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Technical Note

Optimal design of a new seismic passive protection device made in aluminium and steel

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1. Introduction

In recent years many techniques for the seismic control of structures have been developed. Among these, the metallic hysteretic devices are able to dissipate a great amount of the energy entering the building during a seismic event, thanks to a stable behavior under cyclic loads that produces a wide hysteresis loop. Steel shear panels are examples of elasto-plastic elements, which dissipate energy under a shear behavior. Generally such dampers are known to possess large energy-dissipation capacity relative to their size; they are cost-effective and are able to protect non-structural elements too. Moreover, the shear panels may be easily installed and substituted in the structure. As disadvantage, this kind of energy dissipating devices can dissipate energy only after they sustain inelastic excursions. As a consequence they are ineffective for vibrations that produce interstory drifts smaller than the yielding drift of the device. To overcome this constraint, Rai and Wallace and Foti and Diaferio proposed shear panels made in aluminium alloys. In fact, these alloys are very ductile with a yielding limit lower than ordinary steel. Numerical and experimental researches have been developed on aluminium shear links. Foti and Nobile performed characterization and shaking-table tests on some aluminium shear panels showing instability phenomena and problems of the connections of the devices to the structure.

The aim of the present note is to find out the optimum geometrical configuration of an aluminium-steel shear panel in order to dissipate a large amount of the seismic energy.

2. Design of the aluminium-steel shear panel

The effectiveness of metallic dissipative devices depends on two main characteristics: a low yielding interstory drift, which could guarantee the protection of the structure even in the range of small vibrations, and a wide plastic behavior, which could maximize the energy dissipation. Moreover, a high stiffness of the device in the out-of-plane direction should be guaranteed in order to prevent instability of the device in that direction. On the basis of these considerations, a shear panel composed by a central aluminium plate and two lateral open-squared steel plates has been

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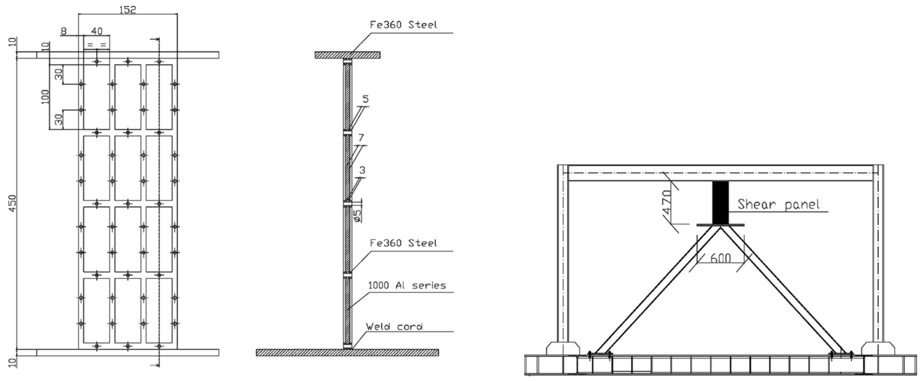
Table 1 Material properties

	Material properties	Fe360	1000 Al series
σ_y	Yielding stress [N/mm^2]	235	30
σ_R	Ultimate tensile strength [N/mm^2]	360	90
A	Elongation to failure [%]	26	40
E	Young modulus [N/mm^2]	206000	70000
H	Plastic modulus [N/mm^2]	20000	5000



(a) (b)

Fig. 1 (a) Geometrical configuration of the dissipating shear panel, (b) Localization of the aluminium-steel device in the structure

proposed. In particular, Fe360 steel and 1000 aluminium alloy series have been chosen, respectively, for the external plates and for the web of the specimen. The choice of the aluminium alloy is due to its low yielding stress and its wide plastic range (see Table 1).

Steel plates provide the necessary stiffness to the panel, while aluminium is the preferential energy dissipating area. In order to assure load transmission between the different panels, slip phenomena between steel and aluminium plates must be avoided; therefore, it has been decided to realize some openings in the steel plates, where the central aluminium plate emerges for a few millimeters (Fig. 1(a)) and a certain number of bolts have been inserted in correspondence of the steel stiffeners to improve the connection between the three plates. In Fig. 1(b) the standard solution for the insertion of the panel in structures is schematically represented. The bulk zone has been assumed equal to 470×600 mm.

In order to define the geometrical configuration of the device an analysis of optimization with the aid of the Ansys program has been carried out. Assigned a possible initial shape and configuration of the panel, where some dimensions and characteristics have been maintained in a parametric form, the modelization has been performed using 20 nodes SOLID90 elements (with a parabolic form function). The mechanical behaviors of steel and aluminum have been described by means of bilinear curves, whose parameters have been defined in agreement to the properties shown in Table 1. In such analysis the panel has been embedded to the low end and bound with a double pendulum to the top end, in order to take into account the modality of assembly of the device (Fig. 1(b)).

The geometrical parameters of the panel have been chosen executing an optimization ruotine that maximized the energy dissipated in the aluminum slab, assuming a maximum displacement of the top of the panel of 4 mm, equal to the 0, 2% of the interstory height of a frame, that is in the range 2, 5-3, 0 m.

In the optimization analysis, four different conditions have been considered as restraints:
- the maximum aluminium stress, set equal to the ultimate tension stress of the aluminum (c.f., Table 1);
- the total height of the panel, varying in the range 420-470 mm;
- the width of the panel, varying in the range 100-250 mm;
- the maximum shear force, which is chosen in order to adapt the device to the dynamical behavior of the examined frames. The variation range of the geometrical parameters that describe the configuration of the panel and the optimum set obtained for different values of the operational range of the shear forces, [10-20]kN, [20-40]kN, [40-80]kN, [80-150]kN, have been collected in Table 2, so that the optimization procedure automatically selects the best solution for each class of the shear load.

It is possible to notice that for a relatively low increment of shear, the better solution is obtained essentially modifying the thickness and the amplitude of the openings of the aluminum panel. On the contrary, the solution obtained for a shear load of 150 kN significantly differs, since the aluminum window is practically doubled in width. In other words, an increase of the cross-sectional shear load initially produces a moderate and then an elevate increase of the total width of the panel. In Fig. 2 the characteristic curves of the four proposed panels are shown and compared. Successively, a buckling analysis has been performed for each panel, so as to determine the

Table 2 Optimum and final set of the geometrical parameters for the aluminium-steel device with different shear working loads

	Geometrical Parameters	Variability range	20 kN [10-20 kN]	40 kN [20-40 kN]	80 kN [40-80 kN]	150 kN [80-150 kN]
n_x	Horizontal windows	2-6	3	3	3	3
n_y	Vertical windows	1-4	4	4	4	4
b_1	Lateral steel stiffener width [mm]	5-10	8	8	12	15
b_2	Aluminium window width [mm]	30-200	40	60	70	180
b_3	Internal steel stiffener width [mm]	5-10	8	8	12	15
h_1	External steel stiffener height [mm]	5-12	10	10	15	10
h_2	Aluminium window height [mm]	30-200	100	100	95	100
h_3	Internal steel stiffener height [mm]	5-12	10	10	15	10
t_1	Steel plate thickness [mm]	1-4	1	4	3	4
t_2	Aluminium plate thickness [mm]	1-4	3	1	3	2
t_a	Aluminium window projection [mm]	1-4	3	3	3	2

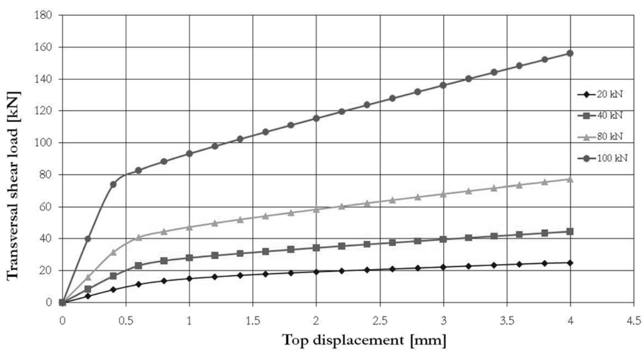
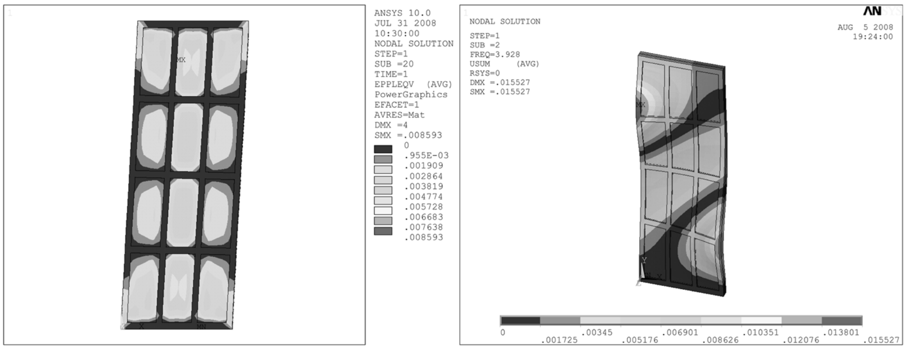


Fig. 2 Comparison of the global behavior of different shear panels



(a) (b)

Fig. 3 (a) Plastic deformation and (b) instability modes of the aluminium device of 20 kN with 12 openings (n_x = 3 horizontal and n_y = 4 vertical)

correspondent conditions for stability problems.

In Fig. 3 the map of the plastic deformation and the first instability mode for the panel proposed for the operational range [10-20]kN of the shear force is shown. The first instability mode happens at 3,928 mm.

3. Choice of the panel

The four designed panels have been optimized and verified in order to cover the values of the shear forces falling back in the range [l0-150]kN. In the design of the protection system of the structure, the engineer can choose the most suitable panel to insert in the structure. Such choice should be made on the basis of the expected shear force for the panel, once that it will be inserted in the structure.

The methodology that is proposed in order to execute a correct evaluation of such force and, consequently, a correct choice of the panel to install, is the following:

1. Definition of a simplified model of the structure where the diagonals will be modified in order to directly connect their end to the structure, that is without the shear panel;
2. Perform a seismic analysis of the simplified model in order to evaluate the maximum shear force at the node where the panel will be inserted;
3. Choice of the device for which the shear force before determined falls back in the operational range of the panel.

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