博士論文審査報告書
Doctor Thesis Screening Results Report

論文題目
Thesis Theme
Experimental and Numerical Study on Mechanical Behavior of Steel-Concrete Composite Bridges Subjected to Hogging Moment

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The primary aims of Mr. Lin’s dissertation are to provide a comprehensive understanding of the static and fatigue behavior of steel-concrete composite girders subjected to hogging moment through the experimental study and numerical investigation, and to make an extension study on the mechanical behavior of the curved steel-concrete composite girders under negative bending, and finally to demonstrate the design equations for predicting the ultimate strength of such girders. The whole content area is divided into two main parts—the mechanical behavior including the static loading behavior and fatigue behavior of straight steel-concrete composite girders under hogging moment, and its application to curved steel-concrete composite girders. Because of this, his dissertation consists of seven Chapters.

The first Chapter is concerned with an introduction to the background of the topics and the motivation behind the research. One of the first important studies on continuous composite steel and concrete bridges with monolithic decks was published by Sherman in 1954 (Sherman, 1954). Thereafter, some detailed studies were conducted to investigate the performance of the composite girder in the support region. However, the actual performance of composite girders with different types of shear connectors, new materials such as rubber-latex, and the fatigue behavior under different load levels of repeated load and so on are still unknown and need to be clarified. In this Chapter, he mentioned motivation, research objectives, approach and organization of the present thesis in details.

Chapter 2 is devoted to an experimental investigation on mechanical behavior of steel-concrete composite beams subjected to hogging moment. A total of four specimens were tested under point load in the mid-span. Two of the composite beams with headed studs as the shear connectors, while the other two specimens are using Perfo-Bond Strips (PBLs) as the connection devices between the steel girder and the concrete slab. Ultimate load bearing capacity of composite sections in negative moment region was calculated and compared with experimental values. Crack formation, crack widths development process and strain distribution of the composite section before and after cracking were observed in the experiment. His main conclusions lie in that: (1) The current specifications such as AASHTO, JSCE, and EUROCODE-4 can provide appropriate values for ultimate strength of a composite girder under negative bending moment; (2) Both PBLs and Stud connectors are effective as shear connective devices. The PBL connectors can slightly improve the rigidity of the composite girder under both the serviceability limit state and the ultimate limit state in comparison with stud connectors. Stud specimens have relatively better mechanical behaviour in regarding to initial cracking and crack closure loads of test specimens; (3) The location of composite neutral axis is affected by the rubber-latex and it moves between the cross-sectional elastic neutral axis and the plastic neutral axis. The location of the composite neutral axis was found to be the same as un-cracked section before cracking. After cracking, tension stiffening of the concrete is suggested to be considered when determining the location of the neutral axis; (4) Strain hardening effect of reinforcements was suggested to be ignored. The phenomenon of “crack closure” was observed for all test specimens, and thereafter the crack width was found keep as a constant. Additionally, average crack spacing on concrete slab was found mainly dependent on the transverse reinforcement spacing, and the maximum crack spacing specified by current specifications was proved to be appropriate values when compared to the test results; (5) The interface slip distribution was found closely related to crack pattern of the concrete slab for composite beams under hogging bending moment. Support conditions were considered to be another influential factor; (6) The application of rubber-latex can be beneficial to reducing the noise pressure levels. Flexural stiffness of the shear connectors was also found to be enhanced by using rubber-latex mortar. Besides, adhesion bonding effects of rubber-latex on interface were confirmed in the test by comparing with the specimen without using rubber latex mortar.
Chapter 3 deals with the study on a fatigue behavior of composite girders subjected to hogging moment. A brief description about the final static tests followed by the fatigue tests is also made. His conclusions and recommendations deserving priority are: (1) When the repeated load is equivalent to the initial cracking load of composite girders under hogging moment, limited number of unrecoverable cracks might occur with the increase of the number of load cycles; simultaneously, the cracking stiffness was found decrease, and the crack width at the same load level was found increase. Flexural strain of the studs is very small, and the necessary bond forces on the interface are mainly from the friction forces, but not shear forces of studs: (2) When the repeated load is equivalent to the stationary cracking load of composite girders under hogging moment, unrecoverable cracks and residual crack width occurs in the initial static test, but with the load cycles increase, some new unrecoverable cracks may also occur at the beginning of the fatigue test. However, when the number of load cycles increase to a certain extent (such as 100000 in the present test), most of cracks are recoverable cracks if the initial residual crack width was not considered. In addition, failure of the bond stress between studs and surrounding concrete was observed in the initial static test and the subsequent static tests, flexural stiffness of studs would become smaller with the increase of the load cycles: (3) No practical change was found on girder stiffness or residual displacement when the repeated cyclic load was limited to the initial cracking or stationary cracking loads. Besides, the changes of the rebar strains are found directly correspond to the crack pattern of concrete slab, and the strain jump of the rebar is caused by the crack of the concrete slab: (4) When the repeated load is smaller than the initial cracking load, the fatigue test with 200 millions cycles repeated load does not show any obvious effects on the ultimate loading behavior of composite girder under negative bending moment; however, when the repeated load is larger than the initial cracking load, the fatigue test with larger repeated load will reduce the girder stiffness in the inelastic stage and the ultimate load carrying capacities of such girders.

In Chapter 4, the numerical results are given and compared with the experimental values in order to find a reliable modeling method for such girders. Two overturned simply supported steel-concrete composite beams with different shear connectors such as Studs and Perfo-Bond Strips (PBLs) were tested under concentrated load in the mid-span. On the basis of the experimental observations, he built up a three-dimensional FE model capable of analyzing the composite beams subjected to negative bending moment. Strength and load bearing capacity, sectional strain distribution and movement of composite neutral axis before and after cracking were observed in the test and compared with the numerical results, and the results predicted by this modeling method are in good agreement with those obtained from the tests. His research results indicate that the proposed numerical models can simulate the test specimens well in regard to load-deformation response, sectional strain distribution, Rebar yielding and crack developing process on the concrete slab, and it follows that his numerical method can be served as a basis for the design of composite bridges under negative bending moment. Besides, the perfect bond assumption for concrete-reinforcement interface was proved suitable before rebar yielding, but relatively large difference was produced after rebar yielding.

Chapter 5 describes the state-of-the-art about the analysis, design and construction of curved composite girders. The horizontally curved steel-concrete composite girder bridges have excellent properties, such as quick construction, good seismic performance, saving construction formwork and convenience in spatial arrangement, etc, which have greatly promoted the application of such bridges. In this Chapter, he discussed about the latest research achievements on the analysis, design and construction behaviors of curved composite steel and concrete bridges, which can be served as a basis for the further study. From the literature review he pointed out that there are still numerous of problems need to be served, one of which is about the inelastic behavior of continuous steel-concrete composite girders in support regions. The ultimate strength needs to be defined, and mechanical behaviors of such girders need to be investigated.
Chapter 6 gives an extension study which was based on the analysis of mechanical behavior of curved steel-concrete composite girders under negative moment by using the proposed numerical models in Chapter 4. He analyzed 6 curved steel-concrete composite I-girder numerical models with different curvatures. The load-displacement relations, loading capacities, strain distribution and movement of the sectional neutral axis as well as the interaction between ultimate bending and torsion moment were presented. He made clear that the initial cracking load, girder yielding load and the ultimate load of curved composite girder under negative moment were decreasing as the curvature increase; and the reduction equation for predicting the load carrying capacity of the curved composite girder with different curvatures were proposed on the basis of the numerical results. Besides, ultimate bending and torsion moment of present numerical models in curved composite girders were calculated and compared with results in typical straight steel-concrete composite girders, and the failure pattern of curved composite girders was found to be changed from bending failure to torsional failure with the increase of the curvatures. Finally, he proposed a simplified bending–torsion interaction equation to illustrate the bending-torsion interaction for steel-concrete composite beams under hogging moment.

Finally, in Chapter 7, summary and conclusions are made. His study may give some useful suggestions on mechanical behavior of both straight and curved steel-concrete composite girders subjected to hogging moment, and his numerical modeling methods can be used to make a further parametric study on interesting parameters. However, it is worth noting that in conjunction with the static and fatigue experimental testing of single overturned composite I-girders under negative bending, the FE model should be extended to model the behavior of actual continuous girders. Furthermore, various parameters affecting the composite girders with double or triple I-girders and box-girders in different profiles in negative bending should be investigated. Further research on interface property is also suggested to be conducted.

His dissertation gives the useful suggestions on mechanical behavior of both straight and curved steel-concrete composite girders subjected to hogging moment. A detailed numerical modeling has been developed which incorporates into a new design methodology. Last but not least, his research results may devote to the development of numerical study on the design of both straight and curved steel-concrete composite bridges subjected to hogging moment.

The referees recognize that his paper devotes the development of the bridge engineering and meets given requirements of a doctorate (Doctor of Engineering).

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