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Moment coefficients for design of waffle slabs with and without openings

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ABSTRACT

The direct design method recommended by ACI is commonly used for the design of flat slabs. Since the flexural stiffness of the waffle slab varies along the span, it is expected that the distribution of moments is different from that of flat slabs. Current design procedures do not provide recommendations specific of waffle slabs. Designers smear the contribution of the ribs and use the design guidelines for flat slabs to design ribbed slabs. In addition, the effect of openings on the response of waffle slabs is not fully explored. Therefore, modified moment coefficients are needed for waffle slabs. In this paper, numerical simulations using ANSYS are used to study the response of waffle slabs with and without openings. The main objectives of this paper are: (1) to obtain the design coefficients for the column and the field strips of the internal panel of a waffle slab and (2) to study the effect of openings and stiffening ribs on the design coefficients. Ninety Linear and non-linear analysis models using ANSYS were performed in the study to evaluate the response of various waffle slabs under uniform loading. The main parameters evaluated are the column size, the solid portion size, the opening size and its location, and the effect of stiffener ribs around the opening. The non-linear finite element model was verified using existing experimental results for two waffle slabs. The moment coefficients developed in this paper were used to modify the existing ACI flat-slab coefficients to be used for waffle slabs.

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1. Introduction

Waffle slab structures are defined as a combination of a flat flange plate, or deck, and a system of equally spaced parallel ribs. Waffle slabs are more efficient in resisting lateral loads than flat slabs, and they are suitable for large spans between columns. Various approximate methods of analysis for ribbed plates based on the analysis of an equivalent orthotropic plate were developed. The individual panels are divided into column and middle strips, and proposed moment distribution coefficients are presented by Reiss and Sokal [1]. The waffle structures are analyzed as grids with ribs having little or no torsional rigidities [2]. In 1979, Tebbett and Harrop [3] proposed alternative theoretical moment coefficients for internal, edge and corner panels of ribbed and solid flat slabs, and concluded that the solid regions around columns attract load and cause a redistribution of the bending moments in the column strips. Kennedy [4] studied the effect of rib orientation in the carrying capacity of waffled slabs. His results indicated that the orthogonal shaped waffle slab had a superior ultimate load carrying capacity of 20% higher than the 45° non-orthogonal waffle slab. Shehab El-din and Elshihy [5] in 1993 evaluated the effect of the size of the solid portion on the bending moment and shearing forces developed in the panel. Abdul-Wahab and Khalil [6] investigated experimentally the response of simply supported, isotropically reinforced, square waffle slabs under a midpoint patch load.

The methods recommended by the design codes, such as ACI 318-08 [7] and BS 8110-1997 [8], allow the waffle slab to be designed in accordance with the provisions for a two-way spanning flat slab. BS 8110 [8] code limits the dimensions of openings in flat slabs according to the location of the openings. In addition, BS 8110 [8] requires that the effective perimeter be modified when the openings are located from the face of the column at a distance less than six times the effective depth of the slab. ACI 318-08 [7] provides limits for the size of the opening according to its location along the panel.

Currently, the equivalent frame method and the direct design methods [7] are commonly used for the design of flat slabs. The direct method is the more popular of the two, which defines moment coefficients to distribute the total panel moment between column and field strips. Since this method was developed for flat plates, engineers either use the direct method for waffle

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