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Experimental and numerical analysis of a multi-stiffened pure aluminium shear panel

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ABSTRACT

The current paper deals with a detailed numerical study carried out on a pure aluminium shear panel and implemented through a FEM numerical model calibrated on the results obtained by an experimental test. The comparison between experimental and numerical data, in terms of dissipative capacity, maximum hardening ratio, secant shear stiffness and equivalent viscous damping factor, is carried out in order to show that the proposed model is reliable enough to well interpret the actual behaviour of the specimen, which exhibits many buckling phenomena and large plastic deformations. The proposed model is therefore profitably used to detect the exact displacement levels corresponding to the activation of the main buckling phenomena, as well as the stresses acting on the boundary bolted connections, which may result the weak point of the system. Moreover, the main outcomes of a parametrical study, which are implemented on the basis of the calibrated numerical model, are critically discussed and properly analysed, in order to define the erosion factor of the shear strength due to buckling.

1. Introduction

It has been proved that shear panels may represent an effective system for passive seismic protection of new and existing steel framed structures for both low and high intensity earthquakes, due to the remarkable lateral stiffness, high strength and large ductility they are able to provide [1–3]. As a base material, to produce new devices for passive seismic protection of structures, also the use of common aluminium alloys has been proposed [4]. In particular, very recently, pure aluminium shear panels have been launched as an alternative solution to the conventional panels made of both mild steel and low yield steel [5].

In order to investigate the seismic performance of different types of pure aluminium shear panels, a wide experimental campaign has been undertaken in recent years by authors.

In detail, the adopted material used for shear panels is the AW1050A alloy, an almost pure aluminium, which, after a proper heat treatment, offers a very low conventional yielding strength ($f_{0.2}$ equal to about 20 MPa), with a conspicuous strain hardening ($f_u/f_{0.2}$ equal to about 4) and a very large ultimate strain (e_u larger than 40%).

Tested panel specimens have been stiffened according to several rib configurations, in order to investigate different local slenderness ratios. In addition, two different stiffening techniques, namely based on welded and bolted ribs, have been analysed.

Two basic types of shear panels have been considered, namely large size aluminium shear panels to be employed as a full-bay type (therefore loaded by a direct shear force) and small size aluminium shear panels to be employed as a bracing type (therefore loaded by a diagonal tensile-compression force).

Generally speaking, all the tested specimens highlighted a good cyclic behaviour with a large ductility before collapse, even though their performance has been influenced by the applied welds and was limited by the premature failure of the surrounding bolted connection, which represented the main weak point of the system.

In the current paper, a global overview on the whole ongoing research activity is presented, summarizing the main results of the experimental campaign. Then, the interest will be focused on the numerical modelling of one bracing-type pure aluminium shear panel (BTPASP), in order to set up a reliable numerical model, which could be used to perform detailed parametrical studies. Finally, a parametrical study, implemented on the basis of the calibrated numerical model, is described, in order to set up a curve able to describe the erosion factor of the shear strength due to buckling. This issue is correctly faced by Eurocode 9, but the provided formulation refers to current aluminium alloys, which are very different by the base material used for the proposed system. Therefore an extension of results is necessary, as it is one of the main purposes of the present study.

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2. Framing of the study

2.1. General

The research activity carried out on pure aluminium shear panels started by planning an experimental campaign related to six prototypes of full-bay type shear panels, characterised by an in-plane dimension 1500×1000 mm^2 with a thickness t of 5 mm, which were tested under cyclic shear loading; two specimens were made of aluminium alloy AW5154A, which is a material commonly used for many structural applications, and four specimens were made of the aluminium alloy AW1050A H24, which was selected as a surrogate of pure aluminium, at that time it representing a very innovative material never employed for structural purposes [6–9]. In a succeeding phase, four tests under cyclic diagonal loading on square bracing-type pure aluminium shear panels with side length 500 mm and thickness 5 mm have been carried out [10,11].

In both cases the aluminium panels have been inserted into a rigid articulated steel frame, by using high-strength bolted connections.

In order to limit the buckling phenomena, the shear panel specimens were stiffened, mainly by means of welded ribs, which have been arranged according to square grids with side length b varying from 500 to 125 mm, consequently obtaining a local slenderness ratio b/t ranging from 100 to 25 as it is possible to observe in Fig. 1 for panels having a bracing type configuration.

It is worth noting that the full-bay type scheme allowed the effects of the overturning moment of the shear load on the cyclic performance to be considered. Moreover, the diagonal loading tests performed on bracing-type specimens allowed to detect a lower limit value of the local slenderness below which further improvements of the cyclic performance cannot be achieved.

Based on the results of the experimental tests, numerical studies have been implemented [12], in order to set up specific numerical models to be used as a sort of virtual laboratory to develop parametrical analyses [13]. In the past, three numerical models related to three full bay panel typologies were developed, while in the present paper the numerical model of a bracing type pure aluminium shear panel is introduced for the first time.

In the following Section, an overview on the principal results obtained by both the above experimental and numerical studies is provided. In addition, particular attention is devoted in defining the mechanical behaviour of the base material.

2.2. The adopted material

The aluminium alloy AW1050 A H24, with thickness $t=5$ mm, has been selected as base material for the ongoing study. Preliminary uniaxial tensile tests, performed according to the specifications provided by RILEM [14], have been carried out. The results of such tests highlighted that the commercial selected alloy actually provided a significantly higher conventional yielding strength ($f_{0.2}$) and a lower ultimate deformation (ε_u) with respect to the suggested nominal values. In order to enhance the ductile features of the material, also reducing the conventional yielding strength, a heat treatment process has been therefore planned and applied. The specimens have been submitted to a cycle of heat treatment characterised by different phases with constant temperature, each one having duration of four hours. The successive tensile tests have shown a considerable improvement of ductile properties with a significant reduction of yielding strength and an increase of the elongation at rupture. In particular, a conventional yield strength $f_{0.2}=18$ MPa and an ultimate elongation ductility ε_u of about 50% have been registered, as it is possible to observe in Fig. 2a, where the curves obtained from eight tests on the used material are depicted, and, more clearly, in Fig. 2b, where the mean curve obtained by tests is compared to the true stress–true strain curve used for the numerical model presented in the current paper.

In addition, since the characterisation of the cyclic behaviour of a low yield strength material is very important, as the isotropic hardening component could influence favourably the dissipative effect of the devices made of this type of material with a reinflating of the hysteretic cycles, specific tensile-compression cyclic tests on pure aluminium specimens have been carried out. The specimens were equipped with a steel "jacket" able to inhibit out-of-plane deformations due to buckling phenomena in compression (see Fig. 3a). The obtained results showed an important dissipative behaviour (see Fig. 3d) characterised by full hysteretic cycles, a substantial iso-resistance for each displacement level and the existence of an isotropic hardening component. A proper numerical model of the above specimens has been also implemented (see Fig. 3b and c). This will be described in Section 3.3.

2.3. Testing of pure aluminium shear panels

In the following, a brief overview on the performed cyclic tests on pure aluminium shear panels is provided highlighting the main results obtained. As far as full-bay type shear panels are concerned, three base configurations have been initially tested. They were equipped with welded longitudinal and transversal ribs having a simple rectangular cross section (depth of 60 mm and thickness of 5 mm). The cyclic behaviour of such specimens was significantly influenced by both the sheeting shape distortion produced by weld shrinkage and the heat effects due to the welding process, which produced premature buckling phenomena. However, the experimental buckling phenomena did not hinder to the development of maximum shear strength of the system. On the other hand, it is useful to remark that, due to both the low strength of the adopted aluminium and weakening due to bolt holes, the failure of perimeter bolted connections actually limited the ultimate deformation of the specimens [7]. Subsequently, in order to improve the cyclic performance of the system, fully exploiting the plastic resources of the base material, an additional experimental test has been carried out. In particular, in order to avoid the aforementioned drawbacks, an aluminium shear panel stiffened by steel channel ribs bolted to the basic sheeting by using friction high-strength grade 8.8 steel bolts has been also tested, providing a significant improvement in the response of the system [8].

In the whole, the obtained results for the aforementioned full-bay type shear panels showed that their structural response, in terms of both energy dissipation and damping capability, is significantly favourable for medium-large lateral displacements, while some slipping phenomena were observed for small deformation levels.

In order to improve the dissipative behaviour of the tested pure aluminium shear panels for limited inter-storey drift values, a different prototype, with reduced side length, has been proposed, so to establish a favourable ratio between the inter-storey drift displacement of the relevant primary structure and the shear deformations of the applied panels. Therefore, bracing type pure aluminium shear panels (BTPASPs) have been proposed as an effective passive control device to be applied to both steel and RC moment resisting frames. An experimental campaign has been set up in order to characterise the main behavioural parameters of specimens having different aspect ratio values. The aluminium panels, which were characterised by a side length of 500 mm and a thickness of 5 mm, were equipped with welded rectangular-shaped ribs, equally placed on the two faces of the panels, characterised by a depth of 60 mm and made of the same material