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Shear response of expanded metal panels

P. Teixeira [a], G. Martínez [a], C. Graciano [b,*]

[a] Universidad Simón Bolívar, Departamento de Mecánica, Apdo. 89000, Caracas 1080-A, Venezuela
[b] Universidad Nacional de Colombia, Facultad de Minas, Departamento de Ingeniería Civil, Medellín, Colombia

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ABSTRACT

This paper aims at investigating the quasi-static shear response of expanded metal panels. A nonlinear finite element analysis of standard and flattened expanded metal panels subjected to shear loads is conducted. For both panel types, the influence of the cell orientation is also analyzed. Numerical models are validated against experimental results available in the literature. Thereafter, the numerical models are used to study the structural behavior of the expanded metal shear panels in depth. Furthermore, a parametric analysis is conducted in order to investigate the influence of cell geometry parameters and panel size on the shear response of the panels. The results show that shear response depends mainly of cell geometry and panel length, whereas the effect of the panel height is almost negligible. Finally, the results are also used to examine the suitability of expanded metal panels for steel plate shear walls.

1. Introduction

Designing passive energy dissipation systems for earthquake resistant structures requires predictable and controlled responses. Passive energy dissipation systems encompass a range of materials and devices for enhancing damping, stiffness and strength, and can be used both for seismic hazard mitigation and for rehabilitation of aging or deficient structures [1]. The principal function of a passive energy dissipation system is to reduce the inelastic energy dissipation demand on the framing system of a structure [2]. In general, these systems might also provide lateral bracing in multistory buildings.

For passive energy dissipation, various mechanisms are used: metal yielding, phase transformation of metals, friction sliding, fluid orificing, and deformation of viscoelastic solids or liquids. Among them, metal yielding is one of the most popular and numerous metallic dampers have been proposed in the literature [3]. Moreover, these mechanisms were incorporated into the design of structural fuses used to concentrate damage on disposable and easy to repair structural elements [4]. Aristizabal-Ochoa [5] proposed the use of a DKB (Disposable Knee Bracing) system that dissipates energy by the formation of plastic flexural hinges at its ends and midspan when the building is subjected to severe lateral loads. Chan et al. [6] investigated experimentally the performance of a yielding shear panel device (YSPD) that utilizes energy dissipation through plastic shear deformation of a thin diaphragm steel plate welded inside a square hollow section. Later on, Chan et al. [7] proposed a renewed version of the YSPD by perforating the diaphragm, and as a result more stable force–displacement hysteresis was obtained.

In current structural engineering practice, steel plate shear walls (SPSW) are also employed to provide lateral load strength to structural frames to withstand wind and earthquake loadings. SPSWs are built-up members composed of a robust frame and infill plates, and their resistance depends on tension field action in the infill. Therefore, it is necessary to address appropriately both the strength of infill plates and that of the framing members, to avoid the introduction of excessive forces that may increase column demand in the surrounding frame members [8]. On the one hand, framing members are usually designed to work within the elastic range. In contrast, infill steel plates are designed to rely on the development of tension field action providing postbuckling strength. In the literature, there are different ways to reduce the transmitted forces, by either weakening the infill plate through perforations [9–12] or slits [13,14], using low-yield carbon steel [15] or using very thin plates [16,17].

Recent investigations conducted by Bhowmick [10] have demonstrated that there is a reduction in shear strength for SPWs with a single perforation as the diameter of the hole increases. Bhowmick et al. [11] conducted a nonlinear analysis on the influence of circular perforations on the shear strength of SPWs. The results showed that both the diameter of the holes and their spacing control the decrease in shear strength of the system.

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[*] Corresponding author. Tel./fax: +57 4 425 51 50.
E-mail address: cagracianog@unal.edu.co (C. Graciano).

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As seen in the review, expanded metal panels exhibit various advantages for shear wall systems. These panels are manufactured in a single process upon in-line expansion of partially slit metal sheets, producing diamond like patterns, leading to a lightweight mesh composed of strands connected in a continuous manner through nodes. In addition, these meshes are usually made from low-yield carbon steel. Expanded metal panels [18] are basically produced in two basic types: standard expanded metal (EMS) and flattened expanded metal (EMF). These two panel types are quite different in geometry and mechanical properties, since the EMF type undergoes additional cold work, in which the EMS sheet is passed through a cold-roll reducing mill then increasing the material yield strength.

Smith et al. [19] conducted a review of international patents regarding possible applications of expanded metal meshes covering several areas within the fields of structural engineering, crashworthiness and biomechanics. In regards to crashworthiness, it has been demonstrated that expanded metal meshes can absorb energy by plastic deformation mechanisms [20–24]. Dung [25,26] conducted an investigation aimed at finding an application for expanded metal meshes for seismically retrofitting of reinforced concrete moment resisting frames. A complete study was conducted on pure shear behavior of expanded metal meshes subjected to monotonic and quasi-static cyclic loading, using experimental, theoretical and numerical approaches. The responses for EMS and EMF panels were also compared.

This paper aims at studying the structural behavior of expanded metal panels subjected to shear loading. Firstly, the study is conducted by means nonlinear finite element analysis of EMS and EMF panels. Once the numerical models are validated with experimental results taken from the literature, a parametric analysis is conducted to investigate the influence on the shear response of: (a) the expanded metal panel type, EMS and EMF; (b) the cell orientation; (c) the size of the expanded metal cell, including the strand cross section; and finally (d) the panel size. The results are examined for the suitability of expanded metal panel for steel plate shear walls.

2. Numerical model

This section presents a numerical study on the nonlinear shear response of EMS and EMF panels. Fig. 1 shows a schematic view of an EMS cell, the geometry of the pattern is mainly characterized by two orthogonal axes, L_1 is the major axis and L_2 the minor, in addition, t is the strand thickness, and w is the strand width. Fig. 2 shows the two cell orientations investigated herein for each panel type, namely $\alpha = 0°$ for cells oriented horizontally, and $\alpha = 90°$ for cells oriented vertically.

A series of finite element models are developed using the implicit static structural solver ANSYS [27]. Large deflections are considered into the model to capture the nonlinear response of the shear panel due to metal plasticity, out-of-plane plate buckling and high strain levels. Fig. 3 shows a schematic view of a shear tests setup, similar to the experimental mounting used by Dung [26]. In order to obtain only the shear response of the infill panel, the expanded metal panels (infill) are attached to a significantly stiffer frame *ijkl*, composed of four infinitely stiff elements. In Fig. 3 the element *kl* is considered as clamped, it means that all degrees of freedom along this are restrained. Additionally, the frame is pin-jointed in every corner (i, j, k and l), and a load P is applied to element *ij* to achieve a desired lateral displacement. Contacts between infill panels and the frame are modeled using multi-point linear bonded constraints to address a bonded condition.

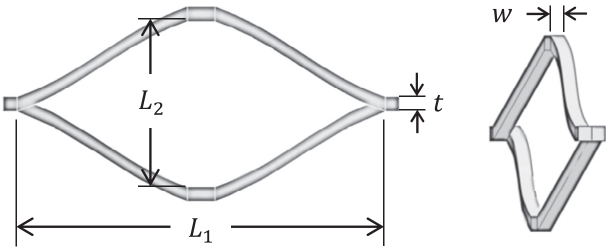

Fig. 1. Nomenclature for an expanded metal cell.

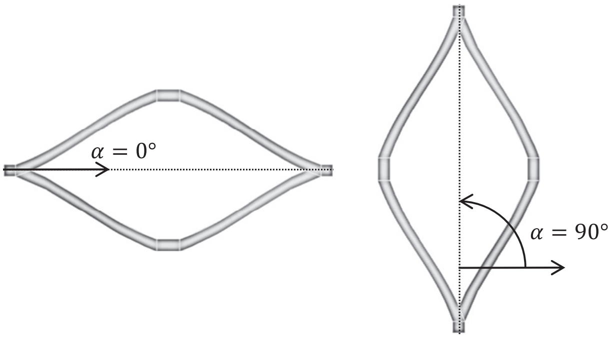

Fig. 2. Cell orientations.

Fig. 4 shows an outline of the mesh configuration for EMS and EMF cells. These cells were modeled with hexahedral high order SOLID 186 elements [27] suitable for large strain analyses. This hexahedral element has a quadratic shape function fitting better both the curvature and the rectangular cross section of the cells. During the flattening process, in order to transform EMS cells (Fig. 4a) into EMF types (Fig. 4b), the strands of the cells are twisted and rolled undergoing additional cold-work that increases the yield strength for EMF meshes [28]. In this regard, Dung [26] reported yield strength values for EMS panels of $S_y = 337$ MPa; and for EMF panels of $S_y = 380$ MPa. Further information regarding material specifications and geometry of the initial shape imperfections were not available. The material was modeled using a classical bilinear isotropic hardening model (strain rate independent) that uses two slopes to represent the stress–strain behavior, in the elastic range a Young's modulus $E = 205$ GPa was considered. In the plastic regime, a tangent modulus $E_t = 2100$ MPa, and a ultimate strain $e_u = 0.029$ were assumed.

As seen in Fig. 4a, EMS cells exhibit a misalignment between two consecutive strands that represents a geometric imperfection for the numerical analysis. In contrast, the imperfection is eliminated for EMF panels (Fig. 4b), therefore for these panels the initial shape imperfections were modeled using the first buckling mode with a maximum amplitude δ.

The load–displacement responses of the panels under pure shear are obtained through a controlled displacement approach, a load-step control strategy is adopted to solve the nonlinear problem. Initially, the load is divided into 50 steps, and the convergence rate of the Newton–Raphson scheme adjusts the load increment step to optimize time solution in order to achieve convergence and final solution.

Table 1 shows the three cell geometries used in the numerical analysis. For validation purposes, the numerical models were elaborated with Type A meshes with $\alpha = 0°$ and $\alpha = 90°$. Hence, four models, namely EMS A0, EMS A90, EMF A0 and EMF A90, were validated using the experimental measurements obtained by Dung [26]. In this nomenclature, the first three characters correspond to the panel type (EMS–EMF); the fourth character is the mesh size (A–B–C) from Table 1, and the ending number refers to the cell orientation (0°–90°). Fig. 5 shows the panel dimensions where