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Seismic behaviors of steel plate shear wall structures with construction details and materials

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ABSTRACT

In order to have a systematic and comprehensive comparison of seismic behaviors of steel plate shear wall structures with different construction details, a numerical method was proposed, which was proved accurately to predict the performance of structures with published quasi-static tests. Then, eight typical steel shear wall models with different structural construction details were established. Also an advanced stiffened low yield point steel plate shear wall was proposed to avoid excessive out-of-plane deformation. The seismic behaviors of above nine shear wall models were fully compared and analyzed, and key issues, such as energy-dissipating capacity, ductility, out-of-plane deformation and the effect of tension field on the columns were discussed in depth. The results showed that: in high-intensity seismic area, load-carrying capacity, hysteretic behaviors, failure modes, seismic ductility and economic performance should be taken into account comprehensively to choose the appropriate form of steel plate shear wall structure; the proposed low yield point steel plate shear wall with T type stiffened ribs could most effectively improve the energy dissipation capacity and ductility, and lessen the impact of tension field on the columns, besides, it had better load-carrying capacity and smallest out-of-plane deformation. This method provided a good way for improving the seismic behaviors of steel shear wall structures.

1. Introduction

Recently, Steel frame–steel plate shear wall structure is a research hotspot for its excellent performance on resisting lateral deformation, so it has already been used in many high-rise steel buildings. Due to large steel consumption, low utilization efficiency of material and poor welding performance of thick steel plate shear wall, thin steel plate shear wall structures are paid more attention in current studies. This kind of structure has larger height to thickness ratio λ of infill panel ($\lambda > 150$), therefore, when a small horizontal force is applied, the buckling of steel panel occurs earlier with larger out-of-plane deformation. And then, the tension fields of thin infill plate are formed, making the structure continue to resist the horizontal force. These tension fields will be transmitted directly to the frame columns, resulting in a greater impact on frame columns [1,2]. In order to improve the seismic behaviors of thin steel plate shear wall structures, research works are mainly focused on two aspects. On one hand, the design principle of "strong frame, weak wall" is proposed in the view of performance matching. Currently, many scholars have suggested various structural constructions of shear walls based on this principle, including shear panel with openings [3,4], shear panel slotted at both sides [5] and shear panel with vertical slits [6–8], as shown in Fig. 1. On the other hand, the buckling of steel infill plate in advance will lead to larger out-of-plane deformation with loud sounds, which may adversely affect the comfort demands and using of requirements. Some researchers have presented several stiffened steel plate shear wall structures (for example, cross-stiffened, groined stiffened and diagonal stiffened steel plate shear walls [8–11], as shown in Fig. 1) and buckling-restrained measures [12] to delay and lessen the buckling behaviors of panels. Some other researchers also proposed low yield point steel plate shear wall structures [3,13] based on new materials, indicating that this kind of structure had better ductility and energy dissipation capacity [14,15] due to the better seismic behaviors of low yield point steel [16,17]. All the works above have significant effects on improving the energy dissipation capacity of steel plate shear walls, and reducing the adverse impacts of buckling on structures.

In this field of researches, most of the studies, however, focused on one or a few construction details. No systematic and comprehensive comparison of seismic behaviors of steel plate shear walls with different construction details has been implemented. Due to high costs of tests, comprehensive comparison is difficult to carry out only by means of test method, and also some seismic indexes cannot be obtained by experiments (e.g., fracture tendency and the effect of tension field on

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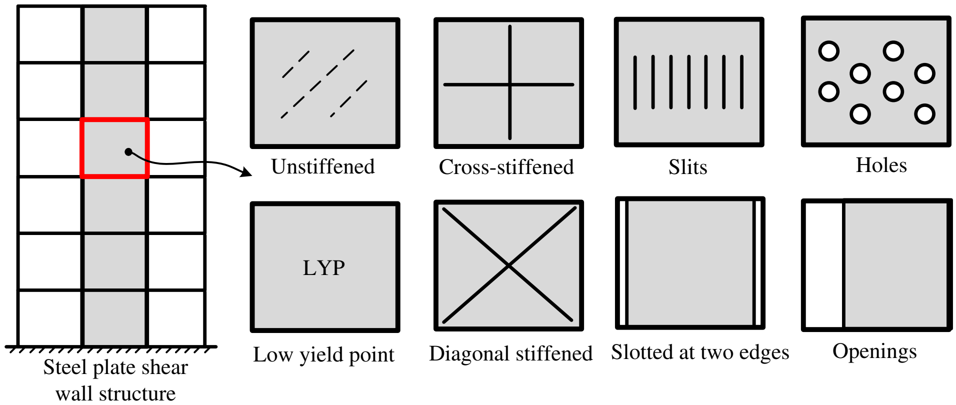

Fig. 1. Steel plate shear wall structures with different structural construction details.

the columns). Therefore, the numerical simulations are widely used currently. The more accurate finite element model for parametric analysis is particularly important. However, due to the severe non-linear behaviors of reciprocating two-way tension fields, the constantly changing out-of-plane deformation and the zero or even negative stiffness phenomena, the accurate numerical simulation of thin steel plate shear wall structures subjected to cyclic loading is difficult to achieve. Furthermore, the responses of materials under cyclic loading and monotonic loading are quite different [18]. The traditional method cannot accurately predict the cyclic behaviors, local buckling phenomena and pinching phenomena. Therefore, a more efficient and accurate finite element method should be proposed for thin steel plate shear wall structures.

In this study, many improved construction details of steel plate shear walls were summarized. Firstly, the finite element models of thin steel plate shear wall under cyclic loading patterns were established using ABAQUS software. The computing platform, element selection, meshing, the initial imperfection and steel cyclic constitutive models were introduced in detail. Geometric nonlinearity and material nonlinearity were considered adequately. The results of numerical simulation were compared with typical experimental results. The proposed method was proved to accurately simulate and predict the seismic behaviors, including capacity and stiffness degradation caused by out-of-plane deformation, pinch phenomena of curves, failure modes and fracture positions, which provided a strong tool for carrying out further analysis. Then, based on the verified finite element method, eight typical steel shear wall models with different structural construction details and unstiffened low yield point steel shear wall model were established within common sizes, and their load-carrying capacity, hysteretic behavior, degradation characteristics, fracture index, failure modes, energy-dissipating capacity, especially ductility, out-of-plane deformation and the effect of tension field on the columns were deeply analyzed. Besides, to lessen the out-of-plane buckling phenomenon and improve the load-carrying capacity of low yield point steel plate shear wall, an advanced stiffened low yield point steel plate shear wall was proposed, and its seismic behaviors were also compared with all others above. Finally, a direct suggestion was given for engineers to choose proper construction details according to the specific demands of actual projects. It was expected to provide a reference for engineering applications.

2. Finite element analysis

In order to study the behaviors of the steel plate shear wall structures, an efficient and accurate finite element method should be obtained. All parts of models are presented in more detail as follows.

2.1. Model description

A typical steel plate shear wall structure generally consists of edge beams, edge columns, infill panel, beam-to-column connections, and fish plates, as shown in Fig. 2. It was proved in reference [19] that the fish plate could be neglected in finite element model, which would not affect the simulated results. Both H-shaped frame and infill panel are modeled in ABAQUS with shell element S4R, to avoid shear locking phenomenon. In order to accurately simulate the plate buckling, initial defect should be imposed on the panel by rewriting the inp file. The process of imposing initial defect is achieved by using Command "imperfection" to modify the coordinates of nodes. Reference [1] drew a conclusion that residual stress had little effect on behaviors of steel plate shear wall, which could be ignored. Therefore, the residual stress will not be considered in the finite element modeling.

The boundary conditions and loading patterns are in accordance with typical tests. The loading process contains two steps. Firstly, the vertical loads are applied on the top of edge columns to simulate the axial forces, and the impact of second-order effect is taken into account.

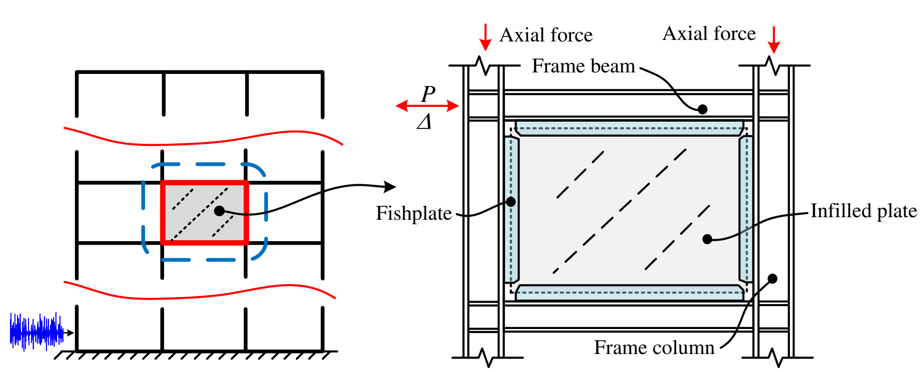

Fig. 2. Typical element of steel plate shear wall.