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Shear resistance of pinned connections of precast members to monotonic and cyclic loading

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ABSTRACT

One of the major issues in the design of precast structures against earthquakes is the proper design of their connections, mainly the beam-to-column joints. Many different types of such connections are used worldwide, as monolithic, emulative and dry pinned ones. The latter case is the most common solution in southern Europe and elsewhere for single-storey or low-rise precast buildings, and is the subject of the experimental research reported in this paper. The experiments were performed at the Laboratory for Earthquake Engineering of the National Technical University of Athens, Greece in the framework of the European FP7 project, SAFECAST. Precast beam and column elements connected with dowels were tested under monotonic and cyclic, pure shear loading and the research was focused on several design aspects, as the shear ductility capacity of the connections and the effect of various parameters on their strength. The parameters examined include the diameter D of the dowels, their number, their distances d and d_n from the edges in the longitudinal and the transverse direction of the beam respectively, and the strength of the grout of their ducts. Improvements in the design were also proposed and tested experimentally. The results show that, for small values of the ratio d/D, the strength of the connection is lower in the pull direction than that in the push direction for both monotonic and cyclic loading, due to the early spalling of the cover concrete that occurs. Compared to the strength for monotonic loading, the cyclic response shows significantly lower resistance, less than half the monotonic one. The results for cyclic loading also show that significant values of shear ductility can be achieved by dry pinned joints, provided that the concrete cover of the dowels has sufficient thickness. Comparisons between the experimental results obtained for various design parameters show that secondary effects related to the number of the dowels can occur for large forces during monotonic loading, but are less important for cyclic response. A formula is proposed for the calculation of the shear strength of pinned connections, which can be used in seismic design.
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1. Introduction

Precast reinforced concrete constructions have been used for more than half of a century. Due to many advantages that they possess, as the fast and economic construction, the small amount of the on-site required labour work and the minimized influence on the weather conditions that affect the construction time and the quality of the structure, their application is spreading considerably and successfully all over the world, making prefabrication one of the leading construction techniques.

Although the safety of precast constructions during earthquakes has been recognized as one of the most important issues in the design, surprisingly enough, only limited experimental research has been conducted on the resistance of connections of precast members and the behaviour of the structure as a whole.

The seismic performance of precast structures greatly depends on the type of the connections, their position into the structural system and the type of the structural system itself. An overview of the research and development for the design of precast framed structures can be found in the fib Bulletin No. 27 [1], in earlier reports by Elliott [2] and Simeonov et al. [3] and in ATC-08 [4]. Recently, fib Bulletin No. 43 [5] was published, in which considerable information on practically every type of beam-to-column connection is given concerning its design and behaviour. However, these guidelines were based merely on the resistance of the connections to monotonic loading and do not directly reflect the influence of strength and deformability of the connections on the overall behaviour of a precast structure.

The most notable effort on the experimental investigation of the earthquake response of precast structures has been the PRESSS (Precast Seismic Structural Systems) project [6–9] carried out in USA and Japan. In the framework of this project, a 60% scale,

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30 ft. × 30 ft. five-storey building with several types of connections was tested at the University of California, San Diego. The major objective of this project was to issue design guidelines for broader acceptance of the precast concrete construction in seismic zones and to develop new concepts and technologies for precast systems to be applied in regions of high seismicity; thus, it does not comply directly to the main problematic of traditional techniques of prefabrication as they usually appear around the world.

Semi-rigid connections were examined extensively within the European project COST C1 Action [10], in which 25 countries and more than 125 research centres were involved. A wide range of materials and geometries were studied; the results, however, showed significant diversion [11–16]. Significant work related to the behaviour of several types of precast connections was reported by many other researchers (Imai et al. [17], Watanabe [18], Priestley and Tao [19], Nakaki et al. [20], Ersoy and Tankut [21], El Debs et al. [22], Rahman et al. [23]).

Most of the above-mentioned research has been focused on the seismic behaviour of specific types of connections, mainly moment resisting ones, since in many countries (USA, New Zealand, Japan, Australia, etc.), rigid connections are preferred for beam-to-column joints. However in Europe (Italy, Greece, Spain, Portugal, Slovenia, etc.) and elsewhere (Turkey, Armenia, etc.), simple dry pinned beam-to-column connections are traditionally used for single-storey or low-rise precast, mainly industrial, buildings.

Little investigation has been reported on pinned connections that are materialized by dowels, e.g. by Leong [24] who proposed improvements of perfectly pinned dowel connections. The dowel mechanism was investigated extensively by Vintzeleou and Tassios [25,26], while Tsoukantas and Tassios [27] conducted an analytical investigation on the shear resistance of connections between linear precast elements under monotonic and cyclic loading and proposed design values for the shear resistance of each connection and its corresponding shear slip for rough and smooth surfaces.

Recently, significant experimental and numerical research on the seismic behaviour of precast structures with dry pinned connections was conducted in the framework of the "Growth" FP5 project of the European Commission, "Precast EC8: Seismic behaviour of precast concrete structures with respect to Eurocode 8 (Co-Normative Research)". The project focused on the overall nonlinear behaviour of structures with several types of connections and on the global ductility that can be attained (Negro et al. [28], Carydis et al. [29], Psycharis et al. [30], Kramar et al. [31]). However, a detailed investigation of the seismic response of the connections was not performed.

Considering the limited research that has been conducted on structures composed by linear precast elements with pinned beam-to-column connections, the experimental research presented herein aims at the investigation of their shear resistance to monotonic and cyclic loading and at recommendations concerning their design towards the improvement of their seismic response. This investigation was carried out at the Laboratory for Earthquake Engineering of the National Technical University of Athens, Greece (NTUA), within the framework of the FP7 project of the European Commission, "SAFECAST: Performance of innovative mechanical connections in precast building structures under seismic conditions. More details on the experimental results that are reported in this paper and on the experimental investigation performed in other Institutions within the SAFECAST project can be found in [32].

It is known that there are numerous alternative pinned-connection mechanisms used worldwide in precast systems and, evidently, the results presented herein cannot cover all the cases. However, the design issues that are discussed and the conclusions that are drawn can be extended to other similar systems, beyond the specific ones examined.

2. Experimental setup

The primary objective of this experimental research was to investigate the effect of various design parameters on the resistance of pinned beam-to-column connections under pure shear monotonic and cyclic loading. This type of connection represents the common solution in precast construction practice in many countries in Europe and elsewhere, mainly for single-storey industrial buildings.

The specimens represented a typical pinned connection of linear precast members and consisted of the end parts of the beam and the column that were connected by steel dowels (Fig. 1). The experimental setup is shown in Fig. 2a. Each specimen was subjected to monotonic or cyclic, displacement-controlled loading, applied to the rear end of the beam, while the column was securely fastened to the strong floor of the Laboratory. For the tests, a

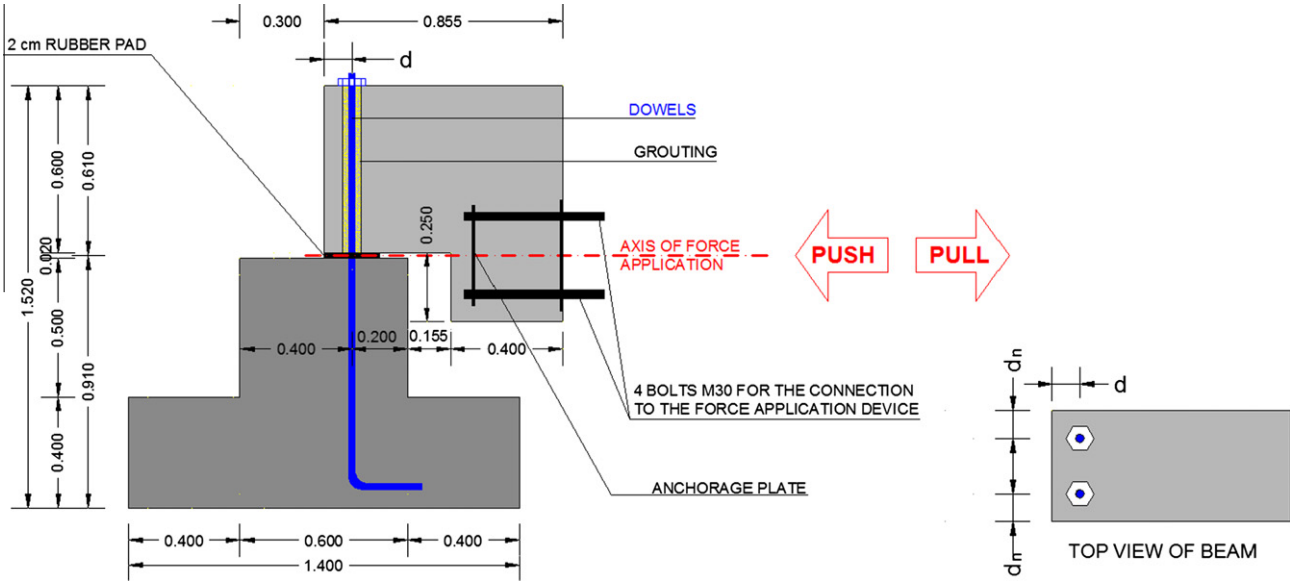

Fig. 1. General layout of the specimens.

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