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Introduction of stiffened large rectangular openings in steel plate shear walls

S.A.A. Hosseinzadeh [1], Mohsen Tehranizadeh *

Department of Civil Engineering, Amirkabir University of Technology, 424 Hafez Ave, Tehran, 15875-4413, Iran

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ABSTRACT

The nonlinear behavior of steel plate shear walls (SPSWs) with stiffened large rectangular openings used as windows or doors in buildings is studied. A number of SPSWs with and without openings are numerically analyzed, and the results are utilized (a) to characterize the behavior of SPSWs with the openings, (b) to study the effects of various opening features as well as size of local boundary elements (LBE) around the opening and thickness of infill plates on either side of the opening and (c) to investigate the changes in the system strength, stiffness and ductility due to the introduction of the openings. Results show that the procedure addressed by AISC Design Guide 20 for design of beams above and below the opening level is not perfect. Use of thicker or thinner infill plates or weaker profiles for the LBE can alter the yielding sequence in the system. Notably, the type, location and geometry of stiffened openings are not influential themselves on the system strength, although different LBE sizes required for different openings may have some effects. The introduction of stiffened openings in different SPSWs increases both the ultimate strength and stiffness, while somewhat decreases the ductility ratio.

1. Introduction

Steel plate shear walls (SPSWs) have been increasingly utilized as a lateral force resisting system, which resist both earthquake and wind forces. This structural system has been used in significant buildings beginning decades ago, and implementation has accelerated since the recent years [1]. They provide an effective and economical solution for new construction as well as retrofitting of existing structures. A conventional SPSW consists of thin stiffened or unstiffened steel plates surrounded by horizontal and vertical boundary elements (HBE and VBE) that can be multiple stories high and one or more bays wide.

Early designs of SPSWs were based on the concept of preventing shear buckling in the infill plate by using either thick infill plate or by adding stiffeners to the infill plate, but in recent years, the idea of utilizing the post-buckling strength with the use of thin unstiffened infill plate has gained wide acceptance from researchers and designers globally. Typical SPSW has slender infill plates that are capable of resisting large tension forces by developing diagonal tension fields in the infill plate, but little or no compression. They should be expected to buckle under very small lateral loads or even considered pre-buckled under their own weight prior to loading. It is known that plastic deformations in SPSWs should primarily be provided by the infill plates [1,2] and that the boundary members should be designed so as to develop the full tension strength of the infill panels.

Numerous research programs and large-scale experiments have been shown that this system possesses high level of initial stiffness, strength, ductility and robustness under cyclic loading [3–12]. SPSWs offer significant advantages over many other lateral load-resisting systems in terms of foundation cost, saving steel, performance, ease of design, speed and simplicity of construction and usable space in buildings [1,13]. They can also be accommodated to allow different types of openings within their infill plates.

To date, experimental and analytical research on thin unstiffened SPSWs is mainly focused on the behavior of SPSWs with solid infill plates (i.e. without openings) and thus, limited research on various types of openings in SPSWs or shear panels has been performed.

Roberts and Sabouri-Ghomi [14] conducted a series of quasi-static cyclic loading tests on unstiffened steel plate shear panels with centrally placed circular openings. Based on the test results, the researchers recommended that the strength and stiffness of a perforated panel can be conservatively approximated by applying a linear reduction factor to the strength and stiffness of a similar solid panel. Deylami and Daftari [15] analyzed more than 50 models with a rectangular opening in the center of the panel using finite element method to investigate the effects of some important geometric parameters, such as plate thickness, the opening height to width ratio, and the areal percentage of the opening. The opening had only two stiffeners with limited length on its vertical edges which were not continued across the height of the panel. They concluded that the introduction of the opening, even at relatively small percentage, caused an important decrease of shear capacity. In thinner steel plate shear

* Corresponding author. Tel.: +98 21 6454 3030; fax: +98 21 6454 3037.
E-mail addresses: ahosseinzade@gmail.com, ahosseinzadeh@aut.ac.ir (SAA. Hosseinzadeh), dtehz@yahoo.com (M. Tehranizadeh).
[1] Tel.: +98 21 6454 3073; fax: +98 21 6454 3037.

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