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Tensile and shear resistance of bolted connectors in steel-FRP hybrid beams

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Abstract

Demountable connectors have been rarely applied in steel-FRP hybrid structures due to the lack of research, which could prove their reliable structural performance. In typical applications, e.g. in multi-girder hybrid decks, the connectors are not only subjected to longitudinal shear forces, but also to substantial tensile forces originated from the uneven load distribution between the girders. Therefore, the aim of this study is to investigate the feasibility of three types of bolted connectors in steel-FRP hybrid structures by examining their shear and tensile resistance. To that end, push-out and pull-out tests were conducted to determine respectively, the shear and tensile strengths of the connectors. The suitability of the connectors in typical multi-girder hybrid steel-FRP deck applications is concluded from the test results.

Keywords: Bolted connectors, circular economy, steel-FRP hybrid structure, pull-out test, push-out test.

1 Introduction

Hybrid bridges consist of Fibre-Reinforced Polymer (FRP) pultruded or sandwich panels mounted on the top of longitudinal steel girders with the help of fasteners and/or an adhesive connection. Steel-FRP hybrid structures represent an excellent option for the renovation of bridges, where the original deck structure is deteriorated, while the main load carrying members are in good condition. Application of FRP decks – due to the high strength-to-weight ratio of the material - enables fast installation with minimum traffic hindrance and minimum additional weight that is imposed on the existing structure. The success of designing competitive hybrid steel-FRP structures heavily depends on the structural performance of the deck-to-girder connection.

Figure 1. Push-out (left) and pull-out (right) tests

There has been extensive research on adhesive [1] and grouted shear stud connection [2] between the steel beam and the FRP deck, but bolted connection was rarely examined due to the localised load transfer. Additionally, demountable connectors promote reuse of the steel girders and FRP deck at a later stage, stimulating a circular economy. This study focuses on three types of demountable, bolted deck-to-girder connections.

2 Experimental program

2.1 Connector types

Three types of mechanical connectors were applied in the test specimens: two kinds of blind bolts (namely Ajax and Lindapter Hollo-Bolt) and a novel, hybrid joining technology. The key feature of Ajax system is the foldable washer, which enables installation from under the FRP deck through predrilled holes. The primary component of the Lindapter system is the expandable sleeve, which opens up during tightening of the bolt. The third connection type, referred to as 'Injected shear connection' hereinafter, comprises an embedded bolt and coupler located in the middle of a cylindrical hole in the sandwich panel and an outer bolt, which connects the embedded components to the top flange of the steel beam. The hole of the deck is filled with small steel balls and injected with polymer resin after the installation of the mechanical connectors, thus providing large tolerances for execution but zero clearance.

2.2 Push-out and pull-out test set-ups

The specimens consisted of two vacuum infused sandwich panels with integrated webs, which were connected to HEB260 steel profile by two shear connectors on each side (Figure 1). In total, 8 push-out tests were performed following the recommendations of Annex B of Eurocode 4. The slip between the steel beam and deck elements were measured by 4 vertical LVDTs next to connectors, while the force of the hydraulic jack was continuously recorded.

The pull-out test specimens composed of a square sandwich panel, in the middle of which a mechanical connector was inserted, connecting the top facing of the panel to a steel inlet plate of the set-up (Figure 1). The bolt was pulled by a hydraulic jack, while the panel was hold down with a hollow section profile. All in all, 9 tests were conducted, the force and the stroke of the jack was recorded.

3 Discussion

3.1 Results of push-out tests

The specimens with blind bolted connectors failed by bearing damage of the FRP together with bolt yielding. Typical damage pattern of Ajax connector is shown in Figure 2.

Table 1. Average resistances (per connector)

Type of connection	Shear resistance [kN]	Tensile resistance [kN]
Ajax	207,4	58,7 (95,7)
Lindapter	164,3	42,6 (61,3)
Injected	120,0	69,3 (88,3)

The Ajax shear connector proved demountablity, although it is impossible to mount it again in second life cycle. The Lindapter connector was not found to be demountable due to the extensive bending of the bolt. The bolt shear failure governed the ultimate resistance of SRR injected connectors. However, the sandwich panel and the injection piece were not damaged, therefore reuse of the panel in second life cycle is possible. The average shear resistance of the connectors shown in Table 1 differ considerably, although in each specimen M20 bolts of grade 8.8 were used. The reason is the larger shear area in case of Ajax and Lindapter connectors due to the additional sleeves around the bolt.

3.2 Results of pull-out tests

Delamination of FRP was the dominant failure mode in the specimens with blind bolted connectors (Figure 2). Values in Table 1 show peak load before delamination which is followed by sudden 20-30% drop of force. The Ajax and Lindapter showed force recovery after delamination resulting in ultimate resistances (values in parentheses) at approx. 20 and 30 mm axial displacement respectively. Failure mode of the injected connector was by deboning at interface between SRR and embedded connector without delamination resulting in very good resistance to ”first crack” of this connector compared to the other two.

Figure 2. Typical failure pattern of Ajax connector in push-out (left) and pull-out (right) tests

4 Conclusions

Experiments on three types of bolted connections for steel-FRP hybrid structures show variability of shear and tensile resistance in range of 30-40%. This implies feasibility of all examined connectors depending on application and prevailing criteria. Advantages per type are: shear resistance for Ajax, easy installation for Lindapter and tensile resistance, full interaction and demountability for injected connector.

References

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