[13] studied the effect of stiffness degradation of seismic isolation rubber bearings on the seismic response of frame structures. Yang Wei-guo[14] studied the effect of vertical stiffness degradation of laminated rubber bearings on the seismic response of frame structures. Kim, Dookie[15] studied the capacity degradation of base-isolated nuclear power plants considering the aging of rubber materials used in LRB isolation devices. Gheryani, MH[16] studied the influence of the mechanical properties of high damping rubber bearings on the dynamic response of multi-story isolated buildings under bidirectional near-fault earthquakes. Delaviz, A[17] studied the influence of mechanical property degradation (pinching, stiffness degradation and strength degradation) in the load-deformation relationship of the superstructure of the friction pendulum system on the seismic vulnerability and reliability results. At present, the research on seismic isolation bearings in bridges mainly focuses on the influence of bearing type and its arrangement on the seismic response or seismic performance of the bridge structure, and the research on the degradation of its performance on the seismic response of the structure is mainly concentrated in the field of frame structures, while the research on the degradation of its performance on the seismic response of in-service bridges is relatively small.

In this paper, a four-span continuous girder bridge is taken as the research object, and the finite element models with different degradation degrees of the vibration isolation bearings are established and the time course analysis of seismic response is carried out respectively. By comparing the bearing response and pier response of each model under seismic action, the effect of the degradation of the vibration isolation bearing performance on the seismic response of the bridge in service is obtained, which provides a reference for the detection, monitoring and seismic performance evaluation of the same type of bridges.

2 Engineering Profile and Spatial Dynamic Analysis Model

2.1 Project Overview

This paper takes a continuous girder bridge as a dependent project. One of them is selected as the object of analysis, the span combination of 4 × 45 m. The superstructure adopts C55 concrete and Q345qDNH steel, structural form of steel-mixed combination of beams; abutment piers using C30 concrete, structural form of double-column piers; the foundation adopts C30 concrete, structural form of pile foundation. Bearing are used horizontal force dispersion type rubber bearing.

2.2 Spatial Dynamics Analysis Models

Modelling Spatial Dynamics Analysis. Using finite element program, a finite element model has been developed for seismic response analysis, and the computational model is based on the X-axis in the downward direction of the bridge, the Y-axis in the transverse direction of the bridge, and the Z-axis in the vertical direction.

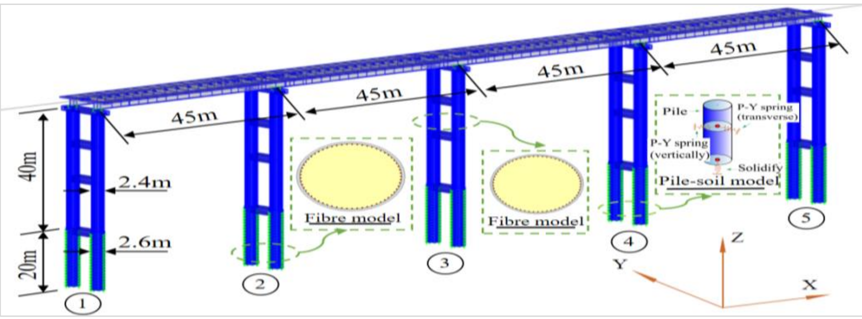


Fig. 1. The finite element model of whole bridge.

The main girder, transition pier and main pier pier in the model are simulated by beam unit; the foundation uses M-method to simulate the pile-soil effect, and the stiffness coefficient of the soil spring under the seismic action is taken as two times of the static action. In order to get more accurate analysis results, all the loads are converted into mass for calculation. Horizontal force dispersing rubber bearings are used in this bridge, all of which are simulated by means of a connection property unit (plastic-Wen connection unit)[18].The finite element model of the whole bridge is shown in Fig. 1. The initial values of the bearing parameters and their degradation parameters are shown in Table 1, and only the relevant parameters of the main pier bearing are listed here.

Table 1. Initial value of main pier bearing parameters and degradation parameters.

Parameter name	Vertical stiff-ness(kN/m)	Horizontal equivalent stiff-ness(kN/m)	Initial horizontal stiffnes(kN/m)	Yield strength(kN)
Initial(degradation 0%)	1229000	3920	39200	952
Condition 1(degradation10%)	1106100	3528	35280	856.8
Condition 2(degradation20%)	983200	3136	31360	761.6
Condition 3(degradation30%)	860300	2744	27440	666.4
Condition 4(degradation40%)	737400	2352	23520	571.2
Condition 5(degradation50%)	614500	1960	19600	476

Structural Dynamic Characteristics. In order to better analyse the effect of the degradation of the performance of the vibration isolation bearing on the seismic response of the in-service bridge, the dynamic characteristic analysis of the continuous girder bridge in this paper has been carried out, and the main dynamic characteristics of the finite element model of the bridge have been obtained, and the comparison of its first 10 orders of self-oscillation period is shown in Table 2.

Table 2. The natural vibration period of in-service bridges under different degradation degrees of bearings.

Order	Cyclicality(s)										
	0	10	10/0	20	20/0	30	30/0	40	40/0	50	50/0
1	5.02	5.08	1.25%	5.16	2.77%	5.26	4.64%	5.40	6.99%	5.58	10.05%
2	3.07	3.20	4.16%	3.36	8.71%	3.56	13.71%	3.80	19.26%	4.12	25.50%
3	2.60	2.71	4.06%	2.85	8.51%	3.01	13.42%	3.21	18.90%	3.48	25.09%
4	1.35	1.39	3.10%	1.44	6.33%	1.50	9.72%	1.56	13.27%	1.63	17.01%

5	1.31	1.35	3.13%	1.40	6.40%	1.45	9.81%	1.51	13.39%	1.58	17.16%
6	1.19	1.23	3.34%	1.28	6.84%	1.33	10.54%	1.39	14.45%	1.47	18.61%
7	1.19	1.23	3.34%	1.28	6.84%	1.33	10.54%	1.39	14.45%	1.47	18.61%
8	1.14	1.17	2.90%	1.22	6.77%	1.28	10.85%	1.34	15.17%	1.42	19.74%
9	1.13	1.15	1.44%	1.15	2.16%	1.16	2.94%	1.17	3.78%	1.18	4.68%
10	0.73	0.74	0.75%	0.74	1.51%	0.75	2.27%	0.75	3.04%	0.76	3.82%

As can be seen from Table 2, the degradation of the performance of the vibration isolation bearing has a significant effect on the self-oscillating period of the in-service bridge and increases with the increase in the degree of degradation. For example, for the second order vibration pattern, the period increased by 13.71% at 30% bearing performance degradation and 25.50% at 50% bearing performance degradation.

3 Ground Vibration Input

According to the safety assessment report of the dependent project and China seismic Parameter Zoning Map (GB18306-2015), the basic seismic intensity at the bridge location is VI degree, the peak acceleration of ground vibration is 0.05g, the defence category is B, and the site type is II site. In this paper, one E2 ground shaking (50-year exceeding probability of 2.5%) is selected as the horizontal (longitudinal and transverse) ground shaking of the bridge, and the seismic response is analysed by the two ground shaking inputs of longitudinal+vertical and transverse+vertical for the finite element calculations, and the vertical ground shaking is taken as 2/3 times of the horizontal ground shaking. The ground shaking acceleration time curve generated from the seismic code response spectrum is shown in Fig. 2.

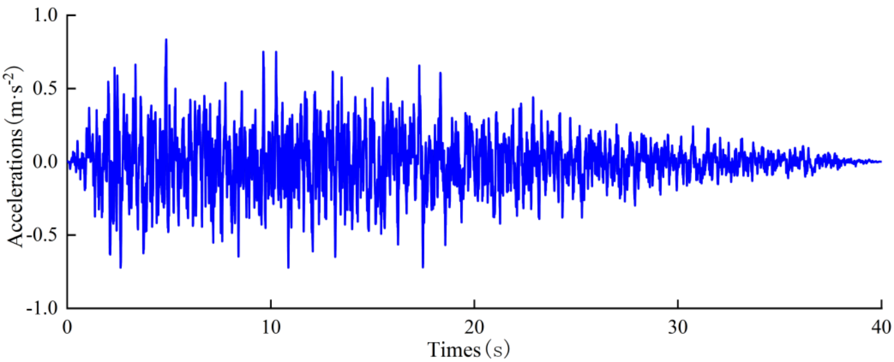


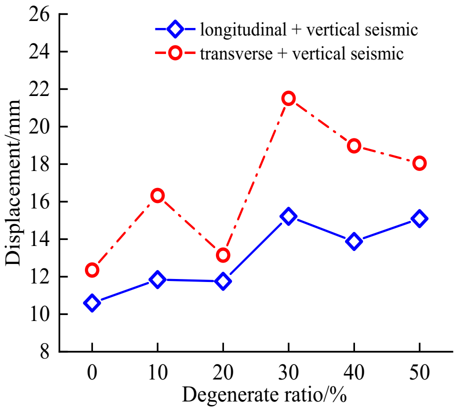
Fig. 2. Acceleration time history curve of E2 seismic action.

4 Seismic Response Analysis

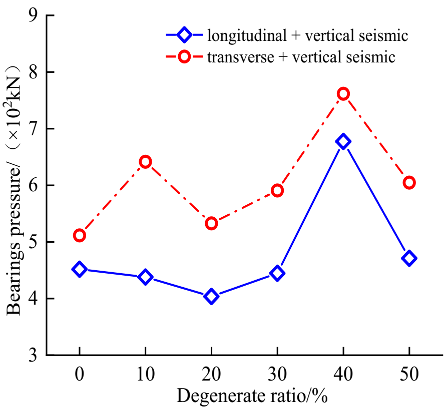
The seismic response of in-service bridge with degraded performance of isolation bearings is obtained by considering the constant load as the initial state of bridge structure calculation in the nonlinear time course analysis. Because of the symmetry of the structural form, type of bearing and arrangement of the background bridge, only the left two spans are analysed in the calculation results of this paper.

4.1 Effect of Bearing Performance Degradation on Bearing Seismic Response

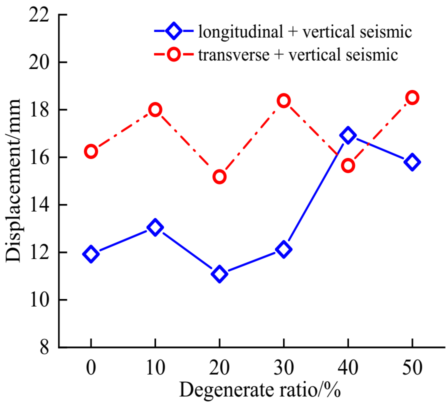
As shown in Fig. 3, the displacement and vertical reaction force response of the in-service bridge under E2 seismic action is calculated and analysed for different values of bearing performance degradation.



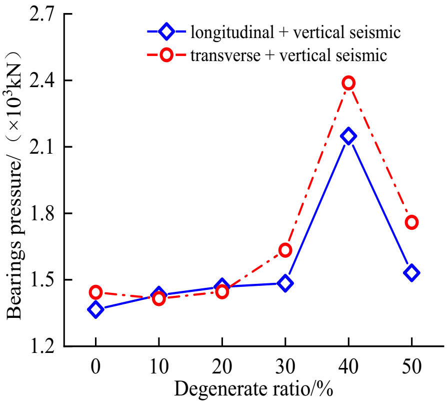
(a) Pier 1 bearings displacement



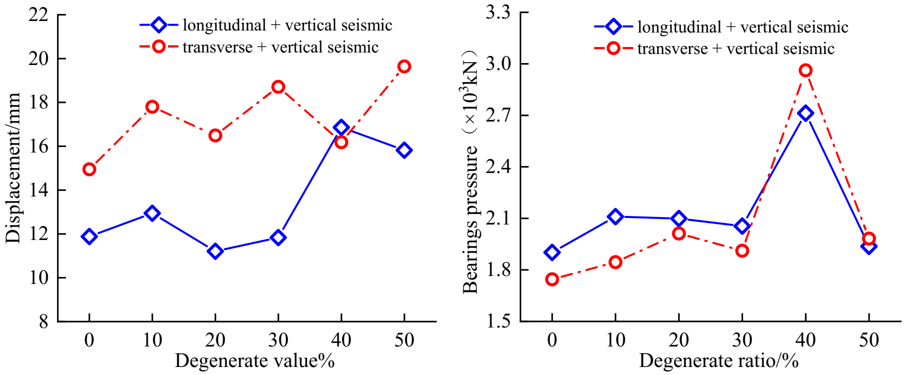
(b) Vertical reaction force of pier 1 bearings



(c) Pier 2 bearings displacement



(d) Vertical reaction force of pier 2 bearings



(e) Pier 3 bearings displacement (f) Vertical reaction force of pier 3 bearings

Fig. 3. The displacement and vertical reaction force response of each bearing under E2 seismic action

As can be seen from the figure, with the increase of bearing performance degradation, under the E2 longitudinal + vertical seismic, the longitudinal displacement of pier 1 bearing overall tendency to increase, in the degradation of 30% to reach the amplitude. Pier 2 and pier 3 bearing longitudinal displacement first slightly increased and then decreased and then increased again, in the degradation of 40% to reach the amplitude. Pier 1 bearing vertical reaction force first decreased and then increased, in the degradation of 40% to reach the amplitude. Pier 2 and pier 3 bearing vertical reaction force overall tendency to increase, in the degradation of 40% to reach the amplitude. Pier 2 and pier 3 supporting force overall trend of increasing. The vertical reaction force of pier 2 and pier 3 is increasing as a whole, and reaches the magnitude at 40% degradation.

Under the E2 transverse + vertical seismic, the overall transverse displacement of pier 1 bearing showed an upward trend, and reached the amplitude at 30% degradation. Pier 2 bearing transverse displacement in addition to the degradation of 20% and 40% of the time to reduce, the rest of the increase in degradation of 50% to reach the magnitude of the pier 3 bearing transverse displacement overall trend, and reached the magnitude of degradation of 50%. Pier 1 and pier 3 bearing vertical reaction overall trend of increasing, and reached the magnitude at 40% degradation. Pier 2 bearing vertical reaction force except for degradation of 10% slightly reduced, the overall trend of increasing, and reached the magnitude at 40% degradation. The vertical reaction force of pier 2 support has an overall increasing trend except for a slight decrease in degradation of 10%, and it reaches the magnitude in degradation of 40%.

4.2 Influence of Bearing Performance Degradation on Seismic Response of Pier

In order to analyze the influence of bearing performance degradation on the seismic response of existing bridge piers, the bottom and top of each pier are selected as control sections, and the bending moment and shear response of each control section under E2 earthquake are given in Fig. 4 and Fig. 5.

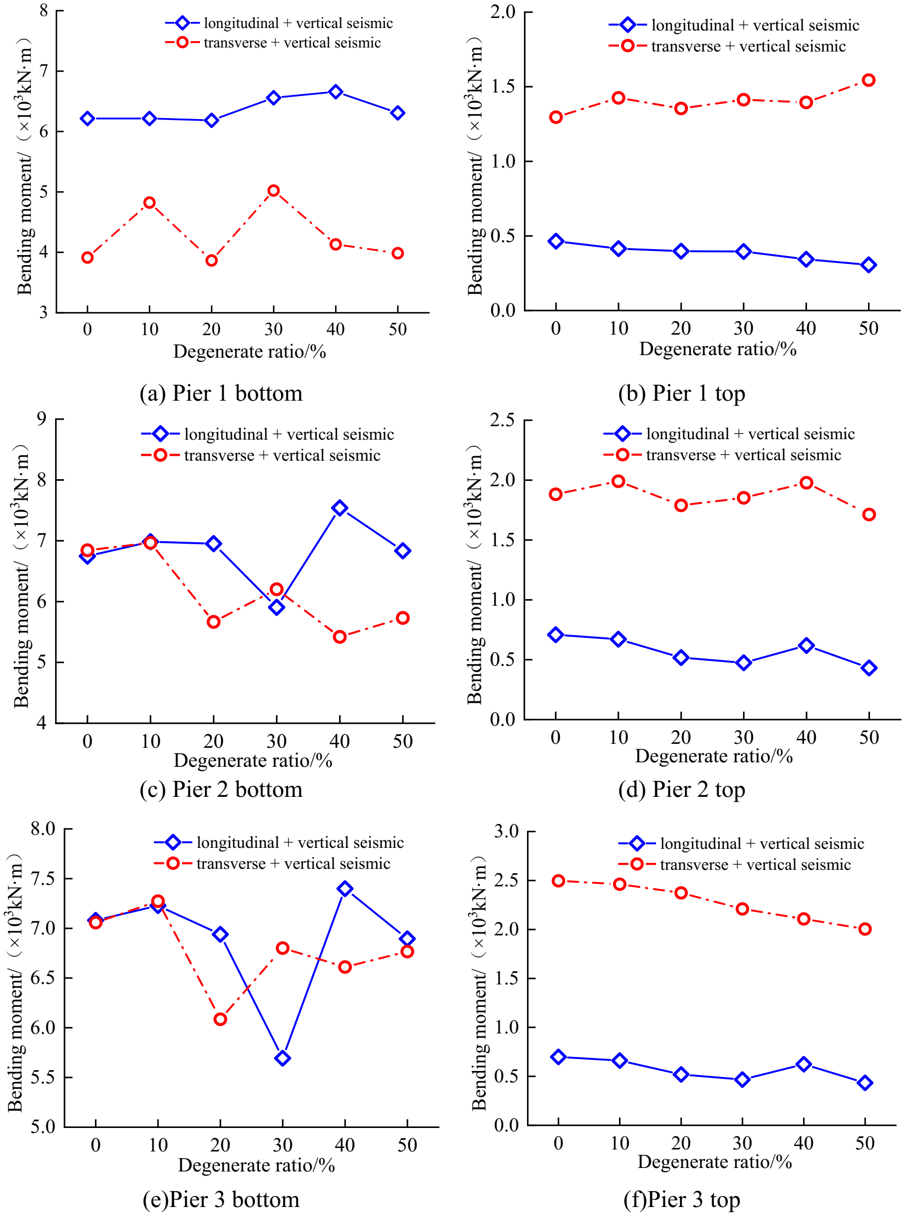
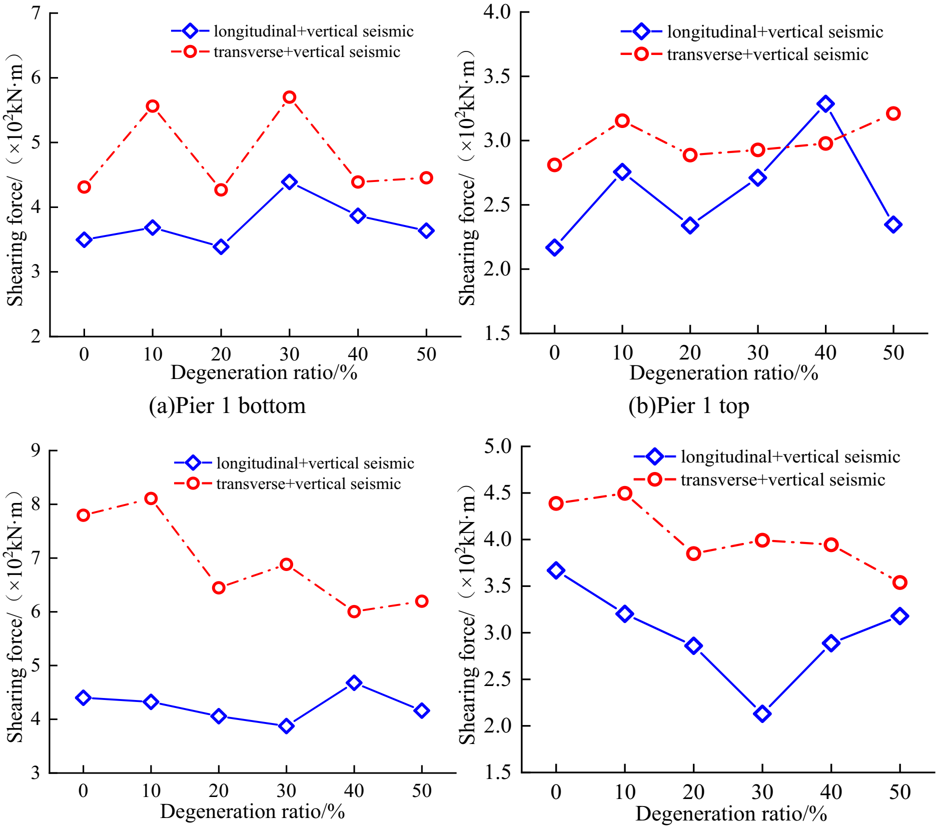


Fig. 4. Bending moment response of each key section under E2 seismic action

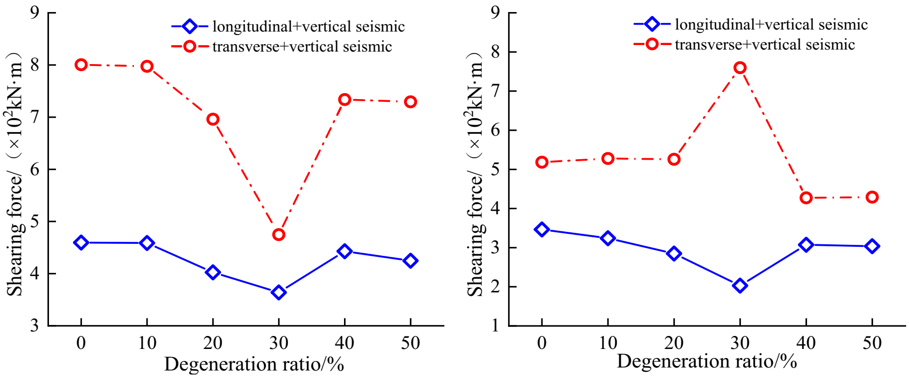
As can be seen from Fig. 4, with the increase of bearing performance degradation, under the E2 longitudinal+vertical seismic the bending moment at the bottom of pier 1 slightly decreased except when it was degraded by 10% and 20%, and the overall trend was upward, reaching the amplitude when it was degraded by 40%. The bending moment at the bottom of pier 2 decreases when it is degraded by 30%, but the whole moment shows an upward trend, and reaches the amplitude when it is degraded by 40%. The bending moment at the bottom of pier 3 increases when it is degraded by 10% and 40%, but it shows a downward trend as a whole and reaches the amplitude when it is degraded by 40%. The bending moment of pier top of pier 1, pier 2 and pier 3 shows a downward trend.

Under the E2 transverse+vertical seismic the bending moment at the bottom of pier 1 decreases slightly when it degenerates by 20%, but increases as a whole, and reaches the amplitude when it degenerates by 30%. The bending moment at the bottom of pier 2 and pier 3 decreases after 30% degradation reaches the amplitude. The bending moment at the top of pier 1 increases with the degradation of bearing as a whole, and reaches the amplitude when the degradation is 50%. The bending moment at the top of pier 2 is slightly increased when the bearing is degraded by 10% and 20%, but it decreases as a whole. The bending moment at the top of 3 pier decreases with the bearing degradation.



(a)Pier 1 bottom (b)Pier 1 top

(c)Pier 2 bottom (d)Pier 2 top



(e)Pier 3 bottom (f)Pier 3 top

Fig. 5. Shear response of each key section under E2 seismic action

As can be seen from Fig. 5, with the increase of the degree of degradation of the bearing performance, under the E2 longitudinal + vertical seismic the bottom shear of pier 1 shows an overall increasing trend except for a slight decrease in degradation of 20%, reaching the magnitude in degradation of 30%. Pier 2 bottom shear increases in degradation of 40%, the overall trend of decreasing. Pier 3 bottom shear decreases as a whole. Pier 1 top shear shows an overall trend of increasing in degradation of 40%, reaching the magnitude. The top shear of pier 2 and pier 3 showed an overall decreasing trend.

Under the E2 horizontal+vertical seismic, the shear force at the bottom of pier 1 decreased slightly when it degenerated by 20%, and the overall trend was increasing. The shear force at the bottom of pier 2 increased slightly when it degenerated by 10%, and the overall trend was downward. The shear force at the bottom of pier 3 decreases with the degradation of bearing. Pier 1 top shear force increases as a whole. The shear force at the top of pier 2 shows a downward trend except for the degradation of 10%. The shear force at the top of pier 3 first increases and then decreases, and reaches the amplitude when it degenerates by 30%.

5 Conclusion

In this paper, a four-span continuous girder bridge is taken as a research object to compare and analyse the effect of bearing performance degradation on the seismic response of in-service bridges under seismic action for continuous girder bridges with vibration isolation bearings. Based on the results of the analyses, the following conclusions were obtained:

(1) The degradation of the seismic isolation bearing performance of a continuous girder bridge has a large effect on its self-oscillation period, and as the degree of bearing degradation increases it leads to a reduction in the stiffness of the bridge structure and a larger period.

(2) With the increase of the degradation degree of the isolation bearing, the horizontal displacement and vertical reaction force of the bearing at the transition pier, the secondary main pier and the main pier show an overall increasing trend under the longitudinal and transverse bridge direction seismic action.

(3) With the increase of the degradation degree of the isolation bearing, under the longitudinal seismic action, the bottom moment of the transition pier and the secondary pier increases as a whole, the bottom moment of the main pier decreases as a whole, and the top moment of the transition pier, the secondary pier and the main pier decreases as a whole. In the transverse seismic action, the transition pier pier bottom and pier top bending moment overall increase, the secondary main pier and the main pier pier pier bottom and pier top bending moment overall decrease.

(4) With the increase of the degradation degree of the isolation bearing, in the longitudinal direction of the seismic action, the transition pier pier pier bottom and pier top shear overall increase, the secondary pier and the main pier pier pier bottom and pier top shear overall decrease. In the transverse seismic action, the transition pier pier bottom and pier top shear overall increase, the secondary pier pier bottom and pier top and the main pier pier bottom shear overall reduction, the main pier pier pier top shear first increased and then reduced.

(5) This paper analyses the effect of degradation of isolation bearing performance on the seismic response of in-service continuous girder bridges in Zone VI, while the effect of degradation of isolation bearing performance on the seismic response of bridge structures under different seismicity levels, types of bearings and their combinations, and types of bridges still needs further study.

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