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FEM analysis on failure development of group studs shear connector under effects of concrete strength and stud dimension

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ABSTRACT

Group studs, arranging studs in group, has been applied as shear connectors in steel and concrete composite structures for over 50 years. Concrete strength and stud dimension are the crucial factors affecting the failure appearance of shear studs in push-out test, which mainly consists of stud shear fracture, stud bending deformation and local concrete crush. Since the detailed failure development has rarely been concerned, a parametrical push-out FEM analysis with damage plasticity models on failure development of group studs with effects of concrete strength and stud dimension was executed. In this study, concrete compressive strength of 30 MPa, 40 MPa and 50 MPa, shank diameters including 13 mm, 16 mm, 19 mm and 22 mm and stud heights including 80 mm and 100 mm were the parameters. In general, it was found that when under effect of concrete strength, shear stiffness of stud with large shank diameter performed more stable while its shear strength may be influenced more apparently. Meanwhile, the analyzed concrete damage, stiffness degradation and ultimate deformation of stud were discussed as well. The failure development of push-out model was reflected by the development of equivalent stud bending arm in terms of shear transfer between steel and concrete through studs, which experienced three steps due to the degradations of concrete and stud modulus. It also shows that models with lower concrete compressive strength or more flexible stud in combination with high concrete strength can lead to relatively obvious stud bending deformation.

1. Introduction

The application of shear studs as shear connectors between steel and concrete in composite structures has an over 50 years history. Compared with other kinds of shear connectors, shear studs gets economical and constructional advantages. As to the arrangement of studs welded on steel flange, group arrangement is more favorable in constructional perspective than arranging dispersedly which can be referred to as normal arrangement, for example precast concrete slab can be easily installed. On the other hand, literature information [1–3] shows stud shear stiffness and strength would be unfavorably affected by group arrangement. The steel and concrete interlayer interaction would more likely become partial interaction. The well established push-out test is a prevalent way to reflect mechanical behavior of shear connectors. Oehelers derived the static load–slip curve by executing push-out tests and found that studs embedded in strong concrete were stiffer than those in weaker concrete, etc. [4]. Hanswille executed a parametrical study on fatigue behavior of shear studs through cyclic push-out tests [5,6]. Moreover, it has been revealed that parameters such as stud dimensional and material properties are vital factors to mechanical behavior of shear studs [7,8].

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The push-out failure can be used for representing ultimate situation of stud shear connector, nearby concrete and other related materials, which mainly includes stud shear fracture in combination of bending deformation and concrete crush. These failure modes are interacted with one another in terms of material properties, stud dimensions, etc. So far, the development of such interaction has not been fully understood due to its strong nonlinear performance and complex material constitutions, even through those carried out push-out tests basically providing load–slip curve, stud stiffness and strength.

On the other hand, mechanism of load transfer between steel flange and concrete through studs in push-out tests has been pointed out by some research literatures [9], arguing that stud bending deformation is affected by the material degradations during push-out test. Thus as long as the stud bending deformation characterized by force and bending arm are derived in advance, material degradations of concrete and studs can be indirectly reflected, which would significantly contribute to the understanding of failure development of push-out test. The detail will be expanded in the following content.

In this sense, a related FEM analysis on failure development of group studs under effects of concrete strength and stud dimension was executed. Meanwhile, the analyzed load–slip curves, ultimate failure modes, stud stiffness and strength were presented and discussed as well.

2. Numerical analysis works

2.1. Analysis models set up

2.1.1. General

The dimension size of numerical model is shown in Fig. 1, which was designed based on Eurocode 4 [10]. In the model, four studs were designed on each steel flange, equaling to that of standard push-out specimen. The vertical and lateral spacing of studs were respectively 65 mm and 50 mm. The shank diameters varied from 13 mm to 22 mm while stud heights included 80 mm and 100 mm. The 3D image of such model is shown in Fig. 2.

The relevant parametric models are listed in Table 1, which were categorized into six parametrical model groups in light of shank diameter and stud height. The shank diameters were 13 mm, 16 mm, 19 mm and 22 mm while stud heights were 80 mm and 100 mm. The specific values of concrete strength were 50 MPa, 40 MPa and 30 MPa as listed in the second row of Table 1. The model labels listed from the second to fourth column of Table 1 can express the basic model attributes sequentially including concrete strength and stud dimension. For example, C50GA shows a model with concrete compressive strength of 50 MPa (C50), belonging to parametrical group A (GA). In the table, d is the stud shank diameter while L is the stud height. The ratio of L to d shows stud flexibility.

2.1.2. Loading and boundary conditions

All the parametrical models were analyzed through ABAQUS explicit module. Nonlinear material constitutions were involved. In light of geometrical symmetry, a quarter part of specimen was simulated. As shown in Fig. 3, three-dimensional eight-node reduced integration element (C3D8R) was used to simulate concrete, studs and steel plates while two-node three dimensional truss element (T3D2) was introduced to simulate embedded reinforcements.

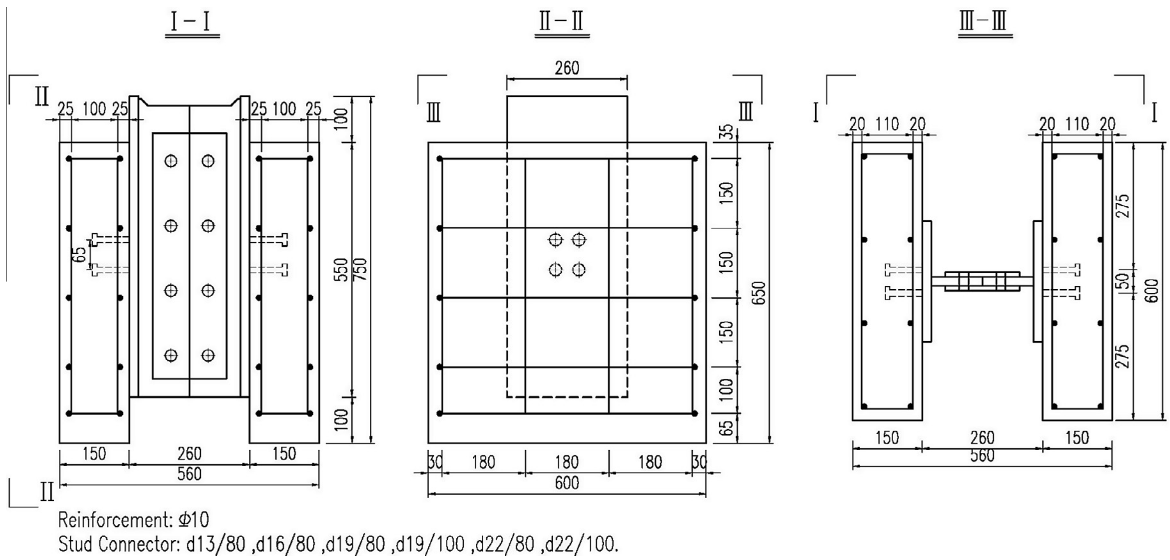

Fig. 1. Layout of FEM model for parametrical study (mm).