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Pseudodynamic tests on a full-scale 3-storey precast concrete building: Behavior of the mechanical connections and floor diaphragms

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ABSTRACT

A full-scale three-storey precast building was tested under seismic conditions at the European Laboratory for Structural Assessment in the framework of the SAFECAST project. The unique research opportunity of testing a complete structural system was exploited to the maximum extent by subjecting the structure to a series of pseudodynamic (PsD) tests and by using four different structural layouts of the same mock-up, while 160 sensors were used to monitor the global and local response of each layout. Dry mechanical connections were adopted to realize the joints between: floor-to-floor, floor-to-beam, wall-to-structure; column (and wall)-to-foundation and beam-to-column. Particular emphasis was given to the seismic behavior of mechanical beam–column connections, as well as to the response of floor diaphragms. Thus, the in-plane rigidity of three pretopped diaphragms with or without openings was assessed. In addition, two types of beam-to-column connections were investigated experimentally, namely hinged beam–column connections by means of dowel bar and emulative beam–column joints by means of dry innovative mechanical connections. Therefore, the seismic behavior of floor diaphragms and pinned beam–column connections in a multi-storey precast building was addressed experimentally. The results demonstrated that the proposed new beam-to-column connection system is a viable solution toward enhancing the response of precast RC frames subjected to seismic loads, in particular when the system is applied to all joints and quality measures are enforced in the execution of the joints.

1. Introduction and background

The research on the seismic behavior of precast concrete structures is very limited if compared to traditional cast-in situ frame reinforced concrete (RC) structures. In fact, in spite of the overgrowing diffusion of this kind of structures, their peculiar characteristics and, in particular, their response to seismic excitation, have not been so thoroughly investigated and univocally determined at present. From a general point of view, there are two alternatives to design precast structures. One choice is the use of precast concrete elements interconnected predominantly by hinged connections, whereas the other alternative is the emulation of monolithic RC construction. The emulation of the behavior of monolithic RC constructions can be obtained using either "wet" or "strong" (dry or partially dry) connections. A "wet" connection between precast members uses cast-in-place concrete or grout to fill the splicing closure. Precast structural systems with wet connections must then comply with all requirements applicable to monolithic RC constructions. A "strong" connection is a connection, not necessarily realized using cast-in situ concrete that remains elastic while designated portions of structural members undergo inelastic deformations under the design ground motion.

The state-of-the-art on the seismic design of precast concrete building structures comprises a limited number of scientific reports. The ATC-8 action – "*Design of prefabricated concrete buildings for earthquake loads*", in the proceedings of its workshop [1] contains eighteen state-of-practice and research papers and six summary papers in particular related to the precast systems in New Zealand, Japan, USA and Europe. Simeonov and Park (1985) [2] addressed the seismic behavior of specific joints used in large panel precast systems of the Balkan region. Another major project, called PRESSS (PREcast Seismic Structural Systems), was made in the 1990s. Specific structural systems with ductile dissipative connections using unbonded PT tendons were addressed by the US and Japanese researchers [3–5]. A relatively recent state-of-art report was published by the fib-Task group 7.3 [6] reporting on (at that time) latest developments on the seismic design of precast concrete building structures in New Zealand, Mexico, Indonesia, Chile, USA, Slovenia, Japan and Italy. In other related documents [5,7,8] special attention is given to the seismic behavior and analytical modeling of the connections. However, although these are the most comprehensive existing documents, they cover only some

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specific precast structural systems and connections. The Balkan project was strongly oriented to large panel systems, which were extensively used in Eastern Europe but are nowadays outdated. Most other works are limited to moment resisting precast frames based on the emulation of the monolithic structural systems.

The present research is focused on the categories of dry connections, consisting of mechanical devices, which are the most common type in modern precast buildings in Europe. The advantages of dry connections, in terms of quick erection, maintenance, reuse, make them even more appealing in an environmentally friendly, life-cycle performance oriented perspective. Fig. 1 illustrates each category of connection between the different structural elements creating the structural body of a precast building. The *first category* of connections is that between adjacent floor or roof elements. These connections are those affecting the diaphragm action of the roofing of precast structures. The *second category* refers to connections between floor or roof panels and supporting beams. These connections enforce and guarantee the perimetral restraints of the diaphragm made of the panels in its in-plane behavior. The *third category* refers to connections between columns and beams. The beam-to-column joints ensure the required degree of restraint in the frame system. The *fourth category* of connections used to join columns and foundations is typically realized by positioning the precast columns into pocket foundations. Finally, the *fifth category* comprises connections between wall (or cladding panels) and slab elements.

The seismic behavior of the first four categories of connections was investigated in the framework of the SAFECAST project that included, among other tasks, reference pseudodynamic (PsD) tests on a full-scale 3-storey precast concrete building, carried out at the European Laboratory for Structural Assessment (ELSA) of the European Commission in Ispra. This paper investigates the seismic behavior of mechanical beam–column connections, as well as the response of floor diaphragms through the results of those tests.

2. Test structures and investigated parameters

The test structure was a three-storey full-scale precast residential building, with two 7 m bays in each horizontal direction as shown in Fig. 2. The structure was 15 × 16.25 m in plan and had a height of 10.9 m (9.9 m above the foundation level) with floor-to-floor heights equal to 3.5 m, 3.2 m and 3.2 m for the 1st, 2nd and 3rd floor, respectively. The columns cross-section was constant along the height of the structure, equal to 0.50 × 0.50 m, with 1% longitudinal reinforcement (8∅20). Along the main direction there were beams, with a maximum and minimum width of 2.25 m and 1.85 m, respectively. In the orthogonal direction there were slab elements. Detailed description about the geometry and reinforcing details of all structural members used, namely precast concrete columns, beams and walls, is given in the companion paper by Negro et al. 2012 [9]. This paper is focused on the seismic response of: (a) the precast floor diaphragms and (b) the mechanical connections used between precast concrete members.

The SAFECAST specimen was constructed with a special structural layout which allowed four different structural precast systems to be tested. Thus, the behavior of several features was experimentally examined. The possibility of creating rigid floor diaphragms without any concrete topping, a practice that could sensibly speed the construction time of the structure, was investigated through the three different pretopped floor diaphragms that were incorporated among the floors. In addition, the behavior of two types of mechanical beam–column connections was investigated. Firstly, the seismic behavior of "traditional" for the European countries pinned beam–column connections was assessed experimentally for the first time in a multi-storey building. In this case, the columns are expected to work mainly as cantilevers. Then a second type of beam–column connection with innovative mechanical devices which allow for the realization of dry fixed connections was applied and experimentally validated.

The first specimen (prototype 1) comprised a dual frame-wall precast system, where the two precast shear wall units were connected to the mock-up. In this structural configuration, the effectiveness of the three floor systems in transmitting the in-plane seismic storey forces to the vertical elements of the lateral resisting system was investigated. In the second specimen (prototype 2), the building was tested in its most typical configuration, namely with hinged beam–column connections by means of dowel bars. The possibility of achieving emulative moment resisting frames by means of a new connection system with dry connections was investigated in the third and fourth structural layouts. In particular, in the third layout (prototype 3) the beam–column connections were restrained only at the third floor, whereas in the last fourth layout (prototype 4), the connection system was activated in all beam–column joints.

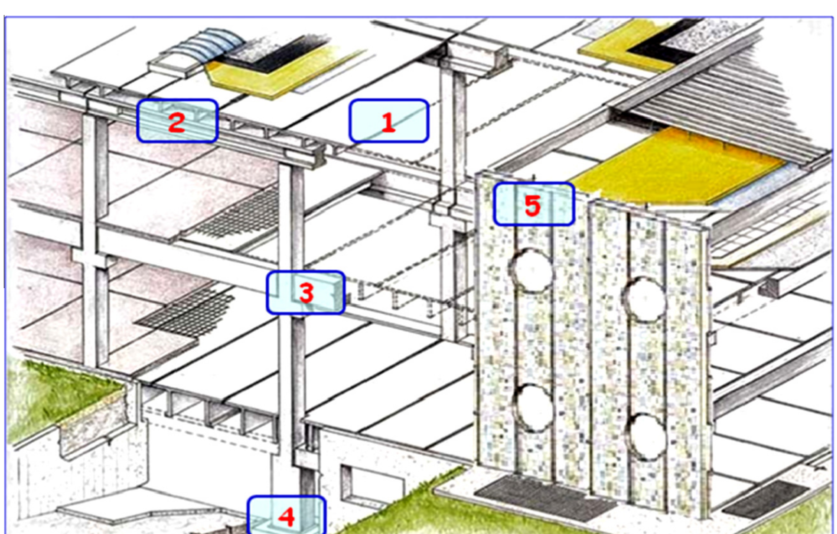

Fig. 1. Categories of connections between the different structural elements of a precast concrete building.