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# Analytical investigation on failure development of group studs shear connector in push-out specimen under biaxial load action

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ABSTRACT

Arranging studs in group, referred to as group studs shear connector, has been applied in steel and concrete composite structures many years for its constructional efficiency. Nowadays, many long span composite bridges with group studs have been designed with wide transverse cantilevers and web spacing. The cantilever self-weight and passing-by moving loads thus make the studs under biaxial load action consisting of longitudinal shear force and transverse bending-induced action. The stud mechanical failure appearance and its development are not clear enough in this condition. In this case, we carried out a parametric push-out FEM analysis with introduced damage plasticity material models. In this study, effect of biaxial load action has been concerned in parametric models with different stud dimension and concrete strength. We found that biaxial load action could increase the stud shear stiffness and strength. And concerning push-out failure mode, the analysis showed that biaxial load action reduced concrete damage and resulted to a more obvious stud shear failure with less bending deformation. During the failure development, it tended to increase the capabilities of both stud and concrete of supporting local stress concentrations but slightly reduce the stud bending deformation extension. In addition, concrete strength and stud flexibility would affect the stud failure composition as well.



## 1. Introduction

In recent decades, steel and concrete composite girders have been widely applied in many kinds of civil infrastructures. And stud has become one of the most frequently used shear connectors in such composite structures for over 50 years. This is due to its economic advantage. Arranging studs in group, referred to as group studs, is believed to benefit constructional efficiency. However, shear load action would become more locally concentrated around the connection area. Nowadays, many long span composite bridges have been designed with wide concrete cantilevers and web spacing, most of which are with group studs for concrete slab prefabrication and pre-stress effect introduction. The cantilever self-weight and passing-by vehicle loads may lead to significant transverse bending action. In this case group studs shear connector is actually under biaxial load action composed by bridge longitudinal shear force and transverse bending action. Due to load concentration characteristic, biaxial load action effect on group studs may be serious and significant. Chen et al. carried out a parametrical study on such biaxial load action, indicating that it may favorably raise the stud shear stiffness [1]. In addition, Pallares et al. executed a generalization study on studs under combined action of shear and tension forces [2]. Mirza et al. carried out a study on the effects of axial and shear load on the behavior of shear stud [3]. Regarding concrete strength, literature

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information [4–7] presented that it was crucial to stud mechanical behavior. These studies are all related to non-uniaxial load action effect. But in general, failure development was not concerned in detail.

In fact, the push-out failure development, resulted by the material degradations, has not been entirely concerned in either of push-out test and numerical analysis. This is because of the observation difficulties in test and complex material constitution for analysis accuracy. However, Oehelers et al. proposed a load transfer mechanism between steel and concrete through studs in push-out tests [8]. It actually contributes to the way of grasping the basic feature of push-out failure development. Based on such mechanism, if we can derive feature of stud bending deformation development in push-out process, material degradations of concrete and studs can be indirectly reflected. Even though this can be only a qualitative analysis, it would be significantly good to the understanding of push-out failure development. In this sense, Chen et al. carried out a numerical study on group studs push-out failure development in condition of uniaxial load action. But biaxial load action has not been concerned yet [9].

Therefore, we carried out analytical investigation on group studs push-out specimen under biaxial load action. 45 push-out models were established for concerning effects of biaxial load action, concrete strength and stud dimension. In addition, nonlinear material constitutions and damage plasticity models were introduced in the analysis.

## 2. Numerical analysis works

### 2.1. General

The dimension of push-out FEM model is shown in Fig. 1. In the model, four studs have been designed on each steel flange. The stud shank diameters vary from 13 mm to 22 mm while stud heights include 80 mm and 100 mm. The vertical and lateral spacing of studs are respectively 5$d$ and around 3.85$d$, where $d$ is the stud shank diameter. It was based on Euro code 4 [10]. The reinforcement diameter is 10 mm. The 2nd and 3rd horizontal reinforcement positions in push direction were adjusted in terms of the stud vertical spacing for removing the effect of stirrups as much as possible. The depicted 150 mm distance between them in Fig. 1 is related to the case of stud shank diameter 13 mm. Others cases were in terms of such relative positions between studs and reinforcements.

The relevant parametric models are listed in Table 1, categorized into five groups in terms of stud dimension. The shank diameters include 13 mm, 16 mm, 19 mm and 22 mm while stud heights include 80 mm and 100 mm. 50 MPa, 40 MPa and 30 Mpa of concrete compressive strength are introduced in the analysis. The model labels can express the basic attributes sequentially including concrete strength, stud dimension and load action. For example, C50GABM1 shows a model with concrete compressive strength of 50 MPa (C50), belonging to parametrical group A (GA) and under biaxial load action formed by lateral loads of 36 kN (BM1) as shown in Fig. 2.

The loading patterns in the analysis are shown in Fig. 2. It can be seen that biaxial load action consists of vertical push load and lateral loads. The lateral loads are for initiating transverse bending action. On the other hand, uniaxial load action only contains vertical push load. The detail load procedures are listed in Table 2. Concerning biaxial load procedure, lateral loads were applied on models in the first load step of analysis and then combined with vertical push load in the second step. As to uniaxial load procedure, vertical push-load had been the only load action since the analysis started. The lateral load values in biaxial load action analysis included 36 kN and 76 kN. They were determined by the expected maximum bending-induced concrete crack widths, including 0.15 mm and 0.30 mm. Eq. (1) [11] is the equation for determining the lateral load values. In Eq. (1), $\omega_R$ is the maximum crack width, $C_1$ is the reinforcement surface shape coefficient, $C_1$ = 1.0, $C_2$ is the load effect coefficient, $C_2$ = 1.0, $C_3$ is the mechanical behavior coefficient, $C_3$ = 1.15 for slab under bending moment, $M(F_b)$ is bending moment induced by lateral loads $F_b$, see in Fig. 2, $M(F_b) \approx F_b \cdot l_b$, where $l_b$ is the length of moment arm, $d_r$ is the diameter of reinforcement, $\rho$ is the tensile reinforcement ratio in transverse direction of push load, $A_r$ is the area of reinforcements under tension

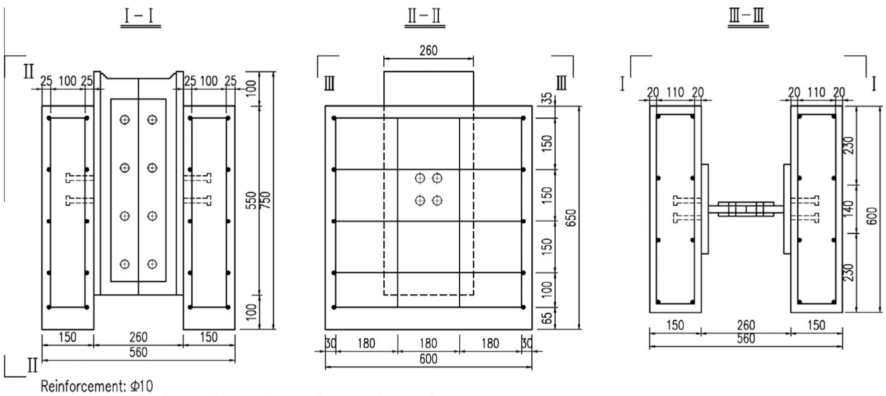


**Fig. 1.** Layout of FEM model for parametric study (mm).