Steel-Concrete Interface Behavior and Analysis for Push-Out
By Youn Ju Jeong*, Hyeong Yeol Kim**, Hyun Bon Koo***, and Seong Tae Kim**

Abstract

This paper presents the behavior characteristics of steel-concrete interface and analysis method to simulate interface behavior by using push-out results for steel-concrete composite members. In order to analyze the partial-interaction behavior of steel-concrete interface, the interface is idealized by a number of interface elements. A total of 9 push-out specimens were tested and the test results were utilized to provide the properties of interface element in the analysis. To validate the present study, using a commercial structural analysis program, nonlinear structural analysis were performed for the push-out specimens, and the results of analysis were compared with the test data. The results of this study have shown that the nonlinear, slip-softening, as well as linear-elastic behaviors of steel-concrete interface can be efficiently and accurately simulated by the method of analysis presented in this paper.

Keywords: analysis model, interface behavior, partial-interaction, push-out, steel-concrete

1. Introduction

Recently, various types of steel-concrete composite members have been designed, applied to new structures and used as the integrated parts of the structures such as bridge decks and girders. The major advantage of steel-concrete composite members over the conventional reinforced concrete members is that the cross-section can be significantly reduced, if composite action can be obtained between steel and concrete. Since natural bond may not be effective for composite action, several different types of shear connection systems are provided for the steel-concrete composite members to obtain the composite action. However, the full-composite action cannot be obtained since the steel-concrete composite members show partial-interaction behavior due to the deformation and slip at the interface under the applied loads.

For these reasons, most current design codes for steel-concrete composite structures do not consider full-composite action in the design process. If non-composite action is assumed in the design, the materials can not be effectively utilized, nor can the main advantage of steel-concrete composite structure be realized. Therefore, in order to design the steel-concrete composite members more reasonably and economically, an accurate and efficient method of analysis to predict the structural partial-interaction behavior should be established.

The characteristic of interface behavior that the relative slip occurs between steel and concrete is a general phenomenon occurring at most steel-concrete composite members (Johnson, 1994; Oehlers and Bradford, 1999; Ivan et al., 1997). Such interface behavior has an influence on the shear flow between steel and concrete. Furthermore, it causes the partial-interaction behavior to change the structural performance such as deflection, load, and failure mode (Soh et al., 1999; Veljkovic, 1996; Oehlers et al., 2000). Accordingly, for the steel-concrete composite members, interface behavior and partial-interaction behavior have a close relationship with each other. Therefore, both experimental and analytical studies are required to accurately predict the interface and partial-interaction behaviors of the steel-concrete composite members.

However, while the existing studies on the interface behavior of steel-concrete composite members have been concentrated mainly on examining the ultimate load of shear connectors via push-out tests so far this time, it has not been so attractive to connect these experimental and analytical studies to structural partial-interaction. In addition, many of the studies have shown poor correlation between tests and analysis results. They depend on just assumptions or have insufficient verifications on the modeling and analysis method (Salari and Spacone, 2001; Jeong and Jung, 2002).

In this paper, an experimental and analytical studies are conducted to compose idealized model for the properties of interface element according to the degree of interaction and to verify analysis model by using interface element for the analysis of partial-interaction behavior at the steel-concrete interface. Steel-concrete composite member considered in this study is a steel-concrete composite bridge deck consisting of corrugated steel plates, longitudinal stiffeners, studs, reinforcing bars, and concrete as shown in Fig. 1. In order to analyze the partial-interaction behavior of steel-concrete interface, the interface is idealized by a number of interface elements. A total of 9 push-out specimens were tested and the test results were utilized to provide the properties of interface element in the analysis. The results of the push-out tests are compared with those of nonlinear structural analysis performed in this study.
2. Modeling of Steel-Concrete Interaction

2.1. Modeling Methods

If the interaction behavior of a steel-concrete composite member with a stud shown in Fig. 2(a) is modeled with finite element method, either a detail or a global model is usually used (Soh et al., 1999; Veljkovic, 2001).

As shown in Fig. 2(b), in the detailed model, which is used for examining the behavior of a stud and the adjacent concrete locally and precisely, steel plate, concrete, and stud are directly idealized by a number of conventional finite elements. Since this modeling method requires a large number of elements, it is inefficient for practical application (Veljkovic, 2001).

On the other hand, the global model shown in Fig. 2(c), which is introduced recently, models the interface with a specific element to take into account the interaction behavior. In this method, the steel-concrete interface is idealized by a number of interface elements and the properties of interface element are determined as the results of push-out test. This method is useful to examine the global behavior of structures because it is comparatively easy to model and actual interactions can be simulated appropriately. Although push-out test is required in this analysis method, complicate nature of interface behavior between steel and concrete can be accurately implemented into the analysis. Furthermore, since this method uses the test results, realistic behavior at the interface including initial frictional bonding, nonlinearity, and slip-softening can be also taken into account in the analysis (Soh et al., 1999; Veljkovic, 2001).

2.2. Partial-Interaction Modeling by Interface Element

The stud of a steel-concrete composite member is designed so that it can take shear force ($t_s$) acting on the boundary surface of the two materials, and normal force ($t_n$) to be separated from each other. Accordingly, for partial-interaction modeling by interface element, the property of interface element simulating interaction is comprised of two terms, shear and normal force, and the degree of interaction in each term may be expressed in the traction-relative slip relation as the following (Frits and Peter, 1998; Soh et al., 2002; Salari and Spacone, 2001).

$$
\begin{pmatrix}
\frac{t_n}{n} \\
\frac{t_s}{t}
\end{pmatrix}
= 
\begin{bmatrix}
k_n & 0 \\
0 & k_t
\end{bmatrix}
\begin{pmatrix}
\frac{u_n}{n} \\
\frac{u_t}{t}
\end{pmatrix}
$$

(1)

where, subscripts $n$ and $t$ are the normal and tangential direction for interface respectively, while $k_n$ and $k_t$ are the stiffness in each direction. Generally, such two coefficients are expressed by stress per unit length, tangential stiffness by nonlinear function, and normal stiffness is assumed by linear-elasticity (Frits and Peter, 1998; Soh et al., 1999). The traction-relative slip relation of the respecting terms may be configured via tests or via micro structural analysis.

For the tangential direction, tangential traction-relative slip relation, very complicating mechanism such as the micro crack of concrete, and stud deformation is presented, so it is more direct method to use test data. While the measuring of the degree of interaction is unavailable under flexural behavior, it is desirable to use push-out tests of which the specimen and the test are simple and economical (Veljkovic, 2001). Accordingly, in this paper, a tangential traction-relative slip relation depending on the degree of interaction is derived from the push-out test.

For the normal direction, normal traction-relative displacement relation, it is hard to examine by tests, so generally the tensile zone is ignored and the compression zone is defined with stiffness strong enough to have no influence on local and global behavior through sensitivity analysis (Soh et al., 1999). If the normal stiffness is too large, numerical instability may occur. Therefore, to avoid such problems, it is known to be desirable that the normal stiffness be approximately 100 or 1000 times of tangential stiffness, or is between elasticity moduli of concrete and steel materials comprising of the boundary surface, $E_c < k_n < E_s$, (Soh et al., 1999; Jeong and Jung, 2002).

3. Interface Behavior by Push-Out Test

3.1. Push-Out Test

To examine the behavior characteristics of steel-concrete interface depending on the degree of interaction, push-out tests were performed. As shown in Fig. 3(a), push-out specimens were fabricated so as to be interacted by a stud of $\phi 16 \times 80$ mm with corrugated steel plate of 9 mm in thickness and concrete, so that it can have the same cross-sectional profile with a steel-concrete composite deck as shown in Fig. 1. The stud space ($s$) has three parameters of the degree of interaction: 250 mm, a reference generally used for steel-concrete composite deck; 150