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Seismic response of precast structures with vertical cladding panels: The SAFECLADDING experimental campaign

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ABSTRACT

The *SAFECLADDING Project* was aimed at improving the connection systems between cladding panels and precast RC buildings in seismic-prone areas. Three design criteria have been assessed: *isostatic*, *dissipative* and *integrated*. They can be realised using different strategies, which are represented by several test set-ups within the experimental campaign.

The paper describes the results obtained with vertical panels arrangement and the comparison with the bare frame, which is the reference for the current design practice that considers panels like non-structural elements. The mock-up and the test sequence were designed to assess all setups with a single frame structure. The mock-up was a one-storey building, made by two parallel frames with two bays and square columns, inserted into pocket plinths. The building was designed for earthquake actions according to the Eurocode 8. Each setup was assessed using increasing levels of action, either with cyclic or pseudo-dynamic tests. The latter were performed both for serviceability and ultimate limit states. The experimental programme for vertical-panels and the bare-frame arrangement involved ten different setups, resulting in a total of twenty-eight tests.

As for the *isostatic* criterion, the results confirm that considering panels as simple masses without stiffness is far from the real system behaviour, even using apposite devices to uncouple panels and frame displacements. In fact, despite a previous and positive experimental qualification, several devices failed in operative conditions tests.

Conversely, the *integrated* criterion requires to bear high loads, transferred by the frame through connections, which becomes the weak point for this configuration, as demonstrated by different failures of bolts and connections.

The reliability of the *dissipative* criterion has been confirmed by twelve tests completed without any damage. This solution in fact combines lower relative displacements with limited loads within connections, avoiding both the compatibility problems and excessive forces.

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1. Introduction and background

Precast Reinforced-Concrete (PRC) buildings, assuming that their connections are properly designed, have seismic performance comparable to cast-in-situ RC structures, as it has been demonstrated by several research projects in recent years [1]. When adequately designed for earthquake actions, the frame –made up by PRC elements and joints– maintains its efficiency. On the contrary, the façade cladding and mostly the connections with the frame, might meet with failure in the same conditions [2,3].

The design hypothesis that considers panels as simple masses –without stiffness– is far from the real behaviour of the frame-cladding system [4]. That hypothesis can be admissible only with a small inter-storey drift, where panels and frame coexist without significant interactions. Otherwise, when greater drifts exceed the relative displacement allowed by the clearance, panels act as a part of the seismic resisting system [5]. In this manner, the load within the joints becomes proportional to the storeys mass, and no more to the mass of claddings. Connections cannot carry those actions in-plane, thus the fastenings break. The issue would not be solved even assuming that joints are able to sustain so high loads. In fact, for PRC one-storey buildings a reduction of seismic actions is assumed, due to the energy dissipation developed by plastic hinges at the columns base. Unfortunately, to activate that mechanism a large deformation would be needed, but the stiffening effect –caused by panels– limits the drift running out the fastening capacity before the development of a large displacement. Therefore, panel joints

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Nomenclature

d_{max}	maximum displacement [mm]	Ptb	Panel-to-beam [connection]
R_{max}	maximum restoring force [kN]	Ptc	Panel-to-column [connection]
E_d	total dissipated energy [kJ]	Ptf	Panel-to-foundation [connection]
BF	Bare-Frame	PtF	Panel-to-Frame
DC	Design Criterion	PtP	Panel-to-Panel
DS	Design Strategies	PGA	Peak Ground Acceleration
DHP	Double-Hinged Panel	PRC	Precast Reinforced-Concrete
EC8	Eurocode 8	PID	Proportional-integral-derivative [controller]
ELSA	European Laboratory for Structural Assessment	PsD	Pseudo-Dynamic [test]
FA	Façade Arrangements	RP	Rocking Panel
FBD	Friction-Based Devices	SLS	Serviceability Limit State
IS	Integrated System	sR	simple Retain [connection]
ISF	Isostatic Sliding Frame	ULS	Ultimate Limit State
L-D	Load-Displacement [graph]	VPA	Vertical Panels Arrangement

collapse before exploiting the frame overstrength. Different earthquakes, occurred over the last years, have validated on field these results, inter alia: L'Aquila 2009 [2], Grenada 2010 and Emilia 2012 [3].

2. The SAFECLADDING research project

The SAFECLADDING Project was conceived to increase knowledge about seismic performance of existing PRC structures with cladding panels and to investigate new solutions for possible improvements, as well as to propose new methods to tackle the above described issues in new buildings. Leaving temporarily apart the issue of existing buildings, different theoretical approaches to connect frame and panels may be classified according to three different *design criteria* [2].

2.1. Design criteria to connect frame and panels

2.1.1. Isostatic

The frame deformation-demand is allowed by a relative clearance that uncouples the motion of frame and panels. The two systems are *kinematically uncoupled*, except for the out-of-plane displacements, Fig. 1a.

2.1.2. Integrated

Panels and frame have a coupled motion: the system is *kinematically paired*, Fig. 1b. Panels become part of the seismic resisting system and they act as the main restraints in the horizontal direction thanks to their higher stiffness. As a consequence, the connections must be over-proportioned to carry the higher loads transferred by the frame, according to capacity design rules.

2.1.3. Dissipative

Specific devices can balance the overall building response, reducing the displacement and keeping the load below an imposed threshold, determined by the connections themselves, Fig. 1c. Like in the isostatic configuration, the systems are *kinematically uncoupled*, but they are also constrained by *inelastic links*, like friction devices, see [6,10,11], or yielding devices: [7,8]. The joints between structure and panels –or among the panels– must be designed to dissipate energy during the earthquake shock, see [9,12].

2.2. Strategies to implement isostatic and dissipative design criteria

Although the *isostatic*- and *dissipative-design criterion* are equivalent in kinematic terms, different results may be obtained just changing the way to connect frame and panels, using the same criterion [14]. Taking advantage of this, different *Design Strategies* (DS) for the structural system may be chosen. Those are represented by different test setups used within this experimental campaign.

2.2.1. Isostatic Sliding-Frame (ISF)

Like an ideal uncoupled system, the *Isostatic Sliding-Frame* is –in principle– the easiest way to disconnect frame and panels. To achieve this result, avoiding the issues that affect *in-use* systems [2], the introduction of proper connections (sliders) has been proposed. They only restrain out-of-plane motions, reproducing the hypothesis typically assumed in the current practice, but in a safer way, Fig. 2a. Vertical panels are simply leant on the foundation, or better clamped to it, while the relative swaying of the frame must be allowed by sliders. The ISF design strategy should not be confused with the *in-use* connections for vertical panels, which are typically weak shear keys, also known as *hammer-headed straps*

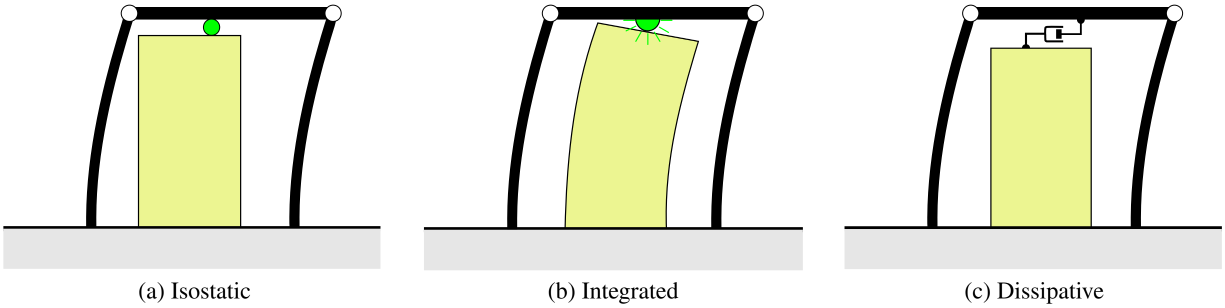
(a) Isostatic (b) Integrated (c) Dissipative

Fig. 1. Design criteria to connect frame and panels.

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