FUNDAMENTAL STUDY ON EXPERIMENTS FOR TORQUE SHEAR TEST TO EVALUATE BONDING STRENGTH OF STEEL-CONCRETE JOINT

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ABSTRACT

For better design and construction of steel-concrete hybrid structures, it is important to evaluate the strength and behavior of their joints: e.g. headed studs. However, the contribution of the adhesion and friction along the steel-concrete interface are ignored in such mechanical joints. We here try to propose a new torque shear test system by which the shear strength of the friction and adhesion can be evaluated appropriately. The test specimen has a cylindrical interface in mortar block, and it becomes the interface subjected to the torque shear loading.
The results showed that cracks initiated on the side of the specimen were due to the boundary conditions rather than strength of steel-mortar interface and they should be prevented, and the maximum shear stress and residual shear stress were insensitive to the additional reaction force on the steel cylinder of the torque shear test system.

Keywords: torque shear test, steel-concrete joint, adhesion, friction

1. INTRODUCTION

The headed stud shear connectors are widely used as a mechanical connector of steel-concrete hybrid structures, and the research on this joint extends back to the 1950's (Viest 1956; Pallarés 2009). In Japan, several composite plate girder bridges also use the headed stud as a mechanical shear connector between concrete slab and upper flange of the girder, but there are many plate girder bridges without shear connector on the girder (which have brief slab anchors as shown in Figure 1). This is mainly because the steel-concrete interface is not considered as a joint at design based on the Japanese bridge code. Such a non-composite plate girder bridge makes up the great proportion of road bridges due to the history of Japanese bridge code.
However, it was shown that the non-composite plate girder bridges behave as composite girders (Yamada et al. 1998). The natural bonding strength of steel-concrete interface without any mechanical connector was measured experimentally by push-out test focusing on the composite action of the non-composite plate girder bridge (Yamada et al. 2001). At the same time, FEM analysis showed the

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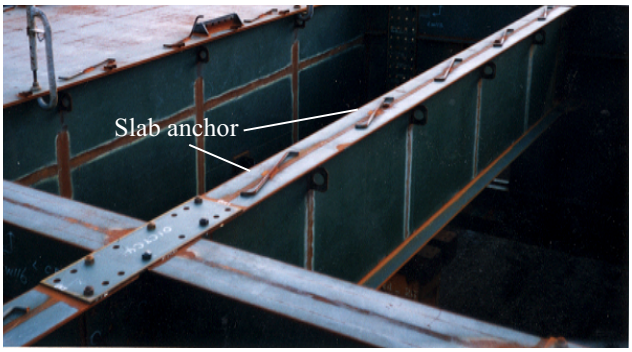

Figure 1 : Upper flange of non-composite plate girder bridge with slab anchor under construction (before pulled up).

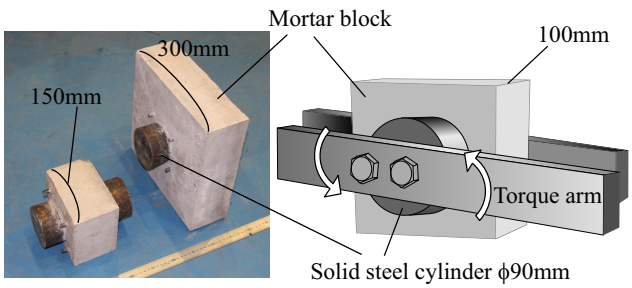

Figure 2 : Specimens with cylindrical steel–mortar interface and schematic image of the torque shear test.

shear stress occured on boundary plane of the push-out specimen was non-uniform and concentrated on the end of the plane.

The natural bonding strength of steel concrete interface is not too weak to be ignored, and it is important to evaluate the behavior of it for better design, construction and numerical analysis of hybrid structures. We here propose a new specimen and test method which uses a cylindrical interface with no end toward shear direction to prevent stress concentration for appropriative evaluation of the shear strength of the adhesion and friction between steel and concrete.

2. TORQUE SHEAR TEST SPECIMEN

The specimens and schematic image of the torque shear test are shown in Figure 2. Specimens are made by mortar casting. A solid steel cylinder is buried in a mortar block, and the steel surface area in contact with the mortar simulates the steel-concrete interface of hybrid structures. Mixture of the mortar is shown in Table 1. Aggregate is omitted for stability of mortar property, and a spiral reinforcement is embedded around the steel cylinder to prevent disintegration before the test.

The surface of all specimens is covered with mill scale, and the compressive strength of the mortar at each test in this paper is 29.2 ~ 33.3 N/mm^2 (29 ~ 36 days). The property of the mortar and the steel cylinder surface are considered the same, and therefore the test results are compared with each other.

This work reports the behavior of the steel-mortar interface of the new torque shear specimen under some experimental conditions to obtain an effective test method to measure an accurate strength of the adhesion and friction.

Table 1 : Mix proportion of mortar.

Water/cement ratio (%)	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)
50	295	590	1027

2.1. Influence of the size of mortar block

Two types of specimen with mortar block of 150×150×100 mm and 300×300×100 mm as shown in Figure 2 are prepared to investigate the influence of the size of the block, because the lighter the weight of specimen is, the better handling. Both types of specimen have the same cylindrical contact area. The side of mortar block is fixed and supported on a base by steel plates, and torque arms driven by jacks turn the steel cylinder. The details of test machines will be described later.

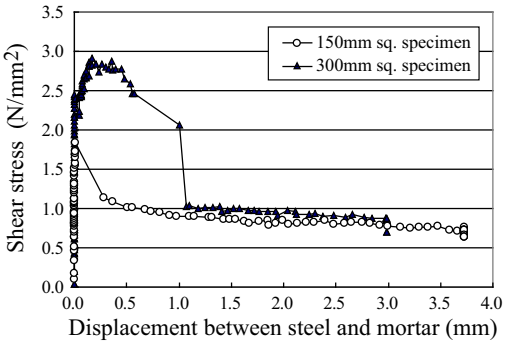

Figure 3 : Shear stress and displacement between steel and mortar for 150 and 300 mm sq. specimens obtained by the torque shear test.

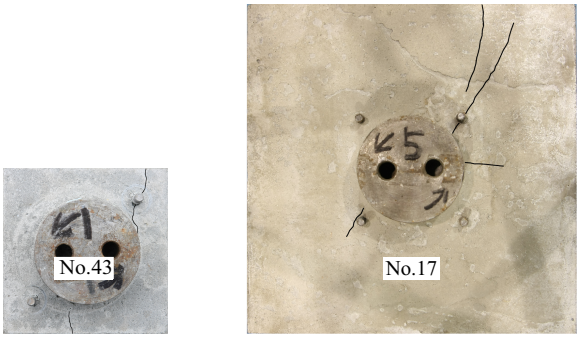

Figure 4 : (Left) Typical crack patterns of 150 mm sq. specimen; (Right) that of 300 mm sq. specimen (visible cracks are traced).

Typical results of torque shear test for 150 mm square specimen and 300 mm square specimen are shown in Figure 3. The figure is plotted with value of shear stress calculated with a load sensed at an end of torque arms as the vertical axis, and slips between steel and mortar at the interface measured by 4 clip gauges for CTOD test as the horizontal axis (average value is plotted).

No displacement could be measured until the shear stress took maximum value in all 150 mm square specimens, and then displacement between steel and mortar began to decrease suddenly with small jump(s) of displacement, at the same time the specimen sometime made sound. On the other hand, a maximum shear stress value of 300 mm square specimen was measured after beginning of slip, and sudden decrease of shear stress was observed later as compared with the 150 mm square specimen. After sudden decrease of the shear stress, the shear stress settles on a constant value in both cases.

The maximum value of shear stress could be indicated the strength of adhesion between steel and mortar, and the constant value which appeared after the peak could be indicated the strength of the friction, hence the maximum value of shear stress is called shear strength and the constant value is called residual shear stress, in this paper.

Table 2 : Summary of torque shear test for 150 and 300 mm square specimens.

Case	Quantity	Max. shear stress (N/mm^2) [a]	Residual shear stress (N/mm^2) [a,b]
150mm sq. specimen	15	2.01 (0.32)	0.82 (0.09)
300mm sq. specimen	3	3.49 (0.43)	1.14 (0.13)

[a] Standard deviations are in parentheses, [b] The mean value from 1.5 to 2.5mm

The test was carried out more than three times a case, and maximum shear stress and residual shear stress: the mean value of shear stress from 1.5 to 2.5 mm, are listed in Table 2, and their standard deviations are also shown in parentheses. Both of the maximum shear stresses in Table 2 was larger than 0.5 N/mm^2 obtained in previous push-out test (Yamada et al. 2001), and the maximum shear stresses of 300 mm square specimen was larger than that of 150 mm square specimen.

Typical crack patterns of each case are presented in Figure 4. The direction of propagation of the cracks in 150 mm square specimen can not be judged by the crack pattern. However, it can be seen, by focusing on the crack pattern difference from 150 mm square specimen, that short cracks of 300 mm square specimen initiated near the steel-mortar interface, propagated, and then stopped at the middle of the mortar block. The behavior of 300 mm square specimen's graph around the maximum point in Figure 3 could be due to the short cracks. And the sudden stress-drop could be due to the penetrated crack in the upper right corner, and it can be seen that the crack initiate at the side of specimen and propagate inward.

2.2. Control of crack initiation on the side of the specimen

There is the possibility that the crack which arises from the side of the specimen brings sudden stress-drop and decrease the maximum value of this test, and the crack initiation is due to boundary conditions rather than bonding strength. To prevent form crack initiation on the side of the specimen, steel mesh was embedded near the surfaces around the side of mortar block of 150 mm square specimen as shown in Figure 5, and the torque shear tests were carried out.

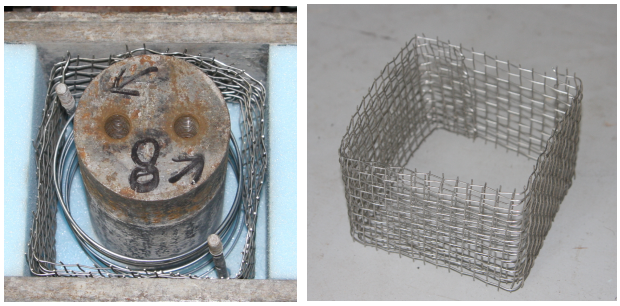

Figure 5 : Steel mesh embedded in a mold to prevent the side of specimen from cracking.

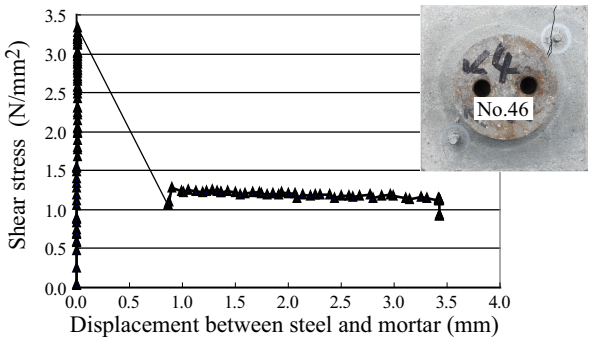

Figure 6 : Shear stress and displacement between steel and mortar for 150 mm sq. specimens with steel mesh, and its crack pattern.

Table 3 : Summary of torque shear test for 150 mm square specimens with steel mesh and without reinforcement.

Case	Quantity	Max. shear stress (N/mm^2) [a]	Residual shear stress (N/mm^2) [a,b]
150mm sq. specimen with steel mesh	3	3.12 (0.60)	0.94 (0.19)
150mm sq. without reinforcement	3	2.12 (0.06)	0.49 (0.26)

[a] Standard deviations are in parentheses, [b] The mean value from 1.5 to 2.5mm

The typical results of the torque shear test are shown in Figure 6 and Table 3. The maximum stress was increased, and the stress drop was also increased in Figure 6, the residual stress was almost the same as previous two types of specimen. However, the crack pattern does not have outstanding features which indicate the propagation direction.

Torque shear tests on the specimen without any reinforcement (without the spiral reinforcement) were carried out to check the influence of mortar's shrinkage or creep at the same time, and they could complete without collapse before and during the test. These result are summarized in Table 3. The spiral reinforcement was related the residual shear stress on this test because the residual shear stress was much decreased as shown, and some specimens disintegrated when the clamps and torque arms were removed after the test.

3. TEST MACHINE AND INFLUENCE OF ADDITIONAL REACTION FORCE

Torque shear test machines used in this study are shown in Figure 7 and Figure 8. Both test systems are composed of jack, two torque arms and specimen clamps. A torque arm is a steel bar of 50×30 mm rectangular cross section and 1000 mm long (from loading point to loading point), and two torque arms are bolted on both side of the steel cylinder at the center of the arms.

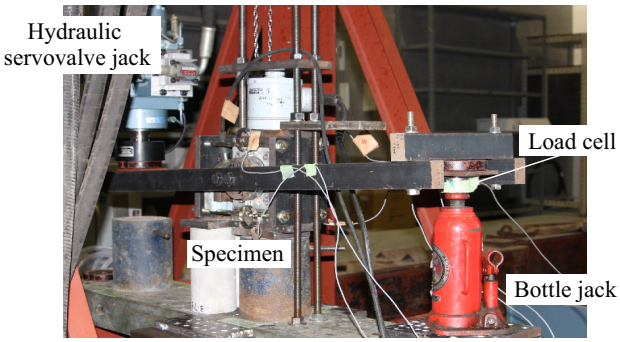

Figure 7 : Dual jack torque shear test system.

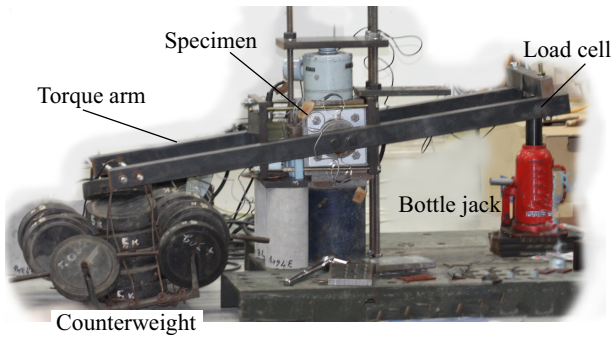

Figure 8 : Single jack torque shear test system.

The dual jack system shown in Figure 7 uses a hand operated bottle jack as active actuator, and a hydraulic servovalve jack as passive actuator. Active load is measured by a load cell placed between the bottle jack head and torque arm bracket, and the load cell controls the passive actuator of dual jack system to generate the same load as the bottle jack. All above results shown in this paper were obtained by this dual jack system.

Here is the single jack system shown in Figure 8, it uses definite counterweight during the test instead of passive actuator in dual jack system. This system has an advantage over dual jack one in that it is more simple and easy to construct and operate. However, the single jack system works without making counterbalance. Specifically, the steel cylinder fixed in torque arms is exposed to down force in the early loading stage. As bottle jack's force increase up, the force pressing the steel cylinder down on become smaller, and one time they become on balance. The force, which is the reaction force of bottle jack and counterweight, works to lift up the steel cylinder after the balancing point.

There is a fear that the additional reaction force affects the strength of adhesion or friction of the torque shear test. In this paper, two kind of counterweight: one to balance with the maximum shear stress (failure of adhesion) and the other with the residual shear stress (friction), are chosen, and the torque shear tests were carried out with 150 mm square specimens with the spiral reinforcement (and without steel mesh).

Table 4 : Summary of torque shear test by single jack system.

Case	Quantity	Max. shear stress (N/mm^2) [a]	Vertical force of max. shear (kN)	Residual shear stress (N/mm^2) [a]	Vertical force of residual shear (kN)
CW 100kg	6	2.22 (0.43)	−3.19	0.87 (0.11)	0.38
CW 200kg	3	1.92 (0.10)	−0.66	0.90 (0.01)	2.08
By dual jack system [b]	15	2.01 (0.32)		0.82 (0.09)	

[a] Standard deviations are in parentheses, [b] For comparison and already shown in Table 2 as "150 mm sq. specimen "

Result of these tests are listed in Table 4. The maximum shear stress of the test with counterweight of 100 kg obtained under vertical force of about −3 kN was almost the same or a little larger than one by the dual jack system, and the residual shear stress of the test with counterweight of 200 kg obtained under vertical force of about 2 kN was also almost the same as one by the dual jack system. These results indicate the influence of the additional reaction force is insignificant. However, above facts about the influence of residual shear stress are mismatched to the effect of the spiral reinforcement as mentioned and Coulomb's friction law, and they are not trivial.

4. CONCLUSIONS

A new specimen and test instruments that use cylindrical steel-mortar interface were proposed in order to obtain an effective test method to measure the shear strength and behavior along the steel-concrete interface accurately. The dual and single jack systems were experimentally produced and torque shear test were carried out under some experimental conditions. It was found that cracks initiate on the side of the specimen were due to boundary conditions rather than strength of steel-mortar interface and should be prevented. Also, the test results showed that the maximum shear stress and residual shear stress were not so affected by the additional reaction force of the torque share test systems proposed here.

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