A Comparative Study on Static Shear Force-Slip Behavior of Stud Shear Connector

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1. Introduction

The objective of this study is to find out relatively better correlation between the experimental and numerical findings of static shear force-slip behavior of stud shear connector of steel-concrete hybrid structures. A series of push-out tests was conducted under the pulsating and alternating load condition for the estimation of static strength of stud and to measure strain behavior of stud. Shear force-slip behavior of each of the specimens was also recorded during experiment. Among the tests part of tests conducted by the author.

In this study, nonlinear Finite Element Technique including Timoshenko Beam Theory is used for the numerical analysis of the stud and the result is compared with experimental findings.

Composite steel-concrete construction is widely used in buildings and bridges, even in regions of high seismic risk. The increased use of this type of construction in regions of high seismic risk recently led to a concerted research effort within the framework of the U.S.-Japan program [1].

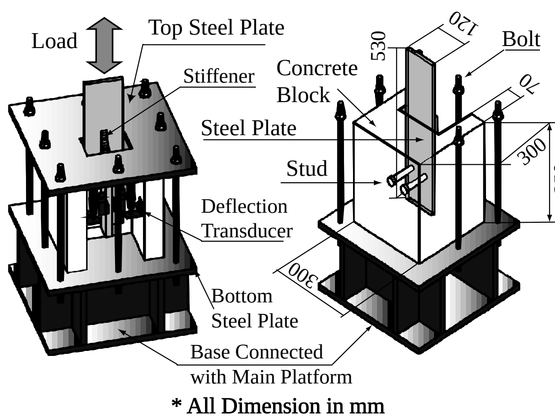

Fig. 1 Test Specimen

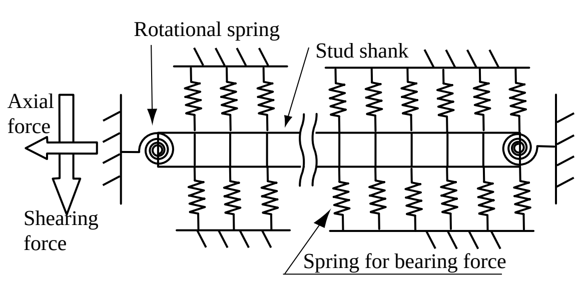

Fig. 2 Numerical Model of Stud

2. Test Specimen

The test specimen provided for the experiment shown in **Fig. 1**. The selection of the dimension of specimen was done mainly based on the purpose how to conduct static and fatigue test for pulsating and alternating load respectively. A pair of headed studs having 13 mm diameter and 100 mm length was fastened on one side of steel plate (530 mm×120 mm×13 mm) and at other side another steel plate named as stiffener (350 mm×60 mm×19 mm) was fastened by welding. The purpose of the stiffener is to increase the stiffness of the steel plate and to provide sufficient resistance against buckling. The shape of the concrete block has been selected to prevent any rotation during experiment. The static alternating as well as pulsating load was applied to the specimens by clamping the top of the steel plate with the head of the loading actuator.

Prior clamping the specimen was properly positioned with steel plate and nut-bolt arrangement. Displacement transducers were used for the measurement of relative displacement between concrete block and steel plate at the same level of stud shear connectors.

3. Static Test

In static test both the pulsating and alternating loading was applied on the specimens respectively. One sided either tensile or compressive loading cycles repeated up to the failure of the specimen under pulsating static load test. On the other hand, complete reversal loading cycles (from compression load to tension load or vice versa) repeated up to the failure of the specimen under alternating static load test. Relative displacement between concrete block and steel plate and strain at mid length of the stud measured at each loading steps during experiments.

4. Numerical Analysis

Two dimensional nonlinear Finite Element Technique including Timoshenko Beam Theory was used for the numerical analysis of the stud. The model of the stud and surrounding concrete is shown in **Fig. 2**. The stud is used in the composite or hybrid structure to transfer the bearing force between concrete and stud itself in the transverse direction of its stud's shank. The stud is modeled as beam-column element with geometrical and elasto-plastic material nonlinearities. For geometrical nonlinearity, finite displacement and infinitesimal strain problem has been taken in account since it is rational and realistic for gen-

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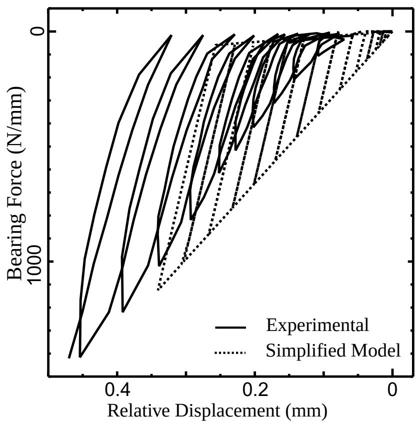

Fig. 3 Bearing force versus relative displacement curves

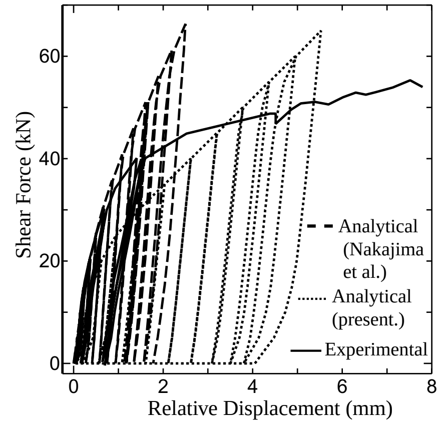

Fig. 4 Shear Force-slip relation for pulsating load condition

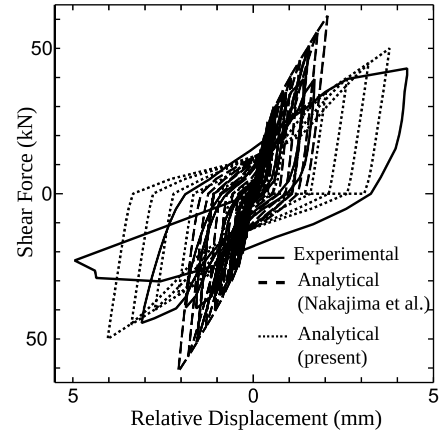

Fig. 5 Shear Force-slip relation for alternating load condition

eral framed structure that include beam-column element also. For computational plasticity, all the components of stress for stud 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 hardening law and also constitutive relation of elasticity have been considered within the frame work of return mapping algorithm [2] for numerical analysis. Two shear stress component viz. normal component along longitudinal direction and one shear component in cross section are considered and all other components are assumed as zero. The 100 mm stud is divided into 20 beam-column elements and the stress-stain 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 of elasticity.

The surrounding concrete of the stud is modeled as bearing spring. Mechanical properties of material nonlinearity of the bearing springs have been obtained from bearing test of concrete. The bearing springs are arranged between stud and the virtual fixed end. The spring is considered as one-dimensional element having the capability to resist compressive force only and the resistance against tensile force is assumed to be zero in the numerical analysis.

During experiment, the stud is also subjected to axial tensile force in addition to applied vertical shear force. This axial force is assumed to be proportional to vertical displacement at base of the stud. The proportional factor is determined based on the axial strain of the stud. Moreover, one rotational spring is provided at base to simulate a rotation of the base plate and another at tip of the stud to provide rotational restriction due to stud head.

5. Discussion of Results

A comparative study of the numerical results with experimental findings has been done to verify the both behaviors of stud. The bearing force versus relative displacement curve obtained from bearing test of concrete is shown in **Fig. 3** in associate the numerical analysis. The shear force-relative displacement (slip) relationship is shown in **Fig. 4** for static pulsating loading. The same relationship under static alternating load condition is compared in **Fig. 5**. The ordinate is the shear force applied to one stud and the abscissa is the average value of relative displacement (slip) for experimental findings and corresponding nodal displacement in case of numerical analysis. In both the figures numerical responses agree reasonably well with experimental findings. Nakajima et al. [1] also analyzed the same model. They considered three types of spring viz. bearing, horizontal and rotational spring at each intermediate node as the behaviors of concrete. Bernoulli-Euler Beam Theory was used in literature [1] that does not include the shear deformation and shearing stress contribution on yielding of materials of stud. On the other hand, Timoshenko Beam Theory that supports the shear deformation and shearing stress contribution on yielding of materials was included in present analysis. Timoshenko beam Theory constitutes an improvement over the Bernoulli-Euler Theory. That is why the two analytical results differ from each other both in **Fig. 4** and **Fig. 5**.

Another variation is found out from experimental and present numerical analysis in both **Fig. 4** and also in **Fig. 5**. This difference may be developed because of considering the steel plate as linear rotational spring and also the concrete replaced by one dimensional bearing spring with linear plastic hardening. From bearing test of concrete (**Fig. 3**), it is observed that the hardening characteristics is somewhat nonlinear.

REFERENCES

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