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Effects of cast-in-place concrete topping on flexural response of precast concrete hollow-core slabs

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ABSTRACT

Results of a study focusing on the flexural response of precast prestressed concrete hollow-core slabs with cast-in-place concrete topping are presented. The experimental part of the study included load testing of five precast concrete hollow-core units. The numerically determined flexural response of test specimens was later compared with the experimentally obtained behavior. Results demonstrate that a major composite action is valid between the hollow-core unit and the topping slab under load levels corresponding to uncracked state of the cross section. Existence of a topping slab resulted in improvements in the cracking moment and initial stiffness of hollow-core units. The beneficial effect of topping slab on the ultimate moment capacity was observed to be limited, mainly because of the loss of composite action prior to reaching the ultimate moment capacity. Horizontal shear strength at the interface between hollow-core unit and topping slab was determined (1) through limited number of pushoff load tests and (2) through calculations considering the load level corresponding to initiation of significant relative slip using the basic mechanics of materials approach and the simplified code expression. The measured and computed interface shear strength values were observed to be significantly lower than the horizontal shear strength values specified by the ACI and AASHTO Specifications.

1. Introduction

Prestressed concrete hollow-core panels have been widely used throughout the world in concrete and steel structures, including buildings, parking structures, and bridges. One of the most common use of these elements is in floor systems, where precast prestressed concrete hollow-core panels are used together with a cast-in-place (CIP) concrete topping to form a load-resisting composite floor system. The composite behavior in these structures is desired because of the increased strength and stiffness under vertical loads and for resisting and transmitting forces resulting from diaphragm action under lateral loads.

Manufacture of precast concrete hollow-core units mainly involves machine casting operation. These units are typically manufactured either by extrusion of really low-slump concrete, or slip-forming of a relatively higher slump concrete. These manufacturing techniques do not usually allow the use of any reinforcing bars crossing the interface between the hollow-core unit and the CIP concrete topping. Therefore, the primary horizontal shear force transfer mechanism between hollow-core panels and the concrete topping is through bond at the interface. There is an uncertainty, however, whether the horizontal shear stress capacity at the interface will be sufficient to allow a fully composite behavior under flexural loading when the concrete topping is placed over machine finished surface of a hollow-core unit with no intentional roughening. Current design specifications also addresses the concern for insufficient shear force transfer at interface surfaces and specify a minimum roughening amplitude of 6.3 mm for the surface to be considered as roughened [1,2].

Studies focusing on flexural behavior of composite hollow-core units are very scarce. Dowell and Smith tested prestressed concrete hollow-core bridge deck panels with three different levels of roughening applied on the surface of hollow-core units prior to casting of topping concrete [3]. During load testing of specimens, no sign of horizontal slip was observed between the hollow-core units and the CIP topping with any of the surface roughening levels studied. Measured moment capacities of the specimens were reported to exceed the predicted capacities assuming a fully composite behavior. Scott tested a hollow-core slab unit with a CIP concrete topping and the agreement between the calculated and measured moment capacity and deflection values suggested a full composite action between the hollow-core unit and the topping

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[4]. It was reported that the surface of the hollow-core unit did not comply with the surface roughness requirements of the ACI Code, as the unit had a smooth top surface and no intentional roughening was applied. Different from other more recent experimental studies on precast concrete hollow-core units, the specimen in Scott's study was tested by placing solid concrete blocks on top of the composite slab. With this type of loading, it is highly possible that the additional friction force that developed under the effect of the applied weights resulted in relatively higher horizontal shear force capacity at the interface between the hollow-core unit and the topping concrete, as compared to applying a line load using a hydraulic cylinder.

Due the fact that precast concrete hollow-core units typically do not have any transverse shear reinforcement, the shear strength of these members has to be carefully looked at during the design stage. Moreover, with the use of relatively deeper units, the size effect on the shear strength becomes more significant. As a result, shear strength of hollow-core units has been studied extensively [5–12]. Through these studies, it is shown that web-shear strength of relatively deep hollow-core units may be smaller than those predicted by current design specifications. Studies focusing on the shear behavior of composite hollow-core units revealed the beneficial effect of CIP concrete topping on improving the shear strength of the units.

In order to ensure a proper bond between the CIP concrete topping and the precast hollow-core panels, the surface of the panels must be clean, free of laitance, and thoroughly saturated prior to casting of topping concrete [13]. American Concrete Institute specifies a maximum horizontal shear stress of 0.55 MPa for composite concrete flexural members with no reinforcement crossing the interface, provided that the contact surface is intentionally roughened [1]. A horizontal shear strength of 1.65 MPa is specified in AASHTO LRFD Bridge Design Specifications for concrete placed against a surface intentionally roughened to an amplitude of 6.3 mm, while the horizontal shear strength is reduced to 0.52 MPa if the surface is not intentionally roughened [2]. It should be noted that AASHTO LRFD Bridge Design Specifications uses a modified version of the shear friction concept to calculate the horizontal shear strength and requires a certain amount of reinforcement to be provided at the interface. The horizontal shear strength at interface between concrete surfaces has been studied extensively [14–22]. These studies mainly focused on the effect of concrete strength and the type of surface treatment on the interface shear strength. Because these studies were mostly conducted toward understanding of the shear–friction theory, the specimens usually included dowel reinforcement crossing the interface. The experimental findings obtained from these studies were used to evaluate the accuracy of horizontal shear strength equations available in several design codes, as well as to propose new design equations.

The current study aims at contributing to the understanding of the behavior of composite hollow-core units under flexural loading. The main effort focused on identifying the extent to which a CIP concrete topping placed over the as-cast surface of precast concrete hollow-core units improves the flexural behavior. The experimental study included load testing of five precast concrete hollow-core units. The numerically determined flexural response of test specimens was later compared with the experimentally obtained behavior.

2. Testing program

Five precast concrete hollow-core units were tested under flexural loading. The naming convention used for the specimens is given in Table 1. The specimens were divided into W and N series, which has nominal widths of 120 cm and 55 cm, respectively. As shown in Fig. 1, hollow-core slab units were 15 cm deep and reinforced only with 9.5 mm diameter Grade-270 seven-wire straight prestressing strands positioned 4.5 cm from the bottom surface of cross section. Hollow-core units in W series specimens had eight strands, while those in N series specimens had only four strands. In three of the specimens, a 5 cm thick CIP concrete topping was cast on top of the hollow-core unit prior to load tests, while the remaining two units were tested with no topping. A welded wire mesh with 6 mm bar diameter and 15 cm bar spacing was used inside topping slabs at approximately the mid-depth of slab to control cracking due to shrinkage and temperature effects.

Table 1
Properties of specimens.

Specimen	Specimen width (cm)	Topping?	Compressive strength of topping concrete (MPa)
W-B	120	No	–
W-T	120	Yes	31.1
W-T-R[a]	120	Yes	30.2
N-B	55	No	–
N-T	55	Yes	32.3

[a] Two ends of concrete topping in this specimen were restrained.

The hollow-core units used in the test specimens were provided by a local precast concrete producer in Ankara–Turkey. The units were shipped to the Structural Mechanics Laboratory of Atilim University, where concrete toppings were cast and the load tests were performed. The design concrete compressive strength for the hollow-core units was specified as 30 MPa but no information was available regarding the measured compressive strength of concrete used to cast the units and the level of available stress in the strands. The measured compressive strength values for topping concrete used in composite specimens are given in Table 1.

The specimens were tested under monotonically increasing displacement loading until failure occurred. Loading was applied with an electrically-controlled hydraulic cylinder at the center of a 460 cm long clear span as a line load, as shown in Fig. 1. Roller supports were provided at the two ends of specimens. The load was distributed through the entire width of specimens with the help of a steel spreader beam attached at the end of the hydraulic cylinder. In order to achieve a uniform transfer of the load from the spreader beam to the specimens, a 15 cm wide strip of neoprene pad was placed between the spreader beam and the top surface of specimens.

The specimens were instrumented with displacement transducers (i.e. linear potentiometers) and data from these transducers were continuously collected by a data acquisition system and the measurements were monitored during the load tests. Location of the transducers on specimens is indicated in Fig. 1. Two displacement transducers were used to measure the vertical deflection of specimens at the midspan section. In composite specimens, the relative slip between the hollow-core unit and the topping was measured with two displacement transducers at each end. Additional slip of prestressing strands during load tests was also monitored by displacement transducers. For this purpose, four strands were instrumented at each end of hollow-core units.

In an attempt to enhance the horizontal shear force capacity at the interface between the hollow-core unit and topping, and to obtain a fully composite behavior, the restraint mechanism illustrated in Fig. 2 was used at ends of Specimen W-T-R. It should be noted that the use of such restraint mechanism does not represent a real-life application. It was only used as a method to improve the horizontal shear force transfer between hollow-core unit and topping slab so that the case of fully composite behavior could be studied.