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Perforated metal shear panels as bracing devices of seismic-resistant structures

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ABSTRACT

Steel Plate Shear Walls (SPSWs) are innovative systems able to confer to either new or existing structures a significant capacity to resist earthquake and wind loads. Many tests have shown that these devices may exhibit high strength, initial stiffness and ductility, as well as an excellent ability to dissipate energy. When full SPSWs are used as bracing devices of buildings, they may induce excessive stresses in the surrounding main structure where they are inserted, so to require the adoption of large cross-section profiles. For this reason, perforated steel panels, which are weakened by holes aiming at limiting the actions transmitted to the surrounding frame members, represent a valid alternative to full panels. In this work, aiming at showing the advantages of such devices, a FEM model of perforated panels has been calibrated on the basis of recent experimental tests. Subsequently, a parametric FEM analysis on different series of perforated panels, by changing the number and diameter of the holes, the plate thickness and the metal material, has been carried-out. Finally, the achieved numerical results have been used to set up an analytical tool to correctly estimate the strength and stiffness of perforated metal shear panels.

1. Introduction

The seismic protection systems based on the use of Steel Plate Shear Walls (SPSWs) consist of stiff horizontal and vertical boundary frame elements and infill plates. SPSWs possess good ductility and high energy dissipating capability under cyclic loading and they are also characterized by high initial stiffness, resulting very effectively in limiting the inter-storey drift of concrete or steel framed buildings. In addition, by using shop-welded or bolted connection type, the erection process can be facilitated, allowing a considerable reduction of constructional costs.

There are two types of SPSW systems, namely the "standard system" and the "dual system" [1]. In the "standard system", SPSWs are used as the lateral load resisting system, so beams and columns are designed to transfer vertical loads only. In the "dual system", also the boundary members, generating a moment resisting frame, contribute to resist lateral loads. Generally, these systems are located in perimeter frames of the main structure or around staircases, they occupying an entire span or a part thereof. Moreover, they can be stiffened or unstiffened, depending on the design philosophy. In the first case, SPSW may be provided with bending stiffeners, which improve the structure dissipative behaviour. Alternatively, the same behaviour can be attained by using low yield strength metals, namely low yield steel [2] or aluminium [3], as base materials for plates. When unstiffened thin panels are used, they immediately buckle under in-plane loads, but additional loads can be carried due to the tension-field mechanism, i.e. the development of tensile strips in the plate main diagonal direction [4]. From recent studies, it was found that the panel ideal behaviour is obtained for width/height ratios between 0.8 and 2.5 [5]. As a consequence, the boundary frame members have to be designed to support the tension-field mechanism developed by the plate. The tension-field action may induce in the frame members large forces demand, which gives rise to the adoption of high depth profiles. A number of solutions have been proposed to alleviate this condition, based on connection of the infill plate to the beams only [6], on vertical slits [7], on thin light-gauge cold-rolled steel [8], on low-yield strength steel [9,10], on perforated SPSW [11] and on aluminium plates [12,13].

In this paper, the attention is focused on the use of perforated SPSWs, in order to limit the construction costs deriving from their installation into the structure. Therefore, a FEM model, implemented with ABAQUS [14] and calibrated on the basis of previous literature experimental tests on panels with a central hole, has been developed in order to set up a parametric analysis on devices having different configurations of holes.

In conclusion, the achieved numerical results have been used to propose analytical tools under form of design charts for evaluating both the shear capacity and the initial stiffness of perforated metal shear panels.

2. Previous researches on unstiffened perforated panels

The first studies aimed at evaluating the behaviour of unstiffened steel panels were presented during the first '80s of the last century

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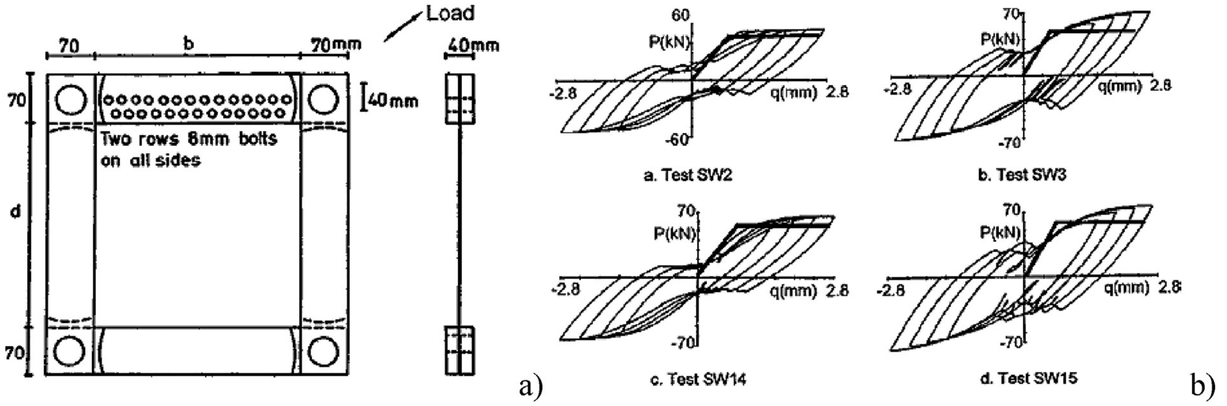

Fig. 1. Specimens tested by Roberts and Sabouri-Ghomi [16] (a) and their experimental cyclic responses with the equivalent bilinear diagrams provided by Eqs. (1) and (2) (b).

[15]. In 1991, on the basis of experimental diagonal tests performed on SPSWs within a pinned joint frame (Fig. 1), Roberts and Sabouri-Ghomi [16] proposed a theoretical method, namely the Plate-Frame Interaction (PFI) method, for calculating the shear capacity F_{wu} and the stiffness K_w of the steel plate device. The contribution of the plates only can be obtained through the following equations:

$$F_{wu} = b\, t\left(\tau_{cr} + \frac{1}{2}\,\sigma_{ty}\sin 2\vartheta\right) \tag{1}$$

$$K_w = \frac{\left(\tau_{cr} + \frac{1}{2}\,\sigma_{ty}\sin 2\vartheta\right)}{\left(\frac{\tau_{cr}}{G} + \frac{2\,\sigma_{ty}}{E\sin 2\vartheta}\right)}\frac{b\,t}{d} \tag{2}$$

where t, b, d are the thickness, width and height of the steel plate, respectively, E and G are the Young and shear elasticity moduli of the steel plate materials, σ_{ty} is the tension-field stress in the plate yielding condition, ϑ is the diagonal tension-field angle, measured from the

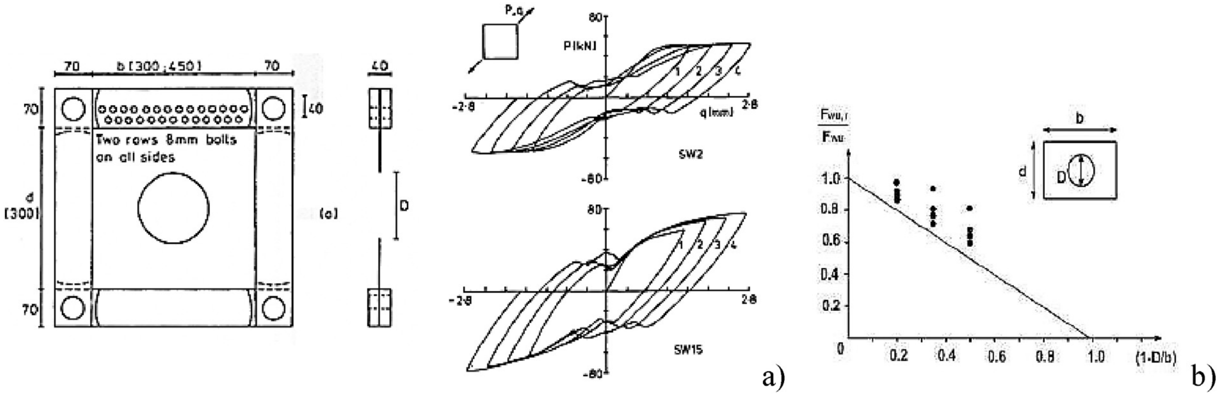

Fig. 2. Specimens tested by Roberts and Sabouri-Ghomi [18] (a) and linear reduction factor (b).

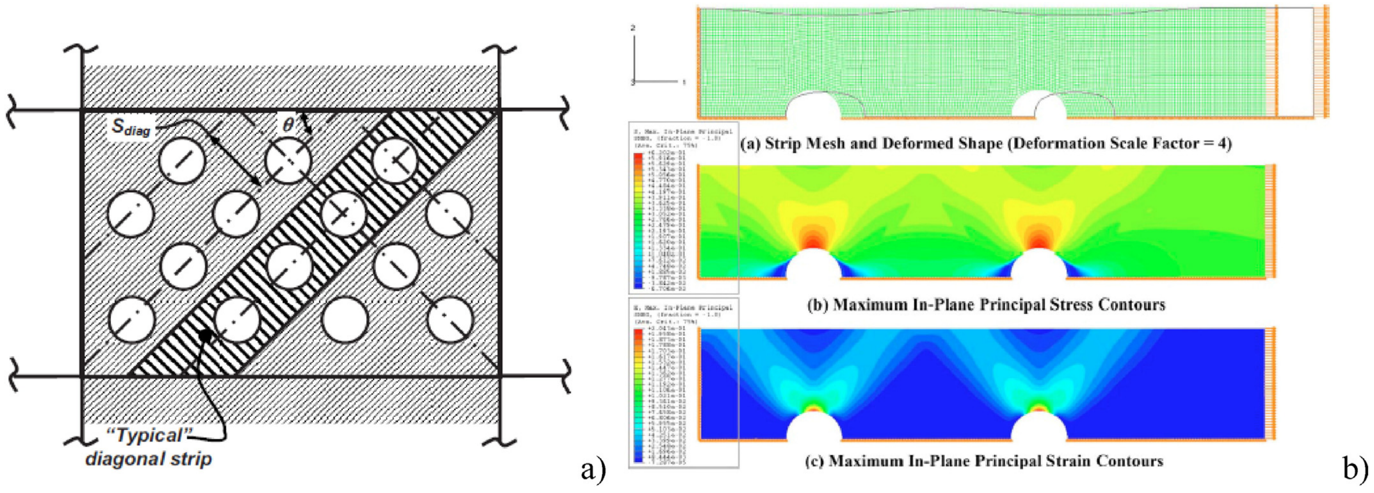

Fig. 3. The perforated SPSW studied by Purba and Bruneau [11] (a) and FEM analysis results on a perforated semi-strip (b).