NUMERICAL MODELING OF COMPOSITE BEHAVIOUR OF GROUPED STUDS

Md. Khasro Miah[1]

Akinori Nakajima[2]

Ahsanul Kabir[3]

ABSTRACT

The aim of this study is to compare the numerical model of grouped stud behavior with the experimental results to validate the model under pulsating load. To this end, a numerical model is developed to estimate the static behavior of studs in grouped arrangement, which is often used in the composite structures. The precision of the numerical evaluation mostly depends on the appropriate modeling of shear force transmission from the stud shank to surrounding concrete. This is achieved by employing one-dimensional nonlinear bearing springs and the characteristic responses are estimated from trial and error method.

Key Words: Grouped studs, Numerical analysis, Nonlinear FEA, Bearing force, Slip, Base strain

INTRODUCTION

In recent years, a number of multiple span bridges are designed with more emphasis to reduce the construction cost and labour. Accordingly, the continuous composite girder bridges with two main girders are frequently constructed to satisfy the demand. Conventionally, headed studs as the shear connectors are arranged uniformly on the top flange of the girder. Frequently, prestressed concrete slabs have been adopted as deck slab in the composite girder bridge construction. The prestressing along the longitudinal direction of the concrete slab transfers large extra stress in the steel girder simultaneously by the conventional jack up-down method. The extra stress is unnecessarily confined both in the concrete slab and steel girder. On the other hand, the grouped stud arrangement (Shim et al., 2004) technique can be employed effectively for prestressing across the

---

[1] Prof., Dept of Civil Engineering, Dhaka Univ. of Engg. and Tech., Gazipur, Bangladesh

E-mail: mkhasro@duet.ac.bd;mkhasro@gmail.com

[2] Prof., Dept. of Civil Engg., Graduate School of Engg., Utsunomiya University, 7-1-2 Yoto, Utsunomiya, Japan

[3] Prof., Dept. of Civil Engg., Bangladesh Univ. of Engg. and Tech., Dhaka, Bangladesh

transverse direction of the concrete slab in which prestressed force is applied without connection between the concrete slab and steel girder. In this regard, a number of pockets (Figure 1) are left for the multiple studs used in group for the concrete slab at the time of concreting. After concreting the slab except the pockets, the prestressed force is applied to the concrete slab alone and finally the slab is connected with the steel girder through the pockets having shear connectors by non-shrinkage mortar.

Experimental results are obviously the vital data to observe the actual behavior of the structure or its components. The numerical analysis is an alternative to study the structural behavior and check its performance with the experimental responses. For the validation of the numerical results, a comparison between the experimental and numerical results is necessary. In this study, pipe stud shear connectors (Nakajima et al., 2003) are used instead of solid studs for the experimental investigation of multiple studs (Miah et al., 2005) in the push and pull-out specimen. The pipe studs are used to measure the base strain, which is rather impossible if solid studs are used.

Figure-1. Grouped stud arrangement
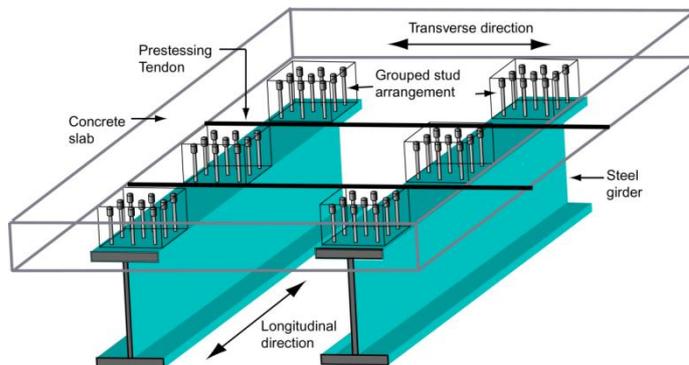
The authors present the numerical analysis, which is carried out on the multiple studs of grouped arrangement for pulsating load. For the numerical analysis, appropriate modeling of the bearing characteristics of concrete surrounding the stud shank is necessary as the accuracy of the numerical evaluation significantly depends on it. In the numerical analysis with multiple studs, an assumed bearing characteristic derived by trial and error approximation has been employed successfully.

EXPERIMENTAL PROCEDURE

The push and pull-out test specimen with grouped pipe studs is shown in Figure 2. This arrangement is used for the experimental investigation. Three pairs of pipe studs were welded to the base plate. The pipe studs were embedded through the opening at the base steel plate and welded from outside the pipe as shown in Figure 2. To provide sufficient resistance to the base

steel plate against plate bending, another steel plate (stiffener) was welded to the base steel plate on the other side. Relevant dimensions are shown in Figure 2.

One pair of strain gauges was installed at the base and another pair at the mid height of each pipe stud. Four 10mm diameter longitudinal deformed bars and four 6mm diameter stirrups with unequal spacing (155mm and 110mm) were used to prevent any premature cracks in the concrete block. The inside area of the pipe stud was filled with cement mortar to minimize the effect of local deformation of the pipe section during tests.

The load is applied at the top of the base plate of the specimen by the loading actuator. Three pairs of displacement transducers are fastened at three levels of the studs to measure the slip between the concrete block and the base plate. The main objective of selecting the shape and size of the specimen is to realize easy application of the pulsating load for the static and fatigue tests. During application of load, the slip between concrete block and the base plate was measured at each of the three stud levels. Strains were measured at the base and mid height of each stud shank.

Figure-2. Test specimen details
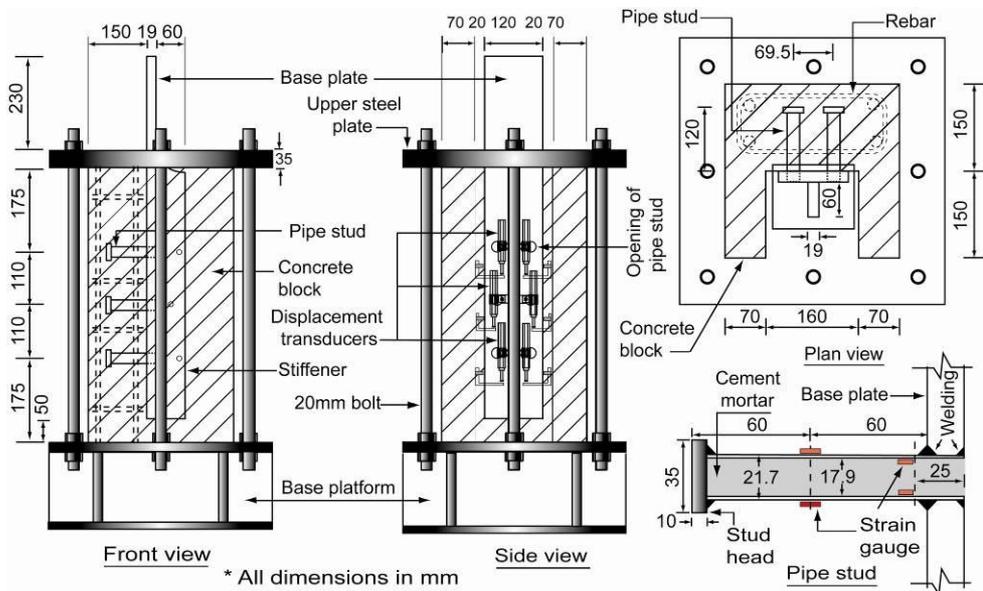
NUMERICAL MODELING

The shear force applied to the composite system is transmitted through as the bearing forces between the stud and the surrounding concrete in the transverse direction (Miah et al., 2004) of stud shank. From symmetry of the specimen, only half of the specimen (Figure 2) is modeled for numerical solution. This numerical model is shown in Figure 3.

Figure-3. Numerical model of the test specimen
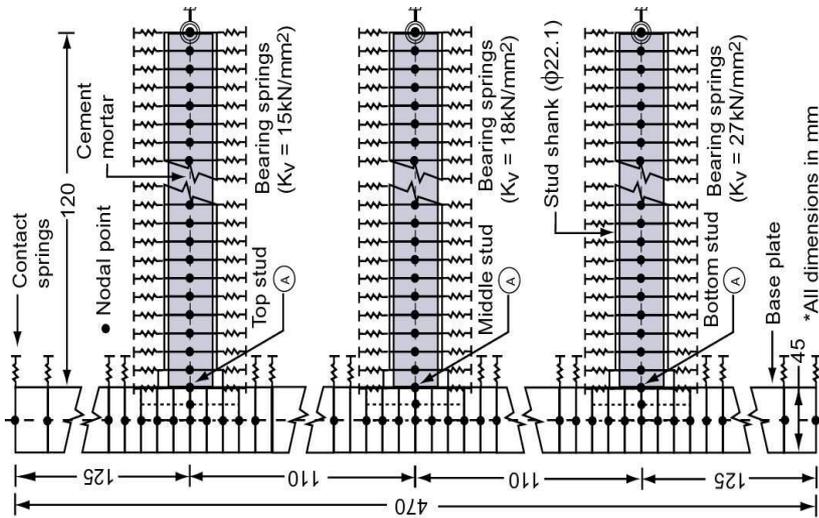
Two-dimensional nonlinear finite element method along with the Timoshenko beam theory is employed for the numerical analysis. The numerical analysis is based on approximate modeling of the base plate behavior, concrete-stud contact response to loading and the base plate-concrete contact.

The material properties such as Young's modulus, **E** and Poisson's ratio for the stud and base plate **μ** are taken as 210kN/mm^2 and 0.30 respectively. On the other hand, values of initial yield stress, **σ** and the effective shear coefficient **κ**, (Hutchinson, 2001) are assigned 235N/mm^2 and 0.575 for the stud and 293N/mm^2 and 0.867 for the base plate respectively. The kinematic hardening parameter, **H** is assumed 1% of the Young's modulus, **E**. Two stress components for instance one normal component in longitudinal direction and another shear component in cross section are considered. A particular stress integrating algorithm with minor modification of the return mapping algorithm (Simo, 1998) is considered here for the simulation of the above plastic constitutive relation with two stress components.

The constitutive relation for the stud and base plate materials is shown in Figure 4(a). The interaction force between the stud shank and concrete is modeled as one dimensional bearing springs with nonlinear hardening and the constitutive relation is shown in Figure 4(b). However, linear hardening is considered in case of stud and base plate. As bearing characteristics of the concrete vary along the height of the base plate, different relations at different levels of the studs are considered as shown in Figure 4(b). The unloading stiffness or spring constant K_V per unit length along the stud shank is estimated by trial and error to match the experimental results and are taken as 15kN/mm^2 and 27kN/mm^2 for top and bottom studs respectively. One-dimensional return-mapping algorithm (Simo, 1998) is used for the bearing springs. The spring constant K_h of the

contact springs (Wriggers, 2002) is estimated by trial and error method and is taken as large as 170kN/mm^2. It is assumed that the spring works only in compression.

Figure-4. Constitutive relations of different materials

(a) Stud and base plate   (b) Bearing spring
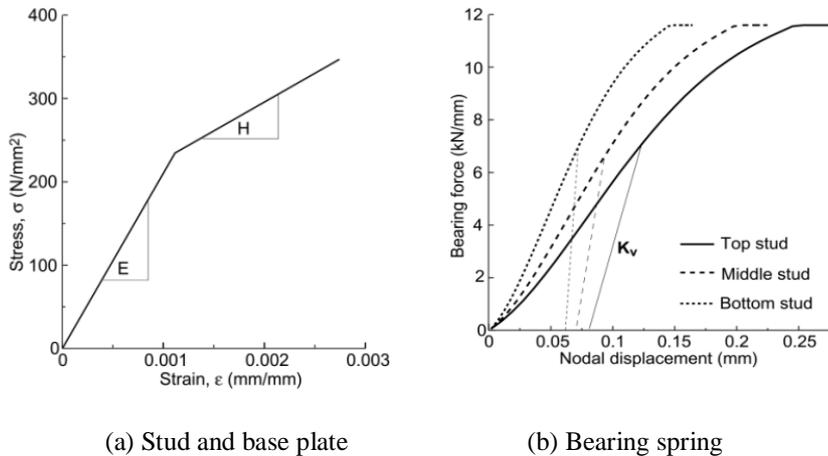
RESULT AND DISCUSSION

Under pulsating load, the shear force-slip relations at the top and bottom stud levels obtained from the numerical analysis of the grouped studs are shown in Figure 5. The numerical result of each stud level is compared with the corresponding experimental records respectively, for example Figures 5(a) and 5(b) are the shear force-slip relations at the top and bottom stud levels respectively under the pulsating load. The slips are estimated by the vertical displacement at the nodal point **A** (Figure 3) of each stud level of the numerical model.

From Figure 5, it is observed that the numerical results agree fairly well with the experimental data under the pulsating load condition. So, the numerical approach presented here appears to model the slip behavior reasonably well for the grouped stud connections. The strain behavior estimated from numerical analysis is compared with the experimental results at the base of the stud shank for the pulsating load. The shear force-direct strain relations are shown in Figure 6. The direct strain at the stud base is found larger in the top compared to the bottom stud levels both in the experiment as well as in the numerical analysis.

Figure-5. Shear force-slip relations under pulsating load

(a) Top stud level   (b) Bottom stud level
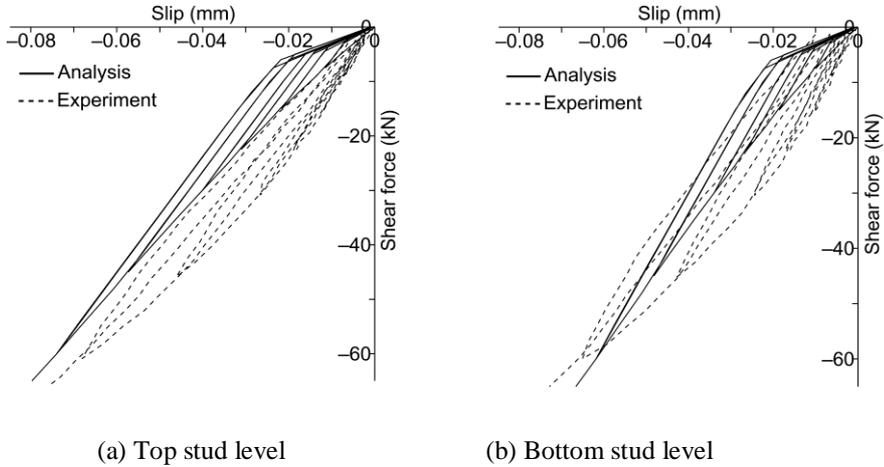
The agreement between the numerical and experimental results is better at the top stud level compared to the bottom. The loading as well as the unloading stiffness follows the same path as the linear hardening is taken into account in the numerical analysis. The numerical method estimates somewhat higher strains than the experimental values.

Figure-6. Shear force-direct strain relations at base under pulsating load

(a) Top stud level   (b) Bottom stud level
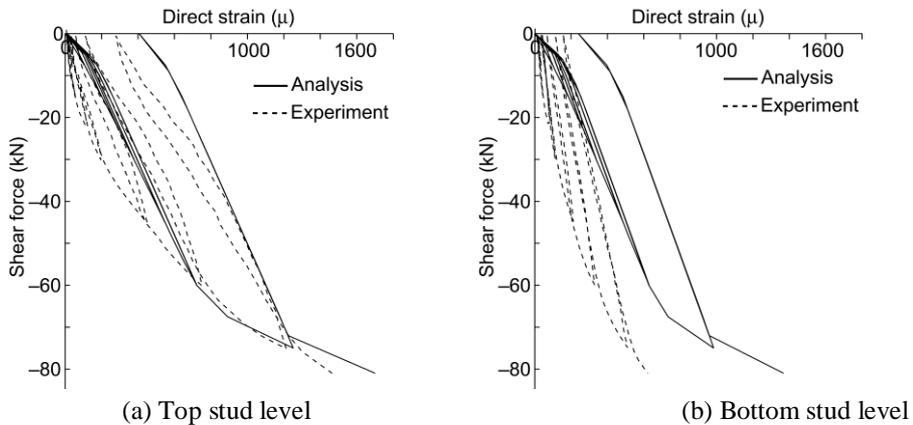
CONCLUSION

The proposed numerical model of the push and pull-out test specimen with grouped stud arrangement has been found suitable for investigating the composite behavior of the grouped studs. The characteristics of the bearing springs incorporated in the numerical model are derived on trial and error basis and are found to model the behavior reasonably well. The numerical predictions of

the grouped stud arrangements agree closely both qualitatively and quantitatively with the experimental behavior.

REFERENCES

Hutchinson, J.R. (2001) "Shear coefficients for Timoshenko Beam Theory" ASME Journal of Applied Mechanics, Vol. 68, pp.87-92.

Miah, Md. K., Saiki, I. and Nakajima, A. (2004) "Numerical evaluation of static behavior of stud shear connectors" JSCE Journal of Applied Mechanics, Vol.7, August, pp.571-578.

Miah, Md. K., Nakajima, A., Saiki, I., Kadogaki, T. and Ooe, H. (2005) "An experimental study on shear force distribution among studs in grouped and ungrouped arrangements" Journal of Structural Engineering, Vol. 51A, March, pp.1509-1520.

Miah, Md. K., Nakajima, A. and Kabir, A. (2005) Numerical Model for Predicting Composite Behavior of Stud Shear Connector, Proc. of the Japan-Bangladesh Joint Seminar on Advances in Bridge Engineering, August, pp.81-90.

Nakajima, A., Miah, Md. K., Kadogaki, T., Saiki, I. and Ooe, H. (2003) Experimental evaluation of strain behavior of stud shear connector through shear transmission, Proc. of 5th Japanese-German Joint Symposium on Steel and Composite Bridges, September, pp.481-492.

Shim, Chang-Su, Lee, Pil-Goo, Yoon, Tae-Yang (2004) "Static behavior of large stud shear connectors" Engineering Structures, Vol.26, pp.1853-1860.

Simo, J.C. and Hughes, T.J.R. (1998) Computational Inelasticity.

Wriggers, P. (2002) Computational Contact Mechanics, John Wiley & Sons.