Review of research on dynamic characteristics and seismic behavior of pc composite box-girder bridge with corrugated steel webs

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Abstract. The PC composite box-girder bridge with corrugated steel webs, as a new type of bridge structure, has obvious advantages in structure and distinct mechanics characteristic. So it has been widely applied in the engineering field. However, we have been lack of Research on the dynamic characteristics and seismic performance of the bridge. Based on a large number of documents, this paper expresses some research about the dynamic characteristics and seismic performance of the PC composite box-girder bridge with corrugated steel webs from four aspects: dynamic characteristics Analysis, dynamic characteristics test, influence factors of dynamic characteristics, and seismic performance analysis, and proposes that we should pay more attention to the theoretical analysis in the dynamic characteristics and monitoring of actual bridges to lay a solid foundation for the development of this new kind of bridge.

Key words: PC composite box-girder bridge with corrugated steel webs; dynamic characteristics; seismic performance.

1. Preface

Long-span bridges usually use the prestressed box-girder structure, which has good flexural and torsional properties, good stability, and strong applicability of various construction methods. However, long-span prestressed concrete box girder bridges usually have prestressed steel bundles placed in the webs. The webs are generally thicker and the weight usually accounts for 1/4~1/3 of the beam's self-weight, and the beam body self-weight will increase significantly with the increase of the span. Therefore, the burden of its lower structure is obviously heavier, which seriously affects the spanning ability and economy of such bridges. Therefore, The PC composite box-girder bridge with corrugated steel webs came into being.

Compared the PC composite box-girder bridge with corrugated steel webs with traditional prestressed concrete box-girder bridge, due to the use of light corrugated steel plate as the web, reducing the structural weight, the main beam weight can be reduced by about 25% to 30%. From the perspective
of structural dynamics, the self-weight of the superstructure of the bridge can be reduced, which can significantly reduce the seismic response of the structure, and can effectively reduce the seismic damage, that is, the seismic performance of the structure is improved.

2. Analysis of dynamic characteristics of PC composite box-girder bridge with corrugated steel webs

Compared with the traditional PC box girder, the composite box-girder bridge with corrugated steel webs has undergone great changes in structural characteristics and mechanical characteristics. Domestic and foreign scholars have studied its dynamic characteristics and obtained some research results.

In 2007, Jiang Xueqiang et al. [1] based on the basic theory of structural dynamics, established a reasonable finite element model, and analyzed the natural frequencies of the PC composite box-girder bridge with corrugated steel webs model bridge and its corresponding self-vibration mode. The results show that compared with the concrete box girder, the torsion first-order frequency of the composite box-girder bridge with corrugated steel webs is lower; and the prestressing degree has little effect on the vibration frequency of the PC composite box-girder bridge with corrugated steel webs.

In 2008, Yin Hang et al. [2] established a finite element model of PC composite box-girder bridge with corrugated steel webs combined simply supported beam bridge, and established a finite element model of concrete simply supported box girder based on the principle of static stiffness equivalent. Comparative analysis of the dynamic characteristics of the two are obtained: the corrugated steel web is used to reduce the overall torsional stiffness of the structure, and has little effect on the vertical and lateral stiffness. The reduction of the torsional stiffness can be compensated by the provision of the diaphragm; compared to the concrete box-girder, the natural vibration frequency and torsion frequency of the box-girder bridge with corrugated steel webs combined simply supported are lower; the torsional rigidity of the box-girder bridge with corrugated steel webs is lower, which makes it much formation of the low-order torsion.

In 2010, Li Pengfei et al. [3] established a finite element model to compare the dynamic characteristics of single-box double-chamber, double-box single-chamber simply supported box-girder bridges with corrugated steel webs and single-box double-chamber concrete simply supported girder bridges, obtained: Compared with the single-box double-chamber concrete box-girder combined simply supported, the torsional rigidity of the single-box double-chamber simply supported box-girder bridges with corrugated steel webs is small; for the corrugated steel web section, the torsion-resistant stiffness of the double-box single-chamber cross-section is not as good as the single-box and double-chamber, its overallity is even worse.

In 2013, Zhang Yongjian et al. [4] used the energy variation principle to derive the vibration frequency calculation formula considering the structural shear deformation and shear lag effect for the characteristics of the box-girder with corrugated steel webs. The analysis results show that: The shear deformation and shear lag effect greatly affect the vibration frequency of the PC composite box-girder bridge with corrugated steel webs. Considering the influence of this influence, the vibration frequency of the PC composite box-girder bridge with corrugated steel webs is reduced. The degree of reduction increases rapidly with the increase of the calculation frequency order, so the influence of the vibration frequency of The PC composite box-girder bridge with corrugated steel webs needs to be taken into account.

3. Experimental study on dynamic characteristics of PC composite box-girder bridge with corrugated steel webs

Japanese scholars found in the model test and dynamic characteristics analysis of The PC composite box-girder bridge with corrugated steel webs – Yinshan Yuxing Bridge: the vibration characteristics of the bridge are between the steel bridge and the concrete bridge; in the dynamic load experiment, the corrugated steel plate amplitude smaller, it can be considered that there is no fatigue problem [5].

Japanese scholars found in the experimental study of different systems composite box-girder bridges with corrugated steel webs: the vibration characteristics of these bridges are between steel bridges and
concrete bridges, and it is not easy to cause full-bridge resonance caused by external prestressed steel bundle [6].

In 2006, Li Mingyuan et al. [7] conducted a field test and theoretical study on the dynamic characteristics of Chinese first composite box-girder bridge with corrugated steel webs. The results show that the top four-order vibration frequency are higher than concrete box girder bridges with a similar span, indicating that the bridge has a high bending stiffness.

In 2008, Ren Hongwei et al. [8] deduced the formula for calculating the torsional vibration frequency of composite box-girder bridge with corrugated steel webs, considering the influence of diaphragms, established a finite element model of box-girder bridges with corrugated steel webs, and made the experimental model of box-girder bridges with corrugated steel webs and concrete box-girder; the analysis and comparison of theory derivation results, the finite element results and the experimental results show that the reasonable setting of the diaphragms can effectively improve the torsional stiffness of box-girder bridges with corrugated steel webs. Further research is needed to properly arrange the diaphragms to meet the torsional performance in the case of not increasing the self-weight a lot.

In 2008, Zhang Yongjian et al. [4] carried out a dynamic analysis of a set of box-girder bridges with corrugated steel webs, and obtained the actual vibration frequency, and compared with the simple girder theory, theoretical derivation formula and finite element calculation results, it is concluded that: shear deformation and the shear lag effect have a great influence on the vibration frequency of the composite box-girder bridges with corrugated steel webs. Considering the influence of this influence, the vibration frequency of the PC composite box-girder bridge with corrugated steel webs is reduced. The degree of reduction increases rapidly with the increase of the calculation frequency order, so the influence of the vibration frequency of The PC composite box-girder bridge with corrugated steel webs needs to be taken into account.

In 2011, Yan Wei et al. [9-10] designed and fabricated composite test box-girder with corrugated steel webs, and used the experimental method to study the dynamic performance of box-girder with corrugated steel webs. Through the finite element simulation, did further research on the influence of diaphragms on the dynamic characteristics of box-girder bridges with corrugated steel webs. The influence of the position and number of diaphragms on its dynamic characteristics and the selection of the optimal number of diaphragms were analyzed.

In 2016, Zhang Chao et al. [11-12] designed and fabricated a 1:10 scale experimental model of a three-span single-chamber double-chamber composite box-girder with corrugated steel webs, and carried out dynamic characteristics experiments. Compared the vibration mode frequency with the results of finite element analysis, the error between the two is small, indicating that the proposed test plan is feasible.

4. Analysis of factors affecting dynamic performance of pc composite box-girder bridge with corrugated steel webs

4.1. Influence of external prestress on dynamic performance of composite box-girder bridge with corrugated steel webs

In 2007, Zhang Junjie et al. [13] analyzed the influence of the setting of external prestressing tendons on the dynamic characteristics of PC composite box-girder with corrugated steel webs based on Ayaho Miyamoto's calculation method. In the analysis process, the prestress loss was considered, but the contribution of the external prestressing tendon itself to the stiffness and its own vibration are neglected. The effects of shear deformation and shear lag on the dynamic characteristics of this type of bridge are analyzed. The results show that when the prestress increases, the natural vibration frequency increases uniformly, but the effect is not significant; the superposition of each batch of prestressed tendons results in a decrease in the natural frequency.
4.2. Influence of diaphragm on dynamic performance of composite box-girder bridge with corrugated steel webs

In 2008, Liu Baodong et al.[14] produced an experimental model of composite box-girder with corrugated steel webs, established a finite element model of composite box-girder with corrugated steel webs and ordinary concrete box-girder based on the principle of static stiffness equivalent. Compared the experimental with finite element results, it shows that the composite box-girder with corrugated steel webs has low rigidity; in order to improve the torsion resistance of corrugated steel web, it is better to set the diaphragms in the end region; The torsional stiffness decreases as the mid-diaphgram approaches the mid-span; the diaphragm is set too large to increase its self-weight, the cost is increased, the setting of diaphgram is too low, the torsional performance is not good, so the number of the diaphragms needs to be reasonably set.

4.3. Influence of geometric parameters of corrugated steel web on dynamic performance of composite box-girder bridge with corrugated steel webs

In 2006, Liu Baodong et al.[15] analyzed the effects of parameters such as wide-span ratio, high-span ratio, thickness of corrugated steel webs on the dynamic characteristics of simply supported composite box-girder bridges with corrugated steel webs with equal section, and obtained: local warping stiffness reduce when the wide-span ratio is reduced. When the high-span ratio reduce, the vertical and torsional stiffness of the box-girder with corrugated steel webs is reduced, the lateral bending stiffness and the local stiffness of the upper flange plate are increased. Increase of the thickness of the corrugated steel webs can increase the torsional stiffness of the box-girder, but the degree is limited.

5. Seismic performance analysis of pc composite box-girder bridge with corrugated steel webs

In 2010, Wang Chao et al.[16] established a finite element model for a PC composite box-girder overpass bridge with corrugated steel webs in Shanghai, and analyzed the response spectrum under ground motion. The results show that under the action of longitudinal ground motion excitation, the internal force of the main girder is large, the bending moment and the shearing force are maximum at the middle fulcrum; the bottom of the middle pier has a large reaction force but the two both sides piers are small.

In 2010, Li Dongyi et al.[17] analyzed the dynamic characteristics of composite box-girder bridges with corrugated steel webs based on ANSYS and MIDAS platforms. The results show that the E1 seismic action has large transverse deformation due to its small horizontal bending stiffness. The vertical seismic action has little effect on the displacement and internal force of the medium and small span bridges, so the vertical seismic action needn’t be checked. In the seismic time history analysis and calculation, the longitudinal and vertical mixed earthquakes will produce mixed deformation; When calculating the displacement responds, the lateral deformation is large and the longitudinal deformation is minimum.

In 2013, Mou Kai et al.[18] mainly studied the Donghe No. 3 Bridge from the aspects of finite element modeling, seismic wave and its input direction determination, structural ground motion characteristics and seismic response combination. The analysis results show that the system of this bridge is reasonable, the pier-girder consolidation increases the torsional stiffness of the bridge and reduces the displacement of the pier’s bottom; the internal force of the bridge varies with the curvature. When the curvature is small, the small change of the seismic input direction has little effect on the internal force.

6. Conclusion

At present, domestical scholars mainly focus on the PC composite box-girder bridges with corrugated steel webs bending resistance, torsion resistance, bearing capacity, stability and shear buckling mode of corrugated steel webs. But the research results of long-span continuous girder bridges’ dynamics characteristics and seismic performance are relatively few. There are no relevant monitoring data to monitor some built PC composite box-girder bridges with corrugated steel webs, and the theoretical
calculation values cannot be verified. Therefore, based on the existing research datas, the finite element theory analysis of the dynamic characteristics and seismic performance of the PC composite continuous box-girder bridges with corrugated steel webs should be carried out, and the dynamic performance monitoring should be carried out to fully understand this type of the bridge. On this basis, it can better develop this type of bridge.

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