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Structural performance of rigid shear connectors in concrete encased steel composite columns

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Abstract

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Concrete encased steel (CES) composite columns possess a wide variety of advantages in constructing concrete-steel composite frames. In order to achieve the composite behaviour of these columns, it is necessary to transfer the force between steel and concrete, effectively. Therefore, shear connectors should be used on the contact surface between concrete and steel. In this research, behaviour of the rigid shear connectors in CES composite columns is numerically studied. The results – obtained from the finite element analysis – were validated against the experimental results. Afterwards, parametric studies were conducted to investigate the effective parameters on the behaviour of the rigid shear connectors. The results show that the length, the thickness and the penetration depth of the shear connector, the compressive strength of concrete and the thickness of concrete cover have a noticeable effect on the strength and stiffness of the shear connector. Moreover, increasing the length and the penetration depth of the shear connector, and the thickness of the concrete would increase the residual strength level. In general, the rigid shear connector is mobilized under a much smaller slippage

stiffness of the shear connector. Moreover, increasing the length and the penetration depth of the shear connector, and the thickness of the concrete would increase the residual strength level. In general, the rigid shear connector is mobilized under a much smaller slippage (between concrete and steel), as compared to the stud shear connector, and provides greater stiffness and strength. Moreover, due to being encased in reinforced concrete, it can also provide sufficient ductility. Finally, based on the parametric studies, a formula is suggested to predict the ultimate shear capacity of the rigid shear connector in the CES composite columns.

Introduction

Regarding technical and economic issues, concrete-steel composite sections have been highly considered in order to construct high-rise buildings. CES composite columns are one of the most significant composite sections that provide higher strength and stiffness than conventional steel or reinforced concrete columns. To ensure the composite performance of these sections, it is necessary to properly distribute the force between concrete and steel. In this sense, mechanical shear connectors are commonly used to increase the amount of force distributed in the interface of concrete and

columns. To ensure the composite performance of these sections, it is necessary to properly distribute the force between concrete and steel. In this sense, mechanical shear connectors are commonly used to increase the amount of force distributed in the interface of concrete and steel. Shear connectors can be divided into two categories, i.e. ductile and rigid connectors. Previously, in railway bridges, rigid shear connectors were used with a hoop to prevent the uplift of the concrete deck [1]. Considering earthquakes, when structure is subjected to heavy forces, the concrete deck is easily uplifted from its place and, then, separated from the shear connector due to the low penetration depth of the shear connector in the concrete and the lack of sufficient containment. Due to the poor behaviour of these composite beams and slabs, the rigid shear connector gradually gives way to the ductile shear connector. Currently, a wide range of ductile shear connectors; including, stud, C-shaped, L-shaped and Perfobond shear connectors are used in concrete-steel composite components.

Stud shear connectors are widely used in composite beams and slabs. Loading conditions [2], [3], material strength [4], stud dimensions [4], deck profile [5] and various connector arrangements [6], [7] mainly affect the behaviour and resistance of stud shear

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A wide variety of numerical and laboratory studies has also been carried out on C-shaped and L-shaped shear connectors and, accordingly, the resistance of these shear connectors was evaluated regarding different types of high-strength and fiber-reinforced concretes [9], [10], [11] and under different angles [12], [13], [14]. Moreover, different relations were presented in order to predict the shear capacity [15].

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According to a research conducted on the concrete-filled tubes (CFT), the use of angle shear connectors, bolted shear connectors and different patterns of stiffeners, led to a reduction in slippage between the concrete and the steel and improved the axial load-bending moment interaction capacity, stiffness, and energy dissipation capacity [16], [17], [18], [19]. Furthermore, the results indicated that the angle shear connector had greater stiffness, less slippage and more load capacity, as compared to the stud [19].

The conducted study on the shear connectors in the composite beam-column-brace connection area showed that the amount of slippage between concrete and steel was not enough to mobilize the stud shear connector [20]. Recently, rigid shear connectors were used in the connection area between the steel beam and the reinforced concrete column (Fig. 1) [21], [22] and also in the connection area of steel beam to the CFT column (Fig. 2) [23], [24], [25], [26] and, the connection behaviour was investigated experimentally. The results showed that the amount of slippage measured at the steel–concrete interface during the loading process was very small (less than 1 mm) and the rigid shear connectors had enough stiffness and strength to transfer loads

[21], [22] and also in the connection area of steel beam to the CFT column (Fig. 2) [23], [24], [25], [26] and, the connection behaviour was investigated experimentally. The results showed that the amount of slippage measured at the steel–concrete interface during the loading process was very small (less than 1 mm) and the rigid shear connectors had enough stiffness and strength to transfer loads without significant slippage. In addition, the first author investigated the behaviour of rigid shear connector in concrete-filled steel box experimentally and numerically. The results of this research indicated that the rigid shear connector was able to transfer high level of force in small slippages [27].

The aforementioned shear connectors have some specific restrictions and advantages, regarding fabrication, installation or structural behaviour, which justify their use in different composite components. Regarding CES composite columns, it is necessary to note that the concrete and steel work together without significant slippage, especially, in the area of the beam-to-column connection where a high level of shear stress must be transferred between the concrete and the steel. Moreover, because CES composite columns include concrete, steel profile and longitudinal and lateral reinforcements, the use of shear

concrete, steel profile and longitudinal and lateral reinforcements, the use of shear connectors with small dimensions and less number is preferred. Herein, based on the required characteristics, the use of rigid shear connectors in CES composite columns was numerically investigated. Considering CES composite columns, because the shear connectors are encased in reinforced concrete, the shear connectors cannot separate from the concrete and, accordingly, the rigid shear connector can provide high resistance and stiffness. Significantly, the increase in strength continues until failure occurs in the concrete. In this sense, the present study aims at investigating the structural behaviour of rigid shear connectors; including, shear capacity, stiffness, ductility and failure modes under the effect of some specific parameters such as length, width and thickness of shear connectors, concrete strength and thickness of the concrete cover on shear connectors. Finally, a formula is proposed to predict the ultimate shear capacity of the rigid shear connector in the CES composite column.

Section snippets

Objectives and scope of work

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The composite performance of CES composite columns depends on the effective transfer of force between the encased steel profile and the concrete. Herein, rigid shear connectors are intended to be used in the load-transfer in the steel–concrete interface. Considering the fact that a new application is proposed here, a comparison was made with stud shear connector as a ductile shear connector in order to show the advantages of using this type of shear connector in CES composite columns.

Since…

Finite element modeling

Due to the high cost of experimental tests, extensive numerical studies have been conducted to investigate the behaviour and determine the resistance of shear connectors [28], [29], [30], [31]. In this sense, the finite element program ABAQUS was used to consider geometric and material nonlinearity, large deformations and damage of concrete.

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In this study, the models were simulated using static analysis in ABAQUS/Standard. In order to obtain correct and accurate results from numerical models, it …

Verification

Regarding the present research, rigid shear connections were installed on a steel profile enclosed in reinforced concrete. The specimens examined in this research do not exactly match the conditions of specimens tested in the literature (in terms of specimen shape, loading condition and failure mode). Therefore, in order to have accurate validation of numerical models, three conducted experimental program (by Arevalo et al. [45], Nasrollahi et al. [46] and Ahmadi et al. [27]) were considered…

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Reference model specifications

The CES composite column model examined in this study consists of five main parts; including, concrete block, middle steel profile, rigid shear connector, reinforcement mesh, and upper and lower rigid plates. Regarding the reference model, concrete block with the size of 500mm×300mm×300mm and IPE200 as a middle steel profile were used. The dimensions of the shear connectors were 20mm×20mm×80mm, the diameter of the transverse rebar was 10mm, and the diameter of the longitudinal…

Comparison of the behaviour of stud and rigid shear connector

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Two prominent features of the rigid shear connector are its high stiffness and strength, as compared to the conventional ductile shear connectors. These characteristics, along with small dimensions of the rigid shear connector, make this type of shear connector feasible candidates for CES composite columns, even more favorable than other types of shear connectors. The amount of residual strength (at least 60% of the peak strength) in all specimens indicates the reliable behaviour of this type…