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FE analysis of steel-concrete composite structure with partial interactions

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ABSTRACT

A numerical model considering slip behavior of steel-concrete composite structure is introduced. This model is based on a linear bond stress-slip relation along the interface. Single node was considered at the interface of steel and concrete member in FE analysis and it improves analytical problems of model that takes double nodes at the interface. The slip behavior is simulated by modifying material properties of steel element contacting concrete according to the derived formulation. Decreased elastic modulus simulates the slip occurrence at the interface and decreased yield strength simulates drop in stiffness of structure. Numerical FE analysis applying this model was compared with experimental studies.

1. INTRODUCTION

Steel-concrete composite structures such as reinforced concrete, composite T-beam and SC(Steel-concrete) panel are popular in construction of bridges, buildings and plants. The structural behaviors of these composite structures are complicated due to different material properties of steel and concrete elements and slip behavior between two structural components. The structural analysis based on perfect bond assumption often overestimates the resisting capacity and underestimates the deformation of the structure. Therefore analysis of composite structures should be performed with exact demonstration of partial interaction considering the slip along the interface.

Many experimental and analytical studies was conducted on bond-slip mechanism and attempted to simulate composite structures with partial interaction. Most of these studies were based on a double node concept to represent the relative

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slip between the concrete and steel element. However, analysis taking double nodes located at the same position for each material element causes complicated analysis model and decreases efficiency. Thus this study introduces a finite element model which can include bond-slip deformation assuming perfect bond at the interface between two materials without taking double nodes.

2. Bond-slip stiffness

Composite structures are usually equipped with shear studs between concrete and steel elements to unify the behavior of total structure. According to the experimental studies of shear studs, load-slip relation is almost linear up to half of the shear strength. Further increase in slip cause stiffness to be reduced gradually until the shear strength V_{max} is reached.

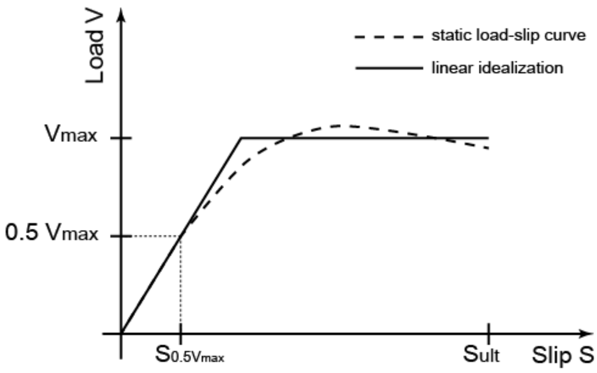

Fig. 1 load-slip curve of shear stud

Among empirical formulas representing shear force-slip relation of stud, the formula mentioned in Eurocode4 (1994) is selected for computational convenience. The maximum shear force V_{max} and the slip $S_{0.5V_{max}}$ corresponding to $0.5V_{max}$ are determined by following Eqs. (1) and (2), where d_{sh} is the diameter of the shear connector in mm, f_u is the ultimate strength of steel and f_c is the compressive strength of concrete in MPa.

$$V_{\max} = 0.8 f_u (\pi \cdot d_{sh}^2 / 4) / 1.25 \tag{1}$$

$$S_{0.5V_{\max}} = (80 \cdot 10^{-3} - 86 \cdot 10^{-5} f_c) \cdot d_{sh} \tag{2}$$

Then, elastic stiffness of shear stud K_S is defined as the mean stiffness under applied load $0.5V_{max}$ as Eq. (3)

$$K_s = \frac{V_{\max}}{2 \times S_{0.5V_{\max}}} = \frac{V_{\max}}{(0.16 - 0.0017 f_c) \cdot d_{sh}} \tag{3}$$

3. Proposed model

This study introduces model to demonstrate bond-slip relation at the interface of steel and concrete elements to simulate decreased load capacity and increased deformation of structure. In order to overcome the disadvantages of taking double nodes at the interface, this model assumes perfect bond between two materials and the bond-slip behavior was considered by modifying material properties of steel element according to the following procedure.

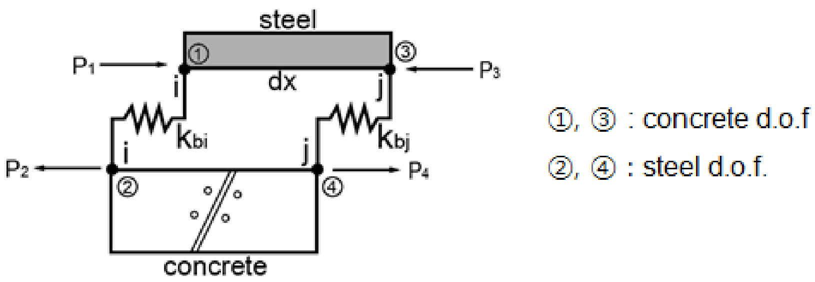

Fig. 2 nodes at the interface of composite structure

The steel and concrete nodes located at the same position are linked as bond element and force-displacement relation between adjacent nodes is as Eq. (4), where k_s is the steel bar stiffness (EA/L) and k_{bi}, k_{bj} are stiffness of the bond link parallel to the bar axis.

$$\begin{Bmatrix} F_C \\ F_S \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_3 \\ F_2 \\ F_4 \end{Bmatrix} = \begin{bmatrix} k_{bi} & 0 & -k_{bi} & 0 \\ 0 & k_{bj} & 0 & -k_{bj} \\ -k_{bi} & 0 & k_s + k_{bi} & -k_s \\ 0 & -k_{bj} & -k_s & k_s + k_{bj} \end{bmatrix} \begin{Bmatrix} u_1 \\ u_3 \\ u_2 \\ u_4 \end{Bmatrix} = \begin{bmatrix} K_{CC} & K_{CS} \\ K_{CS} & K_{SS} \end{bmatrix} \begin{Bmatrix} u_c \\ u_s \end{Bmatrix} \tag{4}$$

Rearranging expression above in terms of concrete results in Eq.(5), where

$$\{F_C^*\} = [K_{CC}^*]\{u_c\} \tag{5}$$

$$\text{where,} \quad \{F_C^*\} = \{F_C\} - [K_{CS}] \cdot [K_{SS}]^{-1} \cdot \{F_S\}$$

$$[K_{CC}^*] = [K_{CC}] - [K_{CS}] \cdot [K_{SS}]^{-1} [K_{CS}]$$

After calculations for evaluating the inverse and multiplications, the local stiffness matrix of steel element including the effect of bond slip is derived.

$$[K_S^{EQ}] = [K_{CC}^*] = \frac{k_s k_{bi} k_{bj}}{k_s(k_{bi} + k_{bj}) + k_{bi} \cdot k_{bj}} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \tag{6}$$

Since E_S^{EQ} is proportional to K_S^{EQ}, the equivalent elastic modulus is as follow.

$$E_S^{EQ} = \frac{E_S(k_{bi} \cdot k_{bj})}{\frac{at}{b} \cdot E_S(k_{bi} + k_{bj}) + k_{bi} \cdot k_{bj}} \tag{7}$$

Modifying material properties of the steel element contacting concrete element with equivalent elastic modulus calculated from Eq. (7) and yield strength derived from equilibrium of work done by shear studs and work done by modified steel element due to slip behavior simulates the structural behavior of composite structure with perfect bond assumption.

4. Application

Push-out test of 25mm diameter studs, B series (concrete compressive strength of 49.4MPa) experimented by Shim et al. (Shim 2004) is employed to verify the accuracy of the propsed FE model. The finite element analysis was performed with commercial finite element software, ABAQUS 6.13. Concrete block, steel girder and studs are modeled by 8 nodes solid elements (ABAQUS C3D8R). Fig. 2 presents a comparison of the experimental result with FE analysis obtained from the proposed model. As shown in this figure, the perfect bond assumption overestimate the stiffness of the structure, otherwise modifying material properties of steel element derived from the proposed model shows similar result with experimental result in stiffness in elastic range and shear strength of the structure

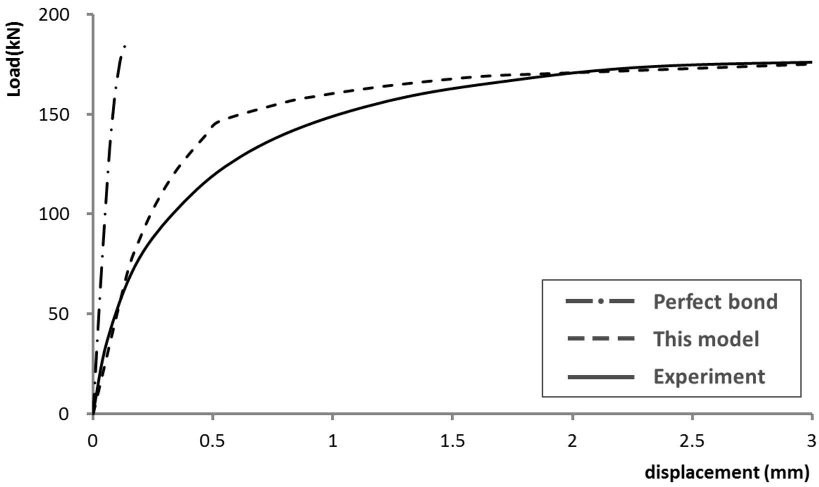

Fig. 3 load-displacement of push out-test

5. Conclusion

This paper introduces an steel-concrete composite structure model assuming perfect bond between steel and concrete interface and considering bond-slip behavior by modifying the material properties of steel element. The proposed model can be used effectively to predict the structural behavior of composite structures.

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