Nonlinear Static Study on Group Studs under Biaxial Action

Kyoto University, student member, Chen XU
Kyoto University, professor member, Kunitomo SUGIURA

1 Introduction

Group studs are known as shear connectors in steel and concrete composite bridges. Currently, many composite bridges are characterized by long lateral cantilevers. The shear studs are actually under biaxial action consisting of interlayer shear force and lateral bending moment induced by the cantilever and passing by moving loads. The lateral bending moment can result in the initiation of bending-induced cracks on concrete slabs. Since stress concentrations on concrete and stud both initiate at very early load stage near the stud root position as reflected in many push out tests, nonlinear simulation is important if accurate shear stiffness evaluation or failure mode prediction is concerned. The damage plasticity model, defining a damage factor of the elastic modulus to simulate damage evolution of individual material, is a way to reflect the material softening stage. It is supported in the general FEM software ABAQUS. Thus the analysis on group shear studs based on material constitution with damage plasticity was carried out. Moreover, an experiment was introduced to confirm the reliability of FEM analysis.

2 Numerical model setup

Concerning the biaxial action and bending-induced initial cracks on mechanical performance of group studs, the lateral bending moment and shank diameter were the parameters. The loads imposed on the model consisted of a vertical push load and symmetrically distributed lateral loads for activating lateral bending moments as shown in Fig.1. The combinations of these two kinds of loads depended on the analysis cases which included (Ⅰ) uniaxial action, (Ⅱ) biaxial action and (Ⅲ) bending-induced initial cracks and varied with the load steps.

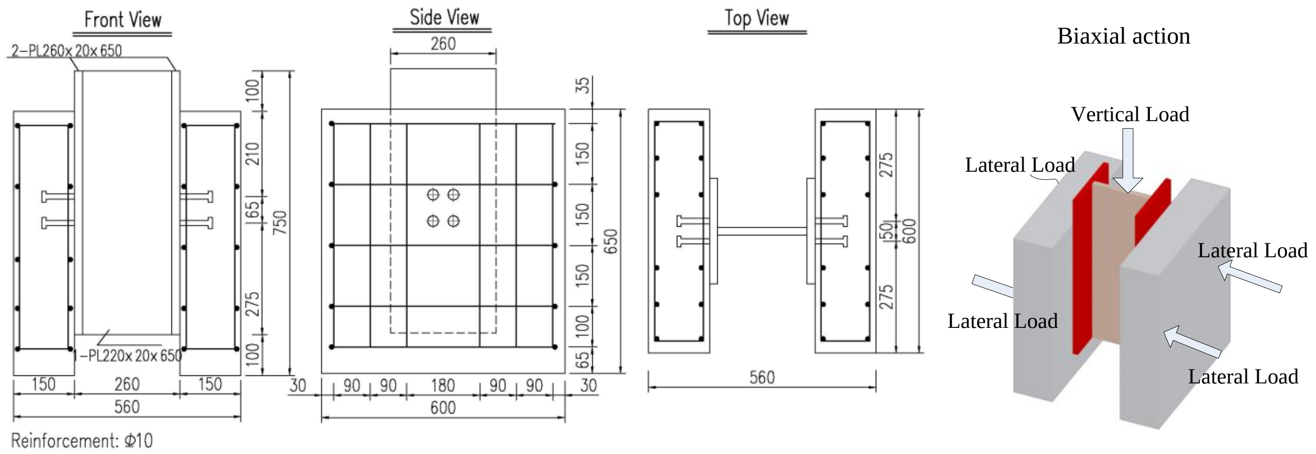

Fig.1 Layout of FEM model for parametrical study

As shown in Fig.1, the number of studs welded on each steel flange was 4, equaling to that of standard push out specimen. The vertical and lateral spacing of studs were respectively 65mm and 50mm. The related FEM model based on this design and the vertical load was exerted in the form of displacement. The damage plastic models were combined to simulate nonlinear mechanical behavior of the concrete and stud. By introducing the damage variable D, the plastic stage, especially the softening stage, can be expressed as a process of modulus degradation. The labels and analysis parameters of the FEM models are generalized in Table 1.

Table.1 Generalization of parametrical models

Group	Model Label	Case	d(mm)	L(mm)	L/d	F_b(kN)
A	groupA	Ⅰ	13	80	6.15	0
	groupABM1	Ⅱ	13	80	6.15	36
	groupABM2	Ⅱ	13	80	6.15	76
	groupACM1	Ⅲ	13	80	6.15	36
	groupACM2	Ⅲ	13	80	6.15	76
B	groupB	Ⅰ	22	80	3.64	0
	groupBBM1	Ⅱ	22	80	3.64	36
	groupBBM2	Ⅱ	22	80	3.64	76
	groupBCM1	Ⅲ	22	80	3.64	36
	groupBCM2	Ⅲ	22	80	3.64	76

(Note: d: shank diameter; L: stud height; F_b: lateral load value.)

Keywords: group studs, biaxial action, bending-induced crack, damage plasticity, shear stiffness, FEM analysis
Correspondence: C-1-3-251, Katsura Campus, Kyoto University. 615-8540. 075-383-3164; email: xuc568@hotmail.com

There are ten FEM models which can be categorized into 2 groups in light of shank diameter. Regarding the lateral loads, they were determined by bending-induced maximum concrete crack width. Specifically, the lateral loads respectively inducing maximum crack widths of 0.05mm and 0.2mm were separately applied. Thus the corresponding forces were 36kN and 76kN.

3 Numerical analysis

As listed in Table 2 which includes the related results of analysis cases Ⅰ, Ⅱ and comparison, it reveals the shear stiffness increased because of the biaxial action. In detail, when biaxial action was activated, the concrete underneath the stud root in the direction of vertical load would be in biaxial compressive status and thus improved the compressive strength. In addition, the shear stiffness increment of each parametrical group exhibits a direct proportion with the ratio of lateral compressive stress σ_b to the uniaxial compressive strength σ_u . However, it can be found that the increase percentage of the shear stiffness appears an inverse proportion with the shank diameter. This proportional relationship at least reveals that the shear stiffness of stud with small shank diameter is more likely affected by the non-uniaxial loading action thus the application of stud with large shank diameter should be a favorable choice in the perspective of stable and controllable stud mechanical behavior. The influence of the biaxial action on the shear capacity is not obvious.

Table 2 Numerical shear stiffness and increment(Ⅰ, Ⅱ, comparison)

Group	d×L(mm^2)	Biaxial Action(kN/mm,MPa)					Increament			
		F_{b0}=0kN	F_{b1}=36kN		F_{b2}=76kN		F_{b1}=36kN		F_{b2}=76kN	
		K_0	K_1	σ_{b1}	K_2	σ_{b2}	K_1/K_0	σ_{b1}/σ_u	K_2/K_0	σ_{b1}/σ_u
A	13×80	128.2	153.2	4.61	184.1	12.10	1.20	0.09	1.44	0.24
B	22×80	255.4	280.6	3.88	299.7	8.16	1.10	0.08	1.17	0.16

（Note: d: shank diameter; L: stud height; F_b: lateral load value; K: average shear stiffness of one stud; σ_b: lateral compressive stress value; σ_u: uniaxial compressive strength, σ_u=50MPa. The numeral subscripts stand for the types of biaxial action.）

As illustrated in Table 3 which includes the related analysis results of analysis cases Ⅰ, Ⅲ and comparison, it shows the shear stiffness reduction. Nevertheless, the effect of the bending-induced cracks on concrete slab on shear capacity of group studs was less significant.

Table 3 shear stiffness and increment(Ⅰ, Ⅲ, comparison)

Group	d×L(mm^2)	F_{b0}=0kN	F_{b1}=36kN		F_{b2}=76kN	
		K_0	K_1	K_1/K_0	K_2	K_2/K_0
A	13×80	128.2	119.7	0.93	107.7	0.84
B	22×80	255.4	242.5	0.95	225.4	0.88

（Note: d: shank diameter; L: stud height; F_b: lateral load value; K: average shear stiffness of one stud; The numeral subscripts stand for the types of biaxial action.）

As to the steel concrete interlayer slip, it can be found that the ultimate slip value was larger when uniaxial action with cracked concrete slab was applied. This tells that push out specimen with lateral bending-induced concrete crack possesses a better steel concrete interlayer ductility than those without the cracks.

4 Analysis reliability

In order to warrant the reliability of FEM analysis, in which damage plasticity models were introduced, a verification study, concerning a push out static test on group studs, was executed. In the FEM verification, the material constitution took the real tested data derived from the push out test. And the damage plasticity model was introduced. The comparison between test and FEM analysis on load-slip curve confirmed the reliability of FEM analysis.

5 Conclusion

The effect of biaxial action and bending-induced cracks on concrete slab on mechanical behavior of group studs was analyzed. The following conclusions may be drawn from the present study:

1. The biaxial action seemed favorable for increasing the shear stiffness of the studs. On the other hand, the application of stud with large shank diameter should be a favorable choice in the perspective of stable and controllable stud mechanical behavior. The shear capacity was less affected.
2. Bending-induced cracks on concrete slab resulted in a reduction of shear stiffness of group studs and improvement of ductility. The shear capacity was less affected.
3. The damage plasticity models were introduced to simulate the material constitutions of concrete and stud in the FEM analysis. The reliability of FEM analysis was confirmed by comparing the analysis results with the test results.