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Performance of Partially Encased Composite Beams Under Static and Cyclic Bending

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ABSTRACT

This paper reports an experimental study on structural performance of partially encased composite (PEC) beams under monotonic and cyclic loadings. A total of nine specimens are tested, covering various link details, beam lengths, and loading schemes. The test results show that the specimens generally fail by fracture of the beam flange accompanied by local flange buckling and damages to the links and concrete. The plastic moment capacity of the composite section is exceeded for all the test specimens. The influences of link spacing and link types on the moment capacity are limited. Compared with the case of pure bending, higher moment capacities can be achieved when the specimens are under combined bending-shear action with a moderate shear span ratio of 3.0. For the specimens with a reduced shear span ratio of 1.5, the factors affecting the peak load are more complex, involving concrete damage, local flange buckling, and shear buckling of the beam web. For stiffness, Eurocode 4 is shown to provide reasonable, but overestimated predictions for the initial stiffness of the specimens, revealing the potential different flexural behaviour between the PEC columns and PEC beams. The specimens also showed good ductility under both monotonic and cyclic loadings, and the cross section classification recommended by Eurocode 4 tends to be conservative. The specimens under cyclic loading show very good energy dissipation capacities with equivalent viscous damping up to 49%.

1. Introduction

Partially encased composite (PEC) members are a class of efficient composite structural members that include an I-shaped steel section (either hot-rolled or built-up) infilled with concrete between the flanges. The concrete part is normally strengthened by longitudinal reinforcements and stirrups in conjunction with a series of shear studs or links (tie bars) connecting the opposing flanges. Compared with normal concrete members or fully encased composite members, PEC members only require formworks for two sides, a case which significantly reduces the construction demand. In addition, the presence of the concrete infill between the steel flanges could effectively mitigate the risk of local and global buckling, and contributes to the overall capacity of the member. Due to the constraining effect brought by the concrete infill, the use of non-compact built-up steel sections may become practical, leading to more economical design solutions. Concurrently, the steel plates also play an important role in confining the concrete infill, and thus the occurrence of damage to concrete may be postponed. Furthermore, PEC members could have better fire resistance performance than bare steel members. These advantages have led to wide applications of PEC members in modern construction.

A number of investigations have been carried out to examine the structural performance of PEC members, where PEC column is one of the most commonly considered member types. Elnashai et al. [1] carried out six tests looking into the cyclic performance of PEC columns, where it was found that the ductility and strength of the columns were closely related to the column load ratio. Hunaiti and Fattah [2] conducted monotonic eccentric axial loading tests on 19 PEC columns, and showed that the shear connectors brought no benefit to the loading capacity, and the final failure mode was mainly governed by local flange buckling and concrete crushing. Elnashai and Broderick [3] examined the cyclic performance of four PEC columns, and found that the capacity of the PEC columns with only transverse links was slightly less than those with additional reinforcing bars, but in general the difference was marginal. Towards more economical and efficient design, especially for middle rise building frames, the performance of PEC columns with slender steel cross-sections have also received great attention [4–7], where particular interest has been given to their seismic resistance. A common finding was that the local buckling capacity of the slender built-up steel columns was effectively increased due to the partial concrete infill, and the member capacity was also influenced by link spacing. Finite element analysis [8–9] was also conducted to provide further insight into the failure response of these members.

Apart from PEC columns, the bending behaviour of PEC beams have also been studied, although the available test data are relatively limited.

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Kindmann and Bergmann [10] conducted an experimental study on 12 PEC beams, and discussed the bending resistance, shear resistance, deformability, and bond-slippage behaviour between steel and concrete. The test results indicated that the concrete could contribute to the overall load capacity of the PEC beams, and the addition of longitudinal reinforcements and stirrups could effectively confine the concrete infill. Assi and Abed [11] examined the potential of using light weighted concrete for PEC beams through conducting 12 tests. It was observed that the stiffness and loading capacity of PEC beams were evidently higher than the bare steel beam counterparts. However, the influence of concrete type seemed to be marginal, although it was claimed that the use of light weighted concrete could be more economical. Continuous PEC beams were recently studied [12], where the concrete infill, exhibiting a slow crack propagation process, was found to help postpone the initiation of beam flange yielding. The shear capacity of PEC beams have also been investigated [13–14], and the benefits from the concrete were confirmed.

It can be seen from the above literatures that continuous research progress has been made on the structural performance of PEC members, and some design rules have also been stipulated [15]. However, there is insufficient information on the combined bending-shear performance of PEC beams, a scenario which is more common (compared with the case of pure bending) for beams in real practice. In addition, the cyclic behaviour of PEC beams was also not fully understood. In light of this, this paper sheds light on the strength and failure behaviour of PEC beams subjected to combined bending-shear actions, and for comparison purposes, the beams under pure bending action are also studied. Cyclic tests are further carried out to understand the seismic performance of the PEC beams under both combined bending-shear and pure bending actions. A detailed discussion is finally made in terms of strength, stiffness, ductility, and energy dissipation capacity of the PEC beams, and some comments are also made on the current design rules for PEC members.

2. Test programme

2.1. Test specimens

A total of nine specimens were tested, where the main parameters included link type, link spacing, beam length, and loading scheme (monotonic or cyclic). The basic geometric configurations of the specimens are shown in Fig. 1(a) and are summarised in Table 1. The specimens were designed with the following considerations: 1) Early local buckling of the compressive flange of the steel cross-section should be avoided prior to yielding; 2) links (tie bars) were employed to mitigate local flange buckling and to offer confinement to the concrete; 3) the normal or inclined section cracking resistance of the concrete may be improved due to the presence of the links. Each specimen was comprised of the main part of beam and two end-plates welded to the ends of the beam. Stiffeners were also adopted to strengthen the

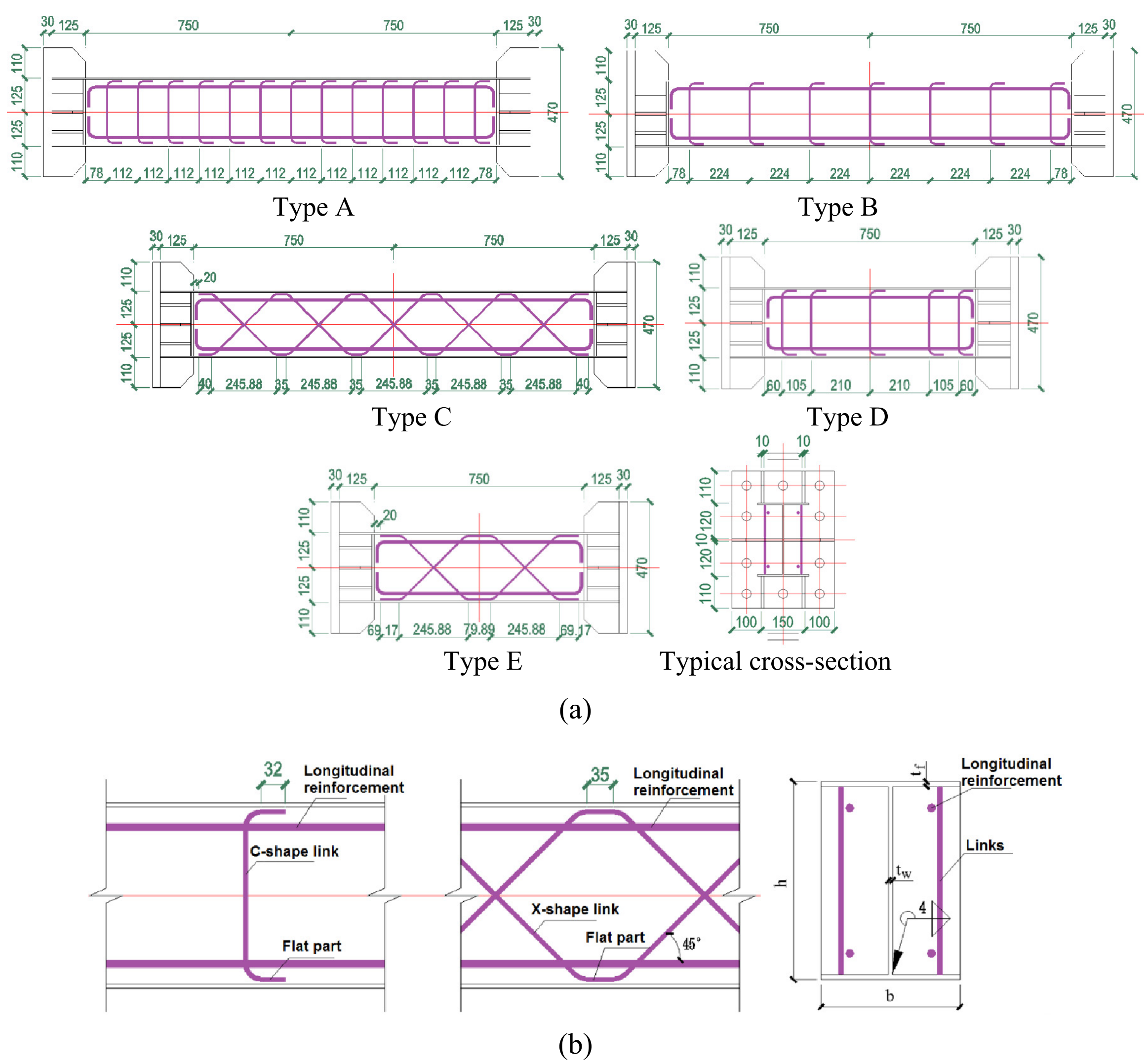

Fig. 1. Test specimens: a) geometric configurations, b) details of links.