Journal of Building Engineering 7 (2016) 224–238

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Seismic performance of precast reinforced concrete buildings with dowel pin connections

F. Clementi*, A. Scalbi, S. Lenci

Department of Civil and Building Engineering, and Architecture (DICEA), Polytechnic University of Marche, Ancona, Italy

ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form
29 June 2016
Accepted 29 June 2016
Available online 30 June 2016

Keywords:
Precast concrete structures
Deformable connections
Dowel pin
Nonlinear static analysis
Nonlinear incremental dynamical analysis
Lumped plasticity
Diffused plasticity
Seismic risk index

ABSTRACT

A key aspect in determining the seismic performance of industrial Precast Structures (PS) are the connections between precast elements. The main issue is the capacity of beam-column connections to allow relative displacements without losing beam seating, and to transfer lateral horizontal forces from the beam to the column, without losing load carrying capacity. Referring to a case study based on an industrial PS located in Italy, this work critically investigates the influence of different variables on the connection behaviour, as well as the results of the different safety assessment approaches. Attention has been paid to provide a comparison between different (linear and nonlinear, static and dynamic) analyses with both lumped and diffused nonlinear models. The analyses highlight the importance of the connection between members in the seismic upgrade of existing PS, and the minor role of the mechanical slenderness of the column when considering weak connections.

1. Introduction

The recent seismic events and the importance of the prevention, grown in the last few years, have highlighted the necessity of assessing the capability of the existing building heritage to sustain earthquakes, in order to improve the average safety level of the population. The adequate modelling of existing Reinforced Concrete (RC) frames is a crucial issue, related as well to the maintenance and to the structural upgrading possibility. The evaluation of the seismic vulnerability of existing buildings has a key role in determining and reducing the impact of an earthquake [1], in particular in precast concrete structures which have suffered severe structural damages. The example is the last earthquake in Emilia Romagna (Italy) in 2012 [2–4].

There are precast industrial buildings from different periods, designed with different codes and located in different seismic areas, which have experienced earthquakes in Europe and the USA [5–9]. The main causes of Precast Structures (PS) damages under seismic actions are connection failure, insufficient ductility, stiffness and strength of the columns, insufficient roof stiffness or slab system. In particular, the absence of adequate connections between structural elements is a very common weakness, which determines the worst collapses and damages. In most cases, an effective beam-column connection does not exist, and the link is guaranteed exclusively by friction forces [10], which of course are not reliable. The frictional connections are typical of existing PS exclusively designed for vertical loads, in zones that in the last decades have been identified seismically hazardous [11].

The dowel system is one of the most common beam-column connections in some areas recently considered as seismic. It is a mechanical device allowing the transmission of horizontal actions [12], and it generally consists of one or more steel dowels embedded in the column and inserted in a beam hole, filled with mortar. Numerical models of PS usually implement this kind of connection as hinge, fixed between structural elements, and it is considered strong enough to avoid failure during earthquakes.

In the literature there are not so many studies on the dowel capacity influence on the overall spatial responses of the structures, on its seismic vulnerability and, more generally, on the seismic risk: one of the most important works is [13] where the concept of robustness of PS is studied. Indeed, several researchers have analysed only a singular dowel pin connection through FEM, but without a global seismic analysis. Recently, significant experimental and numerical researches on the seismic behaviour of new PS with dry pinned connections were conducted in the framework of two European projects: the “Growth” FP5 project, “Precast structures EC8: Seismic behaviour of precast concrete structures with respect to Eurocode 8 (Co-Normative Research)” and the FP7 project, “SAFECAST: Performance of innovative mechanical connections in p.c. structures under seismic conditions”.

* Corresponding author.
E-mail address: francesco.clementi@univpm.it (F. Clementi).

http://dx.doi.org/10.1016/j.jobe.2016.06.013
2352-7102/

The former project focused on the overall nonlinear behaviour of structures with several types of connections and on the global ductility that can be attained [14,15]. The last one focused on the experimental investigation (monotonic, cyclic and dynamic) and the analytical modelling of typical mechanical, dry connections that are used in PS, including beam-column joints [16]. More recent studies [10,12,17,18] were also aimed at developing a specific procedure for the estimation of dowels capacity. In [11] some considerations on the influences of the neoprene beam-column connections are presented, taking into account the elastic deformation of the rubber on two single story/single-span structures. Only the presence of neoprene between beam and column and not in the secondary elements of the roof, is modelled. In Negro et al. [19] a full-scale three-storey PS was subjected to a series of pseudo-dynamic tests. The behaviour of various parameters, traditional as innovative mechanical connections and the presence or absence of shear walls along with the framed structure were investigated. The main conclusion is that the failure of precast industrial buildings, due to loss of support, can occur due to seismic forces even at medium/low intensity because of low resistance of beam-column connection. These considerations have been elaborated directly through capacity equations when the capacity design is not applicable, as in the existing structures.

The dowel pin connection behaviour is quite complex: it is influenced by the behaviour of different materials (concrete and steel), by the contact among elements (e.g. column concrete-dowel and mortar-dowel), as well as by jointed structural elements (e.g. rotational capacity of beam and column). Moreover, as observed in [16], in many countries (USA, New Zealand, Japan, Australia etc.), rigid connections are preferred for beam-column joints, while in Europe (Italy, Greece, Spain, Portugal, Slovenia etc.) and elsewhere (Turkey, Armenia etc.), simple dry pinned connections are traditionally used in frame type buildings. The Italian code [20,21] underlines the importance of the assessment of connection performance, but it does not give a clear indication of the way to do it, considering the deformability and limit resistance of the dowel pin. With the exception of some guidelines in Japan [22], in the USA [23] and in Italy [24], there is no complete code guidance in response to the existing (industrial) PS with deformable connections. In Europe, the codes are just beginning to tackle the problem with Eurocode 8 [25], major information on this issue is contained in [26,27] with some appropriate capacity equations to this problem. Today, sufficient information is available to obtain a realistic model of these connections and it is possible to determine a correct vulnerability PS index.

One of the most common and serious PS damages due to an earthquake is the failure of the beam-column connection [5,6,9,28]. Few research projects [2,11,28–31] have been devoted to the 3D response of existing industrial PS. This situation is very relevant especially in Italy, because between the 1950s and 1990s a large number of constructions built in many industrial districts are nowadays often exposed to high levels of seismic risk. A description of the typologies of reinforced concrete PS present in Italy is reported in [2,28,31] and also in Sect. 2 of [11]. This is the reason why the assessment herein proposed is performed by a rigorous methodology, collecting many accurate data on the buildings characteristics and analysing them by sophisticated analyses, i.e. nonlinear static and incremental nonlinear dynamic analyses (I.D.A.). Finally, the peculiar weakness of the single dowel connection is shown by the case study.

Based on sensitive analyses our main goal is to investigate the influences of:

a) the choice of the capacity equations to evaluate the resistance of the dowel pin; in order to have a better perception of the existing situation of Italian precast RC buildings designed with the CNR 10025/84 [32] and CNR 10025/98 [33];
b) neglecting "*a priori*" possible ruptures of the dowel pins;
c) the types of analysis, i.e. linear and nonlinear, static and dynamic, in terms of seismic index risk;
d) the choice of the nonlinear model, such as lumped and diffused plasticity;
e) the Knowledge Level (KL) which depends on the knowledge of the structures and the resistance of their material (see Table 3.1 of [34]).

2. The case study

One-story industrial buildings represent the most common form of precast construction in central and northern Italy, most of them severely damaged during the last earthquakes. The earthquakes in Emilia-Romagna (2012) caused damages mainly to industrial PS with a huge economic loss: it has been roughly estimated that the direct economic damage reaches about €1 billion, while the induced economic damage reaches about €5 billion [28].

In order to clarify the genesis of the major structural deficiencies of the traditional Italian RC precast facilities affected by earthquakes, a brief introduction of the past and current design practice is presented. Detailed explanations of codes evolution are reported in [1,35] for RC structures and in [28,30,31] for PS.

2.1. Past and actual design practices

Taking into account the last 60 years, the Italian building stock could be split into three periods: from 1962 to 1987 (poor general rules for RC structures), from 1987 to 2002 (first provisions for PS) and 2003 to present (appropriate design code including a specific chapter on PS).

Starting from 1962, Law 1684 [36] and integration Law 1224 (1964) [37] only specify the horizontal actions to consider in seismic zones in Italy, without any particular requirement for PS. In 1965, the Circ. M. LL.PP. n. 1422 [38] forbade the use of horizontal joints without mechanical devices if the ratio V/N was larger than 0.35 (where V is the maximum value of the shear force, N is the expected axial compression force).

The first specific regulations for PS were in the D.M. 1987 [39], which pointed out the role of the connections, considering the transition construction phases. The requirements for structural elements and for connections design are still limited; it is forbidden in seismic zones to use beam-column connections transferring horizontal forces by friction alone. The only prescriptive provision is given for the width of the beam-to-column support not smaller than 8 cm+L/300, where L is the clear beam span in centimetres.

Finally, more detailed suggestions on PS are given in 2003 [40] but were compulsory only for infrastructures or strategic buildings. The current Italian code [20] gives more attention to PS than has been given in the past Italian codes, adopting some Eurocode 8 regulatory previsions [25] about the precast concrete structures in Europe, underlining the importance of the connections. It required to ignore the friction resistance in evaluating the connection resistance between primary and secondary elements.

2.2. Geometry and materials

The reference building analysed herein, has a simple and geometrically regular structural scheme (Fig. 1), which is typically for RC single story precast industrial structures. This building, located in the centre of the Italy, was erected between the end of 1960s and the end of 1970s. It is representative in terms of typology and dimensions, of the industrial buildings present on the territory. To