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Simplified model to predict partial-interactive structural performance of steel–concrete composite slabs

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Abstract

This paper deals with a simplified model to predict the partial-interactive behavior of steel–concrete composite slabs. A series of nonlinear partial-interaction analyses with various degrees of interaction and shear span ratios are conducted to formulate the partial-interactive problem. Through the statistical analysis of these data, a simplified model for the partial-interactive structural performance is proposed. The proposed model is verified by test program. It is clear that a simplified model based on a partial-interaction analysis is a powerful tool to predict the partial-interactive structural behavior of composite members. In this method, only the push-out test for specimens with the same profile as a steel–concrete composite slab is required. This may be attributed to the potential advantage of the proposed method over the conventional method.

Keywords: Simplified model; Partial-interaction; Structural performance; Steel–concrete; Slab

1. Introduction

In general, steel–concrete composite members are composed of steel plate, concrete, and reinforcement. Shear connectors are usually employed to increase the composite action between the steel and the concrete. The natural bonding, friction, and mechanical interlocking actions of shear connectors have a significant influence on the degree of interaction between the steel and the concrete [1,2].

According to the degree of interaction, the steel–concrete composite member behaves in three ways: full-interaction, partial-interaction, and no-interaction, where the partial-interaction term is defined so that it involves the influence of both the partial-stiffness and the partial-strength of shear connection according to the degree of interaction. Generally, in real conditions, the steel–concrete composite members show partial-interaction owing to the deformation of shear connectors and slip at the interface under the applied loads [3,4]. The degree of interaction between the two materials affects the shear flow and strain distribution of the members, and finally it has an influence on the structural performance such as strength, stiffness, and failure mode [1,2]. Therefore, the assumption of full-interaction may cause an overestimation of the structural performance. On the other hand, to assume no-interaction may result in an underestimation of the structural performance. For these reasons, the partial-interaction approach becomes more practical, and a partial-interaction analysis with a degree of interaction is essential for a precise prediction of behavior, and a reasonable steel–concrete composite member design, under the various interface conditions.

The main objective of this study is to develop a simplified model for the partial-interactive structural performance of steel–concrete composite slab, such as the slab system shown in Fig. 1. Similar types of steel–concrete composite slab had been applied firstly in the USA and France to reduce self-weight and the construction cost of the long-span bridge, and, recently, they have been widely used in Japan to improve the structural performance for a two or three girders bridge system [5,6]. The characteristics of the partial-interactive behavior of the steel–concrete composite slabs, under the combined action of shear and bending, are examined by experimental and analytical studies. In the experimental study, a total of nine flexural tests are carried out, using three groups of span length with three different degrees of interaction for each group. In the analytical study, a total of twenty five nonlinear partial-interaction analyses are performed, using five groups of span length with five different degrees of interaction for each group.

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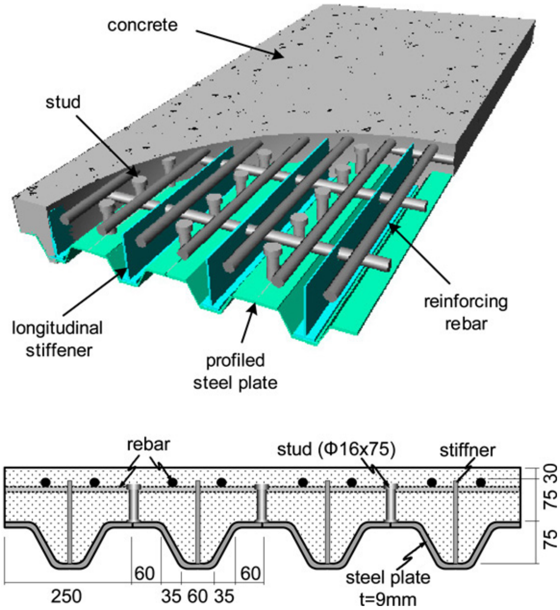


Fig. 1. Steel–concrete composite slab.

Finally, in order to predict easily the partial-interactive behavior of steel–concrete composite slabs and to contribute a more rational design, simplified models for the partial-interactive strength and stiffness are drawn based on the results of the partial-interaction analysis. This model is verified by the empirical "m–k method" [7], from test results and by a partial-interaction analysis series, which are performed additionally.

2. Partial-interaction function

The relationship between the ultimate strength of the composite members in a partial-interaction and a full-interaction can be written as

$$P = \alpha_p \cdot P_{\text{full}} \tag{1}$$

where P is the ultimate partial-interaction strength, α_p the partial-interactive strength factor, and P_{full} the ultimate full-interaction strength. From the gradient of the load–displacement curve obtained for composite members, the relationship between the elastic stiffness of composite members in partial-interaction and full-interaction can also be represented as

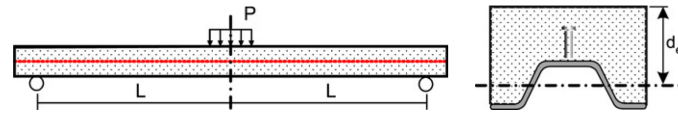
$$K = \alpha_k \cdot K_{\text{full}} \tag{2}$$

where K is the elastic partial-interaction stiffness, α_k the partial-interactive stiffness factor, and K_{full} the elastic full-interaction stiffness. Both the factors range from 0.0 to 1.0. If the factors have a value of 1.0, it means the behavior of the composite members is in the state of full-interaction.

In this study, both the factors in Eqs. (1) and (2) are assumed to be functions of the partial-interaction coefficient (η_{po}) and shear span ratio (ρ_{sd}), as

$$\alpha_p = f_p(\eta_{po}, \rho_{sd}) \tag{3}$$

$$\alpha_k = f_k(\eta_{po}, \rho_{sd}). \tag{4}$$



(a) Shear span length.
(b) Effective depth.

Fig. 2. Shear span ratio.

If the value of these factors, using the partial-interaction coefficient and shear span ratio, can be obtained, the effective strength and stiffness of steel–concrete composite members under the partial-interaction can be easily computed.

2.1. Partial-interaction coefficient

Generally, the composite action of steel–concrete composite members can be categorized into two terms, namely "the degree of shear interaction" and "the degree of shear connection". "The degree of shear interaction" is related to the stiffness-based property while "the degree of shear connection" is the strength-based property, but both are directly related to each other [3]. At the interface of the steel and the concrete, if the shear strength is increased, the shear stiffness is also increased.

In this study, a partial-interaction coefficient (η_{po}) is defined as the average of the strength and stiffness from axial loading condition of push-out, as

$$\eta_{po} = \text{average}\left(\frac{P^a}{P^a_{\text{full}}} \text{ and } \frac{K^a}{K^a_{\text{full}}}\right) \tag{5}$$

where P^a and K^a are the maximum load and elastic stiffness in partial-interaction while P^a_{full} and K^a_{full} are those in full-interaction, respectively. The average values, namely the partial-interaction coefficient, of the strength and stiffness of the composite member under the axial loading can be obtained by a simple push-out test. Therefore, if the push-out test information is available, a designer can easily predict the partial-interactive strength and stiffness of the composite members.

2.2. Shear span ratio

The shear span ratio (ρ_{sd}) is defined as the ratio of shear span length (L_s) to the effective depth (d_e) of a cross-section. The shear span length (L_s) of a simply-supported member shown in Fig. 2(a) is the distance from the loading point to the support. If a concentrated load is applied at mid-span, the shear span length becomes L. The effective depth of a cross-section (d_e) is the distance from the top of the concrete to the centroid of a steel plate, as illustrated in Fig. 2(b).

3. Partial-interaction behavior

To formulate a correlation between the partial-interactive behavior and the degree of interaction of the steel–concrete composite slabs with different shear span ratios, experimental and analytical studies were conducted. Analytical studies are used to formulate a simplified model and experimental studies are used to verify the simplified model. A steel–concrete