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Mechanism study on the low cycle fatigue behavior of group studs shear connectors in steel-concrete composite bridges

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ABSTRACT

Clustering the stud shear connectors with a narrow spacing to form group studs is useful for the concrete slab prefabrication in steel-concrete composite bridges. But the existing test and analysis results have shown that arranging studs in group tends to be unfavorable to the stud static and fatigue performance. The current fatigue design of the group studs may still experience an overestimation or an underestimation problem since the fatigue mechanism study on group studs is rare. Therefore, a parametric push-out analysis was carried out for explaining the fatigue behavior of group studs, particularly the low cycle fatigue aspect with the fatigue life lower than 2 million cycles. There were 12 static and cyclic push-out models in the analysis. Meanwhile, a series of static push-out tests were also introduced to verify the analysis works. According to the static analysis results, the unequal stud shear forces in the group studs, which were indicated by the analyzed static failure mode, resulted in the reductions of stud shear stiffness and strength. According to the low cycle cyclic analysis results, the fatigue damage initiated at the bottom point of the stud root section in the push load direction, which can be called the fatigue critical point. The low cycle fatigue life reduction of group studs, which was evaluated by the analysis results and the introduced multi-axial fatigue damage criterion, can be explained by the uneven cyclic tensile strain and stress distributions on every individual fatigue critical point in the group studs.

1. Introduction

The shear studs are usually applied as a type of shear connector in the steel-concrete composite bridges. They are always arranged in clusters to form group studs for the concrete slab prefabrication. In particular, the studs are welded in groups on the steel flanges with relatively narrow spacing and then covered by the prepared holes of the precast concrete slab. These holes will be filled by the high-strength and low-shrinkage mortar. The stud spacing in a group is usually much smaller than the normally arranged stud. According to AASHTO [1], JSCE [2] and Eurocode4 [3], the longitudinal stud spacing minimums are respectively 6.0 d (shank diameter), 5.0 d or 100 mm, and 5.0 d, and the transverse stud spacing minimums are respectively 2.5 d, d + 30 mm and 4.0 d. The spacing design of the group studs largely bases on these spacing minimums. But concerning the stud amount in a group, there are few related contents in codes. In fact, the stress concentration cannot be the same among the groups with different stud amount and stud size. Generally, it can be seen that the stiffness and strength of group studs tended to be lower [4–7]. And the fatigue test on the group studs also showed the similar feature. Okubo's cyclic push-out test on the group studs showed that the stud fatigue life become lower when being arranged in group [8]. Shim et al. carried out related static and cyclic tests in which the stud spacing ranged from 3.0 to 13.0 shank diameter [5]. His research showed the similar conclusions.

Although the test results had showed that arranging studs in a group may be more or less unfavorable to the stud mechanical performance, there are not so many mechanism investigations, which makes the design of group stud without enough sense. And actually such investigation cannot be fully accomplished without the necessary analysis works. So far, there have been many analysis works concerning about the push-out test process, such as showing the interaction mechanism between the group stud and the surrounding concrete [9], investigating the load action effect [10,11] and so on. However, the mechanism study on the fatigue behavior of group studs is rare. In general, the detail fatigue investigations on the group studs are much less than the static investigations.

Therefore, the mechanism study particularly for understanding how the group arrangement affects the stud fatigue behavior, especially the low cycle fatigue aspect with the fatigue life lower than 2 million, was executed through the parametric analysis. Meanwhile the static feature of group studs were also concerned, which was believed to be necessary for the fatigue mechanism study. In the analysis, the stud amount and stud size were selected as the main parameters.

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Table 1
The static and fatigue analysis model features.

Analysis type		Stud spacing		Stud size		Stud amount in one side	Concrete properties		
Static	Fatigue	Longitudinal	Transverse	d	H		fc	ft	E
A4SN	A4FN	250	100	13	80	4	40.9	4.6	37,000
A4SG	A4FG	65	50	13	80	4	55.0	2.8	30,000
A9SG	A9FG	65	50	13	80	9	55.0	2.8	30,000
B2SN	B2FN	–	100	19	150	2	39.0	3.0	37,000
B9SG	B9FG	95	76	19	150	9	39.0	3.0	37,000
B16SG	B16FG	95	76	19	150	16	39.0	3.0	37,000

2. Analysis works

2.1. Parametric models

The details of the parametric analysis were summarized in Table 1.

There were two types of analysis models in terms of the stud shank diameter (13 mm and 19 mm) and the stud height (80 mm and 150 mm). In each type of the models, there were two kinds of analysis load patterns, including the monolithic and the cyclic ones. The monolithic load analysis was for analyzing the group effect on the stud static mechanical feature, contributing to the main analysis purpose of explaining the group stud fatigue behavior. Concerning the fatigue analysis in particular, 4 load cycles were introduced, which were actually composed by 90 static load steps. The fatigue load range was deduced from the 170 MPa nominal stud shear stress range. And the fatigue load mean was deduced from the 30% of the analyzed stud static shear strength. This can be considered a low cycle fatigue load pattern with an estimated fatigue life lower than 2 million. The low cycle fatigue study is necessary for the overloaded situation on stud. Moreover, it can be a useful reference for investigating the applicability of the current

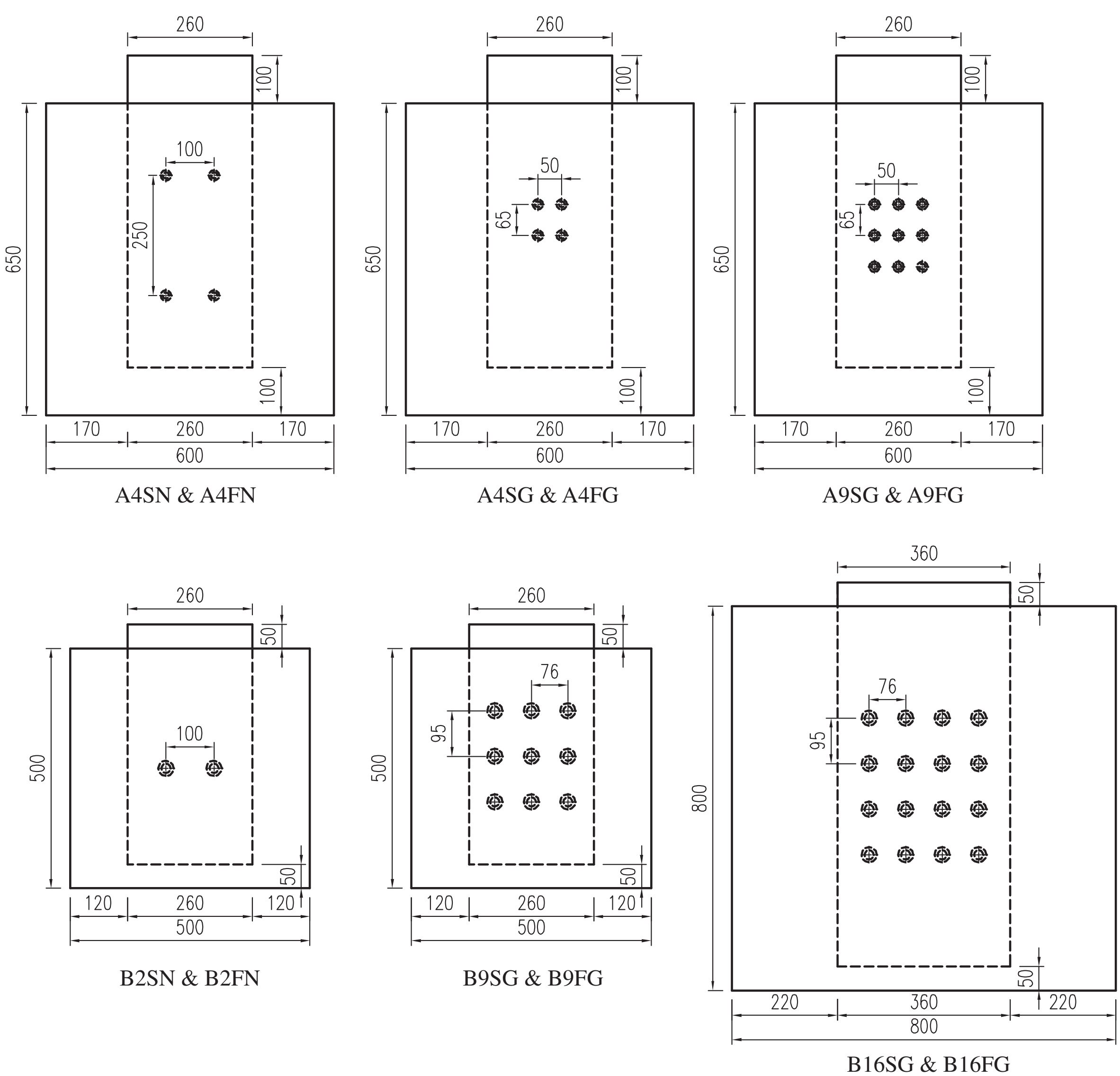

Fig. 1. Geometric dimension of numerical models in Table 1.