論 文

[2176] STRENGTH AND DEFORMATIONAL BEHAVIORS OF STUDS EMBEDDED IN HIGH STRENGTH PRESTRESSED CONCRETE

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ABSTRACT

The strength and behaviors of stud embedded in high strength prestressed concrete was studied experimentally. The average shear force-average slip relationship, and further, shear force-slip relationship of each headed stud along steel anchorage plate were investigated. The effects of type of steel plate, concrete strength and prestress ratio on the strength and stiffness of stud were also inspected. The experiment reveals that the application of Fisher et al.'s equation on maximum shear force of stud can be extended to stud embedded in high strength prestressed concrete. Comparatively, the stiffness of stud is considerably higher than Fisher et al.'s equation. A model obtained by modifying Fisher et al.'s equation represents the average shear force-average slip relationship quite well. The effects of type of steel plate (plain and checker), concrete strength and prestress ratio on the strength and stiffness of stud are small. Also, the shear force-slip relationship of headed studs along steel anchorage plate are different. However, the stiffness of studs approaches each other with increase in prestress ratio.

1. INTRODUCTION

Recent development in construction trend towards large scale structures. In conjunction with this, various approaches have been tried and worked out to reduce the weight of structural members, so that structures can be constructed safely and economically. In the case of concrete bridge, instead of the conventional prestressed concrete girder, one possible method is steel-concrete composite girder which consists of high strength prestressed concrete deck and thin steel web. In this type of concrete composite structure, the connection between steel and concrete components is necessary and the transfer of shear force between the two components is important to be understood. Due to its relative ease and rapid welding process in the plant or at the construction site, headed studs are usually employed to function as shear connectors.

Many research have been carried out on headed stud shear connectors and various equations have been proposed to estimate the strength of stud [1][2][3][4]. The average

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shear force–average slip relationship was also being studied [3]. These research provide valuable knowledge for design of studs in steel–concrete composite structures, however, only normal weight or lightweight concrete were involved. So far, there is still no similar research on headed studs embedded in high strength prestressed concrete yet. In order to provide some basic information towards this aim, this project was conducted to study the shear force transfer mechanism between high strength prestressed concrete slab and steel plate, by investigating the strength and deformational behaviors of headed stud shear connectors.

2. EXPERIMENT

2.1 EXPERIMENTAL CONDITIONS AND DETAILS OF SPECIMEN

The parameters involved were concrete compressive strength (f_c'), prestress ratio (σ_p / f_c') and type of steel plate. Based on these parameters, various combinations were considered and all together two series, which consisted of eight specimens were prepared and tested. The properties of each specimen is listed in Table 1.

Table 1 Properties of specimens

Series	Specimen No.	f_c' MPa	σ_p / f_c'	Type of steel plate
I	1	80	0	Plain
	2		0.3	Checker
	3	40		Plain
II	4	80	0	Plain
	5		0.3	
	6		0.4	
	7	40	0	
	8	100	0	

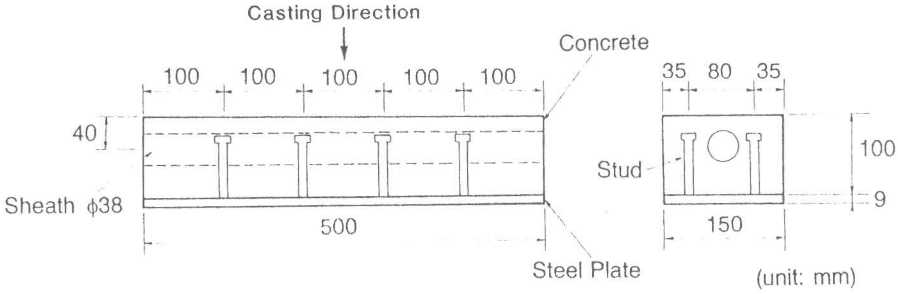
Note; f_c' : compressive strength of concrete
σ_p : prestress

The details of specimens are shown in Fig.1. The specimens were design as half-scale models. In every specimen, eight number of headed studs were welded perpendicularly to a piece of steel plate (SS41, 9mm thick), which were arranged in two rows, four number in each. The spacing of studs was set constant at 100mm. The studs were 9.5mm in diameter (D) and 75mm in height (H); H/D = 7.9 and stud area ratio = 0.95%. The tensile properties of studs are as follows:

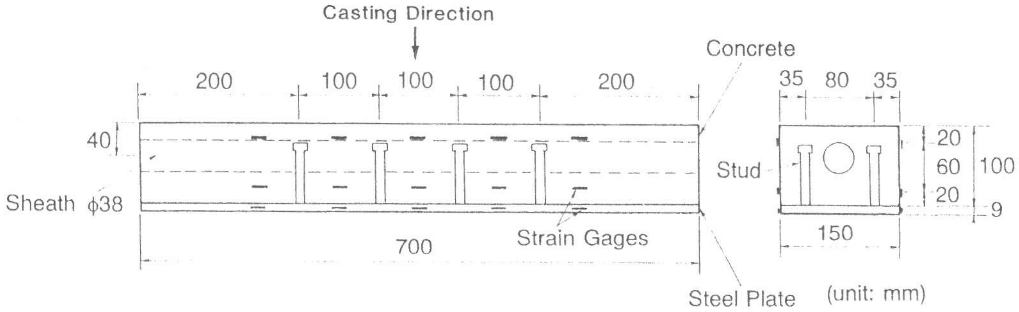
Series	Yield Stress(MPa)	Tensile Strength(MPa)
I	353	430
II	379	474

The cross section of concrete slab was 100mm x 150mm. In order to allow a PC steel bar to be allocated in the concrete slab, a ϕ38mm–sheath was placed 40mm below the upper surface of concrete slab.

For all the specimens in Series II, concrete strain gages were mounted at the center position between each stud in the direction of the concrete axis, two on each side of the concrete section, 20mm from the upper and lower surface of concrete respectively as shown in Fig.1(b). At the same sections, steel strain gages were also mounted onto both faces and at the axis of steel plate.



(a) Specimen of Series I



(b) Specimen of Series II
Fig.1 Details of Specimens

2.2 INSTRUMENTATION AND TESTING PROCEDURES

The experiment performed consisted of two stages :

(1) Prestressing stage

This was the preliminary stage of the experiment. The set-up of test is shown in Fig.2. Prestress force was applied through a ϕ32mm-PC steel bar and data were recorded from this stage onward.

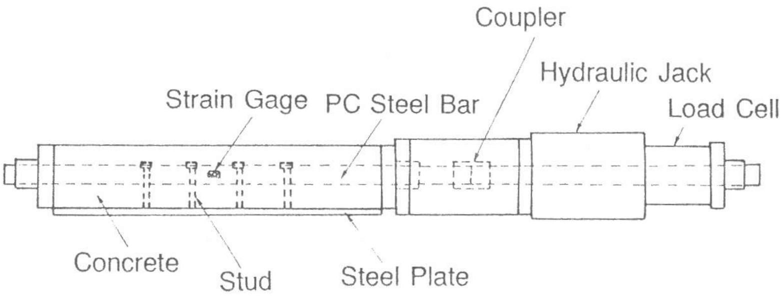


Fig.2 Experiment set-up during prestressing stage

(2) Loading stage

Pushout test was carried out during this stage and the test set-up is illustrated in Fig.3. The specimen was placed and tied firmly to the upper flange of a stiffened I beam by high tensile bolts, where the I beam was earlier tied to a H beam testing bed. Force was applied onto the specimen and data were measured at every force interval of 5kN. Slips at loaded end and free end of the specimen were also measured by two electrical transducers respectively. Measurements were done up to the failure of the specimen.

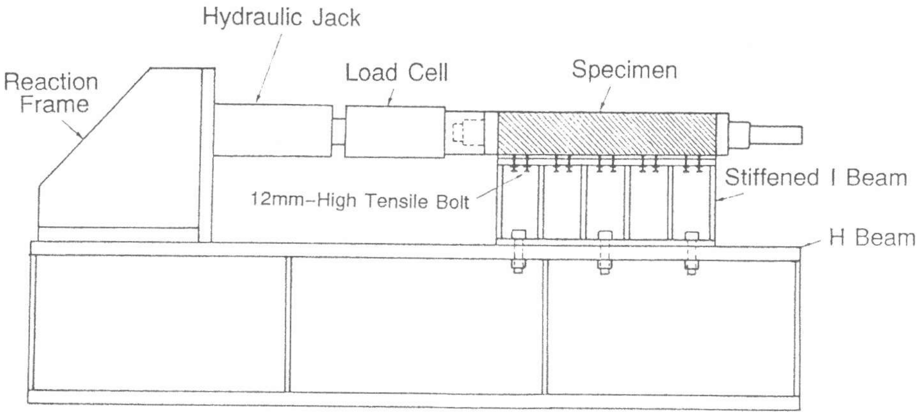


Fig.3 Experimental set-up during loading stage

3. TEST RESULTS AND DISCUSSION

3.1 STRENGTH OF HEADED STUD

Test results of the pushout specimens are presented in Table 2. The maximum shear force per stud (V_{max}) is the maximum shear force applied to the specimen divided by the corresponding number of studs i.e. eight. In this procedure, two assumptions are involved:

1) Shear force was transmitted from the concrete slab to the steel plate only through the studs.
2) Shear force was divided evenly between the individual studs.

Table 2 Concrete strength and maximum shear force per stud

Specimen	1	2	3	4	5	6	7	8
f_c', MPa	78.9	78.9	34.7	81.2	82.4	82.0	40.8	99.6
V_{max}, kN	34.8	36.7	31.1	34.3	37.2	35.5	30.1	35.8

Note; f_c' : concrete compressive strength
V_{max}: maximum shear force per stud

Test results show that there are no significant differences in the maximum shear force carried by each stud for all the specimens, indicating that the effect of type of steel plate (plain and checker), concrete strength and prestress ratio are small.

Fig.4 compares the test results and the equation proposed by Fisher et al. Fisher et al. suggested that their equation is subjected to an upper bound in the strength of stud, which is approached when $(f_c' E_c)^{1/2} \cong$ 130ksi (915MPa). This corresponds to a value of $V_{max} / A_s \cong$ 65ksi (458MPa) or $V_{max} \cong$ 32.5kN in this study. It can be observed that test results agree with this equation. Hence, the maximum shear force of stud embedded in high strength prestressed concrete falls within the application range of Fisher et al.'s equation.

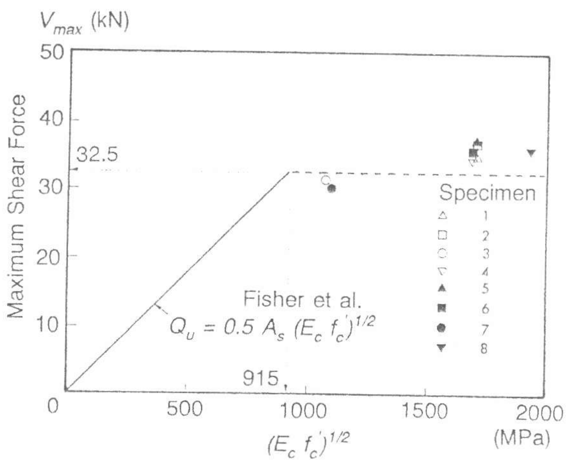


Fig.4 Comparison between test results and Fisher et al.'s equation

3.2 AVERAGE SHEAR FORCE–AVERAGE SLIP RELATIONSHIP

Fig.5 shows a typical average shear force–average slip relationship of stud. The curve shows that at lower level of shear force, the slip is relatively small. However, substantial inelastic deformation is exhibited before failure. It can be observed that the stiffness of stud is considerably larger than the equation proposed by Fisher et. al. which is given by :

$$V / V_{max} = (1-e^{-0.7\delta})^{2/5} \quad (1)$$

where,

V : average shear force

δ : average slip

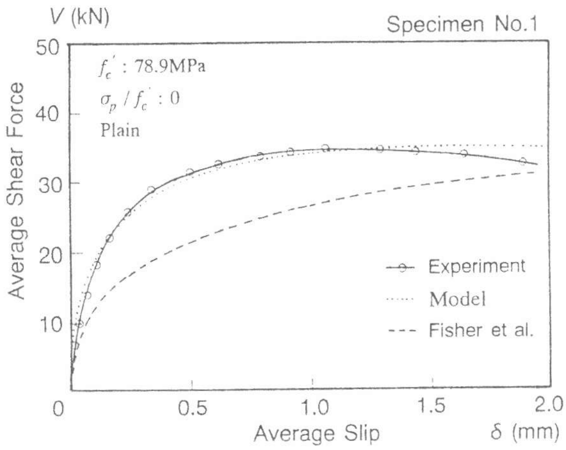


Fig.5 Average shear force–average slip relationship

Average shear force–average slip relationship of all the specimens are compared by non-dimensionalizing the average shear force by the maximum shear force per stud, as illustrated in Fig.6. The results form a narrow band over the entire range of slip, implicating that the influence of type of steel plate (plain and checker), concrete strength and prestress ratio on the stiffness of studs are small. This relationship can be expressed by a model modified from Fisher et al.'s equation as :

$$V / V_{max} = (1-e^{-2.8\delta})^{2/5} \quad (2)$$

which was obtained by substituting the constant −0.7 in Fisher et al.'s equation with −2.8.

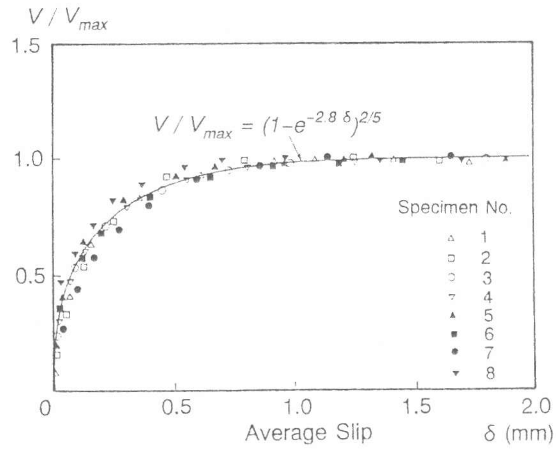


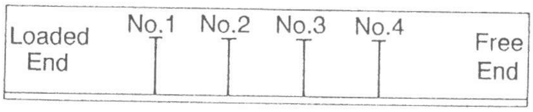
Fig.6 Non–dimensionalized average shear force–average slip relationship

Comparison between this model and test results is also shown in Fig.5.

3.3 SHEAR FORCE–SLIP RELATIONSHIP OF HEADED STUDS ALONG STEEL ANCHORAGE PLATE

From the strain values and slip (at loaded end and free end) measured, shear force–slip relationship of each stud along steel anchorage plate can be determined. The shear force–slip relationship of Specimen No.4 (f_c' = 81.2MPa, prestress ratio = 0) is shown in Fig.7. It can be observed that the stiffness of studs nearby the free end are higher than those further from the free end. Similar pattern of shear force–slip relationship are found in specimen No.7 (f_c' = 40.8MPa, prestress ratio = 0) and Specimen No.8 (f_c' = 99.6MPa, prestress ratio = 0).

Fig.8 shows the shear force–slip relationship of Specimen No.5 (f_c' = 82.4MPa, prestress ratio = 0.3). Negative shear force and slip occurs during prestressing stage. Comparing Fig.7 and Fig.8 find that the stiffness of studs along steel anchorage plate is nearing each other with increase in prestress ratio. This tendency is also observed in Specimen No.6 (f_c' = 82.0MPa, prestress ratio = 0.4).



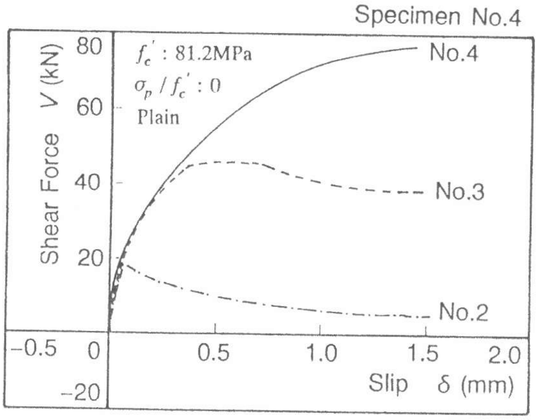


Fig.7 Shear force–slip relationship for specimen with $\sigma_p / f_{c'} = 0$

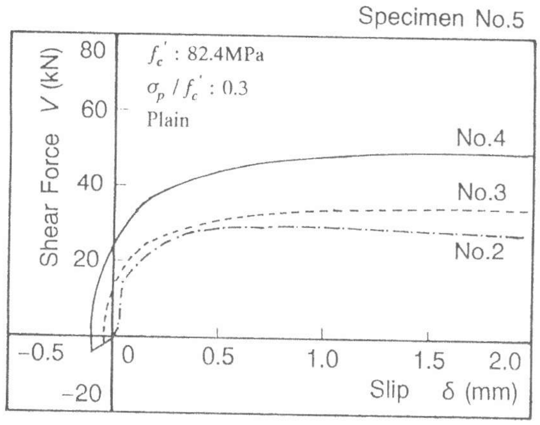


Fig.8 Shear force–slip relationship for specimen with $\sigma_p / f_c = 0.3$

4. CONCLUSIONS

1) The range of application of Fisher et al.'s equation on the maximum shear force of stud can be extended to stud embedded in high strength prestressed concrete.
2) The stiffness of stud in this experiment is considerably higher than the equation proposed by Fisher et al. The average shear force–average slip relationship of the stud can be expressed by a model modified from Fisher et al.'s equation.
3) The influence of type of steel plate (plain and checker), concrete strength and prestress ratio on the maximum shear force and stiffness of stud are small.
4) The shear force–slip relationship of studs along steel anchorage plate are not the same. However, the stiffness of studs tends to become closer to each other with increase in prestress ratio.

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