Engineering Structures 103 (2015) 298–307

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Dynamic behaviour of steel–concrete composite beams with different types of shear connectors. Part I: Experimental study

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ARTICLE INFO

Article history:
Received 4 November 2014
Revised 19 August 2015
Accepted 20 August 2015
Available online 16 September 2015

Keywords:
Dynamic response
Composite beam
Uncertain boundaries
Full-beam testing

ABSTRACT

In civil engineering, composite construction has become increasingly widespread due to the improvement of mechanical properties it provides. Recently, research on the development of post installed or retrofitted shear connectors has been conducted. The benefits of this are the ease of installation and the ease of removal for decommissioning structures at the end of their life. Most of the research in this area is concerned with modified versions of welded shear studs or various threaded rod and nut configurations and refers to only one type of shear connector. Therefore, the suitability of the proposed models across differing shear connection types is unknown. In the first of two companion papers an experimental study has been undertaken to ascertain the dynamic behaviour of identical steel–concrete composite beams with differing shear connection systems. Two blind bolt connector types were used as shear connection systems in steel–concrete composite beams. Alongside these, a welded shear stud specimen, and a non-composite specimen were tested for comparison.

1. Introduction

Composite construction is a term which refers to two or more construction elements joined in such a way as to best leverage each elements mechanical properties. The mechanical behaviour, and therefore modal properties, of a composite beam depend on the bond between the two construction elements. In steel–concrete composites the bond between the steel and concrete is usually achieved using a welded shear stud. The mechanical properties of the shear connectors used, and the spacing between connectors, determines the degree of shear connection. Usually partial shear connection and interaction results due to space constraints rising from the placement of a discrete number of shear connectors in a given space. The first contribution to modelling of partial interaction in composite beams was proposed by Newmark et al. [1]. This model was based on the Euler–Bernoulli beam theory, as such the model and its subsequent derivatives neglect the transverse shear deformation of the construction elements. This leads to over predicting the mechanical and modal properties of the steel–concrete composite beam. This problem is compounded as the aspect ratio of the beam is decreased and the beams resemblance to a one dimensional model is diminished. Improvements over the Euler–Bernoulli method can be made using Timoshenko beam theory which has a first order approximation to the shear deformation, or a higher order beam theory where a non linear approximation to the shear deformation is made. Much research has been conducted to define models on these approaches to match experimental results. Some examples of theoretical models matched to experimental results can be found in references [2–7].

A majority of the work on dynamics of steel–concrete composite beams to date has been conducted on specimens where the shear connection is formed using welded shear studs. However, the welded shear stud has some disadvantages in the manufacturing process. The most obvious being the need for an additional contractor to perform the welding. As a corollary to this, specific quality testing procedures are required after welding in accordance with Australian Standards [8]. Alternatives to the welded shear stud are available. Recently, researchers such as [9–13] have conducted research on the development of post installed or retrofitted shear connectors. Most of the research in this area is concerned with modified versions of welded shear studs or various threaded rod and nut configurations. The benefits of these arrangements are ease of installation and ease of removal for decommissioning at the

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http://dx.doi.org/10.1016/j.engstruct.2015.08.035
0141-0296/

List of symbols

f	frequency (Hz)
f'	compressive strength
$\bar{x}$	mean
yE	experimental modal vector value
A	cross section area
B_i	bending mode i
E	Young's modulus
I	inertia
K	shearing stiffness value
L	length of the beam
P_{xx}	auto power spectral density
P_{xy}	cross power spectral density
P_{rk}	load carrying capacity
T_{xy}	average estimated transfer function
η	damping coefficient
ρ	density
σ	standard deviation
ω	frequency (Rad/s)
$()_0$	vector maximum value
$()_1$	related to concrete section
$()_2$	related to steel section
$()_{eq}$	equivalent
$()_n$	related to natural frequency

end of the life of structures. Sustainability has become increasingly important in civil engineering. Saving materials by achieving composite action in new structures has become increasingly commonplace with much research being conducted on welded shear studs such as [14]. However, with finite resources and expensive construction costs repurposing construction materials or rejuvenating existing structures has become of great interest. This can be achieved by using removable shear connection systems.

It is evident that for the advancement of research in retrofitting and demounting structures, new innovative anchors must be found which are suitable for the purpose. Recently, the authors have developed works based on shear connection systems using innovative anchors, [15–17]. The concrete-steel composite action is achieved with the use of blind bolts to connect structural steel beams to concrete slabs. The blind bolts under consideration can be undone once fitted this makes them suitable for use in both new construction and for where existing steel infrastructure is being rehabilitated. The use of blind bolts in new construction will enable buildings involving multiple dissimilar materials to be connected and will also facilitate the deconstruction of steel structures. The use of blind bolts will also mean easier remediation where steel members may be in jeopardy of fatigue failure in existing infrastructure.

A majority of the research on post installed or retrofitted shear connectors refers to only one type of shear connector. Therefore the suitability of the proposed models across differing shear connection types is unknown. An experimental study has been carried out on a series of full-scale steel–concrete composite beams. The series comprised of three steel–concrete composite specimens and a non composite specimen for comparison. The composite specimens were designed with partial shear connection of approximately 70–80%. This is achieved with the use of three different shear connection types. The steel–concrete composite specimens were accompanied by a set of push tests designed according to [18]. Concrete cylinder tests for compressive strength f'_1 and Young's modulus E_1 were also undertaken. The major objective of the experimental series was to discern the suitability of, and differences between, the shear connection types. To this end all four full-scale steel–concrete beam specimens, accompanying push tests, and concrete cylinders were poured from the same concrete batch. This approach was taken to ensure similar material properties across the experimental series. The specimens were then subjected to vibration based testing methods as these have been widely used in the assessment of civil engineering structures. Summary reviews of the history and varying techniques in the field are available in texts such as [19,20]. Presented in this section are the details of the shear connection types, push tests, material tests, experimental specimens, and their collective results.

2. Materials and methods

2.1. Shear connection types

Fig. 1 illustrates the three different types of shear connectors used in this study. Fig. 1(a) shows a 100 mm M20 8.8 blind bolt fastener referred to as the BB1 type connector hereafter. Fig. 1(b) and (c) show the second blind bolt connector in both closed and open configurations. This works by having a collar that spreads open when the bolt is secured. From here on this connector is known as the BB2 type. Fig. 1(d) shows the conventional welded shear stud that is being tested as a comparison to the BB1 and BB2 type shear connectors. The shear stud connected beam will be referred to as SS from here on. The non composite specimen was used to further illustrate the performance improvements of the shear connected specimens and is hereafter referred to as the NC specimen.

There are some practical considerations when choosing between the BB1, BB2, and SS connection types. Fig. 2(a) shows the required tooling for fitting the BB1 type connector. (A) specialised tool for fitting, (B) the bolt, (C) a folding washer, (D), a solid washer, and (E) the nut. Parts (E), (D), and (C) are placed onto (A) in the order listed. There is a specialised fitting on the threaded end of the bolt which allows this to be joined to the fitting tool (A). The whole assembly can then be fitted from one side of a bolt hole. By contrast the BB2 type connector shown in Fig. 2(b) is supplied ready to be fitted with no assembly required apart from bolt tightening. The SS connector is an industry standard for developing composite action. However, fitting the connector requires welding equipment and suitably qualified tradespeople followed up by quality assurance procedures according to Australian Standards [8]. This makes the SS type connector the most complex to fit.

2.2. Materials

The material tests for the experimental series consisted of concrete cylinders and steel coupon tests. The steel 460UB 74.6 sections used for the push tests and full-scale specimens came from the same manufacture. To test the properties of these sections a series of coupons were taken from the flanges and the webs. The values of Young's modulus E_2, and density ρ_2, gained from the steel coupon tests were found to be almost identical to the generally accepted values for steel of $E_2 = 210{,}000$ MPa and $\rho_2 = 7800$ kg/m^3, therefore the standard values will be used hereafter. The concrete cylinders were poured from the same batch of concrete as the push tests and full-scale beams specimens and stored in the same conditions to ensure comparable material properties. The cylinders were 100 mm diameter and 200 mm in length. Three of the