Journal of Constructional Steel Research 125 (2016) 61–73

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Bolted and welded connectors for the rehabilitation of composite beams

Sameera Wijesiri Pathirana [a,*], Brian Uy [a], Olivia Mirza [b], Xinqun Zhu [b]

[a] Centre for Infrastructure Engineering and Safety, The University of New South Wales, Kensington, NSW, 2052, Australia
[b] Institute for Infrastructure Engineering, University of Western Sydney, Penrith, NSW, 2751, Australia

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form 1 June 2016
Accepted 6 June 2016
Available online 17 June 2015

Keywords:
Composite beams
numerical analysis
push-test
retrofitting
bridges
buildings
steel structures

ABSTRACT

Recent research studies revealed that blind-bolts can be used to strengthen existing composite steel-concrete beams more efficiently and effectively than welded stud connectors. In the general retrofitting operation procedure, the holes created in the concrete slab of composite beams to fix shear connectors are finally backfilled with grout. However, it is clear from a review of the open literature that very few studies have been conducted on the behaviour of shear connectors in grout in retrofitted composite beams. This paper investigates the load-slip behaviour of blind-bolt and welded stud connectors in grout under retrofitted conditions both experimentally and numerically. A series of push-out test experiments was carried out based on the Eurocode 4. The behaviour of retrofitted push-out test specimens during the testing was simulated using Finite Element (FE) models. The concrete and grout properties were modelled by specifying damage criteria using the concrete damage plasticity (CDP) option available in ABAQUS. The effects of height:diameter ratio of the connectors and grout strength on the shear capacity of blind-bolt and welded stud connectors were verified using parametric FE analyses. A modified design equation was proposed to estimate the ultimate shear capacity of bolted connectors in grout. The shear connector properties such as shear resistance, stiffness, ductility and failure modes have been compared and discussed in detail by using the experimental and FE results. These results provide an extended understanding of the feasibility of utilising blind-bolts for retrofitting substandard composite beams.

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 affect 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]. Nevertheless, the useful life of existing substandard composite steel-concrete beams of these structures can be extended by retrofitting them with shear connectors. Pathirana et.al [2] recently tested the flexural behaviour of composite steel-concrete beams retrofitted with blind-bolts and welded-stud connectors. The results of this research study revealed that blind-bolt connectors demonstrated a great ability to achieve composite action in the retrofitted beams.

In the general retrofitting operation procedure, shear connectors are attached to the steel beams of composite beams through holes created in their concrete slabs. The holes are then backfilled with a grout material whose mechanical properties are usually different from those of the pre-existing slab concrete. As a result, the behaviour of these shear connectors in grout in the retrofitted composite beam can be expected to be different compared with their behaviour in concrete in normal composite beams. However, it is clear from a review of the open literature that very few studies have been conducted on the behaviour of shear connectors in grout in retrofitted composite beams. Therefore, this paper investigates the behaviour of blind-bolt and welded stud connectors both in normal concrete and grout using push-out test specimens.

Welded stud connectors have become the most popular type of mechanical shear connector used in composite floor systems in the construction industry. The availability of detailed research [3–7] 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. Generally, in rehabilitation methods shear connectors may need to be attached through holes cored in the concrete slabs of composite beams. Because of this, welding the shank of welded stud connectors to the steel beam inside these holes can be a very difficult and time consuming process. However, this welding issue can't be simply addressed by using ordinary nut and bolt connectors as they cannot be fixed from one side of a structure. In contrast, blind-bolt connectors that can be attached from one side of a structure. Their fixing mechanisms enable more efficient and effective rehabilitation of composite beams using blind-bolts.

* Corresponding author.
E-mail address: i.wijesiripathirana@student.unsw.edu.au (S.W. Pathirana).

http://dx.doi.org/10.1016/j.jcsr.2016.06.003
0143-974X/

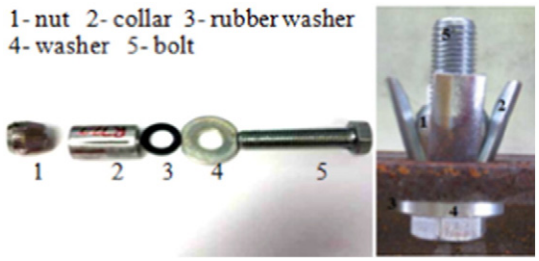

Fig. 1. Blind bolt 1, BB1.

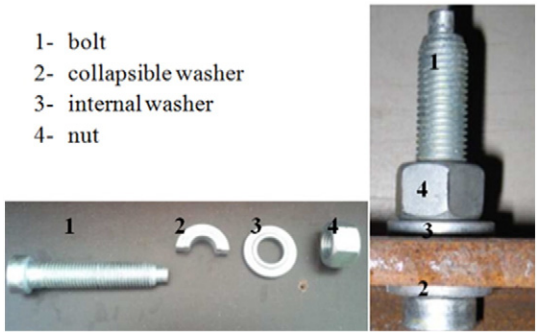

Fig. 2. Blind bolt 2, BB2.

The two bolt types used in this study are referred to as BB1 and BB2 in this paper. Both are M20 - grade 8.8 type bolts. These bolt types are illustrated in Figs. 1 and 2. The ability of being attached and detached from one side of a structure is one of the main advantages of these bolting systems that can be exploited to retrofit composite beams.

In general, due to the lack of detailed research and design guidelines, bolted shear connectors have not been 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 [8] and Pavlović et al. [9] 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 with welded stud connectors. Moynihan and Allwood [10] 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 that of composite beams with welded shear studs. The feasibility of using the bolted connectors to retrofit steel-concrete beams was not investigated in this research study. However, limited research could be found in relation to the rehabilitation of composite steel-concrete beams utilising shear connectors in the published literature. Kwon et al. [11] 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. The behaviour of these connectors in grout under the retrofitted condition was not essentially investigated in this research work. Mirza et al. [12] carried out push-test experiments involving blind-bolts for the first time. The same blind-bolt types were used in this study. The experimental results have highlighted that these bolted connectors demonstrate comparable behaviour and capacity to welded headed stud shear connectors.

Based on the above mentioned literature review, it was found that the research publications concerning the behaviour of shear connectors in structural grout of retrofitted composite beams is extremely rare. Therefore, the behaviour of bolted and welded-stud connectors in grout was further investigated for push-out test specimens retrofitted with blind-bolt (BB1 and BB2) connectors and welded-stud connectors and their behaviour in grout and in normal concrete was compared. To achieve this aim, the push-out tests were carried out in accordance with Eurocode 4 [13].

In addition, the behaviour of the retrofitted push-test specimens during testing was simulated using three-dimensional finite element (FE) models. In particular, the behaviour of the concrete and grout were modelled by specifying damage criteria using the concrete damage plasticity (CDP) option in ABAQUS FE software. The models were validated from the load–slip behaviour determined for the respective test specimens. The validated models were later applied to parametric studies to verify the effects both of the height:diameter ratio of the connectors and the grout strength on the ultimate shear strength of the BB2 and welded-stud connectors.

Further analyses using these parametric results revealed that the equation given in AS 2327.1 [14] for estimating the nominal shear capacity of bolted connectors in grout, which assumes grout failure, does not accurately predict the shear strength attained when BB2 connectors are used. Therefore, based on the results parametric analysis, a modified design equation is proposed for estimating the nominal ultimate capacity of BB2 connectors in grout. It is suggested that these findings may provide an important basis and guidance for the use of bolted connectors in retrofitting composite beams.

2. Push-tests

The behaviour of the blind-bolt and welded stud connectors in normal concrete and grout was investigated using two types of push-out

Table 1
Specimen details, concrete & grout properties and test results.

Specimen label	Connector type	Test type	Compressive strength (MPa)		Elastic modulus (MPa)		Test results				
			Concrete	Grout	Concrete	Grout	S_{ult} (mm)	f_{ult} (kN)	f_{vs} (kN)	f_{ult}/f_{vs}	Failure mode
WS-ST1	WS	N	42	–	31000	–	6.7	119	93[1]	1.28	sw
WS-ST2							6.0	121	93[1]	1.30	sw
WS-RT1	WS	R	45	28	35000	18000	13.8	109	78[2]	1.37	cf
WS-RT2							10.6	105	78[2]	1.33	cf
BB1-ST1	BB1	N	42	–	31000	–	1.9	126	126[1]	1.00	cf
BB1-ST2							0.7	107	126[1]	0.85	cf
BB1-RT1	BB1	R	45	34	35000	20000	2.1	122	95[2]	1.29	cf
BB1-RT2							2.2	105	95[2]	1.11	cf
BB2-ST1	BB2	N	42	–	31000	–	11.6	123	126[1]	0.98	bf
BB2-ST2							8.8	109	126[1]	0.87	bf
BB2-RT1	BB2	R	45	46	35000	23600	6.1	122	124[2]	0.98	bf
BB2-RT2							10.2	131	124[2]	1.06	bf

*N- normal test condition; R- retrofitted test condition: [1] – Eq. (1); [2] – Eq. (2).
*stud-weld failure – sw, concrete failure –cf, bolt shear failure - bf.