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Experimental tests on multiple-slit devices for precast concrete panels

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ABSTRACT

Multiple Slit Devices (MSDs) are plasticity-based dissipative connectors consisting of steel plates provided with slits which lead to a set of elementary beams. In this way, the shear-type behavior of the plate is turned into the flexural-type behavior of the elementary beams, which ensures better energy dissipation. The proposed MSDs are bolted to support steel profiles inserted into appropriate recesses in between precast concrete panels to improve the seismic performance of the earthquake-resisting system. The paper presents the results of monotonic and cyclic experimental tests performed on both connectors and structural sub-assemblies consisting of two full-scale precast concrete panels connected by a MSD. Steel plates with slits of various shape and size are considered. An improved version of the connector capable to dissipate energy through both plasticity and friction and to provide enhanced displacement capacity is also proposed and tested.

1. Introduction

The seismic performance of structural systems can be significantly improved by means of dissipative systems of connections. Multiple Slit Devices (MSDs) are connectors made of steel plates provided with slits which lead to a set of elementary beams dissipating energy based on steel plasticity. The slits can be achieved using different technologies, including laser cutting. When subjected to lateral load, the shear-type behavior of the plate is turned into the flexural-type behavior of the elementary beams, which ensures better energy dissipation based on steel plasticity and higher displacement capacity. The yielding and ultimate strengths of the device depend on both the shape and size of the elementary beams.

This type of device has been developed mainly for use in steel structures and can be considered as an evolution of the Added Damping And Stiffness (ADAS) devices [1–6], where slender butterfly-shaped steel beams are linked together and dissipate energy through plasticity. Several types of plate dissipative devices have been tested by Chan et al., including buckling restrained plates [7], multiple slits with constant depth elementary beams [8], and perforated plates [9]. Oh et al. carried out experimental testing on full scale beam-to-column steel joints enhanced with MSDs [10]. Structural optimization procedures have been applied by Ghabraie et al. to achieve an optimized MSD with hourglass-shaped elementary beams that was also experimentally tested [11]. Recently, Briones and de la Llera developed a metallic dissipative connector based on hourglass-shaped copper elements [12]. Ma et al. developed design procedures and experimental tests on MSDs with different beam depth profiles, including constant and butterfly-shaped profiles [13]. Analytical design tools have been proposed also by Karavasilis et al. [14]. Lee et al. performed experimental and numerical investigations on MSDs where plasticity and friction are exploited for energy dissipation [15].

Several types of dissipative devices can be used for precast structures [16–22]. It has been shown that different types of dissipative systems of connections applied to the cladding wall panels allow to limit the base shear and significantly reduce the drift and consequent damage of precast structures under seismic actions [23–26]. The MSDs investigated in this paper have been specifically designed for use in precast concrete structures as panel-to-panel dissipative connections [27,28].

In the proposed MSDs, the steel plates are bolted to support steel profiles that are inserted into recesses at the interface between adjacent panels, as shown in Fig. 1a. The functioning scheme of the MSD under imposed relative panel-to-panel displacement is shown in Fig. 1b. The MSD is made by mounting two steel plates on support profiles of various shapes. Fig. 2 shows the assembled MSD supported by T-shaped (Fig. 2a), UPN (Fig. 2b), and angle steel profiles (Fig. 2c). For installation, T-shaped and UPN profiles need access from both sides. In addition, UPN profiles need at top and bottom sides larger free room for tightening the internal bolts that connect the profiles to the sockets embedded in the concrete panel. Asymmetric angle profiles involve eccentric forces and torsional actions but need small recesses and allows for installation from one side only, which might be mandatory for application to sandwich concrete panels.

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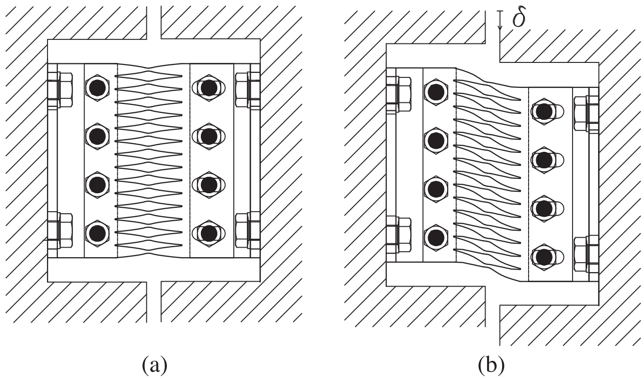

Fig. 1. MSD for precast panels: (a) assembled connection; (b) deformed configuration.

An experimental campaign has been performed at Politecnico di Milano within the framework of the SAFECLADDING research project funded by the European Commission to provide guidelines for a proper seismic design of precast structures with cladding panels and to propose innovative systems of connections [29]. The mechanical characterization of MSDs provided with steel plates with slits of various shapes and sizes have been performed as part of this research project based on monotonic and cyclic experimental tests carried out on both single connectors and structural sub-assemblies consisting of two full-scale concrete panels. An improved version of the connector capable to dissipate energy through both plasticity and friction and to provide a larger displacement capacity has been also developed and tested. The results of the experimental tests are presented and discussed, and design criteria for the MSD device are finally proposed.

2. Experimental tests on connectors

Local tests have been carried out on MSDs under imposed lateral displacements to characterize their mechanical behavior and their stability under cyclic loading at both small and large amplitude displacements.

2.1. Test specimens

The MSDs conceived and tested are shown in Fig. 3. The specimens have been designed with a span to depth ratio of the single elementary beam not larger than four, in order to avoid lateral (flexural-torsional) buckling. The thickness of the plates has been considered not larger than 5 mm, in order to be easily wrought by standard laser cutters. The need of maximizing the area of steel that had to yield led to devices with no more than two lines of slender beams with constant depth profile (specimens type I and type II). Devices with elementary beams having hourglass profile with uniform yielding have been also considered (specimen type III). For this type of device, the varying depth $h = h(x)$ of the elementary beams is obtained as a function of the abscissa x with origin at the beam midspan based on a linear variation of the yielding moment $M_y(x)$ as follows:

$$M_y(x) = f_y t \frac{h(x)^2}{6} = Vx = 2\overline{M_y}\frac{x}{L} \quad (1)$$

where f_y is the yield strength of steel, t is the thickness of the elementary beam, V is the shear force, $\overline{M_y} = M_y\left(\frac{L}{2}\right)$ is the yield moment of the end sections, and L is the length of the elementary beam. This leads to:

$$h(x) = \sqrt{12\frac{\overline{M_y}x}{f_y tL}} \quad (2)$$

The cusp at the theoretical zero-depth at midspan is smoothed to a

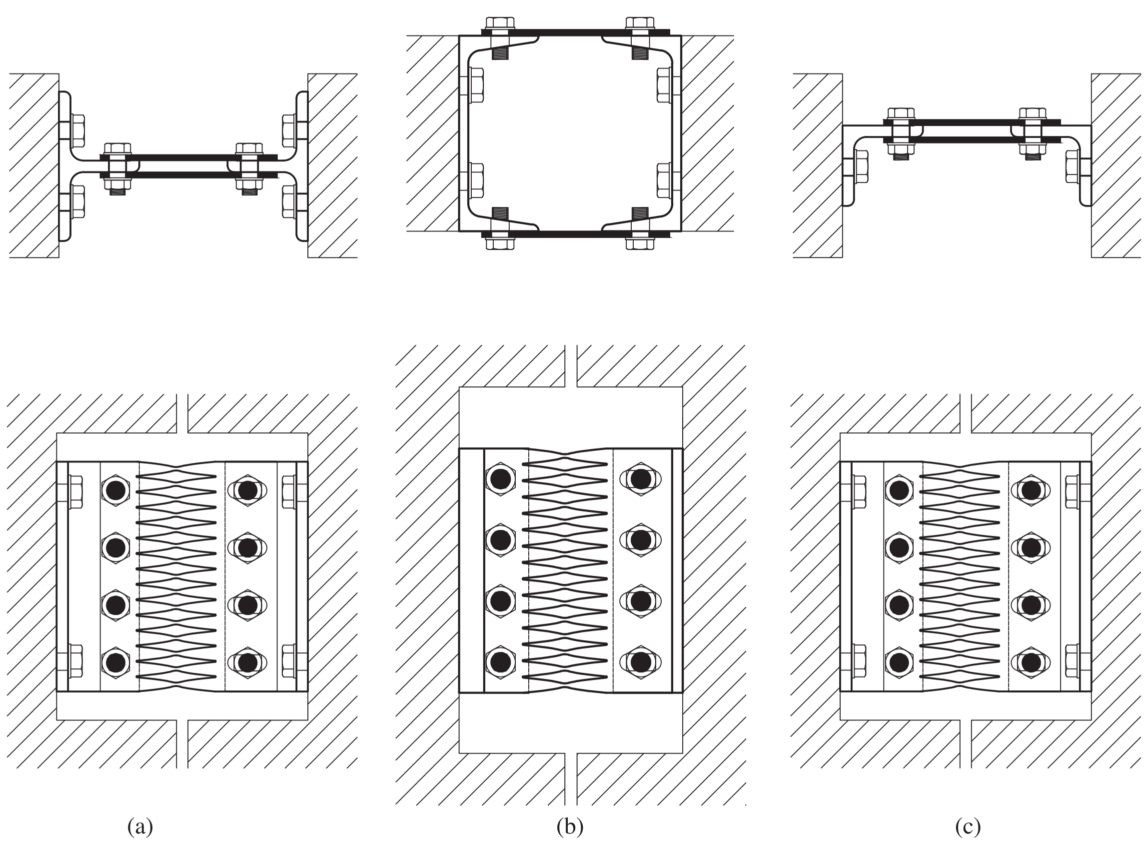

Fig. 2. Assemblage of the MSD with (a) T-shaped, (b) UPN, and (c) angle support steel profiles.

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