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Blind-bolted shear connections for axially compressed RHS columns strengthened with open sections

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ABSTRACT

The process of implementing principles of sustainable development in building for existing structures is much more challenging than for new designs. This issue is particularly acute when it comes to improving the stability of an axially compressed bar elements made of rectangular hollow section (RHS). This paper presents the results of experimental and analytical studies that address the question whether blind bolts BOM may be an effective alternative to bolted fasteners in one-sided lap connections between strengthened bar and strengthening branches. The results of shear tests of single lap connections with blind BOM-R16-4 bolts prove that the structural properties of the tested joints are similar to the structural properties of connections with M16-8.8 grade bolts. Results of the parametric analysis carried out for a perfectly straight axially compressed RHS columns, symmetrically strengthened by two U-shaped branches indicate the special potential of BOM fasteners in applications for joining the walls of strengthened tubular bar and strengthening branches of open cross-section. The analytical results demonstrate that the lack of the main slip in the lap bearing connections of branches with BOM fasteners gains efficiency in strengthening of the axially compressed column in comparison with solutions using bolts. The results obtained provide the basis for the development of an efficient method of strengthening bar elements with closed cross-sections that is characterized by low energy expenditure, in accordance with the principles of sustainable building.

1. Introduction

The process of implementing principles of sustainable building for existing structures is much more challenging than for new designs. One of the reasons for this is a lack of solutions that allow strengthening of existing structures in a way that does not require significant energy expenditure. This issue is particularly acute when it comes to strengthening bar elements with closed cross-sections. Typically, a considerable improvement in the stability of an axially compressed bar made of hot-rolled, rectangular hollow section (RHS) can be achieved by the application of strengthening *via* two shorter cold-formed U-sections (Fig. 1). In this situation, however, the choice of an appropriate connecting system becomes a very problematic issue. This is because the fastening should on the one hand provide the expected level of cooperation between the strengthened tubular bar and the strengthening branches, and on the other hand enable a reduction in the labor required for the fabrication of connections on site.

Currently, connections for structures made of hot-rolled sections or both hot-rolled and cold-formed sections are most often made using manual welding or bolts. Welding, however, as an energy consuming process does not fit into the framework of sustainable development in building, in the context of the strengthening of structural elements. Innovative welding techniques like laser beam welding, widely used in the automotive industry, are only just being introduced into the building industry [1]. Application of standard bolts, in turn, is restricted to connections with access from both sides. Furthermore, popular blind fasteners such as self-drilling and self-tapping screws and blind rivets are mainly used to fasten elements of small thickness, usually up to 3 mm [2–6]. In connecting hot-rolled sections with thicker walls – often encountered in existing structures provided for strengthening – a disadvantage of screws and rivets may be their low shear resistance and the consequent low deformation capacity of a fastening. This translates into the need to use a large number of fasteners in the connections. Furthermore, the difficulty of the drilling process increases with wall thickness, which significantly increases the labor cost of the strengthening process. For the same reasons, innovative systems such as self-pierce riveting joints, clinching joints or shot nailed connections – reported in previous studies [7–9] – have

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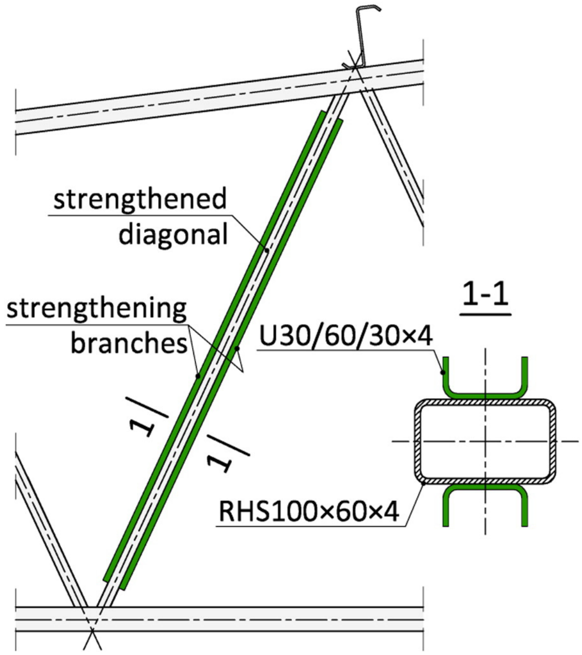

Fig. 1. Strengthening of an axially compressed diagonal made of hot-rolled RHS.

limited application for joining the walls of strengthened tubular bar with strengthening branches.

Hence, current research on connections with innovative blind fasteners is focused on those fastener systems that would be used in connections in place of bolts [10]. This is because bolted connections exhibit the desired structural properties (relatively high shear and bearing resistance, and appropriate bearing stiffness and deformation capacity) [11–15]. The research mainly focuses on the application of innovative blind fasteners in place of high-grade bolts in moment transmitting beam-to-column connections with end plates [16–21]. A review of shear test results may be found in work [22].

Against this background, particular attention should be paid to the works of Wuwer [23] and Swierczyna [24]. They studied the possibility of application of BOM bolts (blind, oversize, mechanically locked) [25] (Fig. 2) in nodes of lattice girders made from RHSs and U-shaped sections. Results of these experimental and analytical studies revealed significant reserves of load capacity, stiffness and ductility of the tested single lap joints in bearing. It has been shown that BOM fasteners can be an alternative to bolts when the connection is only accessible from one side. It should be noted that, to date, BOM fasteners have been used mainly in the automotive industry in slip resistance connections and only occasionally in civil engineering [25,26].

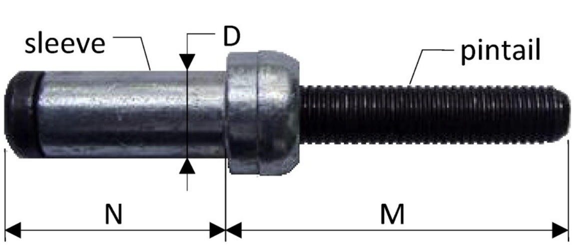

Fig. 2. Blind bolt BOM-R16-4.

Studies carried out by Wuwer and Swierczyna have provided the basis for the thesis that BOM fasteners may be an effective alternative to bolted fasteners in one-sided lap connections between strengthened bar and strengthening branches. These studies, however, were limited to a narrow range of geometrical and material parameters of the specimens, and did not provide the required information to verify the proposed thesis. Therefore, a research program has been initiated. The main focusses of this program are experimental tests of shear connections with BOM fasteners and axially compressed RHS columns, symmetrically strengthened by two U-shaped branches.

This paper presents the results of experimental studies that measure the structural properties of single cut joints with BOM fasteners, under loading conditions similar to those which can occur in connections of the branches of a built-up bar. An assessment of the experimental results obtained has also been carried out, in the context of the existing state of knowledge of the structural behavior of lap joints with mechanical fasteners. Furthermore, results of analytical studies on built-up columns provide indications of the relevance of theses experimental results to the process of strengthening closed cross-section structural bar elements.

2. Experimental program

2.1. Objective and scope

The objective of the experimental investigation was to determine the structural properties of single cut joints with blind bolts (BOM-R16–4) in shear. For this purpose, six identical test specimens were subject to axial tension in a testing machine. The tested elements were fabricated from closed and open steel sections belonging to a batch of sections also used in construction of built-up columns – provided for tests in the next step of the research program.

2.2. Construction of test elements for shear tests

The specimens were fabricated from hot-rolled RHS100 × 60 × 4 out of steel S355J2H and two cold-formed sections U30/60/30 × 4 made of steel S355 (Fig. 3). U-sections were formed using a bending press DURMA AD-S 30220. The U-sections were connected to opposite webs of the hollow section by BOM-R16-4 fasteners, using a pair of fasteners in line.

The catalogue dimensions of the applied BOM-R16-4 bolt are as follows (Fig. 2): $D = (13.4–13.8)$ mm, $M = (49.4–50)$ mm, $N = 32.2$ mm [25]. The fasteners were embedded in holes with a nominal diameter of 14 mm. The end distance ($e1 = 50$ mm) and spacing ($p1 = 100$ mm) of BOM fasteners have been adopted as for bolted connections, according to [27–29] (Fig. 3). Both ends of each of the test specimens were equipped with short sections of the RHS and U-profiles, in order to improve the load capacity of the end fixtures (Fig. 3).

2.3. Specimen dimensions

2.3.1. Cross-sectional parameters

Precise determination of the cross-sectional parameters of the RHS and U-sections was achieved by scanning the cross-sections and then reading out the quantities from the resulting digital image. Table 1 summarizes the measured values of the cross-sectional area A and the thickness: t – averaged for all walls of both tubular cross-section or U-section – and also $t_{RHS,B}$ and $t_{RHS,C}$ – for the two webs B and C of the RHS, respectively.