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Strain gradient effects on flexural strength design of normal-strength concrete columns

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ABSTRACT

The equivalent rectangular concrete stress block has commonly been adopted for the flexural strength design of reinforced concrete (RC) members for decades. In this stress block, the equivalent concrete stress is expressed as $\alpha f'_c$ (f'_c is the uni-axial concrete cylinder strength). Currently, the value of α adopted in various RC design codes is only concrete-strength dependent and equal to 0.85 for NSC. However, in an experimental study conducted previously by the authors on NSC columns subjected to concentric and eccentric axial loads, it was found that α increases significantly as the strain gradient increases. Therefore, the effect of the strain gradient should not be neglected. In this paper, a review on the previous test results on NSC columns is presented and a strain-gradient dependent equivalent rectangular concrete stress block is developed. Based on this proposed stress block, a new flexural strength design method for NSC columns that incorporates the effects of the strain gradient is proposed. A series of column interaction diagrams with various concrete strengths and steel ratios are derived for design purposes. Lastly, these interaction diagrams are compared with the existing column design charts provided in various RC design codes to verify their applicability.

1. Introduction

The evaluation of the total compression provided by the concrete and its resultant location in the compression zone are both essential elements in the flexural strength design of normal-strength concrete (NSC) members. From decades of practice, it is commonly accepted that the nonlinear concrete stress distribution of concrete within the compression zone could be represented by an equivalent rectangular stress block, the area and centroid of which are the same as those of the nonlinear concrete stress distribution [1–4]. The comparison of a nonlinear and an equivalent rectangular stress distribution of concrete is shown diagrammatically in Fig. 1. The width of the equivalent rectangular stress block represents the equivalent concrete stress developed under flexure, while its height represents twice the distance between the resultant concrete compression and the extreme compressive fibre. This method of evaluating the concrete compression developed in bending and its resultant location has been adopted in many of the existing reinforced concrete (RC) design codes [5–8]. For NSC, these codes specify the same value of the ratio of the equivalent concrete stress to the uni-axial concrete cylinder strengths f'_c (denoted commonly by α) which is equal to 0.85. This value was derived many years ago based on the ultimate strength ratio of NSC columns tested under a concentric load to their respective concrete cylinder strength [9,10]. On the other hand, the ratio of the depth of the concrete stress block to the neutral axis depth, denoted commonly by β, varies from 0.80 to 0.85 for NSC as specified in these codes. Table 1 summarises the values of α and β adopted by some RC design codes.

The accuracy of the equivalent rectangular stress block adopted in some of the current RC design codes is investigated by comparing the flexural strength of NSC columns predicted by these codes with that measured by other researchers experimentally [11–14]. The flexural strength comparison is shown in Table 2. The selected columns in Table 2 are subjected to combined bending and a wide range of axial load levels ($P/A_g f'_c$): low ($0 < P/A_g f'_c \leq 0.2$), medium ($0.2 < P/A_g f'_c \leq 0.5$), high ($0.5 < P/A_g f'_c \leq 0.7$) and ultra-high ($0.7 < P/A_g f'_c$). From the comparison shown in Table 2, it is evident that: (1) The theoretical strength is very close to the measured strength for columns subjected to high and ultra-high axial load levels. The difference is less than 5%. (2) The difference between the theoretical and measured flexural strength increases to about 19% and 23% for columns subjected to low and medium axial load levels respectively. The above observations suggest that the currently adopted value of $\alpha = 0.85$ for the equivalent concrete stress developed under flexure could predict accurately the flexural strength of NSC columns subjected to high and ultra-high axial load levels. However, the value is too conservative in the flexural strength prediction of NSC columns subjected to low and medium axial load levels. This is because the value of $\alpha = 0.85$ was obtained

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