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Reduction in flexural strength in rectangular RC beams due to slenderness

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ABSTRACT

This paper presents the results of 15 experimental tests on rectangular slender reinforced concrete (RC) beams. The results reveal limitations in existing theoretical formulations to estimate the failure moment capacity and mode of failure. An improved theoretical formulation is proposed here to predict the critical buckling moment including effects related to nonlinearity and cracking of concrete. Also, following the trends in steel design, an improved measure of slenderness ratio is proposed. Based on a study of 72 test results, it is shown that there is an interaction between flexural tension and instability modes of failure in moderately slender beams. To avoid lateral instability failure, it is suggested that the slenderness ratio be limited to unity. A 'moment reduction factor' is also proposed to account for slenderness effects in RC beams.

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1. Introduction

The behavior of slender reinforced concrete (RC) beams is different from that of normal proportioned beams. Highly slender beams are prone to sudden instability mode of failure. Moderately slender beams are also susceptible to slenderness effects and they may undergo flexural failure at moment values less than flexural capacity corresponding to material failure (M_{uf}). Proper estimation of critical buckling moment (M_{bcr}) is necessary to predict the behavior more accurately as the slenderness depends on relative values of M_{uf} and M_{bcr}. Even though design codes [1–5] specify the slenderness in terms of dimensions of the beam, studies have shown that slenderness of RC beams depends on various design variables also. Design codes presently do not provide any procedure to evaluate M_{bcr}, and also fail to account for the capacity reduction in moderately slender beams on account of slenderness. With regard to the behavior of slender columns, significant research has been carried out worldwide and appropriate provisions have been incorporated in the codes of practice [6,7].

The lateral stability of RC beams was first studied by Marshall in 1948, as reported in Hansell and Winter [8]. Based on the experimental studies conducted, Hansel and Winter [8] proved that the ratio L/b is not a true measure of slenderness as suggested in ACI code. In a subsequent study, Siev [9] experimentally established the influence of reinforcement ratio on the behavior of slender RC beams. Sant and Bletzacker [10] conducted experiments on over reinforced beams and proposed an analytical expression to calculate M_{bcr} and showed the importance of d/b ratio on behavior of slender RC beams. Massey [11] considered the contribution of longitudinal reinforcement as well as stirrups, along with that of concrete, to torsional rigidity of the section. Massey and Walter [12] applied the theory proposed by Massey [11] to simply supported RC beams subjected to central point loading. Revathi and Menon [13,14] conducted experiments on highly and moderately slender RC beams and proposed expressions to estimate M_{bcr} for rectangular beams and reduced flexural strength $M_u = \eta M_{uf}$ for moderately slender beams. They concluded that a wide range of slenderness limits are feasible for different sets of design variables, and proposed a limiting slenderness ratio (λ), by equating the expressions for M_{bcr} and M_{uf} in the following form:

$$\lambda = \frac{C_1}{10C_2}\frac{E_c}{R}\sqrt{\alpha\beta} \qquad (1)$$

where C_1 and C_2 are factors that account for type of loading and beam end conditions respectively; E_c is the elastic modulus of concrete; $R = M_{uf}/(bd^2)$ is the 'flexural resistance factor' for the given beam section (with width b and effective depth d); and α and β are respectively the 'effective flexural rigidity' and 'torsional rigidity coefficients' that account for cracking and tension stiffening.

The proposed expression for M_{bcr} was validated against seven tests conducted by Revathi and Menon [13] as well as three tests conducted by Sant and Bletzacker [10] and eleven tests conducted by Massey [11]. However, there is a need to validate the proposed expressions for M_{bcr}, λ and moment reduction factor η by carrying out further tests on RC rectangular beams including the effects of variations in longitudinal and transverse reinforcement percentages. Recent experimental studies reported in this paper, have exposed limitations in the existing formulations, calling for refinements in the expressions for M_{bcr}, λ and η.

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