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Analysis of auxiliary ribs in steel–concrete joint of hybrid girder

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ABSTRACT

The auxiliary ribs are utilized to reinforce the steel–concrete joints (SCJs) of hybrid girders. However, the demands of the ribs and the design of orthotropic steel decks with the auxiliary ribs are not addressed in design specifications. Solid element models are used to study the auxiliary ribs of the SCJ. The joints with and without auxiliary ribs are analyzed to clarify the demands and the reinforcing effects of the ribs. Stress dispersal efficiency of three typical auxiliary ribs is investigated. The trough–auxiliary rib (TA) joint is analyzed to check the steel deck design assumption and the approach to suppress stress concentration is discussed. The effective length of the auxiliary ribs is studied considering the geometric variations. Results show that the auxiliary ribs enlarge the steel deck and narrow the steel–concrete centroid deviation. The auxiliary ribs disperse about 50% axial force and the stress transmission of the joint is improved. The T-rib inserted in the trough is efficient to reinforce the SCJ with the effective length of 2–4 times the concrete slab thickness. The TA joint with abrupt tip suffers stress concentration and the safety margin of the steel deck is reduced. The joint is improved with about 60% hot spot stress decrease using the gentle tip with crossbeam constraint.

1. Introduction

The hybrid girder is composed of the steel girder in the mid-span and the pre-stressed concrete (PC) girders in the side-spans. The mid-span length is extended due to the balance between the self-weight of the mid and side spans. The hybrid girders are dominant in long span cable-stayed bridges and come to be favorable in moderate and short span beam bridges. The steel–concrete joint (SCJ) of a hybrid girder is crucial to the structural design owing to the abrupt changes of the material and the section properties. A lot of efforts have been made to improve the behavior of the joint such as using the concrete filled steel cells, the end plates, steel encased concrete and so on. Studs, angles, bars and perforated ribs have served as the steel–concrete connectors of the joint. A typical SCJ with cells is illustrated in Fig. 1. The stress intensity of the steel decks is higher compared with the concrete strength. The steel–concrete contact area is limited due to the relatively small cross section area of the steel girders. The overlapped interface may be less efficient for the steel–concrete stress transmission owing to the uneven distributed forces of the connectors. Thus, the auxiliary ribs are usually designed to reinforce the steel cross section area and to reduce the stress intensity of the steel girder.

The auxiliary ribs were used in SCJs of the first few hybrid girders built in the 1970s. The Kurt-schumacher Bridge [1] in Germany used T ribs to enlarge the orthotropic steel decks in the vicinity of SCJ. The Mosel Bridge [2] in Germany used the double T ribs attached to the troughs of the orthotropic steel decks to reinforce the joint. The early application of the auxiliary ribs was followed by the bridges constructed in the 1990s. The Ikuchi Bridge [3] in Japan used the T ribs inserted in the trough ribs to stiffen the steel decks. The auxiliary ribs were inherited by the Tatara Bridge and dozens of moderate and short span hybrid girders in Japan. The auxiliary ribs were employed in Baishazhou Bridge [4] and Taoyaomen Bridge [5] in China following the design philosophy of Germany and Japan. The auxiliary ribs are also used in the bridges built recent years such as Edong Bridge [6] in China and Wesel Bridge [7] in Germany. It seems that the auxiliary ribs have been used in most of the steel–concrete joints of the hybrid girders. However, limited researches involving the auxiliary ribs have been done opposed to the applications. Generally, the auxiliary ribs are designed empirically to reinforce SCJ. The demands of placing the auxiliary ribs and the reinforcing effect have not been clarified.

SCJ of hybrid girder might subject to concrete crush failure owing to the high stress intensity of the steel decks [11]. The auxiliary ribs are intended to provide smooth stress transmission between steel and concrete. Japan Prestressed Concrete Engineering Association (JPCEA) [10] suggests that the auxiliary ribs can be used in the SCJs with steel cells. The composite joints with concrete filled steel cells have larger rigidity compared with the orthotropic steel decks. The abrupt section changes probably lead to the stress concentration in several zones of the joint. The auxiliary ribs are recommended in order to give smooth steel–concrete stress transmission. The auxiliary ribs should be placed to align to the webs of the steel cells. Several types of auxiliary ribs such as T-shape ribs [1], single [4,5] or double [2] T-ribs attached to troughs, T-rib inserted in troughs [3,6] and plate-ribs inserted in troughs [7] have

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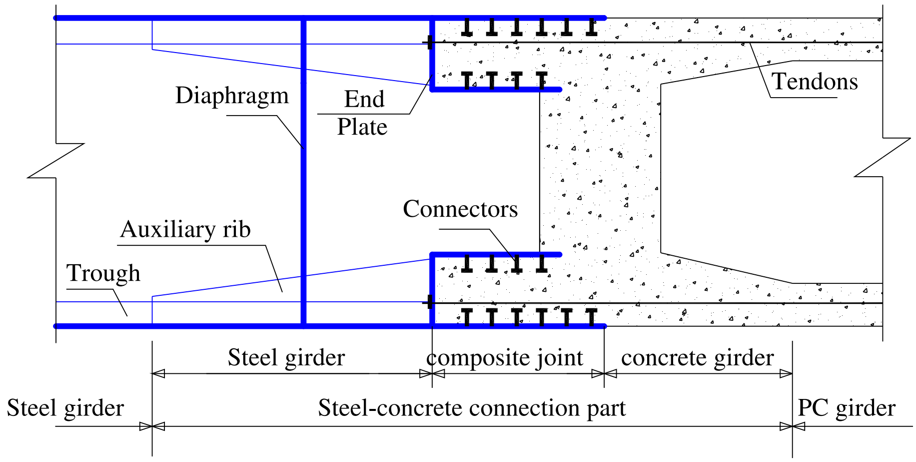

Fig. 1. Side view of steel–concrete joint in hybrid girder.

been used in the joints of the hybrid girders. The stress dispersal by the auxiliary ribs might be a sensible index to evaluate the stress transmission of the joint. However, the stress dispersal efficiency of various types of auxiliary ribs has not been compared. Mechanical benefits and the fabrication convenience have not been discussed.

The design of orthotropic steel decks with troughs or open ribs has been addressed in several design specifications such as Eurocode-3 [8] and AASHTO [9]. However, orthotropic steel decks with both the troughs and the auxiliary ribs have not been specified in most codes. The orthotropic decks with the auxiliary ribs are presumed to be stronger than ordinary orthotropic decks with only troughs in design application, since the cross sectional area is enlarged by the auxiliary ribs. Some tests [4,5] of the SC joints with auxiliary ribs showed that the stresses of the troughs and the auxiliary ribs were smaller than the standard steel girder without auxiliary ribs. However, section change at the trough–auxiliary rib (TA) joint might result in stress concentration. The welded joint of the auxiliary rib end tip and the trough flange have small connection area. The thin trough keeps higher stress while the end tip is the free edge of the auxiliary rib. The abrupt section change of the TA joint may subject to stress concentration [12]. The decks might be weakened by the potential stress concentration [13]. The assumption that the orthotropic steel deck with the auxiliary ribs has higher strength has to be checked.

The length of the auxiliary ribs is one of the crucial design parameters to be determined. According to Saint Venant's principle, the longer rib length should generate better stress dispersal effect. However, the effective length of the auxiliary rib has not been specified. JPCEA [10] suggests that the length of the auxiliary ribs should be no less than five times the height of the ribs or the thickness of the concrete slab to avoid stress concentration. However, the length is determined mainly by the empirical experiences and the quantitative proofs should be provided. The design applications of the rib length have not come to agreement yet.

In this paper, finite element method (FEM) is used to study the auxiliary ribs of SCJ in the hybrid girder. The joints with and without auxiliary ribs are analyzed to clarify the demands and the reinforcing effects of the ribs. Stress dispersal efficiency of three typical auxiliary ribs is discussed. The TA joint is analyzed to check the steel deck design assumption and the modified approach to suppress stress concentration is proposed. The effective length of the auxiliary ribs is studied considering the geometric variations.

2. Finite element models

2.1. Structure details of auxiliary ribs in steel–concrete joint

Edong Bridge crossing the Yangtze River in China is a cable-stayed bridge and is located in Hubei Province. The mid-span length of the bridge is 926 m and is composed of a flat steel box girder. The length of each side-span of the bridge is 287.5 m and the side-spans are composed of concrete box girders to balance the self-weight of the extended mid-span girder. The cross sections of the steel and the concrete girders are presented in Fig. 2.

The bridge construction contract is divided into two parts from the centerline of the mid-span. Each contractor is responsible for one half of the bridge. The pre-stressed concrete girder of the side spans are cast on formworks which are supported by the permanent concrete piers and the temporary steel piers. The concrete pylons are constructed during the construction of the concrete piers and the PC girders. The steel girders are fabricated in steel factories when the concrete structures are cast in-site. Once the concrete pylons are finished, the steel girder segments are shipped from the factory to the site. Each steel segment is lifted and assembled to make the steel girder. For each segmental assembly, two stayed cables in the side span are connected to the concrete girder while the opposite two are connected to the steel girder segment in the mid-span. The temporary steel piers are not removed

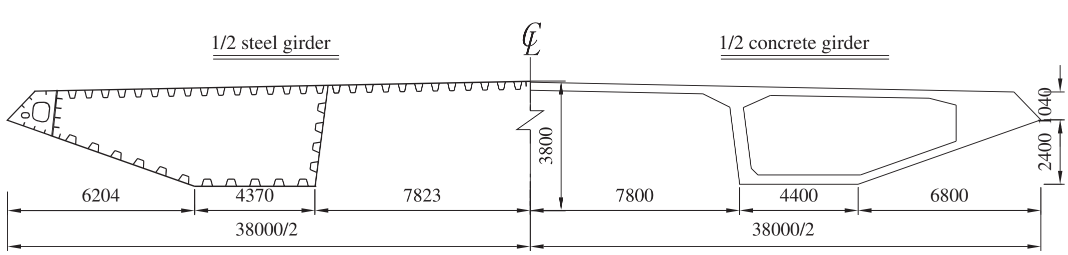

Fig. 2. Cross sections of steel and concrete girder of Edong Bridge (unit: mm).