論 文

[2144] LOAD−DISPLACEMENT RELATIONSHIP OF SHEAR CONNECTOR ALONG STEEL PLATE ANCHORAGE

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1. INTRODUCTION

In steel-concrete composite structure, shear connectors are usually required for development of composite action between concrete and steel. However, some types of structure such as sandwich composite structure, shear connector is also provided for stiffening structural steel plate which also acts as formwork other than strengthens the member. According to this structural type, shear connector such as L, T and plate shape rib is preferable rather than headed stud shear connector.

To provide a basic knowledge for design of composite structure, it is important to know the capacity of shear connectors. Ueda and Chin [1] had conducted a research on single plate shape shear connector and an equation to determine its capacity was developed. They also suggested that the equation can be applied to predict the capacity of group shear connectors conservatively. However, this has not been clarified yet. In real structure, where shear connectors are arranged in group, the load carrying capacity of each shear connector may be influenced by the existence of neighboring boundary and eventually the capacity of plate anchorage may also be affected.

This study is aim to clarify and work out the way to estimate the capacity of plural plate shape shear connectors. To fulfill this purpose, it is necessary to find out the load-displacement relationship of shear connectors along the plate anchorage.

2. EXPERIMENT

The experiment was performed by direct pull-out test. A total six number of specimens were tested. The details of specimens are given in Fig.1 and Table 1. The thickness and width (W) of the bed plate for all the specimens were the same, 6mm and 150 mm respectively, but the length varied with number of shear connectors. Specimens SN-2, SN-4, SN-5, SN-6, SN-7 and SN-8 were provided with 2, 4, 5, 6, 7 and 8 number of shear connectors each. All the shear connectors were plate shape with same dimensions of 150 mm in length, 20 mm in height and 2.3 mm in thickness. Shear connectors were welded perpendicularly to

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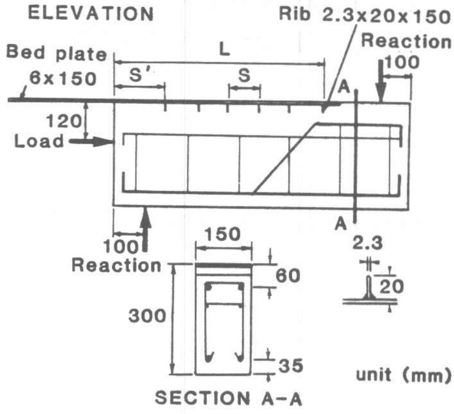

Fig.1 Details of specimens

Table 1 Details of specimens

Specimen	n	S' mm	L mm
SN-2	2	200	300
SN-4	4	200	500
SN-5	5	100	500
SN-6	6	100	600
SN-7	7	200	800
SN-8	8	200	900

Note n : Number of rib
S' : Length of concrete infront of rib nearby loaded end
L : Anchorage length

the bed plate and their spacings (S) were kept constant at 100 mm. Concrete with maximum aggregate size 5 mm was cast in the direction normal to the plane of bed plate. The cross sectional area of concrete portion for all the specimens was 150 mm x 300 mm, while the length varied with number of shear connectors. In order to ensure only the behaviors of force transferred by shear connector could be observed, friction force, possibly induced in between concrete and bed plate, was removed by attaching smooth tape on the inner surface of bed plate.

The experimental set-up is shown in Fig.2. The test specimens was tested on a huge H beam. The bed plate of specimen was fixed to a rigid reaction frame which was tightened to the H beam by prestressing bars. Load was applied to the specimen by a hydraulic jack placed between the specimen and reaction frame. The center of load was 120 mm from the top of specimen. Roller supports were used as vertical reactions to counter the moment developed when load was applied. In order to determine the load carried by each shear connector, strain

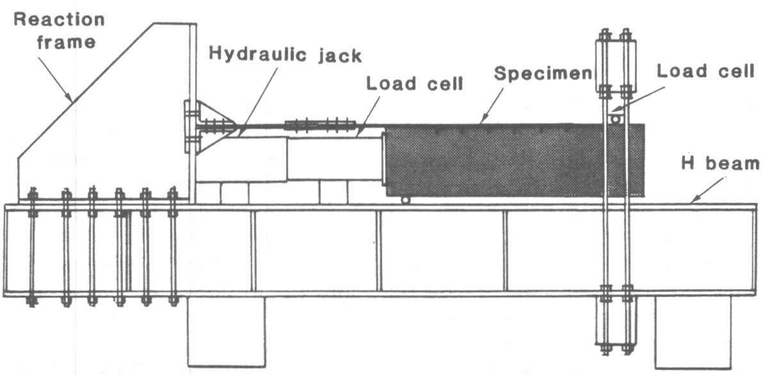

Fig.2 Experimental set-up

gauges were stuck on both faces of the bed plate. Longitudinal displacement of shear connector near the free end was measured by electrical transducer.

3. TEST RESULTS AND DISCUSSION

3.1 FAILURE MODE

The failure mode of all specimens were similar. It was observed that crack firstly appeared at shear connector nearby loaded end. As applied load was further increased, cracks developed from the tip of neighboring shear connectors progressively toward to the free end of plate anchorage. When plate anchorage reached the ultimate capacity, bed plate and contacted concrete suddenly split as an unit from the specimen. Fig.3 reviews the behavior of load carried by each shear connector along plate anchorage of specimen SN-6 up to just before the failure of specimen. At each stage of load applied to plate anchorage, load carried by each shear connector is not equal each other. Shear connectors near to loaded end begin to carry much more load than shear connectors near to the free end. At just before failure of plate anchorage, some shear connectors near loaded end have already reached their capacity and begin to fail to carry load while the other still does not reach their maximum capacity yet. This indicated the progressive failure process occurring in plate anchorage.

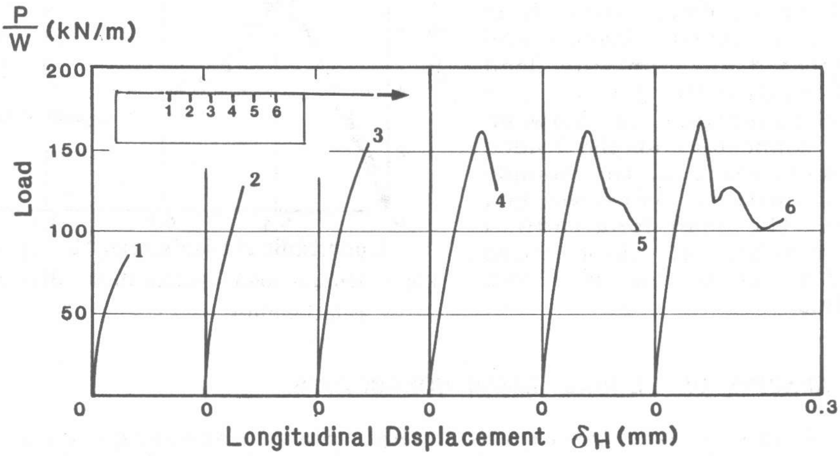

Fig.3 Load carrying behavior of shear connectors along plate anchorage

3.2 LOAD-LONGITUDINAL DISPLACEMENT RELATIONSHIP

Longitudinal displacement of shear connector is defined as the displacement relative to the original position of shear connector in the loading direction.

As shown in Fig.4 is the typical relationship between load carried by each shear connector and its longitudinal displacement. Longitudinal displacement increases almost proportionally with load until load reaches the maximum capacity of shear connector. This maximum load corresponds with load that generated crack from the tip of shear connector. Beyond this point, load suddenly decreases with increase of longitudinal displacement.

Fig.4 also shows that the load-longitudinal displacement relationships of shear connector at loaded end, at free end and in between them are different each other. It is believed that these differences are due to the influence of different boundary conditions. The boundary condition of shear connector at free end seems to have a small constraint in transverse direction normal to plane of bed plate. This caused the easier displacement in load-longitudinal displacement curve as shown in Fig.4. Also, shear connector nearby loaded end is affected by applying load from hydraulic jack. For shear connectors in between shear connectors at the loaded end and free end, the boundary conditions were similar. Hence, the load-longitudinal relationship of them were found to be unique as shown in Fig.5.

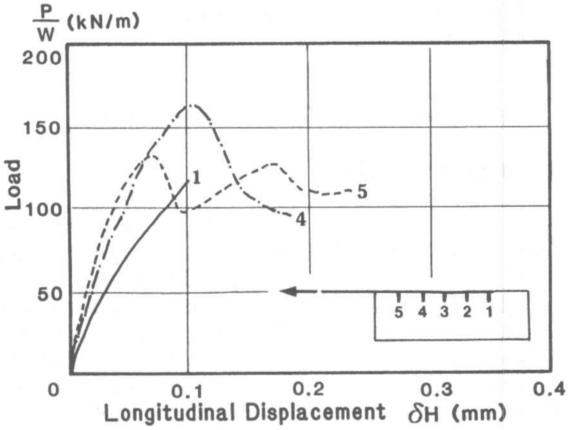

Fig.4 Effect of boundary condition on load-longitudinal displacement relationship

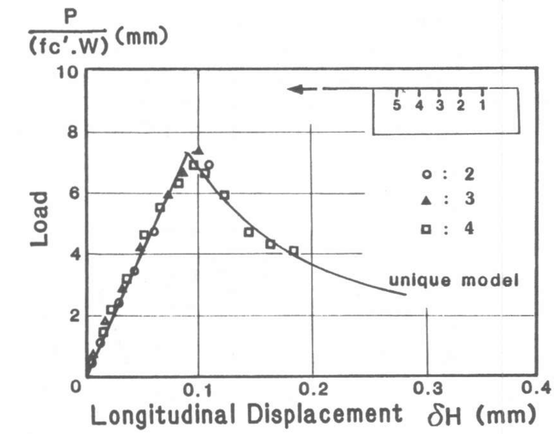

Fig.5 Unique load-longitudinal displacement relationship

3.3 CAPACITY OF PLURAL SHEAR CONNECTORS

Since it was recognized that plate anchorage possess the progressive failure characteristic and load- longitudinal displacement relationships of shear connector exhibit softening behavior. Therefore, the capacity of plate anchorage consisting of plural shear connectors can not be simply calculated by multiplying the capacity of single shear connector and total number of shear connectors. In order to predict the capacity of plate anchorage, load-longitudinal displacement model is necessary to be established. By simple modeling the unique load (P)-longitudinal displacement (δ_H) relationship as shown in Fig.5 with two expressions as follows,

$$P/(fc'.W) = K.\delta_H \qquad \text{for } \delta_H \leqq \delta_{HU}$$

$$P/(fc'.W) = P_{max}.(\delta_{HU}/\delta_H)^c \qquad \text{for } \delta_H > \delta_{HU}$$

where P_{max} : cracking load,
δ_{HU} : longitudinal displacement corresponding to cracking load,
K, c : constants,

load-displacement behavior and capacity of plate anchorage can be calculated. To eliminate the effect of boundary condition on behavior of plate anchorage, shear connector nearby loaded end was not considered. Fig.6 shows the load-displacement behavior of plate anchorage compared between analytical results and test data. It was found that the analysis values quite resembles the test results.

The test results of load carrying capacity for plate anchorage excluding shear connector nearby loaded end also compared to the calculated values given in Table 2. It shows that calculated results obtained by unique load-longitudinal displacement model agree well with the test results except specimen SN-2 which was provided with only two shear connectors. This is due to the influence of free end boundary condition. At just before failure of the specimen, the free end shear connector reached its maximum capacity which is different from the capacity of internal shear connectors. However, for other specimens in which longer anchorage lengths and more shear connectors were used, at just before failure of the specimen, load carried by the free end shear connector was still below its maximum capacity. Consequently, the influence of free end boundary condition is negligible and therefore the model can be used to predict the load carrying

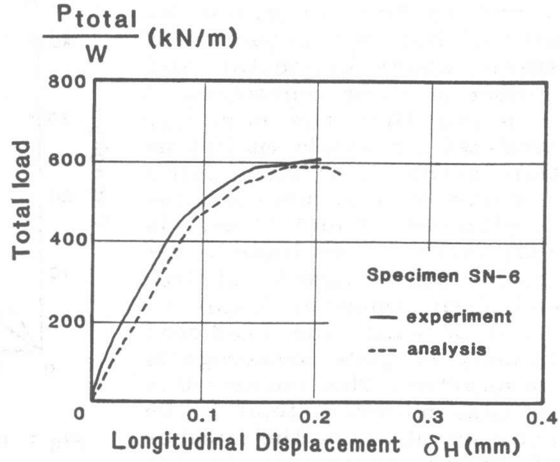

Fig.6 Relationship between total load and longitudinal displacement

Table 2 Comparison between load carrying capacity of plate anchorage from test results and calculations

Specimen	fc′ MPa	Pu(test) kN	Pu(cal) kN
SN-2	31.0	20	34
SN-4	22.2	72	65
SN-5	23.9	81	84
SN-6	21.4	90	88
SN-7	28.5	130	124
SN-8	28.2	150	131

Note
fc′ : Concrete compressive strength
Pu(test) : Capacity of plate anchorage excluding the shear connector nearby loaded end
Pu(cal) : Capacity of plate anchorage predicted by unique model

capacity quite well even though the free end shear connector is included.

Fig.7 illustrates the relationship between the capacity of plate anchorage and number of shear connector provided. The values calculated by unique load-longitudinal displacement model give better results as compared to that obtained by multiplying the capacity of single shear connector and number of shear connectors. It is noted that the capacity predicted by simple multiplication method ($n.P_{max2}$) using maximum load of unique load-displacement model (P_{max2}) is completely overestimated. Although using capacity of free end shear connector (P_{max1}) instead of P_{max2}, the predicted capacity of plate anchorage is conservative. This conservative results, however, tend to be unconservative as the number of shear connector is increased as indicated in Fig.7.

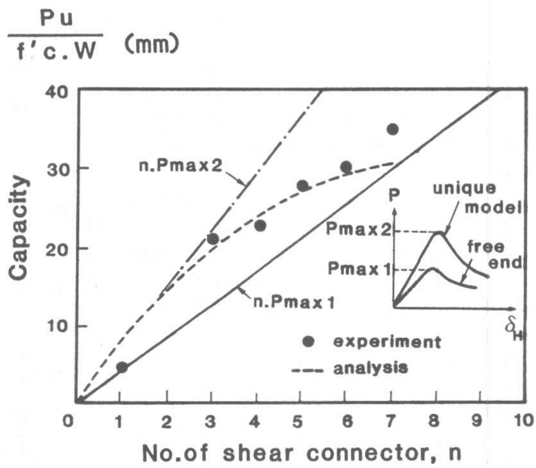

Fig.7 Relationship between load-carrying capacity of plural shear connectors and number of shear connectors

4. CONCLUDING REMARKS

(1) Shear connectors fail progressively, beginning with the shear connector near the loaded end.

(2) Shear connectors along anchorage plate exhibit an unique load-longitudinal displacement relationship except the shear connector at loaded end and free end which are under different boundary conditions.

(3) A simple model stimulating the unique load-longitudinal displacement relationship can be used to predict the capacity of the whole system of shear connectors.

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[1] Ueda,T, & Chin,C.K, "Strength Of Steel Plate Shear Connector", Proceedings of the Second Symposium on Research and Application of Composite Constructions, Kobe, Japan, Sept. 1989, pp. 149-156.