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Original Research Paper

An innovative steel-concrete joint for integral abutment bridges

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ABSTRACT

Integral abutment bridges are becoming rather common, due to the durability problems of bearings and expansion joints. At the same time, among short- and medium-span bridges, multi-beam steel-concrete composite deck with hot-rolled girder is an economical and interesting alternative to traditional pre-stressed concrete solutions. The two concepts can be linked together to design integral steel-concrete composite bridges with the benefits of two typologies. The most critical aspect for these bridges is usually the joints between deck and piers or abutments. In this paper, an innovative beam-to-pier joint is proposed and a theoretical and experimental study is introduced and discussed. The analyzed connection is aimed at combining general ease of construction with a highly simplified assembly procedure and a good transmission of hogging and sagging moment at the supports in continuous beams. For this purpose, the traditional shear studs, used at the interface between steel beam and upper concrete slab, are also used at the ends of steel profiles welded horizontally to the end plates. To better understand the behaviour of this kind of joints and the roles played by different components, three large-scale specimens were tested and an FE model was implemented. The theoretical and experimental results confirmed the potential of the proposed connection for practical applications and indicated the way to improve its structural behaviour.

1. Introduction

The durability of bridge expansion joints and bearings has become an important concern worldwide. It leads the integral-abutment bridge (IAB) concept becoming rather popular in recent years, not only in the newly built bridges, but also in the retrofit of existing ones (Briseghella and Zordan, 2006; Dong et al., 2014; Yannotti et al., 2005; Zordan and Briseghella, 2007). The formulation of IAB dates back at least to the 1930s, and it has been used to address long-term structural problems which frequently occur with conventional bridge designs (Burke, 1993). The original IAB concept was not very manageable at that time. It had several problems related to the post-construction life of

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the structure. Besides, the specific design and soil-structure interaction problems represent a challenge requiring synergy of both structural and geotechnical engineers. The application of IAB based on bridge's maximum length was investigated by Zordan et al. (2011a, 2011b). The IAB concept has received considerable interest among bridge engineers because of the enormous benefits from the elimination of expansive joints and the reduction of installation and maintenance costs. The superstructure of integral abutment bridges can be made continuously through a composite cast-in-place concrete deck slab over steel or pre-stressed concrete girders and sequential diaphragms. With this design, the system constituted by the sub- and super-structure acts as a single structural unit. The monolithic connection between deck and sub-structure, such as piers and abutments, makes IABs different from other conventional bridges and allows for a remarkably increased redundancy for seismic loading and other extreme events (Xue et al., 2014; Zordan et al., 2011a, 2011b). Furthermore, joints in deck are known to be a crucial part in existing bridges, not only because of their own failure and maintenance problems, but also of the significant amount of corrosion damage in girders and other underlying substructures caused by corrosive de-icing salts in run-off water leaking through the joints to the deck (Arockiasamy and Sivakumar, 2005). Hence, the IAB concept has proved to be successful in eliminating a number of problems related to the management of conventional bridges during their service life, and turns out to be economical with reference to both construction and maintenance costs (Tandon, 2005). The United States can boast the widest experience of IABs, measured in number of application. Nevertheless, a limited but meaningful number of bridges within this family, with composite steel and concrete structures, can be found in central Europe, mainly in Luxembourg and France (Hever, 2001). As noted by some studies (Zanon et al., 2014), among short- and medium-span bridges, multi-beam steel-concrete composite deck consisting of hot-rolled girders is an economical and interesting alternative to traditional pre-stressed concrete solutions.

With this bridge type, continuity and hogging moment can be balanced at piers through slab reinforcement, as well as by the connection of the steel beam to a concrete transverse diaphragm by means of a number of shear studs, which are mainly devoted to the shear transmission. Studies on this topic started in 1970 in Australia (Kell et al., 1982) at the request of the Department of Main Roads of Western Australia. In the same period, several composite bridges were also built in the United States.

Regarding beam-to-beam connections for composite bridges, an interesting study published by Dunai et al. (1996) presented an experimental study on an original type of end-plate steel-to-concrete mixed connection, focussing mainly on its rotational stiffness and cyclic deterioration. The originality of the connection resided in the layout of the joint, inspired by conventional column-base connections. In this special kind of connection, tensile forces were transmitted by bolts and/or studs, shear forces were transmitted by headed studs (or shear connectors in general) and compression forces were transmitted directly to the concrete by the bearing end plates.

Haensel (1998) presented results of a research program sponsored by steel fabricator ARBED, which built bridges with an innovative type of connection for composite steel and concrete girders, where the bending moment of the supports at the top flange was transmitted across the bearings by the tensile reinforcement alone, while the bending moment in the bottom flange was transmitted by means of a couple of compression plates through the concrete. Contemporarily to Haensel (1998) and Svadbik and Strasky (1998) presented the "Modular Span Multi-Cell Box Girder System" for short span (from 6 to 30 m) steel bridge structures. The bridge deck was composed of steel modules and a composite concrete deck slab. Multi-span continuous structures assembled from simple spans, joined by concrete cast-in-place diaphragms, were studied. The reactions were transferred from the bearings into the webs by the concrete diaphragms. The webs with shear studs and the diaphragms had reinforcing bars, which resisted splitting forces.

In 2002, a design guide on "Composite Bridge Design for Small and Medium Spans" was published by the ECSC Steel RTD Programme (EU, 2003). The publication, among other things, focused on using shear connectors transferring forces to a concrete diaphragm inside single and continuous composite decks, with different levels of prefabrication for the concrete slab.

A further meaningful example of hybrid composite bridges was the VFT construction method proposed by Schmitt Stumpf Fruhauf and Partner (Weizenegger, 2003). A type of composite girder that could be almost completely prefabricated was developed, with the connection to the abutments using shear connectors.

More recently, the nonlinear response of similar composite joint typologies to those studied in this paper was investigated by Zordan and Briseghella (2009), while Zanchettin et al. (2011) experimentally studied five different configurations of shear studs.

Somja et al. (2012) studied the influence of key parameters governing joint behaviour using FE simulation based on experimental tests.

The above studies mostly regarded monotonic loads and hogging moment, while in integral abutment bridges, a full connection between girders and piers and/or abutments with sagging and hogging moment resistance could be required.

This paper presents the results of an experimental and theoretical study on an innovative beam-to-pier joint. The proposed connection is introduced with a start of a previous connection studied by the same authors (Zordan and Briseghella, 2007). An experimental campaign on three full-scale specimens is introduced, and the main results are discussed in Section 3. Global and local FE models used in the research are described in Section 4. Based on the obtained results, an improvement to the connection is proposed and analyzed in Section 5. Finally, the conclusions are drawn.

2. Joint

The increasing ratio of labour cost to construction materials cost is urging the development of construction techniques.