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Effective compressive strengths of corner and exterior concrete columns intersected by slabs with different compressive strengths

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ABSTRACT

In modern high-rise reinforced concrete buildings, high strength concrete (HSC) has been typically used for column members, while normal strength concrete (NSC) has been generally used for floor slabs. This study proposed a new analytic approach that can reasonably estimate the effective compressive strengths of corner and exterior column members intersected by lower strength concrete slabs. The proposed model was theoretically derived based on strain distributions and constraint conditions at an interface between column and slab members. In addition, the compressive strength test results of isolated, exterior, and corner columns intersected by lower strength concrete slabs reported in the existing literature were compared to the effective compressive strengths estimated by the proposed model. The proposed model provided good accuracy on the effective compressive strengths of the column members intersected by slabs cast with lower concrete compressive strengths. It was also shown that the proposed model successfully reflects the effects of the aspect ratio between the slab thickness and the column width on the effective compressive strengths of the test specimens and their failure modes that changed significantly according to the column–slab compressive strength ratio.

1. Introduction

The strong compressive resistance characteristics of concrete materials can be more effectively utilized in structural column members with the application of high-strength concrete (HSC). The use of HSC makes it possible to reduce the size of columns as well as save the materials of concrete, and thus consequently, effective floor spaces can also be realized [1]. Because the application of HSC to wide floor slabs is not economical,

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they are therefore generally designed and constructed using normal strength concrete (NSC), which are also the same in the cases where column members are cast with HCS materials [1–3]. When the column and floor slab members have different concrete compressive strength grades, the current design provisions in ACI [4], KCI [5], and CSA [6] require that an adequate load transfer at the slab–column joints should be achieved by one of the following three methods; The first method is to construct the floor near the column location using the same strength concrete as that of the column concrete, for which the column concrete shall be poured into the floor up to 600 mm from the column face before hardening of the column concrete according to ACI and KCI or 500 mm according to CSA, and the column concrete shall be well integrated with the floor concrete. This method is simple for the column design because the compressive strength of the column concrete can be applied for the column design. It requires, however, a high level of supervision, careful coordination of the concrete deliveries, and possible use of retarders, which inevitably decreases the constructability [1]. In the second method, the axial strength of the column member is calculated through the floor system based on the lower value of the concrete strength with vertical dowels and spirals as required. However, the experimental results reported by Kayani [7] and Portella [8] showed that an additional placement of lateral or longitudinal reinforcements at the slab–column joint has little effect on the increase of its axial strength, and thus some doubts still remain about the effectiveness of the second method [1]. The third method suggests the effective compressive strength (f'_{ce}) that shall be used for the design of the column member. According to ACI and KCI, if the compressive strength of the column (f'_{cc}) exceeds 1.4 times the compressive strength of the intersecting concrete floor slab (f'_{cj}), the effective compressive strengths of corner and exterior concrete columns (f'_{ce}) can be calculated, respectively, as follows:

$$f'_{ce} = f'_{cc} \quad \text{when } f'_{cc}/f'_{cj} \le 1.4 \tag{1a}$$

$$f'_{ce} = f'_{cj} \quad \text{when } f'_{cc}/f'_{cj} > 1.4 \tag{1b}$$

In CSA, the effective compressive strengths for the corner and exterior concrete columns (f'_{ce}) are calculated differently, respectively, as follows:

For corner columns:

$$f'_{ce} = f'_{cc} \quad \text{when } f'_{cc}/f'_{cj} \le 1.0 \tag{2a}$$

$$f'_{ce} = f'_{cj} \quad \text{when } f'_{cc}/f'_{cj} > 1.0 \tag{2b}$$

For exterior columns:

$$f'_{ce} = f'_{cc} \quad \text{when } f'_{cc}/f'_{cj} \le 1.0 \tag{2c}$$

$$f'_{ce} = 1.4f'_{cj} \le f'_{cc} \quad \text{when } f'_{cc}/f'_{cj} > 1.0 \tag{2d}$$

Many experimental studies have been conducted to investigate the axial load transfer mechanisms of slab–column joints that have differences in concrete compressive strengths between the column and floor slab. Bianchini et al. [9] conducted axial compression tests on a total of 45 corner, exterior, and interior slab–column joints with a key test variable of the compressive strength ratio between the column and slab members (f'_{cc}/f'_{cj}). Based on their experimental results, they reported that the critical compressive strength ratio between the slab and column members, at which the axial load transfer performances of the column members are significantly reduced compared to the monolithic connections, was about 1.4 for the corner and exterior columns, and 1.5 for the interior columns, which had been reflected in the ACI and CSA code provisions, as shown in Eqs. (1) and (2). Gamble and Klinar [2] also conducted axial compression tests on a total of 13 interior and exterior slab–column joints, and they proposed the effective compressive strength of the exterior column (f'_{ce}) as follows:

$$f'_{ce} = f'_{cj} \quad \text{when } f'_{cc}/f'_{cj} \le 1.4 \tag{3a}$$

$$f'_{ce} = 0.32f'_{cc} + 0.85f'_{cj} \quad \text{when } f'_{cc}/f'_{cj} > 1.4 \tag{3b}$$

Axial tests on two corner columns and four isolated columns were conducted by Kayani [7], and it was confirmed that the lateral or longitudinal steel reinforcements additionally placed at the joints increased the ductility of the slab–column joint systems, but did not significantly improve their axial strengths. In Kayani's study, the effective compressive strength of the corner column was proposed based on the test results as follows:

$$f'_{ce} = 2.0\lambda_G \frac{f'_{cc}f'_{cj}}{f'_{cc} + f'_{cj}} \tag{4}$$

where λ_G is the coefficient for the types of joints; 1.25 for the interior columns, 1.0 for the exterior columns, and 0.9 for the corner columns. Shu and Hawkins [3] also conducted compressive strength tests on 54 isolated columns with the test variables of the compressive strength ratio between the column and slab (f'_{cc}/f'_{cj}) and the aspect ratio of the slab thickness to the column width (h/c). On this basis, they proposed the effective compressive strength of the corner column (f'_{ce}), as follows:

$$f'_{ce} = f'_{cj} + A\left(f'_{cc} - f'_{cj}\right) \tag{5a}$$

$$A = 1/(0.4 + 2.66h/c) \tag{5b}$$

A total of 30 slab–column joint specimens including 4 isolated column members were fabricated and tested by Ospina and Alexander [10], and the effective compressive strength for the corner column (f'_{ce}) was presented as follows:

$$f'_{ce} = f'_{cc} \quad \text{when } f'_{cc}/f'_{cj} \le 1.2 \tag{6a}$$

$$f'_{ce} = 1.2f'_{cj} \quad \text{when } f'_{cc}/f'_{cj} > 1.2 \tag{6b}$$

Lee and Mendis [1] conducted compressive strength tests on three square columns and three rectangular columns, considering the aspect ratios of the slab thickness to the column width (h/c) as a key variable. Their test results showed that the effective compressive strength of the column (f'_{ce})