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Comparison of hysteretic performance of stubby Y-type perfobond rib and stud shear connectors

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ABSTRACT

In the composite frame of a building structure in an earthquake-prone area, the shear connection between a concrete slab and a steel beam plays a very important role in distributing the load of the structure and preventing collapse. A shear connection with high stiffness evenly disperses the inertial force created by an earthquake load throughout a pillar to increase the resisting capacity of the structure. In addition, after receiving the seismic loading, the residual strength of the shear connection delays separation of the slab from the beam, thus preventing secondary accidents. However, a beam–slab shear connection of a composite structure that is subjected to frequent seismic excitation receives repeated loadings far exceeding design loadings, thereby greatly reducing its resisting capacity from the level in the original design. The Y-type perfobond-rib shear connector belongs to the new generation of shear connectors developed to overcome the disadvantages of the conventional stud shear connector and the perfobond-rib shear connector. In order to analyze the behavior of the shear connection, fully reversed cyclic loading tests were carried out on a stubby Y-type perfobond rib shear connection and a stud shear connection. Using the test results, the amount of energy absorbed by the connections and changes in their stiffness were verified, which also showed that the former exhibited better hysteretic performance.

1. Introduction

Concrete–steel composites have been used in construction for decades based on their excellent structural performance and low cost. In particular, a concrete–steel composite frame has generally been used in a building structure to reduce the weight of the structure itself and to ensure its stiffness. The beam–slab shear connection of a composite structure that is subjected to seismic excitation receives repeated loadings far exceeding design loadings, thereby greatly reducing the resisting capacity of the shear connection from the level in the original design. The safety of a structure receiving seismic loadings is determined by the energy absorbed and changes in stiffness after repeated cycles [1]. Repeated loadings on a beam–slab composite system are divided into fully reversed cyclic loading and pulsating cyclic loading. Seismic loading is produced under fully reversed cyclic conditions to generate low-cycle fatigue; a working load is produced under pulsating cyclic conditions to generate general fatigue. Since the two types of loading produce different behavior in a shear connection, a fully reversed cyclic loading test is necessary to evaluate its hysteretic performance [2].

A shear connector is embedded between a concrete slab and a steel beam to form a shear connection and transfer shear force between the two materials to produce combined effects. The most generally used shear connector is a headed stud, and it has been investigated by various research groups over the years. Studies on the hysteretic performance of stud shear connections in the beam–slab composite structure of a building's composite frame have been carried out since the 1980s. Hawkins and Mitchell [3] studied the seismic response of a shear connection with a metal deck; they applied reversed cyclic loading and monotonic loading on a push-out test specimen to analyze the failure mode and behavior of the stud shear connection. Bursi and Gramola [4] constructed a pull–push test specimen that consisted of a stud shear connection and carried out monotonic and fully reversed cyclic loading tests to evaluate the hysteretic performance of a composite beam. In addition, they compared test results obtained by using different loading conditions and boundary conditions as variables

Abbreviations: LVDT, linear variable differential transducer; R, rebar; SS, structural steel; ST, stud; SY, stubby Y-type perfobond rib; UTM, universal testing machine.

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in the design. Zandonini and Bursi [5] carried out low-cycle fatigue tests on pull–push specimens, in which stud shear connectors with diameters of 16 and 22 mm were installed. They took into consideration the effect of shear connection to evaluate the shear strength and ductility of a stud shear connector that received receiving low-cycle fatigue loading. In the 2000 s, stud shear connections were investigated analytically and experimentally. Civjan and Singh [6] used pull–push specimens and bare-steel stud specimens to conduct experimental and analytical studies, and their results showed the failure mode of the stud shear connection and a reduction in strength by cyclic loading. Bursi et al. [7] used finite-element analysis to investigate the behavior of a composite frame with a concrete slab and a steel beam for seismic loading, and they analyzed the energy absorbed by the composite frame based on the extent of shear connection. Although their results did not show a large difference in the amount of energy absorbed by specimens that showed different extents of shear connection, a high degree of shear connection is advantageous to preventing separation of the beam and slab.

Recently, studies have been conducted on the hysteretic performance of shear connectors of various forms. Matus and Jullien [8] developed a novel shear connector named ITW-SPIT, which was an improved version of a conventional stud, and carried out a reversed cyclic loading test. The shear connector exhibited high strength and high earthquake resistance when compared to the conventional stud shear connector; the reversed cyclic loading test did not result in failure of the shear connector, which was a problem of the stud shear connector. Maleki and Bagheri [9] analyzed the behavior of a shear connector consisting of a channel shear connector. They carried out reversed cyclic and monotonic loading tests for different types of concrete; when compared to specimens subjected to monotonic loading, specimens that were subjected to reversed cyclic loading showed 10–20% reduction in their shear strength. Shariati et al. [10,11] evaluated the reduction in shear strength and ductility of channel and angle shear connections under reversed cyclic loading to compare their performances as functions of their design. The failure mode of the two shear connectors was also analyzed by concrete crushing or generating a channel fracture.

To attain sufficient composite action in composite systems of building structures and infrastructures, different types of shear connectors must be installed. The headed stud is commonly used to transfer shear force between steel and concrete. The perforbond-rib shear connector was developed in Germany to solve fatigue problems related to stud shear connectors [12]. The puzzle-shaped composite dowel was developed recently, and it has been used in composite bridges [13]. In addition, Lorenc et al. [14,15] conducted experimental and analytical studies with the thickness and shape of a dowel and the concrete compressive strength as design variables. The Y-type perfobond-rib shear connector belongs to the new generation of shear connectors developed to overcome disadvantages of the conventional stud shear connector and the perfobond-rib shear connector [16]. Equations for predicting the shear strength of the Y-type perfobond-rib shear connector have been experimentally developed by considering various design variables [16–18]. The applicability of these equations to a highway bridge was validated by a cyclic loading test that took into consideration the loadings of passing trucks [19]. Although the Y-type perfobond-rib shear connection has excellent shear strength and ductility, it has exceedingly large dimensions that cannot be accommodated in the composite frame of a building structure, and the stubby Y-type perfobond-rib shear connector was developed to allow practical application [20]. Kim et al. [20] carried out a push-out test for a stubby Y-type perfobond-rib shear connection with transverse rebars that had diameters of 13 and 16 mm, and it demonstrated sufficient static performance for application in the composite frame.

Studies on the hysteretic performance of the stubby Y-type perfobond-rib shear connector are necessary for its application in a real composite frame. Therefore, in this study, two pull–push test specimens, one with a stubby Y-type perfobond-rib shear connection and the other with a stud shear connection, were constructed and evaluated in monotonic and fully reversed cyclic loading tests. Details of the design of a general composite frame were taken into consideration, and the energy absorption, stiffness reduction, and residual strength of the two shear connections were compared based on their load–slip curves.

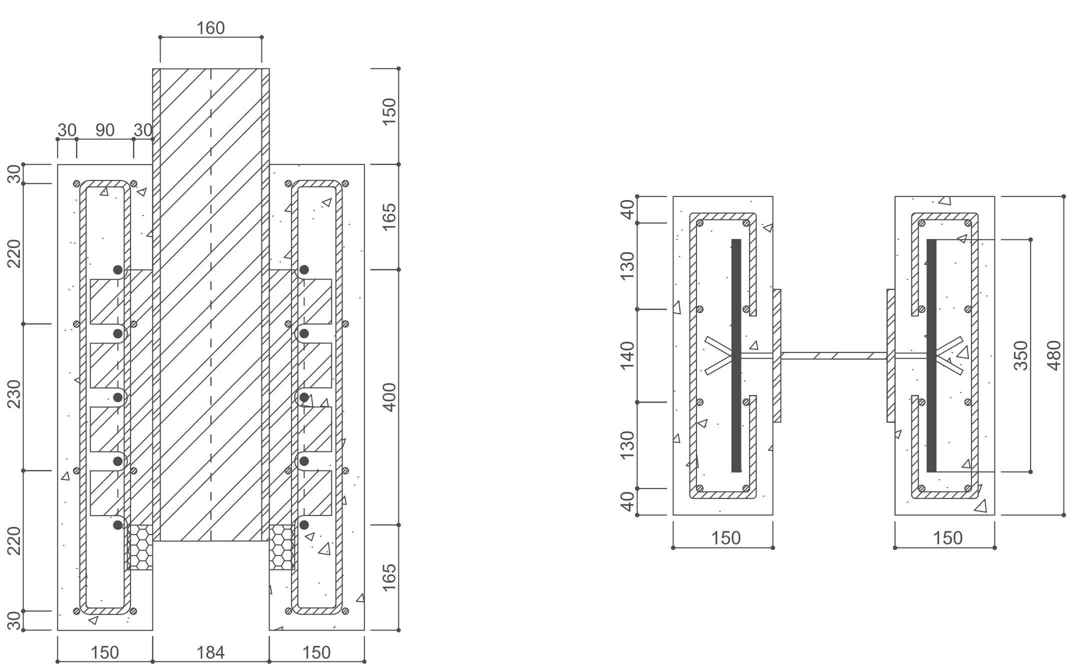

Fig. 1. Specimen for a standard push-out test (unit: mm) [20].