Engineering Structures 169 (2018) 37–54

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Macroscopic modelling of coupled concrete shear wall

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ARTICLE INFO

Keywords:
Coupled shear wall
Microscopic model
Macroscopic model
Coupling beam

ABSTRACT

This study explores several types of macroscopic models, by modifying Multiple-Vertical-Line-Element-Model (MVLEM), to represent the coupled concrete shear wall, with different ways of connection to simulate coupling beam. For this purpose, an existing shear wall in which several openings are symmetrically embedded was studied. The wall was analyzed by the microscopic Finite-Element Method (FEM) in ABAQUS. In order to investigate the macroscopic modelling of the mentioned wall, three different macroscopic coupled shear walls, composed of several nonlinear springs, representing flexural and shear behaviors were studied. The main difference among the three walls is in the type of the coupling beam connection used. Hence, three connections were proposed with different stiffnesses. Unlike the connection, the macroscopic coupling beams for the three models were identical based on moment distribution. In order to model the coupling beam, two separate shear walls were considered which were connected to each other from the uppermost part. Responses of the walls under cyclic, monotonic, and dynamic loadings were compared with those of the verified FEM model. The results indicate that the macroscopic wall with moderate connection stiffness has acceptable consistency in terms of static and dynamic responses of the microscopic model.

1. Introduction

In buildings subjected to seismic excitations, members with the capability of transferring loads to the substructure should withstand lateral loads. Concrete shear walls are one of the resisting members dissipating lateral loads on the structures; their behavior plays an important role in the overall performance of the structures. Consequently, it is essential to use an effective method to model the nonlinear behavior of the shear wall and predict the response of its component. Many modelling methods with acceptable precision have been introduced in the literature. However, researchers seek a desirable modelling target featuring acceptable accuracy and less computational time.

Analytical modelling of the concrete shear wall systems can be accomplished using either microscopic models via Finite-Element Method (FEM) or macroscopic models based on the overall behavior with reasonable accuracy. A practical model to analyze structures should be simple to implement and have acceptable precision in predicting inelastic response. Although microscopic models can provide a detailed definition of the local response, its efficiency and practicality become disputable as far as the nonlinear response of the complicated structures is concerned. In contrast, unlike microscopic models, macroscopic modelling of such a structure results in fewer degrees of freedom; therefore, the stiffness matrix is small and analysis can be carried out faster and more efficiently [1,2].

In the past, basically, six macroscopic models were introduced, including one-component model, two-component model, multi-axial spring model, truss model, multi-spring model, and multi-component model [3]. Kabeyasawa et al. [4] proposed a model for predicting the nonlinear response of the shear wall. In their proposed model, axial springs at the two ends and a rotational spring at the center simulated the flexural behavior, while a horizontal spring modelled the shear behavior. The behavior of their model was modified by Vulcano et al. [5]. They proposed the so-called Multiple-Vertical-Line-Element-Model (MVLEM), in which the horizontal spring that simulated shear behavior located at the center and rotational spring was removed in the model. Wallace et al. utilized a multiple-spring macroscopic model similar to Vulcano et al.'s and improved it by assigning cyclic properties of materials to the springs [6–9]. Not surprisingly, MVLEM element provides and produces sufficient accuracy despite its simplicity; hence, it was utilized by many researchers. Chowdhury et al. employed MVLEM to model a concrete column and demonstrated the effectiveness of the method for slender members [10]. Jalali and Dashti investigated effectiveness of MVLEM in the slender concrete walls by modelling eight shear walls and comparing their performances and computational times [11,12]. A number of analytical models have been proposed to adopt an approach that integrates shear and flexural interactions to predict the response of reinforced concrete squat walls. Fischinger et al. implemented the macroscopic element to predict seismic response of RC

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https://doi.org/10.1016/j.engstruct.2018.04.088
Received 28 September 2017; Received in revised form 28 February 2018; Accepted 26 April 2018

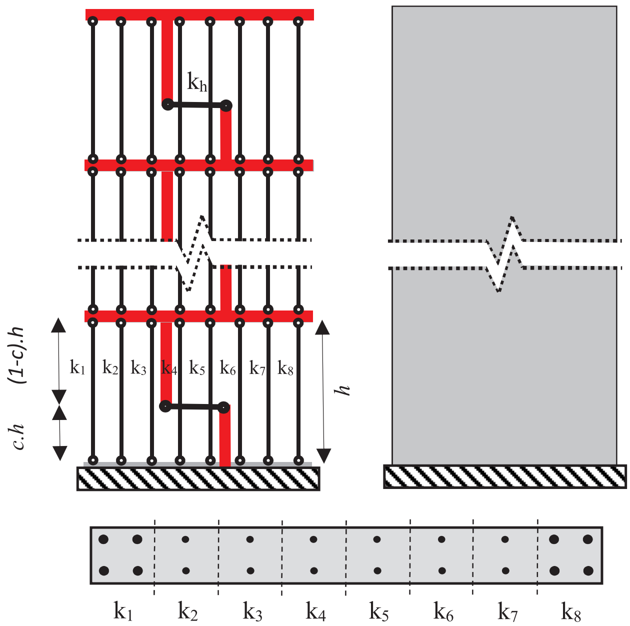

Fig. 1. Sample model assembly of a shear wall and tributary area assignment.

structural walls and H-shape shear walls [13,14]. They used 3D MVLEM that can resist any load from every direction (even the twisting). Jun et al. used this MVLEM in a framework for seismic fragility analysis of RC high-rise buildings [15,16]. The study of Xiaolei et al. confirmed the accuracy of MVLEM in the nonlinear behavior of the shear wall, such as the shifting of neutral axis, shear deformation, local collapse, and collapse mechanism [17]. A macro model-based approach to enabling post-event progressive collapse analysis of shear wall structures was investigated by Bao et al. [18,19]. Yun et al. studied the methodology behind each model and examined the corresponding merits and disadvantages [20].

Table 1
Beam and Column Reinforcements (sizes are in mm).

Item	Main reinforcement	Hoop reinforcement
Side column	8-D19	2-Φ10@75
Beam	2-D13	2-Φ6@100
Loading beam	2-D19	2-D10@100
Wall reinforcement	D6@100	D6@100
Reinforcing bar of opening (vertical)	4-D13	…
Reinforcing bar of opening (horizontal)	4-D13	…

Table 2
Mechanical Properties of reinforcements.

Reinforcement size	Young's modulus (GPa)	Yield strength (MPa)	Ultimate strength (MPa)
D6	204	425	538
D10	180	366	509
D13	189	369	522
D16	194	400	569
D19	183	384	616
Φ	197	985	1143

According to FEMA 356, MVLEM must be used only for modelling rectangular walls and wall segments with height-to-length ratios smaller than 2.5 [21]. In many cases, due to the architectural limitations, several openings need to be included within the shear wall. This action causes severe stress concentration in the wall, especially around the openings [22]. The location of the openings in the shear wall does not follow a special rule, and only architectural demand specifies that. As mentioned, MVLEM elements are suitable for modelling rectangular shear walls; however, the openings distort this uniformity and cause some problems in the macroscopic modelling. This problem arises from the behavior of the coupling beam and its connection to the wall.

The techniques to be implemented for macroscopic modelling of the

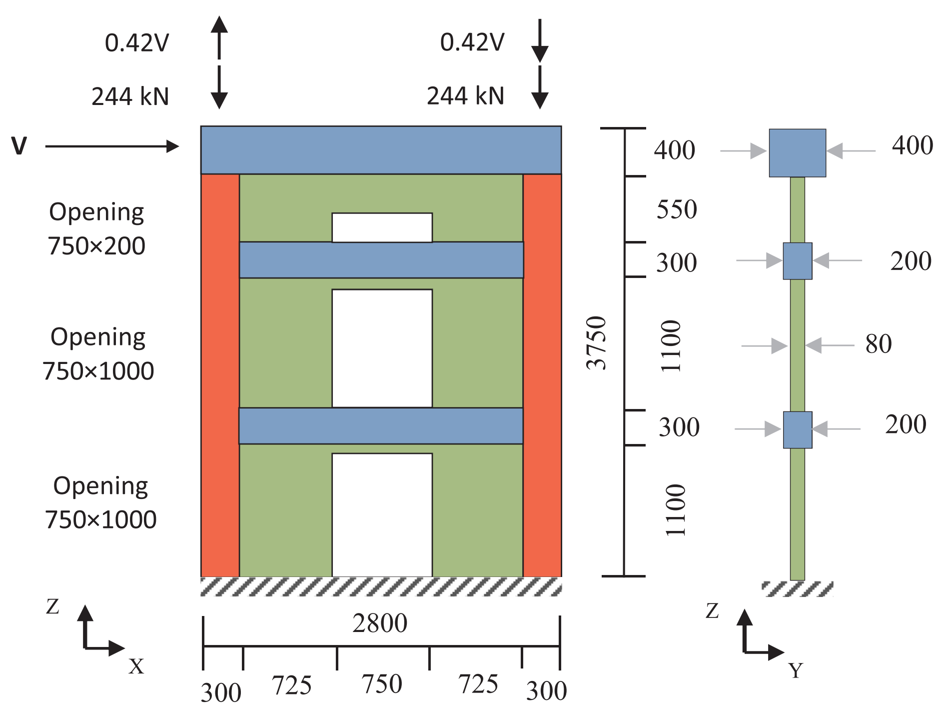

Fig. 2. Geometry of the shear wall specimen (mm).