Hysteresis Behavior of Reinforced Concrete Walls

Piyali Sengupta¹ and Bing Li²

Abstract: Reinforced concrete walls are primary lateral load-resisting systems in numerous multistory buildings and nuclear structures located in seismically active regions. Hence, hysteresis behavior prediction of structural walls is of utmost importance in the context of seismic analysis and design. A hysteresis model of reinforced concrete walls, capable of producing requisite structural degradation and pinching characteristics has been proposed in this research on the basis of Bouc-Wen-Baber-Noori model. Livermore solver for ordinary differential equations and genetic algorithm have been opted for solving the differential equations and identifying the analytical parameters associated with the model, respectively. A database of wall specimens tested under cyclic loading has been accumulated from literature to successfully calibrate the analytical response with the experimental results. Subsequently, relationship between the structural features and the model parameters is resolved based on the wall database by regression analysis. Moreover, to facilitate structural analysis of wall-dominant buildings using the proposed approach, the hysteresis model has been effectively implemented as a user element in the form of a pair of diagonal springs in ABAQUS. DOI: 10.1061/(ASCE)ST.1943-541X.0000927. © 2013 American Society of Civil Engineers.

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Introduction

Reinforced concrete (RC) walls, frequently incorporated in multi-story buildings, experience dead and live loads transmitted by floor systems and lateral loads because of wind and earthquake effects. Experimental studies conducted in recent years indicate that structural walls with limited transverse reinforcement, when subjected to repeated cyclic deformation, possess poor energy dissipation characteristics, resulting in pinched hysteresis loops with significant strength degradation and possible sudden loss in lateral capacity (Hidalgo et al. 2002; Greifenhagen 2005; Kuang 2008).

Thus, a constitutive model capable of producing requisite strength and stiffness degradation along with pinching at all displacement levels is a basic requirement in modeling and design of seismic-resistent RC walls.

Extensive research has been undertaken till date on analytical prediction of hysteresis behavior of RC walls. However, modeling and analysis of RC walls can be conducted at three levels of refinement: microscale, mesoscale, and macroscale modeling methods. In microscale modeling methods, RC walls are divided into finite numbers of small steel and concrete elements. Despite being capable of modeling different loading environment with reasonable accuracy, this method requires high numerical effort for large and complex structures. Mesoscale models are the intermediate scale models that permit utilization of simplified kinematic hypotheses of the theory of beams with a consequent reduction of the size of the equation system, leading to faster analysis than the microscale models. Single or multiple component models, Truss models, and multispring models belong to the category of macroscale models that can represent the overall behavior of RC walls, such as wall deformation, energy dissipation capacity, etc. The macroscale hysteresis models can be broadly classified into piecewise linear or polygonal hysteresis models (PHMs) and smooth hysteresis models (SHMs). In polygonal hysteresis models, such as bilinear degrading stiffness model (Clough and Johnston 1966), trilinear Takeda model (Takeda et al. 1970), bilinear SINA hysteresis model (Saidi and Sozen 1979); variation of stiffness occurs at elastic, cracking, yielding, strength and stiffness degradation, crack, and gap closing stages. Smooth hysteresis models refer to the models with continuous change of stiffness due to yielding but sharp changes due to unloading and deteriorating behavior, like Bouc-Wen-Baber-Noori model (Baber and Wen 1981; Baber and Noori 1985). Kabeyasawa et al. (1983) developed a three-vertical-line elements model (TVLEM) with infinitely rigid beams at the top and bottom floor levels to simulate the pseudodynamic earthquake response of a full-scale seven-story RC wall-frame test structure. In this model, the rotational springs replace the rotational spring of the wall panel. Sittipunt and Wood (1993) demonstrated microscale finite element methods for studying cyclic behavior of RC slender walls. Vulcano and Bereto (1987) modified the outer vertical spring of TVLEM model by using a spring assembly that contains a single topmost spring to denote the uncracked concrete and two parallel springs to represent the cracked concrete and steel, respectively. Vulcano et al. (1988) further replaced the rotational spring by additional vertical springs to simulate the axial behavior and the gradual yielding of vertical reinforcement. Linde and Bachmann (1994) developed a macroelement to represent the inelastic seismic behavior of shear walls controlled by flexure, with modest influence of shear cracking in the hysteretic response. Youssef and Ghaboohar (2001) developed a macroelement comprising of four steel and concrete springs to represent the behavior of steel reinforcement and concrete strut and to define the plastic hinge region and a pair of diagonal springs to represent the shear behavior of the wall. The analytical model proposed by Hidalgo et al. (2002) predicts the inelastic seismic response of reinforced concrete shear-wall buildings, including both flexural and shear failure modes. The analytical model by

¹Ph.D. Candidate, School of Civil and Environmental Engineering, Nanyang Technological Univ., Singapore 639798. E-mail: piya0002@e.ntu.edu.sg

²Associate Professor, School of Civil and Environmental Engineering, Nanyang Technological Univ., Singapore 639798 (corresponding author). E-mail: cbli@ntu.edu.sg

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