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# Numerical analysis on shear stud in push-out test with crumb rubber concrete

Qinghua Han [a,b], Yihong Wang [a], Jie Xu [a,b,*], Ying Xing [a], Guang Yang [a]

[a] School of Civil Engineering, Tianjin University, Tianjin 300072, China
[b] Key Laboratory of Coast Civil Structure and Safety of Ministry of Education, Tianjin University, Tianjin 300072, China

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ABSTRACT

Crumb rubber concrete slabs and steel beams connected by single-headed studs were investigated in this paper. An accurate numerical analysis based on ABAQUS was developed to derive nonlinear material properties and damage plasticity models of concrete with four different rubber contents and reasonable contact algorithms. The reliability of the numerical analysis was verified based on our previous experimental work, and an extensive parametric study was conducted. The analysis results for the stud nominal strengths were compared with those specified in AASHTO LRFD and EUROCODE-4. Furthermore, the typical stress mechanism of the stud in push-out test and the relationship of the tensile force and bending moment that the stud bears were achieved. The bending deformation of the stud was proven to be larger in the crumb rubber concrete. Finally, the effect of welding defect was studied systematically. The results show that the bottom welding defect of the stud is the most dangerous one, especially on the ultimate slip and ductility of the stud.



## 1. Introduction

Steel-concrete composite beams have been widely used in bridge and building structures for decades. As an important component of the steel-concrete beam, the shear connector transfers the longitudinal shear force at the interface between the steel and concrete. Push-out test has been proven to be an effective method for determining the nominal shear strength and ultimate slip of headed shear stud connectors. In the 1930s, the first push-out test was devised in Switzerland [1]. Since then, many researchers have performed tests to investigate the behavior of headed studs [2–7].

Numerical analysis has proved to be an alternative to experimental push-out tests and provides reasonably accurate results with lower cost and in less time. Moreover, more measurement points can be evaluated in the numerical analysis. This more efficient method has begun to accrue significant value in recent years. In 2001, Kim et al. developed linear and nonlinear two-dimensional finite element models and a linear three-dimensional finite element model for a composite beam with profiled steel sheeting [8]. In 2006, Ellobody and Young B used finite element modeling to investigate the performance of a shear connection in composite beams with profiled steel sheeting [9]. In 2009, Huu and Seung [10] developed an accurate nonlinear finite element model for a push-out specimen with large stud shear connectors. In 2012, Chen Xu [11] carried out an FEM analysis of push-out tests with group studs based on their experiment work. He also studied the failure development of group studs [12]. These FEA methods were proven to provide relatively accurate predictions of what was measured.

However, the numerical analyses performed by the researchers mentioned above were all using ordinary concrete slabs. Information on the mechanical performance of a single stud is comparatively less common in the literature. It is well known that welding defects reduce the bearing capacity of studs tremendously. A welding defect is any flaw that compromises the usefulness of the shear studs. There is a great variety of welding defects that may occur, including gas inclusion, lack of fusion, and incomplete penetration. Yet, there have been few numerical analysis studies demonstrating the effect of welding defects on the behavior of the shear stud connectors.

To this end, this paper will focus on the numerical study of a push-out test with crumb rubber concrete slabs instead of ordinary ones. Crumb rubber concrete is a new environment-friendly material. According to previous studies, the deformability of concrete is reflected by the ultimate deformation value under its bearing capacity based on material tests. After adding crumb rubber, the deformability of concrete increases significantly. Furthermore, crumb rubber concrete exhibits ductile failure and better crack resistance [13–15]. Due to the superior properties of crumb rubber concrete, it is used in the paving of tennis courts and parking areas currently but has never before been used in composite beams. We have systematically conducted experimental work on push-out specimens with crumb rubber concrete slabs [16]. This numerical study aims to provide researchers with a better

* Corresponding author at: School of Civil Engineering, Tianjin University, Tianjin 300072, China.
*E-mail address:* jxu@tju.edu.cn (J. Xu).

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understanding of the stress mechanism of a single stud embedded in different rubber mixed concrete slabs during the push-out test procedure and the effect of a welding defect on the behavior of a single stud.

The remainder of the paper is organized as follows. Section 2 details the numerical analysis work based on push-out tests, and the verification of the numerical results using test results is presented in Section 3. Section 4 describes a parametric study based on different rubber contents and stud dimensions. A comparison of the simulation results and national codes are also presented in this part. Section 5 analyzes the stress mechanism for a single stud, and Section 6 shows the effect of a welding defect in the stud in the push-out tests. Finally, Section 7 presents the concluding remarks of this paper.

## 2. Numerical analysis work based on push-out tests

### 2.1. General information

Numerical analysis work was carried out based on our previous experimental work on push-out specimens [16]. The geometry of the specimen is shown in Fig. 1. The section of the rolled H-section steel beam is 200 mm × 200 mm × 8 mm × 12 mm, and the length is 560 mm. The dimensions of the concrete slab are 460 mm × 400 mm × 160 mm.T, and the diameter of the reinforced bar is 10 mm. Four different crumb rubber contents, two crumb rubber concrete compressive strengths and two stud diameters were taken into consideration in the numerical analysis based on tests.

To obtain accurate results from the numerical analysis, all components in the shear connection must be properly modeled. In this paper, the finite element program ABAQUS [17] was used. The main components were the concrete slab, steel beam, shear studs and reinforced bar. Nonlinear material constitutions and concrete damage plasticity models were established in the analytical investigation. Moreover, the reasonable finite element type mesh generation and contact algorithms were adopted.

### 2.2. Finite element type and mesh

Due to the symmetry of the specimen, only half of the push-out test was modeled, shown in Fig. 2. The concrete slab, steel beam and shear stud were all meshed with the solid element C3D8R, and the reinforced bar used truss elements. To obtain accurate results, the same mesh generations were applied on the interaction part for different components, such as the bottom of the studs and the corresponding part of the steel beam, as well as the contact surface of the studs and concrete. The studs and their vicinities used the smallest mesh size of 1 mm. To reduce the analysis time, the non-critical parts used larger mesh sizes of up to 20 mm.

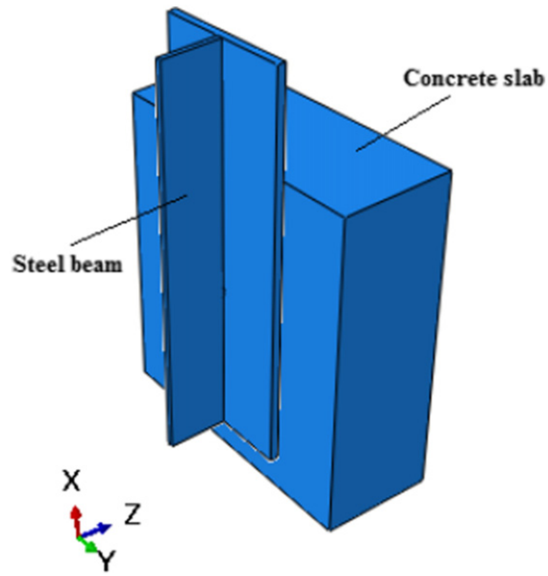


**Fig. 2.** Numerical model of the push-out test specimen.

### 2.3. Interaction and constraint connections

The interactions of the steel and concrete and the concrete and studs in the push-out modeling are the most important and difficult part. Six interactions were included in this analysis, as shown in Fig. 3.

The stud is embedded in the concrete slab, and the shank of the stud's surface is in contact with the concrete slab's inner surface. Sliding

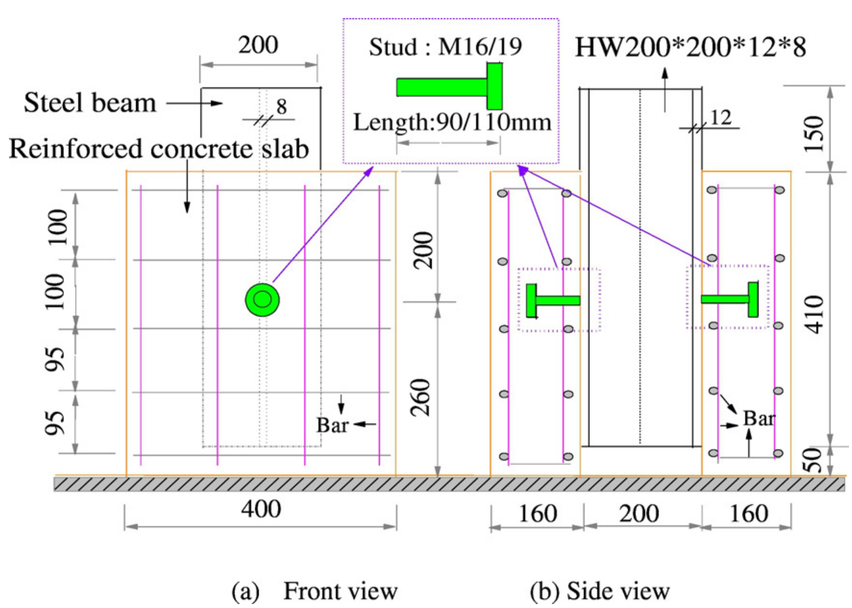


**Fig. 1.** Push-out test specimen [16].