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Analytical model for seismic simulation of reinforced concrete coupled shear walls

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ABSTRACT

Reinforced concrete coupled walls are widely used as the main seismic resistant structural system in high-rise buildings. This paper proposes a new mixed beam-shell model for the seismic analysis of reinforced concrete coupled walls with sufficient efficiency and accuracy on the platform of general finite element software MSC.Marc. Boundary elements at the ends of wall piers are simulated by conventional fiber beam-column elements, while the web of the wall pier is modeled by the layered shell element. Coupling beams are simulated by non-conventional fiber beam-column elements, which can not only take into account the shear and shear-sliding deformation together with various failure modes of conventionally reinforced beams, but also the shear and rebar slip deformation of diagonally reinforced beams. RBE2 link elements are utilized to connect the coupling beams to the wall piers. Eight test specimens reported in the literature are used to validate the proposed model. The mechanism of the coupled wall is thoroughly investigated in terms of the beam deformation, base shear and moment distribution as well as axial force of the wall piers. Furthermore, parametric analyses on specimens with different degrees of coupling and types of reinforcement layouts of coupling beams are conducted. Based on the analyses, the influences of the complex behavior and various modeling parameters of coupling beams on the behavior of coupled wall are revealed quantitatively. As a conclusion of the parametric analyses results, it is recommended that the complicated behavior of coupling beams be accurately considered for most cases in the seismic analysis of coupled wall systems.

1. Introduction

To meet the architectural or other practical requirements, openings are commonly placed in the reinforced concrete (RC) structural walls, thus forming the coupled wall system, which has been widely used in modern high-rise buildings as the main lateral force resisting system. Due to the coupling effects of the beams between the adjacent wall piers, the structure can bear a much larger base moment and shear force with an obviously increased structural stiffness compared to the individual wall piers. In addition, during major earthquakes, the coupling beams can dissipate a large portion of energy and protect the wall piers from severe damage.

Some experimental research has been conducted to investigate the seismic behavior of the coupled wall system [1–5]. However, compared to numerous tests on individual shear walls [6–10] and coupling beams [11–18], tests on RC coupled walls are quite limited. Previous tests have recognized the influences of different types of coupling beams and degrees of coupling and have revealed the redistribution of base shear and moment among wall piers. Among these experimental programs, Lehman et al. [1] completed a test program on one piece of planar coupled wall specimen featured with high-resolution response and damage data, which provides valuable information for the analytical modeling research.

Nowadays, structural analytical models with sufficient accuracy and efficiency are widely and urgently needed to conduct large numbers of elasto-plastic dynamic time-history analyses of different structural systems, so as to support and promote the research on the structural seismic performance and performance-based design method. To date, for the analytical modeling of the important RC coupled wall system, there remains a significant gap in the past research mainly due to the complicated seismic behavior of coupling beams [4,19–21]. Two modeling approaches can be summarized from previous research as shown in Fig. 1: (1) to get higher calculation efficiency, the wall piers and coupling beams are both simulated by beam elements, as shown in Fig. 1(a); (2) to obtain better accuracy, the wall piers and coupling beams are modeled by complex a 2D membrane element or a 3D shell

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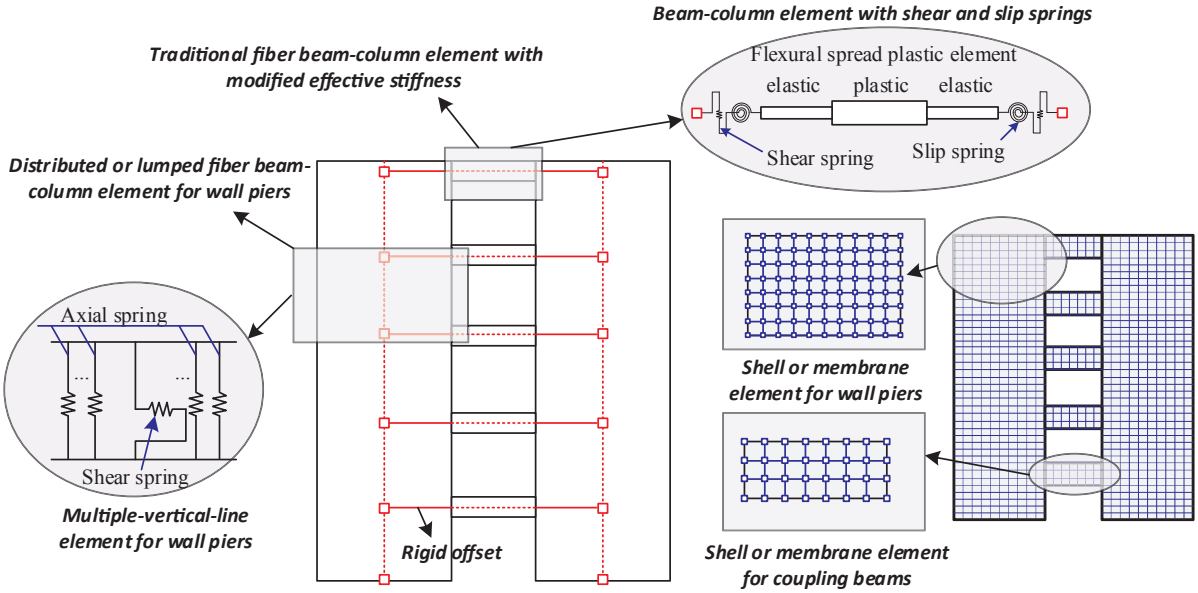
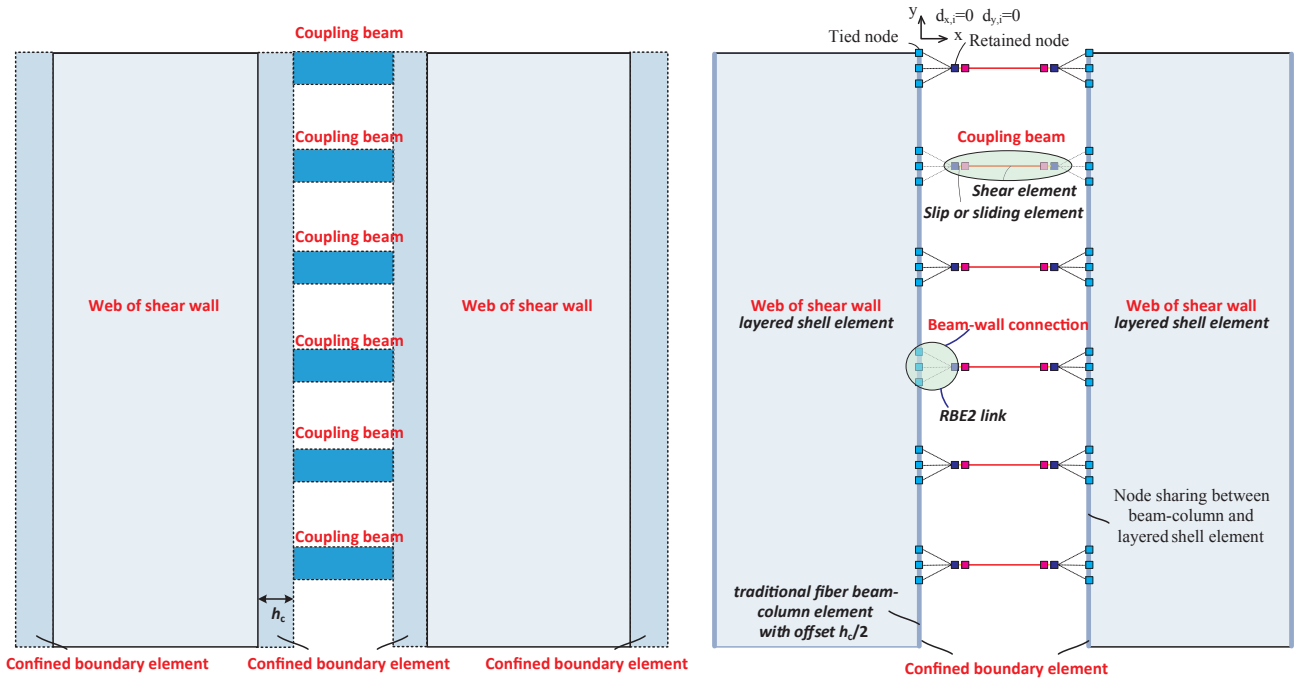


(a) beam-column element (b) shell or membrane element

Fig. 1. Two modeling approaches for RC coupled wall structures.



(a) schematic diagram of typical coupled wall (b) modeling strategy of coupled wall

Fig. 2. Proposed modeling strategy for coupled wall structures.

element, as shown in Fig. 1(b). The first approach cannot capture the complex shear-sliding-slip behavior of coupling beams. On the other hand, despite the fact that several improved beam elements are proposed to simulate the complicated compression-bending-shear or tension-bending-shear behavior of wall piers such as the multiple-vertical-line element [22,23], it is quite difficult to determine the parameters of the model. In addition, the damage state of the wall piers cannot be visually presented to help the designers and researchers easily understand the seismic performance of structures with shear walls or core tubes. The second approach requires too much calculation time due to the complex 2D concrete constitutive relationships; thus it is not suitable for large-scale structural time-history dynamic analysis. What is more, the complex shear, sliding and slip behavior of coupling beams may still not be reasonably reflected by the membrane or shell models.

Therefore, this study aims to propose a mixed beam-shell model for the seismic analysis of the RC coupled wall system with both satisfactory accuracy and efficiency as well as to reveal the influence of the complex coupling beam behavior on the seismic behavior of coupled walls. The authors once proposed two non-conventional fiber beam-column elements for conventionally and diagonally RC coupling beams [24,25], respectively. The elements can accurately consider the complex deformation mechanism and failure modes of RC coupling beams