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ORIGINAL ARTICLE

Evaluating interfacial shear stresses in composite hollowcore slabs using analytical solution

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Abstract Analytical evaluation of the interfacial shear stresses for composite hollowcore slabs with concrete topping is rare in the literature. Adawi et al. (2014) estimated the interfacial shear stiffness coefficient (k_s) that governs the behavior of the interface between hollowcore slabs and the concrete topping using push-off tests. This parameter is utilized in this paper to provide closed form solutions for the differential equations governing the behavior of simply supported composite hollowcore slabs. An analytical solution based on the deformation compatibility of the composite section and elastic beam theory, is developed to evaluate the shear stresses along the interface. Linear finite element modeling of the full-scale tests presented in Adawi et al. (2015) is also conducted to validate the developed analytical solution. The proposed analytical solution was found to be adequate in estimating the magnitude of horizontal shear stress in the studied composite hollowcore slabs.

1. Introduction

Hollowcore slabs are precast/prestressed structural concrete elements that are commonly used in residential and commercial buildings. They have the advantage of higher quality, ease of installation, and reduced construction times compared with cast-in-situ slabs. Floor surface irregularities may rise from the differential camber between adjacent slabs. Thus, to achieve a flat surface finish, a 50 mm concrete topping is commonly cast on top of the hollowcore slabs. Design engineers tend to consider the composite action between the concrete topping and the slabs to increase the load carrying capacity of the floor. This requires roughening of the surface of the hollowcore slab to an amplitude of 6.35 mm or 5.00 mm according to [1] and [6], respectively. Some design engineers require the use of bonding agents in addition to the roughening mentioned in the design standards, which induce additional costs that hollowcore slab manufacturers are keen to avoid. There is a general consensus among manufacturers that the bond between hollowcore slabs with machine-cast surface and topping concrete is sufficient to develop adequate composite action. This emphasizes the need for more studies that shed light on the adequacy of composite action in hollowcore slabs with machine-cast surface.

Most of the literature on composite action of slabs is related to composite steel beams [5,10,7,8] where the concrete topping is attached to the top flange of the steel beam using shear connectors (shear studs). Salari et al. [13] and [12] modeled the shear connectors using spring element and their stiffnesses were evaluated through push-off tests similar to

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Nomenclature

a	distance from edge of hollowcore slab to edge of concrete topping
A_t	cross-sectional area of concrete topping
b	distance from edge of hollowcore slab to the applied concentrated load (P)
b_t	width of concrete topping
E_{hc}	young's modulus of concrete for hollowcore slab
E_t	young's modulus of concrete for concrete topping
I_{hc}	moment of inertia of hollowcore slab
I_t	moment of inertia of concrete topping
K	general interfacial shear stiffness
k_s	interfacial shear stiffness
L	hollowcore slabs length
L_t	length of concrete topping
M_{hc}	internal moment in hollowcore slab
M_t	internal moment in concrete topping
M_T	total external moment
N	normal force
P	concentrated applied load
P_y	yielding load
Q	distributed load on composite slab
u_{hc}	displacement of hollowcore slab at the interface layer
u_t	displacement of concrete topping at the interface layer
V_{hc}	vertical shear force in hollowcore slab
V_T	total external shear
V_t	vertical shear force in concrete topping
Y_{hc}	distance from the interface layer to hollowcore slab's mid-depth
Y_t	distance from the interface layer to the middle of concrete topping
σ	interfacial peel stress
τ	interfacial shear stress
τ_{avg}	average interfacial stress using North American design standards methods
ε_{hc}	strain in hollowcore slab at the interface layer
ε_t	strain in concrete topping at the interface layer

the test conducted by Ollgard et al. [11]. In another type of composite steel beams an adhesive compound, such as epoxy, is utilized to attach the concrete topping to the steel beam instead of shear studs. Luo et al. [9] conducted push-off tests on the bonded composite steel samples to evaluate the shear behavior of the adhesive. The interface between the hollowcore slab and the concrete topping in a typical composite slab does not contain studs or adhesive layers and therefore cannot be addressed using such research studies. However, the push-off tests used by those researchers can be used to estimate the interface shear strength for composite hollowcore slabs.

Steel plates or fiber-reinforced polymer laminates are commonly used to increase the flexural load capacity of concrete beams. These plates are attached to the soffit of the beam using a bonding agent and/or mechanical anchors. Ideally, the ultimate flexural capacity of the retrofitted beam is supposed to be reached prior to delamination of the plate.

Vilnay [15] presented an analytical method to estimate the shear stresses between a reinforced concrete beam and a steel plate bonded to its soffit. The method does not account for the axial deformations of the beam, the bending deformations of the plate, and the shear deformations of the interface layer. It is only applicable for the case of a point load applied at mid-span and assumes zero shear stress under that load.

Smith and Teng [14] proposed an analytical solution to determine the shear stress distributions at the interface. Their approach accounts for the bending deformations of the plate and the axial deformations of the beam. The interfacial shear stress is assumed to be continuous at the point load. This approach can be applied to general load scenarios.

In composite slab systems, the average horizontal shear stress is calculated using the two methods available in the North American design standards [6,1]. The first method utilizes the shear force diagram for calculations and applies only for the case when the concrete topping is poured over the entire slab length. The second method uses the strain compatibility to determine the horizontal shear force in the concrete topping. Both methods assume that the concrete topping is fully bonded to the slab and therefore does not account for the interfacial shear stiffness of the interface. Including the effect of interfacial shear stiffness (k_s) may affect the distribution of the horizontal shear stresses along the interface layer, which needs to be investigated.

Adawi et al. [2] tested four composite hollow-core slabs with concrete topping using push-off tests. The slabs had machine cast finish and lightly roughened surfaces. The slabs were analyzed using linear analytical modeling that provided solutions for the deferential equations governing the equilibrium of the push-off tests. As a result, the shear stiffness of the interface between the hollowcore slabs and the concrete topping was determined for the tested slabs.

Adawi et al. [3] conducted a comprehensive experimental program including sixty-nine pull-off tests, and six push-off and six full-scale tests. Tests were performed on slabs with machine cast and lightly roughened surfaces. The program also included a procedure to evaluate the surface roughness of hollowcore slabs that can be used by manufacturers a quality control measure during production to insure adequate composite action.

In this paper, a brief summary about two composite hollowcore slabs that were tested in full-scale by Adawi et al. [3] is first given. An analytical solution that is based on Smith and Teng [14] approach is then presented. This solution includes the bending and axial deformations of the concrete topping and the hollowcore slab and can be applied to any load case. It also takes into account the effect of the interfacial shear stiffness (k_s) that is neglected in code methods. The interfacial shear stiffness (k_s) is a measure of the resistance of the interface layer to slip deformation. The (k_s) values used in this paper were evaluated using analytical analysis conducted in Adawi et al. [3]. These values may vary between slabs depending on the surface roughness, which can be evaluated using the procedure explained in Adawi et al. [3]. Results of a linear finite element analysis of the full-scale tests are then compared