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Flexural performance of innovative sustainable composite steel-concrete beams

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ABSTRACT

Composite beams comprising of concrete slabs and steel beams joined by conventional headed stud shear connectors are commonly used in modern steel-framed building construction. However, because the headed stud shear connectors are welded onto the top flange of the steel beam and cast into the *in situ* concrete slab, deconstruction of the composite beam and the reuse of its components at the end of structural life in defence to demolition is virtually impossible, which is at odds with the increasing demands placed on improving the sustainability of building infrastructure. As an alternative, an innovative sustainable composite beam and slab system is proposed, in which precast geopolymer concrete panels are attached to the steel beams using high-strength friction-grip bolts instead of cast *in situ* floors with pre-welded headed stud connectors. The advantages of a low-carbon design, both by the use of geopolymer concrete elements and system deconstructability, can be achieved in this proposed system. In this paper, a three-dimensional finite element model is developed to investigate the structural behaviour of the proposed sustainable composite beam and slab system. Material non-linearities and the interaction of the structural components are included in the model. The accuracy and reliability of the finite element formulation developed are validated by comparisons with experimental results. Extensive parametric studies are conducted to elucidate the effects of the change in the concrete panel configuration, the number and diameter of the bolts, the type and strength of the concrete and the grade of the steel beam on the behaviour of the system. The use of modified rigid plastic analysis is assessed, and a modification is suggested to predict the flexural strengths of the composite beams and slab system.

1. Introduction

Composite steel-concrete flooring systems formed by connecting concrete slabs cast *in situ* to supporting steel beams have been widely used in modern frame buildings for decades throughout the world. In such composite beams, mechanical shear connectors are generally used to provide the essential shear transfer at the steel-concrete interface by connecting the concrete slab and the steel beam to ensure effective composite action. The most widely used mechanical shear connector is the headed stud shear connector (type (a) in Fig. 1), since this type of shear connector can provide robust and ductile shear connection and can be easily installed [1].

In recent years, issues related to sustainability and full life-cycle assessments in building construction and usage have become increasingly important. The use of conventional headed stud shear connectors that have to be welded to the flange of the steel beam section and cast into the concrete slab becomes a barrier to the use of composite construction in this evolving paradigm, as they make building deconstruction very energy-consuming and environmentally unfavourable, with the reuse of the components being almost impossible. Accordingly, bolted shear connectors as shown in Fig. 1 are advocated as an alternative to replace headed stud shear connectors in composite beams, in order to facilitate deconstructability [2,3]. However, in contrast to the abundant research findings and design guidance to be found on composite beams with welded headed studs, counterpart research and design rules on composite beams with bolted shear connectors are quite limited. Research on bolted shear connectors appears to be first reported by Dallam [4] over four decades ago. Following this, Marshall et al. [5] conducted experiments to study the use of high-strength friction-grip bolting to provide the shear connection between the concrete slab and steel joist in a composite beam. More recently, Kwon et al. [6–8] studied post-installed bolted shear connectors used to strengthen existing non-composite bridge beams, and investigated their performance under static and fatigue loading. Chen et al. [9] focused on using through-bolt shear connectors for the accelerated con-

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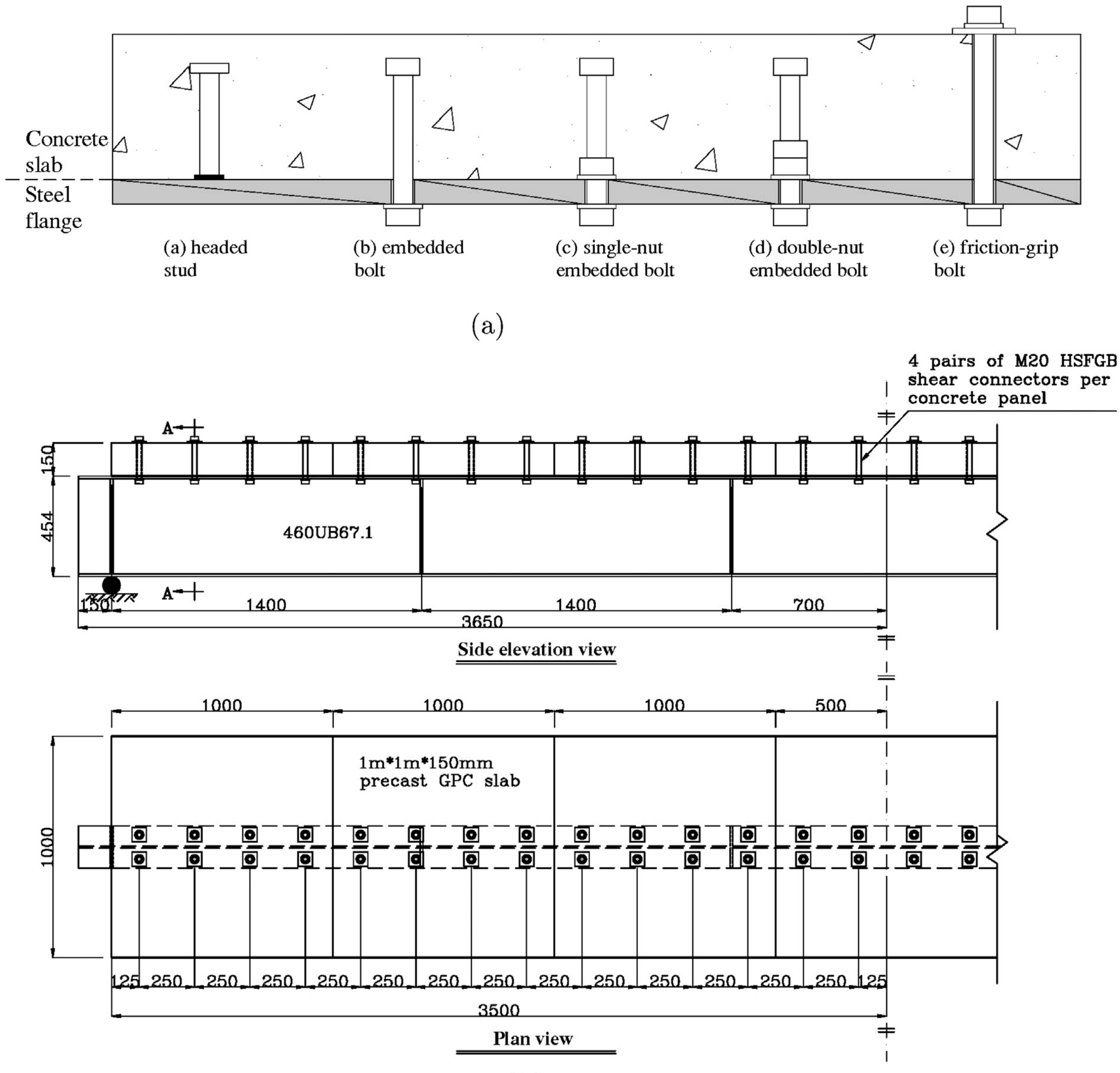

Fig. 1. Bolted shear connectors.

struction of composite bridges, while Pavlovic et al. [10] and Moynihan and Allwood [2] performed push-out tests and composite beam tests respectively to investigate the behaviour of single-nut embedded bolts used as composite connectors for modern buildings. Dai et al. [11] developed a new form of demountable shear connector that is similar to the embedded bolt shear connector and tested their shear resistance and feasibility in composite construction.

Ordinary Portland cement (OPC) has been used as a paste to produce concrete for a great many years. However, the manufacture of OPC is a high-pollution process; it is estimated that the production of 1 tonne of OPC emits 1 tonne of CO_2 into the atmosphere [12]. It is therefore desirable in low-carbon technologies to use alternative low-emission binding agents to replace OPC in concrete, and geopolymers such as fly ash (a coal combustion by-product) and granulated blast furnace slag are waste materials that can be used to produce geopolymer concrete (GPC) [13]. GPC using geopolymers as binders not only has a smaller carbon footprint, but it also has excellent compressive strength, superior durability as well as small shrinkage deformations, making it suitable for structural applications [14]. However, GPC is not quite as readily batched on-site or is as workable by comparison to OPC-concrete, and so its use in precast applications is an important research issue [15]. With the use of high-strength friction-grip bolt (HSFGB) shear connectors (type (e) in Fig. 1), precast GPC slabs have potential application in a sustainable and low-carbon composite structural system. Such a composite beam is shown in Fig. 2, embodying reduced-emissions concrete and steel components in its construction and providing for deconstructability at the end of its service life through unbolting the shear connectors.

Previous research has been carried out by Liu et al. [16] to simulate the behaviour of HSFGB shear connectors in the proposed sustainable composite beam application experimentally using push-out tests and numerically using the finite element method. The load-slip characteristics and the ultimate strength of shear connection achieved using HSFGB shear connectors and precast GPC slabs were studied in this work. This paper takes the next step in developing an accurate and reliable three-dimensional finite ele-