SHEAR CAPACITY OF HEADED STUD CONNECTION BY 3D FEM ANALYSIS

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1. INTRODUCTION

As the durability of infrastructure has raised a concern in the recent years, a bridge deck using ultra high strength fiber reinforced concrete (UFC), which has light weight and high durability has been developed. In order to shorten construction time, the decks are manufactured and jointed with steel bridge girders which are provided with headed studs at the construction site. In the proposed connection method, a non-shrinkage mortar is filled in the space between UFC deck and steel girder. Since the existing design method is applicable for the connection of normal concrete (solid slab), push-out experiment and numerical analysis were conducted to investigate the shear capacity of the new connection. This paper presents a nonlinear finite element model and a comparison of analysis results with experimental results as well as the calculation based on recent design specifications.

2. PUSH-OUT EXPERIMENT

Figure 1 shows layout of push-out experiment. Two studs with diameter of 22 mm were used on each side of H steel girder. In this series, thickness of UFC part was constant of 150 mm, while the length of studs (*h*) and thickness of the filled mortar (*a*) was varied (see **Table 1**). In order to enhance the strength of connection portion, a non-shrinkage high strength mortar was used. The experimental parameters and material properties are listed in **Table 1**.The load was applied on top of H steel as shown in the figure. The details and results of case S-3 are described in the reference papers[1]. The results of cases S-4, S-5 implied that the increase in the stud length and thickness of mortar did not improve the shear capacity of the connection (**Table 1**).

Since there has been no design method for the connection with different materials, the equations proposed by JSCE in Design Specifications for Hybrid Structures[2] were adopted to predict the shear capacity of headed stud shear connection. The shear resistance of a headed stud connector is determined by the smaller value of the calculations using **Eqs. 1 and 2**. While **Eq. 1** represents the failure of concrete, **Eq. 2** represents the failure of stud:

$$V_{sc} = 31A_{ss}\sqrt{(h_{ss}/d_{ss})f'_c} + 10000 \qquad \text{(Eq. 1)}$$

$$V_{ss} = A_{ss}f_{su} \qquad \text{(Eq. 2)}$$

where,
A_{ss} is cross sectional area of stud (mm^2); h_{ss} and d_{ss} are height and diameter of stud (mm), respectively; f'_c is compressive strength of mortar (N/mm^2); f_{su} is tensile strength of stud (N/mm^2).

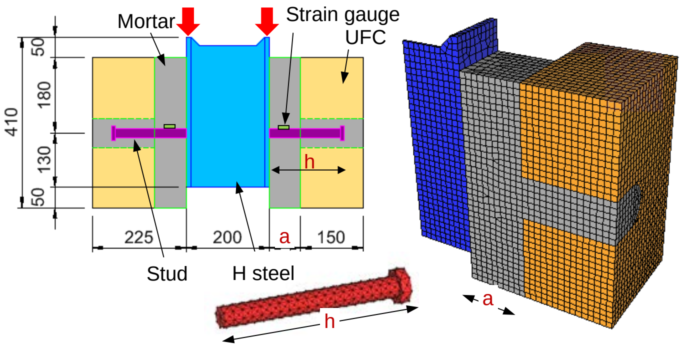

Fig. 1. Push-out test specimen and analysis model

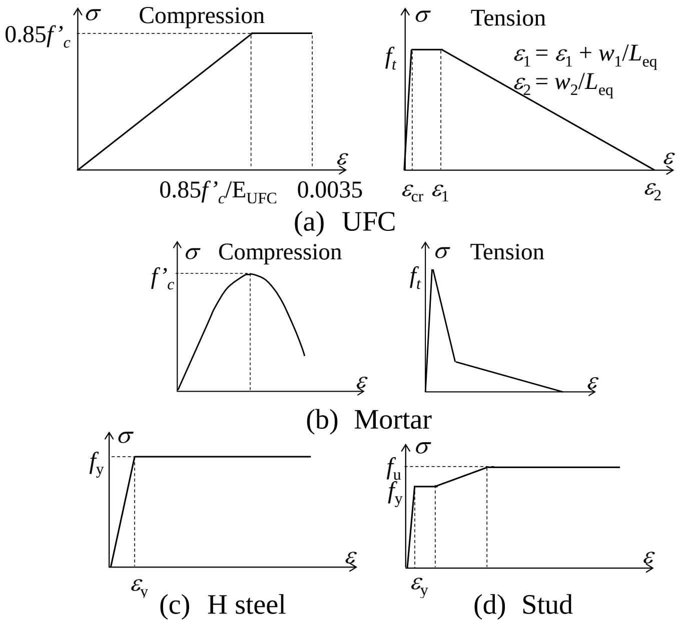

Fig. 2. Stress-strain curves for material modeling

Table 1. Material properties and experimental results

Case	Mortar			UFC	Stud				Ultimate shear load/stud		V^{exp}/V^{cal}
	a mm	Comp. strength N/mm^2	Tensile strength N/mm^2	Comp. strength N/mm^2	Height (*h*) mm	*h/d*	Yield strength N/mm^2	Ultimate strength N/mm^2	Experimental result (V^{exp}) kN	Calculated result (V^{cal}) kN	
S-3[1]	50	68.5	5.2	179.4	150	6.82	346	457	149.3	173.66	0.86
S-4	75	73.2	4.9	202.1	180	8.18	320	457	143.2	173.66	0.82
S-5	100	72.0	5.8	202.1	200	9.09	372	465	151.5	176.70	0.86

Keywords: headed stud, shear capacity, FEM, nonlinear, shear connection, slab joint

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3. FEM ANALYSIS MODEL

Three dimensional FEM nonlinear analysis was also conducted in order to investigate the shear capacity of the experiments. As the specimens are symmetrical, one fourth of the specimens was modeled for FEM analysis (**Fig. 1**). The UFC, mortar, H steel and stud were modeled by solid elements. The total strain fixed smeared crack model was adopted for crack model of UFC and mortar. The nonlinear behaviors of materials in compression and tension are shown in **Fig. 2**. While UFC was modeled in accordance with JSCE design guidelines[3], the stress-strain relationship of mortar was modelled as a parabolic curve in compression and tension softening after cracking was considered in tension behavior. The actual strengths resulting from material compression and tension tests were adopted in the models. The surface interface elements were used to model the interface behavior between different materials. Coulomb friction model was adopted with a friction coefficient of 0.3.

4. RESULTS

The ultimate shear capacities of the experiment and FEM analysis are summarized in **Table 1. Fig. 3** shows the relationship between shear load per stud and the relative vertical displacement, in which the experimental results, the results from FEM analysis and the predictions based on Design Specifications for Hybrid Structures[2] are compared. In the figure, the relative vertical displacement indicates the difference vertical displacement between H steel and mortar portion. The proposed FEM analysis model provided a good agreement with the experimental results. Whereas, the calculations based on existing design equation overestimated both the shear capacity and stiffness of headed stud connection. It can be explained that the existing equations, which were based on the data in which concrete was homogenous material, hence, reduction of stiffness and shear capacity due to interfacial behavior has not been taken into account. **Fig. 4** shows FEM analysis result of the displacements of mortar and UFC portions at the ultimate load. It is apparent that the displacements were different in the upper parts of two portions. The behavior of tensile strain of stud is shown in **Fig. 5**. The experimental value shows the measurement of strain gauge, which was attached on the top surface of the stud (**Fig. 1**). As can be seen, the tensile behavior of stud was simulated accurately by the proposed analysis model.

5. CONCLUSIONS

The shear capacity of headed stud shear connection between UFC slab and steel girder, which was filled by a high strength mortar, was overestimated by the existing equations. The 3D FEM nonlinear analysis model was proposed for evaluating shear capacity of the headed stud shear connection. The shear capacity and tensile behavior of stud compared well with the experimental results obtained from the push-out tests.

REFERENCES

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2) JSCE, Design Specifications for Hybrid Structures, 2014.
3) JSCE, Design and Construction Guidelines for Ultra High Strength Fiber Reinforced Concrete (draft), 2004.

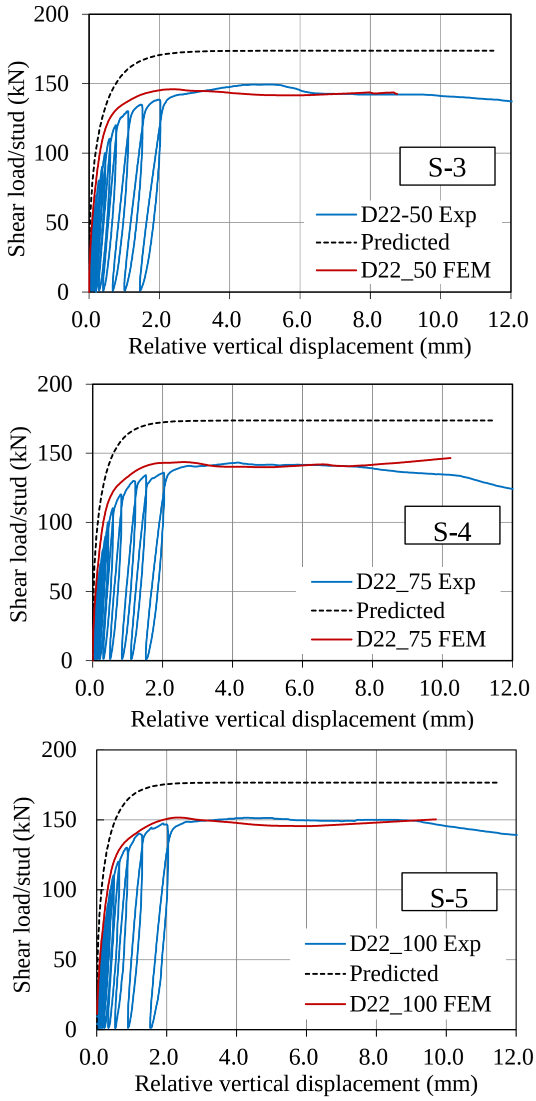

Fig. 3. Shear load – relative displacement relationship

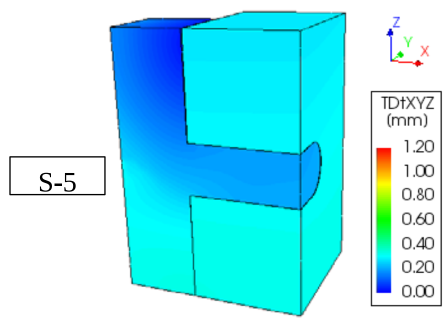

Fig. 4. Displacement of mortar and UFC

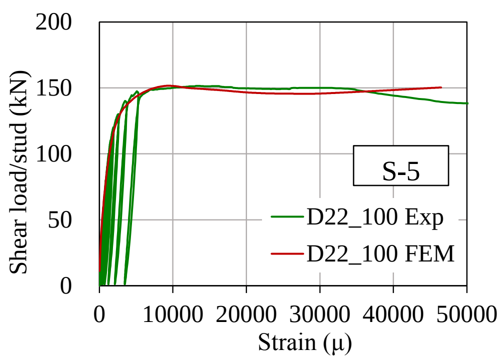

Fig. 5. Tensile strain of studs