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Original Research Article

Behavioral characteristics of hybrid girders according to type of steel–concrete connection

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ABSTRACT

The design of the reinforcement in the transition zone of hybrid girders (i.e., girders composed of concrete girders and steel girders) in terms of the resistance to the transferred load is critical to ensure the integrity of the structure. Although the availability of various types of reinforcement in the transition zone, existing design guidelines are insufficient with regard to the various reinforcing methodologies. To address this shortcoming, this paper focuses on the behavioral characteristics of hybrid girders with respect to prestressing and three types of connections. Flexural tests were conducted using nine hybrid girder specimens that were designed and fabricated using different combinations of shear studs, anchors, lap joints, and prestressing techniques to achieve the steel-to-concrete connection. A numerical model also is proposed to predict the nonlinear flexural behavior of hybrid girders based on the test results and conventional strain compatibility. The results are used to evaluate the contribution of each component of the connection and derive the combination that best provides resistance for hybrid girders.

1. Introduction

The combination of steel and concrete can achieve a composite structure that is able to take full advantage of the properties of both materials. Typically, such a composite structure is composed of one or several steel girders surmounted by a reinforced concrete slab and connected by shear connection. The most common composite bridge structures are girder composite and box girder composite bridges. These configurations have been proven to be efficient for spans ranging between 30 m and 150 m in length [1]. Reinforced concrete girders are the most economical solution for short spans and steel bridges remain the best solution for longer spans due to steel's lighter

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weight compared to concrete; however, steel is costlier than concrete.

In light of these features, a first attempt to combine steel girders and concrete girders was realized in 1972 with the construction of the Kurt-Schumacher Bridge in Germany, a cable-stayed bridge constructed with hybrid girders. This milestone was followed by several other outstanding examples, including the Normandy Bridge in France [2], the Tatara Bridge in Japan [3], and the Cheong-Poong Bridge in Korea [4]. The so-called hybrid girder or mixed girder in such cable-stayed bridges uses steel for the long main span and concrete for the side spans to counterweight the uplift caused by negative reactions [5–7]. A hybrid girder thus resembles a composite girder in that it combines dissimilar materials, but the difference is that the concrete and steel in a composite girder parallel each other in the longitudinal direction whereas a hybrid girder divides the concrete and steel between each end of the girder [8]. Fig. 1 presents a comparison of the structures of composite and hybrid girders.

In a hybrid girder bridge, the transition zone between the steel girder and the concrete girder must maintain continuity by sustaining large loads, including axial force, shear force, and bending and torsional moments. The transfer of such loads is generally achieved by bearing plates, shear connectors, or perfobond strip connectors [5,8]. Kim et al. [9] analyzed the efficiency of the steel-to-concrete connection of hybrid girders by considering three different connection types: (1) post-tension bars and a steel endplate, (2) post-tension bars and top, bottom, front, and back plates, and (3) flange plates and headed studs. Defining a non-dimensional efficiency factor involving the maximum moment, the volume of steel components and the yield stress of each component in the connection, Kim et al. [9] recommended the last connection type as the most efficient among the three types of detail. Note that the use of a front bearing plate was abandoned for other and more efficient alternatives after the Normandy Bridge application. He et al. [10] also studied steel–concrete connections with perfobond strips and found that, based on pushout test results, the shear capacity of one perfobond rib in a twin configuration was about 80% of a single independent perfobond rib. Oh et al. [11] considered the combined use of corrugated web and prestressing for joints and found that the accordion effect of the corrugated web improved the efficiency of prestressing the top and bottom flanges. Kozioł et al. [12] combined perfobond connectors with shear connectors and concluded that, based on the analogy to bolted and welded connections, the combination of perfobond and shear connectors improved the connection's resistance to failure.

Initially, the aim of the hybrid girder bridge design was to span obstacles in the most economical manner possible by placing steel girders and concrete girders consecutively in the longitudinal direction to reduce the bending moments in the main steel span. This aim was accomplished due to the difference in the weight of the steel (lighter) and the concrete (heavier). The hybrid girder bridge design also solved the uplift problem caused by the negative reaction force at the end supports that could occur when the side concrete span was shorter than the main span. Therefore, investigating the steel–concrete transition zone when common connections are applied seemed to be worthwhile. Accordingly, Park [5] proposed a design methodology for joints in hybrid girders that combined steel and prestressed concrete members to fill a design gap in terms of reference data and detailed design standards. Park conducted finite element analysis that considered shear stud connectors and prestressing tendons to connect a prestressed concrete girder and a steel girder. From the parametric study, it appeared that (1) the joint length was more determinant for the load–deflection relationship rather than the shear stud spacing, (2) the required minimum number of shear studs could be obtained when their spacing equaled the height of the girder section, and (3) the cracking moment of the hybrid girder was greater than that of the prestressed concrete girder when using prestressing tendons.

Because most of the aforementioned earlier studies were analytical and were intended to provide basic data for the development of design standards, the present study experimentally examines the structural behavior of hybrid girders in terms of conventional steel–concrete connections. To this end, nine hybrid girder specimens were designed and fabricated for this study using different combinations of steel–concrete connections, including shear connectors, welded anchors as perfobond connectors, lap joints, and prestressing. The used welded anchors in this study are intended to simulate a perfobond connector because of the lack of space to secure holes in the relatively small web of the steel girder. The various combinations were selected based on results obtained by Kim et al. [9], He et al. [10], Oh et al. [11], and Kozioł et al. [12]. In addition, an analytic model is proposed in this paper to predict the nonlinear flexural behavior of hybrid girders based on the experimental results and strain compatibility conditions. The analytic results agree well with the experimental data found from this study and indicate that the proposed analytic model

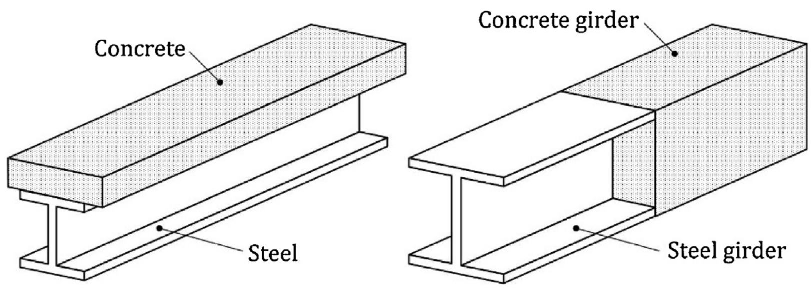

Fig. 1 – Structures of composite (left) and hybrid (right) girders.