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# Friction-based dissipative devices for precast concrete panels

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ABSTRACT

The stability of precast concrete wall panels under seismic action can be ensured by means of dissipative systems of panel-to-panel connections that allow to control the level of forces and limit the displacements. This paper deals with a connection system consisting of friction-based devices inserted into appropriate recesses within the joints between vertical or horizontal panels. The results of experimental tests carried out on single connectors, as well as on structural sub-assemblies consisting of two full scale panels, are presented. The technological choices of materials and components that ensure a stable hysteretic behaviour of the devices are discussed. The effectiveness of the devices in improving the seismic performance of precast buildings under seismic action is also shown based on the results of cyclic and pseudo-dynamic tests on full-scale structural prototypes.



## 1. Introduction

In the last two decades, relevant research advances supported by extensive experimental activities and theoretical studies have been accomplished in the field of seismic design of precast structures [1–7]. Moreover, a well-established framework of design rules for precast concrete systems is incorporated in seismic design codes [8]. However, some issues concerning the seismic behaviour of precast buildings with cladding wall panels are still open, and adequate technological solutions and effective design rules for this type of structures are not yet implemented in current design practice. The limitations of the current design approach have been shown during recent earthquakes in Southern Europe by several structural failures of cladding precast panels due to the inadequate behaviour of the fastening connection systems [9–13].

A research activity has been carried out at European level within the SAFECLADDING project [14] to provide guidelines for a proper seismic design of precast structures with cladding panels and to propose innovative systems of connections. In particular, the use of dissipative connection devices can ensure the stability of the cladding panels under seismic action and improve the seismic performance of the earthquake resisting system by providing energy dissipation capacity under controlled forces and limited displacements [15,16].

Friction Based Devices (FBDs) are mechanical connections inserted into appropriate recesses within the joints between vertical or horizontal concrete panels. They provide dissipation of energy when subject to imposed displacement. An interesting application of this type of device refers to precast structures. Typical precast frame systems are very flexible and provided with stiff concrete cladding wall panels that in current design practice are supposed not to interact with the structure. If the panels are connected to the frame structure by means of statically determined schemes, the use of FBD panel-to-panel dissipative connections make the whole façade much stiffer and integral part of the earthquake resisting system up to the force associated with the friction threshold of the devices.

This type of connection, which usually includes brass sheets to stabilise the hysteretic cycles, can be also considered as a Brass Friction Device accordance to the classification proposed by Schultz et al. [17]. Several other examples of friction-based connectors can be also found in literature [18–23], including for use in precast structures [24,25].

The basic configuration of the FBD has been investigated in [15,26] and further developed in [27–28]. This paper presents the results of experimental tests carried out on single FBD connectors, as well as on structural sub-assemblies consisting of two full scale panels with multiple connectors. Emphasis is given to the technological choices of materials and components that ensure a stable hysteretic behaviour of the FBD devices. The results of cyclic and pseudo-dynamic tests on full-scale structural prototypes are also presented to show the effectiveness of the devices in improving the seismic performance of precast buildings under seismic action.

## 2. Friction-based device

The FBD is made by three elements assembled through bolts, as shown in Fig. 1:

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- *Support profile*, made of mild steel, which connects the device to the concrete panel. The support profile can be T-shaped (Fig. 1a), to obtain a symmetric device-to-panel connection, or L-shaped, for an asymmetric connection. The component is provided with vertical slots, that allow for the relative displacement between the two adjacent support profiles, and with holes or short horizontal slots on the panel side for a bolted device-to-panel connection, or for temporary support of a welded device-to-panel connection. A symmetric profile, e.g. T-shaped, can be symmetrically connected with the panel side, leading to a distribution of forces that avoids any torsion. It requires the assemblage to be made from two sides, in order to tighten all the bolts. An asymmetric profile, e.g. L-shaped, allows the assemblage to be performed from one side only (for cladding panels, generally the inner side of the building). It leads to additional torsional force components in the panel connection.
- *Brass sheet*, provided with two vertically aligned round holes in one side and with two vertically aligned horizontal slots in the other side (Fig. 1a). Two brass sheets connect the support profiles through bolts, providing also a horizontal mounting tolerance which is related to the length of the slots. If the support profiles are forced to mutually slide, friction occurs between the brass sheets and the support profiles.
- *Cover plate*, made of mild steel, having the same geometry of the brass sheet (Fig. 1a). A steel plate covers each brass sheet to avoid its out-of-plane deformation and ensure the correct kinematic of the connection.

Fig. 1b shows an assembled connection with symmetric T-shaped support profiles. Brass sheets and cover plates can be mounted in mirrored or inverted configuration. Fig. 1c shows the axonometric view of the connection with inverted plates. The mirrored configuration yields to a symmetric distribution of forces up to the sliding shear threshold, after which all horizontal reactions due to shear increments coming from the rotational equilibrium of the plates are taken by the support profile adjacent to the round holes of the plates. The inverted configuration always provides a symmetric distribution of forces and is suggested to be adopted.

The connection can be pre-assembled by mounting two support profiles, two brass sheets and two cover plates with bolts, nuts and washers without tightening: it is placed in position between the panels, adjusted and then tightened. Alternatively, the connection can be assembled in site with each component at a time.

Fig. 2 shows the assembled device in the undeformed configuration (Fig. 2a) and under imposed relative displacement (Fig. 2b). Fig. 3 provides a technical drawing of the components of the connection. The maximum displacement allowed by the connection is equal to the length $L_v$ of the vertical slots of the support profile, regardless of the position of installation of the bolts. The installation tolerance in the vertical direction is hence provided by these slots. Horizontal in-plane tolerance is provided by the horizontal slots on brass and steel plates with length $L_h$. The horizontal out-of-plane tolerance is provided by holes or slots on the support profile.

## 3. Tests on single devices

The tests on single devices have been carried out on a uniaxial ± 1000 kN Schenck machine at the Laboratorio Prove e Materiali of Politecnico di Milano through the application of vertical displacement histories (Fig. 2).

### 3.1. Test setup and experimental program

The connection is attached through bolts to two opposite strong L-shaped support elements made of two HEA steel profiles welded together and fixed to the machine through thick steel plates provided with large diameter bolts. In addition to the standard machine instrumentation, two ±150 mm displacement transducers have been installed with magnetic bases in order to measure the exact drift between the L-shaped profiles. Two ±5 mm Gefran displacement transducers have also been placed vertically attached to the support elements. The results presented in the following are cleared from the millimetric movements of the support profiles recorded by those transducers.

Monotonic tests are performed with a constant speed of 0,25 mm/s. Three different cyclic protocols have been applied with a constant speed of 2 mm/s:

- Protocol I consists of constant displacement amplitudes of ±20 mm repeated ten times.
- Protocol II consists of constant displacement amplitudes of ±40 mm repeated ten times.
- Protocol III consists of increasing displacements with amplitudes: 2,5–5–10–20–40 mm. Each amplitude is cycled three times.

The cyclic tests carried out on single connections are listed in Table 1. The tests have been performed with the aim to set up the best configuration of the device and to investigate several technological issues, both regarding the performance of the connection and its operability. These issues include:

- The necessity of using the brass plates;
- The efficiency of sandblasting surface treatment, aimed at increasing the steel-brass friction coefficient;
- The possibility of re-use of the same components after several cycles;
- The behaviour using different types of washers;
- The behaviour using symmetric or asymmetric support profiles.

Additional issues have been explored, including the influence of the speed of the test and the need to control the torque. Cyclic tests performed with a reduced speed of 0,1 mm/s yielded very similar results with respect to those performed at full speed. The use of a dynamometric wrench could increase the installation cost of the connection. However, as clearly shown by the test results with different applied torque, the axial force given to the bolts through tightening is directly related to the slip load threshold.

### 3.2. Use of brass sheets

The use of brass sheets is of economical concern for the device, since these components represent a relevant portion of the total cost of the device. In the device without brass sheets sliding occurs between the steel surfaces of the support profile and the cover plate with a steel-steel friction. Figs. 4a and b show the load vs displacement diagrams of specimens provided with and without brass sheets, respectively. By comparison, it can be noted that a cyclic instability occurred in the case without brass sheets, since the slip load significantly increases with large drifts causing plastic deformation of the support profile, as shown in Fig. 4c. This happened because of the blocking of the steel surfaces, due to a "mechanical welding" effect. None of the performed tests with the traditional configuration of a brass friction device showed this cyclic instability, suggesting that brass sheets are necessary to stabilise the hysteretic behaviour of the device.