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Strengthening of existing composite steel-concrete beams utilising bolted shear connectors and welded studs

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ABSTRACT

This paper considers the flexural behaviour of steel-concrete composite beams retrofitted with two types of bolted connectors and welded stud connectors. Three composite beams, one from each connector type, and four non-composite beams were cast together. Three of the non-composite beams were retrofitted using the three connector types respectively. The connectors were installed through holes cored in the concrete slabs of the beams. The holes were backfilled using structural grout. The beams were then tested under static flexural loading. The load-slip behaviour of these connectors under normal and retrofitted conditions was investigated using push-tests. The flexural behaviour of the retrofitted beams was compared with that of the normal composite beams and non-composite beams. The ultimate loads of the test specimens were compared with the design ultimate loads of these beams calculated using Rigid Plastic Analysis (RPA). The vertical deflection of the beams under serviceable load regimes was also compared. The beam experiments were simulated using Finite Element (FE) models developed with ABAQUS. Material models with damage parameters were specified for the concrete and grout used in the test specimens using the Concrete Damage Plasticity (CDP) option. The effects of the concrete and grout strength, grout-hole size and shear connection ratio on the flexural behaviour of retrofitted beams were investigated by carrying out a parametric analysis. The results obtained from full-scale beam and push-test experiments and also the analytical results from RPA and FE analyses are presented and discussed in detail in this paper.

1. Introduction

Composite steel–concrete beams are widely used in infrastructure such as steel framed bridges, buildings and stadia. Age is one of the many factors that affects the condition and performance of these composite beams in terms of their ability to withstand current and future loading requirements. Recent records show that existing ageing infrastructure needs improvements to prolong their useful service life [1]. The useful life of existing substandard composite steel-concrete beams of these structures can be extended by retrofitting them with shear connectors. Therefore, this paper investigates a method to rehabilitate substandard steel-concrete beams utilising two special types of bolted connectors and welded headed stud connectors.

A concrete slab and a steel beam can be attached by means of shear connection to act compositely. Mechanical shear connectors have been used to develop shear connection for steel-concrete beams from the beginning of the 20th century. Welded stud connectors have become a very popular type of mechanical shear connector used in composite floor systems in the construction industry. The availability of detailed research [2,3,4,5,6] and standard design methods have made welded studs very popular. However welded stud connectors have not been effectively utilised to rehabilitate existing substandard composite beams. One of the most critical problems associated with this type of connector in terms of retrofitting of beams is the difficulty of welding these connectors to composite beams. In rehabilitation methods shear connectors need to be attached through holes cored in the concrete slabs of composite beams. Welding the shank of welded stud connectors to the steel beam inside these holes can be a very difficult and time consuming process.

This paper primarily investigates the feasibility of utilising two novel types of bolted connectors to retrofit existing composite steel-concrete beams. The ability to be attached and detached from one side of a structure is one of the main aspects of these bolting systems that can be exploited to retrofit composite beams. These special bolted connectors are commonly known as blind bolts. The two bolt types are referred to as BB1 and BB2 in this paper. Both are of M20 - grade 8.8 type bolts. The advantages of these connectors are not limited to this aspect only. The bolt installation process that utilises power tools is much faster compared with the welded stud installation process. The installation process does not require heavy equipment to be run along the beams in which the bolts are fixed. Therefore the bolt installation process is

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less complex and faster when compared with that of welded stud connectors. The bolted connectors can also be tightened to a required torque with acceptable precision. Thus, the quality of bolted connections can be effectively assessed by nondestructive methods. Therefore, the reliability of the quality assessment of bolts is also much higher than that of welded stud connectors.

Due to the lack of detailed research and design guidelines bolted shear connectors are not widely used in composite beams. Nevertheless an increasing trend in investigating the use of bolted connectors in composite beams due to their various benefits can be identified in the open literature. Lam and Saveri [7] and Pavlović et al. [8] carried out push-test experiments utilising welded shear studs and different types of bolted connectors and studied the specific behaviour of bolted connectors in contrast to welded stud connectors. Moynihan and Allwood [9] tested three composite beams, of 2 m, 5 m and 10 m length, constructed utilising M20 bolts as demountable shear connectors. Their results suggested that composite beams with bolted connectors demonstrate comparable moment capacities to those of composite beams with welded shear studs. The feasibility of using bolted connectors to retrofit steel-concrete beams was not investigated in this research study. However, not much research work could be found in relation to rehabilitation of composite steel-concrete beams utilising shear connectors in the published literature. Kwon et al. [10] successfully utilised post installable bolted shear connectors to rehabilitate existing non-composite bridges. The author used a type of friction grip bolt and double embedded nut shear connector in the investigation. These bolted connectors were also standard nut and bolt assemblies. Installation of these connectors required access from both the top and bottom sides of the beams. Mirza et al. [11] carried out push-test experiments involving bolted connectors. The authors used the same bolt types discussed in this paper. The experimental results have highlighted that these bolting systems demonstrate comparable behaviour and capacity to welded headed stud shear connectors.

The ability of these connectors to achieve composite action in retrofitted composite beams was experimentally investigated by using full-scale beam specimens herein. The beam specimens were tested under static flexural loading. The slip response of the connectors under retrofitted and normal conditions was also studied by carrying out push-test experiments based on Eurocode 4 [12]. The ultimate design loads of the test beams were calculated based on the rigid plastic analysis (RPA) method using the material properties derived from standard tests. The retrofitted beams were simulated using Finite Element (FE) models developed in ABAQUS. The two blind bolt types used in this study are illustrated in Figs. 1 and 2.

2. Methodology

Seven full-scale beam specimens including three composite beams and four non-composite beams were constructed together. The three composite beams namely CWS-ST, CBB1-ST and CBB2-ST referred to as normal beams utilised the connector types WS, BB1 and BB2 respectively. Three non-composite beams were retrofitted using these connector types after 28 days. The connectors were attached to the beams

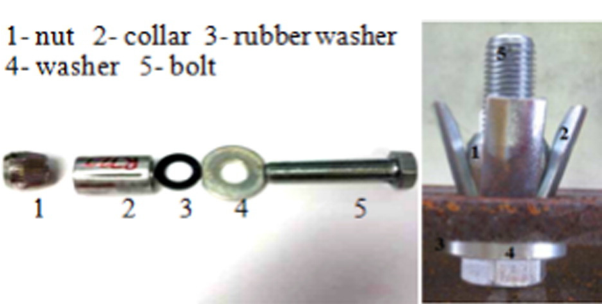

Fig. 1. Blind bolt 1, BB1.

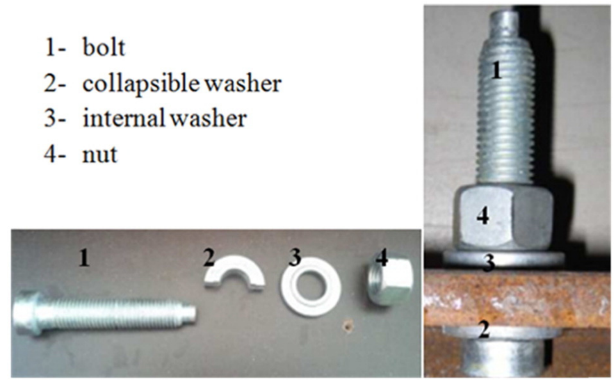

Fig. 2. Blind bolt 2, BB2.

through holes created in their concrete slabs and the steel beams. These holes were back filled using non-shrink structural grout. These beam specimens referred to as the retrofitted beams CWS-RT, CBB1-RT and CBB2-RT, utilised WS, BB1 and BB2 connectors respectively. The beam specimens were tested under static flexural loading condition. The load-midspan deflection curves obtained from these test specimens were used to study and compare the behaviour of these beams.

In addition, a series of companion push-test experiments using these connectors was also carried out based on the Eurocode 4 [12] to study the local behaviour and capacity of these connectors under both the normal and retrofitted conditions. Altogether six push-test specimens were tested. Three push-test specimens namely PWS-ST, PBB1-ST and PBB2-ST referred to as normal specimens utilized the connector types WS, BB1 and BB2 respectively. Another three push-test specimens were retrofitted using these respective connector types. These three push-test specimens namely PWS-RT, PBB1-RT and PBB2-RT are referred to as retrofitted push-test specimens throughout the paper. The load-slip characteristics of these test specimens were analysed to evaluate the local behaviour of the connectors in relation to their stiffness, strength and ductility.

Three dimensional nonlinear FE models were developed using ABAQUS to simulate the retrofitted beams. Material behaviour of the concrete and grout used in the test specimens were specified with damage parameters using the CDP option available in ABAQUS. The FE models were validated using the load-midspan deflection results of the test specimens. The effects of the concrete and grout strength, size of the grout-hole and also the shear connection ratio of the retrofitted composite beams on their flexural behaviour was investigated using the validated FE models.

3. Experimental program

The experimental program using the full scale test specimens and push-test specimens is discussed in detail in this section.

3.1. Details of the full-scale beam specimens

The beam specimens were designed to represent a secondary beam in high rise office building floors. Fig. 3 illustrates the typical geometry of the test specimens. The main components of the beam that include the concrete slab and the steel beam were designed in accordance with AS 3600 [13] and AS 4100 [14] respectively. The composite design was carried out in accordance with AS 2327.1 [15] by following the load requirements given in AS 1170.1 [16]. Details of the beam specimens are provided in Table 1. The beam specimens were designed as partially composite beams to keep the connector requirement for retrofitting process a minimum. AS 2327.1 [15] specifies a lower limit of 50% shear connection ratio for the shear connection capacity for building floor designs. Therefore each composite beam was provided with