Effective Stiffness of Squat Structural Walls

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Abstract: Reinforced concrete (RC) structural walls are the primary lateral-load carrying elements in many structures designed to resist earthquakes. A review of the technical literature shows considerable uncertainty with regards to the effective stiffness of these structures when subjected to seismic excitations, which many design practices currently deal with by employing a stiffness reduction factor. In an attempt to obtain additional information regarding the stiffness of these structures, an analytical approach, combining the flexure and shear components of deformation, is proposed to evaluate the effective stiffness of the RC walls tested. Based on this proposed analytical approach, a comprehensive parametric study comprising 180 combinations was carried out and a simple equation for assessing effective stiffness of RC squat structural walls then proposed, on the basis of these parametric case studies. DOI: 10.1061/(ASCE)ST.1943-541X.0000386.

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Introduction

The past 15 years have seen major developments in seismic design provisions, with a paradigm shift from a force-based approach to a displacement-based one, and an increase in focus on the deformation characteristics of structures. Stiffness properties of reinforced concrete (RC) wall structures can affect the estimation of the fundamental period, displacements, and distributions of internal force response between walls. The magnitude of the effective stiffness depends on the intensity and distribution of stress on a wall cross section, and the extent of flexural and shear cracking. Flexural cracking causes reduction in the net cross-sectional area and moment of inertia, and hence, a reduction in effective flexural rigidity of the wall section. This leads to an increasing difficulty in making accurate predictions of the effective stiffness of RC members. Thus, stiffness reduction factor is employed in the analysis of RC members under lateral loads. In practice, the values of 0.35 and 0.70, the gross moment of inertia for cracked and uncracked walls, respectively, is widely employed. However, this simplification may not be appropriate in many cases because the recommended moment of inertia for walls is independent of the reinforcement content and axial load level.

In the case of RC walls under lateral loads, Priestley (1998) indicated that the Standards New Zealand (NZS) NZS 3101 (NZS 1995) design code recommendations for estimating the stiffness of RC walls fail to recognize the influence of two important factors: the member strength and the reinforcement grade. For stiffness evaluation of RC walls, the wall strength depends significantly on the axial load and reinforcement content. Thus, the recommendations in the NZS 3101 design code (NZS 1995) for stiffness estimation are oversimplified and may lead to an inaccurate assessment of the wall stiffness. To obtain a more accurate evaluation of wall stiffness as determined from the curvature at first yield and the flexural strength, several proposals on how stiffness values can be more realistically assessed have been presented (Priestley and Kowalsky 1998; Priestley 1998; Adebar and Ibrahim 2002). However, Fenwick and Bull (2000) found that these proposals (Priestley and Kowalsky 1998; Priestley 1998) also proved to be oversimplified. To further improve the effective stiffness predictions, they analytically investigated a range of slender rectangular walls with uniformly spaced reinforcement and proposed an expression for predicting the effective wall stiffness as a function of concrete strength, reinforcement grade, and axial loads. As indicated by the research (Fenwick and Bull 2000), the expression proposed for accurately predicting the wall effective stiffness is only justified for slender rectangular walls for which the response is dominated by flexure, and thus, the proposals cannot be applied to RC walls with low aspect ratios because their response may be controlled by shear deformations. This study strives to establish more consistency and accuracy in predicting effective stiffness of these squat structural walls with limited transverse reinforcement.

Previous Research in Evaluating Effective Wall Stiffness

The effective moment of inertia, $I_e$, is defined as the moment of inertia that a uniform, elastically responding wall would have, such that when it is subjected to the lateral force that causes first yield, or a strain of 0.002 in the concrete, it sustains the same deflection. The effective stiffness of walls defined as explained previously is utilized in several previous studies and current design codes. They are briefly reviewed in the subsequent sections.

Research Conducted by Fenwick and Bull

The member effective stiffness can be obtained by the integration of curvatures over the cracked and uncracked sections along the member. The standard beam theory describes the behavior of idealized cracked and uncracked sections and can be used to determine

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