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Experimental characterization and component-based modeling of deck-to-pier connections for composite bridges

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ABSTRACT

Higher stiffness and strength achieved with a reduced overall weight together with an extensive use of prefabrication justify the growing diffusion of Steel-Concrete Composite (SCC) bridges since the early 2000s, especially for the 20 ÷ 80 m span range. Former experimental campaigns aimed at investigating the static response of simply supported continuous composite decks subjected to gravity loads, highlighted deck-to-pier connections, which typically experience negative moments, as critical elements. More precisely, tensile stresses occurring in the concrete slab and compression of bottom flanges of steel girders may cause concrete cracking and steel buckling, respectively. The adoption of Concrete Cross Beams (CCBs) allows for circumventing such issues and represents an enhanced solution for deck-to-pier connections in SCC bridges with continuous deck. In detail, steel girder head plates provided with shear studs transfer compression and shear loads to the CCB whilst additional steel rebars bring tension forces coming from adjacent concrete slabs. Although deck-to-pier connection based on CCBs can be designed with the support of Eurocodes, guidelines are limited to vertical loads and no standard exist for design against earthquakes. In order to investigate the seismic response of deck-to-pier connections based on CCBs and provide relevant design guidelines, an extensive research program was developed within the European Project SEQBRI, which is summarized in this paper.

1. Introduction

1.1. Background and motivation

Higher stiffness and strength achieved with a reduced overall weight together with an extensive use of prefabrication justify the growing diffusion of Steel-Concrete Composite (SCC) bridges [1–3] since the early 2000s, especially for the 20 ÷ 80 *m* span range. Normally, steel girders, whose cross-sections are either rolled or welded on shop, and prefabricated concrete elements form the bridge deck requiring a minimal concreting on site. During the assembly process, simply supported beams carry dead loads of steel girders, formworks and concrete. After concrete hardening, intermediate supports provide moment resistance and the continuous deck carries all loads. Therefore, only non-structural element weight and accidental loads produce hogging bending. A comprehensive overview on recent trends and developments on this subject can be found in [4–6]. With reference to the specific case of small- and medium-span i.e., between 25 m and 40 m, SCC bridges provided with steel girders exhibit advantages in terms of: i) reduced deck cross-section depth that minimizes possible interferences with existing transportation infrastructures in case of overpasses; ii) reduced deck weight that favorably impacts on support settlements; iii) no need for prestressing/post-tensioning of deck concrete slab; iv) faster construction process owing to reduced scaffolding whose role is partially replaced by steel girders [7].

Former experimental campaigns aimed at investigating the static response of a simply supported continuous composite deck subjected to gravity loads highlighted pier supports, which typically experience negative moments, as critical elements. More precisely, tensile stresses occurring in the concrete slab and compression of bottom flanges of steel girders may cause concrete cracking and steel buckling, respectively [8]. Both phenomena affect durability and service life of structure and, therefore, must be taken into account by bridge management [9].

The adoption of Concrete Cross Beams (CCBs) allows for circumventing such issues and represents an enhanced solution for deck-to-pier connections in SCC bridges with continuous deck. In detail, steel girder head plates provided with shear studs transfer compression and shear loads to the CCB whilst additional rebars carry tension forces coming from adjacent slabs. Normally, CCBs are built at intermediate

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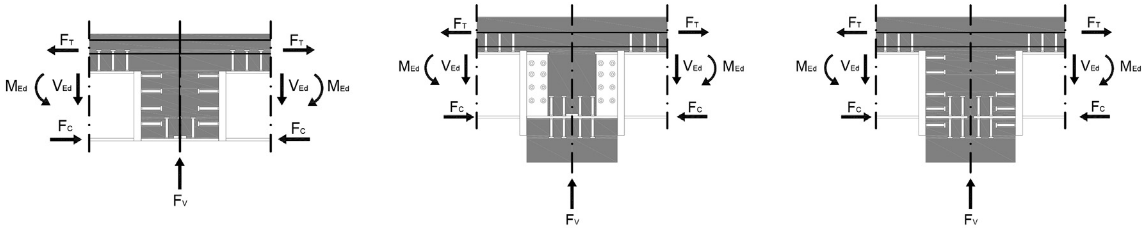


Type A Type B Type C

Fig. 1. Main CCB types according to the DIN-FB-104 standard [19].

supports only, minimizing, or eliminating, onsite welding and bolting. It is important to stress that previous studies conducted on a large bridge portfolio highlighted that SCC bridges based on simply supported and continuous steel girders are most vulnerable to seismic hazard [10]. In addition, a parametric study conducted on a typical SCC bridge and reported in [11] shows that damage is not confined to piers, which are expected to yield, but extends to other components e.g., deck, bearings, and abutments. In the authors' knowledge, most of research on SCC bridges with CCBs is limited to static -gravity- loads. In this respect, [12] describes an experimental campaign based on monotonic tests conducted on a full-scale CCB of a real SSC bridge provided with steel girders and the validation of relevant numerical models. A few studies coped with the transversal seismic response of this structural typology [13, 14], which still lacks of validated numerical models to be used within the Performance-based Earthquake Engineering (PBEE) framework [15]. PBEE merges hazard, risk and vulnerability analysis into a unique probabilistic framework for quantifying performance of structures, which is described in terms of limit states, during their entire lifecycle. As an example, [16, 17] reports PBEE analyses of Reinforced Concrete (RC) bridges subjected to earthquake loading whilst [18] compares the performance of a RC overpass bridge located in California for the two cases with conventional RC columns and with self-centering post-tensioned columns.

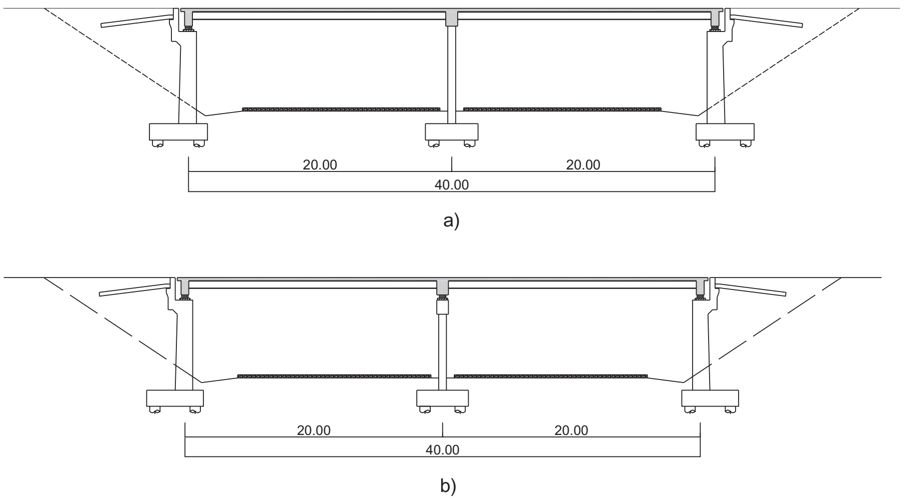
1.2. Scope

Although deck-to-pier connections based on CCBs can be designed with the support of Eurocodes, guidelines are limited to vertical loads and no standard exists for design against earthquakes. In this respect, Fig. 1 reports the schematics of three types of CCB proposed by the DIN-FB-104 standard [19, 20].

As can be appreciated from Fig. 1, for all three cases, a head plate is welded to the end of the steel girder along the entire cross section depth whilst the bottom flange continues inside the CCB. Normally, the top flange of the steel girder is in tension and shear studs transfer the axial load to the CCB whereas contact between adjacent girders -Types A and B- or concrete -Type C- carry compression forces coming from the bottom flange. If tensile forces come from the bottom flange of the steel girder, they are transferred either through the welded connection between the extensions of the flanges -Types A and B- or through vertical shear studs -Type C-. On the other side, shear studs welded on steel girder head plates and parallel to the bridge axis transfer shear forces -Types A and C-. Alternatively, in Type B, a vertical steel web welded to the head plate of the steel girder and inserted into the CCB transfer shear forces through shear studs.

It is noteworthy that the CCB configurations proposed by the DIN-FB-104 standard [19] are designed to carry vertical loads that produce negative moments at intermediate supports, which entails tensile and compressive forces at the top and the bottom flanges of the steel girder, respectively. However, a significant tensile force could arise at the bottom flange in response to seismic loading, especially when the connection between CCB and pier is monolithic. In such a case, CCBs of both Types A and B should be avoided.

In order to extend such structural solution to earthquake-prone areas and provide relevant design guidelines, an extensive research program was developed within the European Project SEQBRI. In detail, the CCB Type B proposed by DIN-FB-104 standard was selected as starting point for developing two novel typologies of intermediate CCB, namely VAR-1 and VAR-2, for SCC bridges built in low and medium intensity earthquake-prone areas. An additional CCB was designed according to Type C of DIN-FB-104 standard [19], which accounts for gravity loads only. In order to validate mechanical models and to



a)

b)

Fig. 2. Longitudinal view of the virtual bridge case studies: a) monolithic deck-to-pier connection; b) simply supported deck-to-pier connection.