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A simplified numerical model for steel-concrete composite flexural members considering bond-slip effect

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ABSTRACT

A simplified numerical model to consider the bond-slip effect in steel-concrete composite structures is introduced. On the basis of a linear partial interaction theory and the use of the bond link element, the slip behavior is defined and the equivalent modulus of elasticity for steel is derived. Single node instead of double nodes is considered at the interface of steel and concrete member in finite element analysis and it leads to a simplified and efficient numerical model.

A solution procedure to evaluate the slip behavior along the interface of the composite flexural members is also proposed. After constructing the transfer matrix relation at an element level, successive application of the constructed relation is conducted from the first element to the last element with the compatibility condition and equilibrium equations at each node. Correlation studies between numerical results and experimental data are conducted with the objective of establishing the validity of the proposed numerical model.

1. INTRODUCTION

The structural behavior of composite structures such as a sandwich panel is affected by bond-slip behavior, however detailed modelling of numerous mechanical shear connectors or studs not only causes convergence problems in finite element method but also decreases the efficiency of numerical analysis in structural level. This study introduces a simplified finite element model of steel-concrete composite structures with partial interactions. The slip behavior is defined based on a linear bond stress-slip relation along the interface. Instead of applying the classical bond link element or bond zone element, modification of the material properties of steel element is adopted to indirectly reflect the bond-slip effect. A solution procedure to evaluate the slip behavior along the interface of the composite flexural members is also proposed.

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The validity of the proposed numerical model is verified by comparing with experimental and previous studies.

2. PROPOSED MODEL

The behavior of slip is usually represented by the relation between the interface longitudinal shear load and the corresponding slip. A simple bilinear load-slip relation of stud connector is adopted and maximum shear force is determined according to Eurocode 4. To address the limitations of taking double nodes at the interface in using the classical bond-slip elements, equivalent steel stiffness that includes the bond-slip deformation is derived based on the concept of bond-link element and is as shown in Eq. (1), where E_S is the elastic modulus of steel, k_{bi}, k_{bj} are stiffness of the bond link at each end of the element, t is the thickness of steel,. a is the width and b is the length of the element.

$$E_S^{EQ} = \frac{E_S(k_{bi} \cdot k_{bj})}{\frac{at}{b} \cdot E_S(k_{bi} + k_{bj}) + k_{bi} \cdot k_{bj}} \tag{1}$$

Even though the equivalent steel stiffness introduced in this study can effectively describe the stiffness of the composite structure considering bond-slip effect, there is a limitation in describing a decrease of the resisting capacity due to partial shear connection. Accordingly, modification of the yield strength is followed on the basis of the energy equilibrium, where the work carried by steel stud is assumed to be equivalent to the strain energy developed by the equivalent steel thickness. Also solution procedure to evaluate the slip behavior along the interface is proposed. After constructing the transfer matrix relation at an element level, successive application of the constructed relation is conducted from the first element to the last element with the compatibility condition and equilibrium equations at each node.

3. APPLICATIONS

The verification of the proposed bond-slip model has been performed through comparison of numerical results with experimental studies for shear connectors and analytical solution for a composite beam using ABAQUS 6.13. 8-node solid elements (C3D8R) are used in numerical modelling of both steel and concrete members. Push-out test for shear stud and flexural behavior of composite beam and sandwich panel are studied.

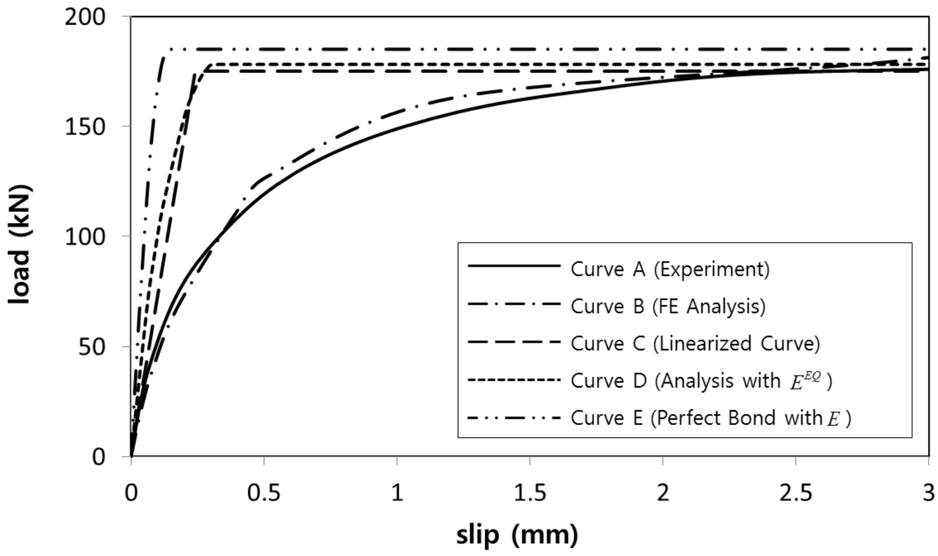

Fig. 1 Load-slip curve of Push-out test

The comparison between numerical results with experimental data of push-out test are shown in Fig.1. It shows that the proposed numerical model effectively simulates the initial stiffness and maximum capacity of the load-slip relation. The introduced model which does not use double nodes can yield significant savings in the number of degrees of freedom required to account for the bond-slip effect and will remove the difficulty arising in constructing finite element mesh in modelling.

Additional comparison of numerical model with experimental data is conducted for steel-concrete composite beam(Chapman 1964, Ansourian 1982) and sandwich panel under flexural load (Shin 2016). The influence of the bond-slip effect is dominant in the sandwich panel compared to composite beam, which is due to the difference in amount of slip occurrence depending on the distance between the neutral axis and the interfacial surface.

4. CONCLUSION

This study introduces a simplified numerical model to take into account the bond-slip effect without using a double node in steel-concrete composite structures. Unlike many other numerical models that have restrictions in the numerical modeling when the bond-slip effect is considered, the proposed model which uses the equivalent modulus of elasticity for steel, can yield significant savings in the number of nodes needed to account for the slip behavior and can be easily implemented into commercialized programs such as ABAQUS by defining material model. The validity of the proposed numerical model is verified through correlation studies between the analytical results and experimental data, and the additional numerical analyses yield the following conclusions: (1) the inclusion of the bond-slip effect with consideration of the equivalent yield strength of the steel plate is important to precisely simulate the structural response of partially bonded composite flexural structures; (2) the bond-slip effect may be ignored at the steel-concrete interface in the compressive stress region; and (3) the proposed numerical model can be effectively used to simulate the bond-slip behavior, while remarkably reducing the complexity in numerical modeling of structures. Although this study deals with member units, the proposed model can show greater efficiency in the analysis of complicated structural level.

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