Investigation on Static Behavior of Stud Shear Connector

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1. Introduction

In this study, static behavior of stud shear connector of steel-concrete hybrid structures was investigated on comparison between experimental and analytical findings. A series of push-out tests were carried out under the pulsating and alternating load conditions for the evaluation of static behavior of the stud [1]. The applied load-relative displacement relation was measured during experiments for both the pulsating and alternating load condition. Numerical analysis was also carried out based on the nonlinear finite element method including Timoshenko Beam Theory and the findings have been compared with the experimental results.

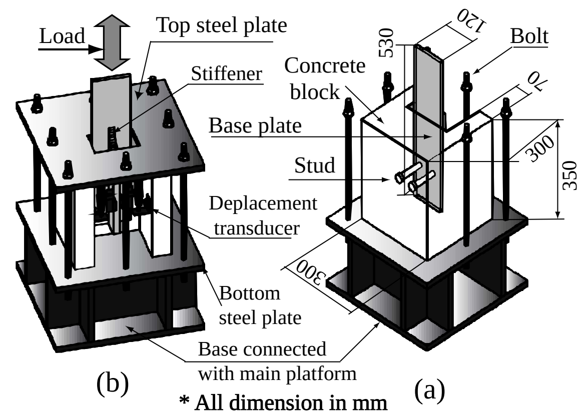

Fig. 1 Test specimen

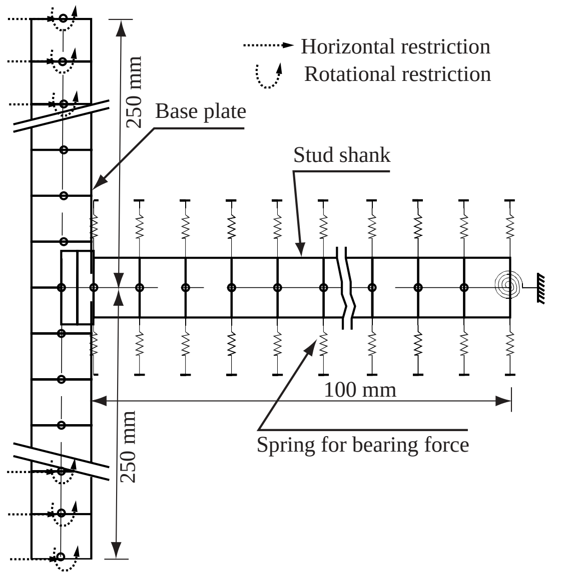

Fig. 2 Numerical model of stud and base plate

2. Test Specimen

The push-out test specimen used for the experimental study is shown in **Fig. 1**. The size and dimension of the specimens were selected mainly in order to conduct static and fatigue test for pulsating and alternating load conditions. A pair of 13-mm diameter and 100 mm long headed studs was welded on one side of base plate (530 mm×120 mm×13 mm). The stud is used in the composite or hybrid structure to transfer the shear force between concrete and stud itself in the transverse direction of the stud shank. Another steel plate named as stiffener (350 mm×60 mm×19 mm) was attached by welding on the other side of base plate. The stiffener is to increase the stiffness of the base plate and to provide sufficient resistance against buckling.

The shape of the concrete block was selected to prevent any rotation during experiment. The specimen was properly positioned [**Fig. 1**(a)] and fixed up with the platform using top steel plate and nut-bolt arrangement [**Fig. 1**(b)]. The static pulsating load as well as alternating load was applied to the specimens by clamping the top of the base plate with the head of the loading actuator. Displacement transducers were used for the measurement of relative displacement between the concrete block and the base plate at the same level of stud shear connectors.

3. Static Test

The push-out static tests were conducted under pulsating load and alternating load conditions respectively. In case of pulsating load, only compressive loading cycles were repeated up to the failure of the specimen. On the other hand, complete reversal loading cycles (from compression load to tension load) were repeated up to the failure of the specimen under alternating load condition. During experiments, the findings were limited to the relative displacement between the concrete block and base plate, strain at mid length of the stud and stain at different locations of the base plate. Data Logger was used to record the necessary data.

4. Numerical Analysis

Two-dimensional nonlinear finite element method in conjunction with Timoshenko Beam Theory was used for the numerical analysis to find out the numerical behavior of the stud. The numerical model of the stud, base plate and surrounding concrete has been shown in **Fig. 2**. The base plate and stud are modeled as beam-column element with geometric and materials nonlinearities. For geometrical nonlinearity, finite displacement and infinitesimal strain problem are taken into account since it is rational and realistic for general framed structure that includes beam-column element also. For computational plasticity, all the components of stress for stud and base plate material must satisfy some conditions required by the classical plasticity, such as yield condition as well as equilibrium.

In order to simulate plastic material nonlinearity, von Mises yield criterion, associate flow rule, kinematic hard-

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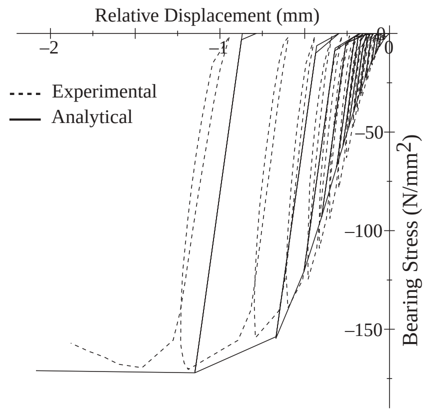

Fig. 3 Bearing force versus relative displacement curves

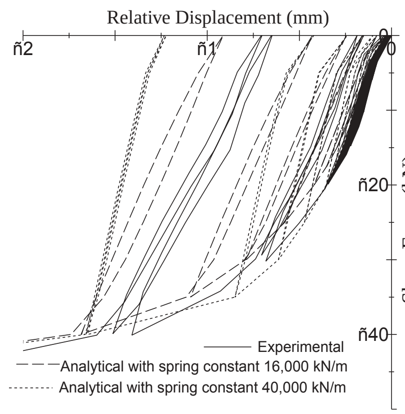

Fig. 4 Shear force-slip relations for pulsating load condition

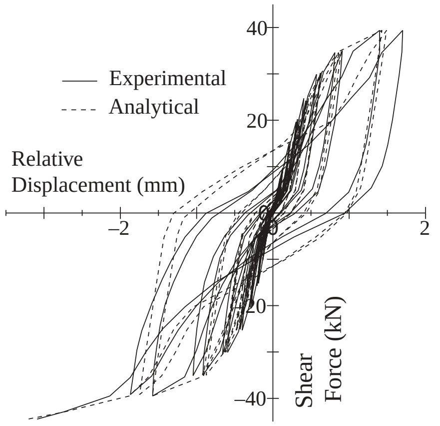

Fig. 5 Shear force-slip relations for alternating load condition

ening law and also constitutive relation of elasticity have been considered within the frame work of return mapping algorithm [2] for numerical analysis. Two stress components viz. one normal component along longitudinal direction and another shear component in cross section are considered and all other components are assumed as zero.

For numerical analysis only 250-mm base plate was considered instead of 530-mm which is symmetrical about the axis of stud. The effect of length of base plate is insignificant on numerical analysis. The surrounding concrete of the stud is modeled as one-dimensional bearing springs. The restoring characteristics of the bearing springs were obtained from the bearing test of concrete and the springs are arranged in between the stud and the virtual fixed end (**Fig. 2**). The 100-mm stud was divided into 20 beam-column elements and the 250-mm base plate was divided into 27 beam-column elements. The stress-strain relationship of the steel material is idealized as bilinear form with kinematic hardening. The tangent modulus in the hardening region is set as 1% of the Young's modulus.

On the other hand, nonlinear force-displacement relation was adopted for the bearing spring that was included nonlinear isotropic hardening law. The bearing springs are considered to resist compressive force only and resistance against tensile force is assumed to be zero. To fit the outlines of the bearing force-relative displacement relation, obtained from bearing test of concrete, a fourth order polynomial curve was taken into account. The relations between bearing stress and relative displacement obtained from bearing test of concrete and also that from numerical analysis have been shown in **Fig. 3** in which the ordinate indicates the bearing stress and the abscissa indicates the relative displacement.

The outlines of both the curves and also the slope of the unloading path agree well with each other. The unloading path follows the linear one because of numerical consideration. The spring constant of the bearing springs was obtained from the slope of the unloading path of bearing force-relative displacement relation. The stud head is modeled as bearing spring as well as rotational spring.

5. Discussion of Results

The analytical results of stud shear connector obtained from 2D nonlinear finite element method have been compared with experimental findings. The analytical shear force-relative displacement (slip) relationship is compared with experimental one in **Fig. 4** for static pulsating load condition (PLC). The same relationship for static alternating load condition (ALC) is compared in **Fig. 5**. The ordinate indicates the shear force applied to one stud and the abscissa indicates the average value of relative displacement (slip) for experimental findings and corresponding nodal displacement in case of numerical analysis. In numerical analysis, spring constant that obtained from concrete bearing test is assumed as 40,000 kN/m for both the PLC and ALC. The comparisons show good agreement but the unloading slope of numerical analysis for PLC is shown in **Fig. 4** not so good.

To examine the effect of spring constant, trial and error method was adopted for finding the spring constant which confirm approximately the same unloading slope with the experimental one. This expected spring constant is 16,000 kN/m, which is about 40% of 40,000 kN/m. The comparison between experimental and analytical responses with spring constant 16,000 kN/m shown in **Fig. 4** is reasonably better than the comparison with spring constant 40,000 kN/m shown in the same figure.

6. Conclusions

The following conclusions may be drawn based on the experimental and analytical findings.

According to **Fig. 3**, it may be noted that the analytical results compare quite well with the experimental values obtained from concrete bearing test. The correlation shown in **Fig. 4** is not so good in case of spring constant 40,000 kN/m, whereas in case of 16,000 kN/m spring constant, it appears that the analytically predicted results are in fair agreement with the experimental results. The comparison shown in **Fig. 5** for ALC also agrees well with each other.

REFERENCES

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2) Simo, J. C. and Hughes, T. J. R., Computational Inelasticity, Springer, 1999.