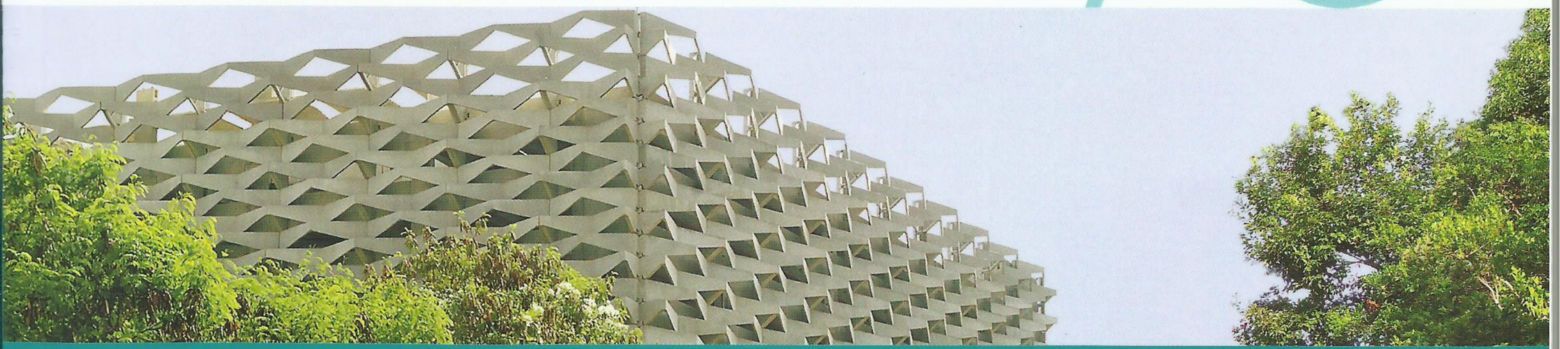
Bulletin 78



Precast-concrete buildings in seismic areas

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State-of-the-art report

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Precast-concrete buildings in seismic areas

Practical aspects

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State-of-the-art report

Task Group 6.10 and PCI

March 2016

Subject to priorities defined by the technical council and the presidium, the results of the *fib*'s work in commissions and task groups are published in a continuously numbered series of technical publications called *bulletins*. The following categories are used:

Category:	**Draft to be approved by:**
Technical report	Task group and chairpersons of the commission
State-of-the-art report	Commission
Manual / Guide to good practice / Recommendation	Technical council
Model code	General assembly

Any publication not having met the above requirements will be clearly identified as a preliminary draft.

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Foreword

Since the mid-twentieth century the industrial prefabrication of concrete structures has acquired an increasing share of the construction market worldwide thanks to its well-known advantages. These advantages include the best use of materials, structural efficacy, flexibility in use, speed of construction, quality consciousness, durability, eco-friendliness and sustainability.

Over this same period, *fib* Commission 6: *Prefabrication* has continued the work of the FIP on issues directly related to precast concrete, such as structural elements, detailing, connections, systems, production, handling, assembling, demounting, as well as items that are indirectly related, like materials technology, structural analysis, building physics, equipment and sustainable development.

Construction in seismic areas is being afforded increasing attention due to the progress of both seismology and seismic engineering. The latter covers the identification of areas considered to be at risk and a deeper understanding of structural response. All types of construction, including those using structural concrete in general and precast concrete in particular, are affected by this development.

The theme was approached in *fib* Bulletin 27: *Seismic design of precast concrete building structures* (2003) by *fib* Task Group 7.3 of *fib* Commission 7: *Seismic Design* (as it was in the old structure), with contributions by this commission. It offered a comprehensive overview of the theoretical bases, design approaches and practices in most advanced countries at that time.

Further experience with precast concrete structures enduring earthquakes of various intensities has come to the fore since then. Most structures have performed well, whereas some, particularly the older ones, showed shortcomings that elicited additional inquiry into their behaviour to learn how to enhance the quality of future designs. Comprehensive research projects run internationally yielded important results on the capacity of precast structures to withstand seismic events. They were particularly useful for improving the local detailing, as well as for evaluating the overall ductility, which proved to be quite comparable with that of cast-in-place structures, thereby helping to define appropriate behaviour factors.

Today we can say that much has been clarified and that the recent experience can be transferred to practice so as to create new buildings that exhibit the performance required. This report aims to update designers on developments and help them in their daily practice. Thanks are due to all members of the task group, particularly to its convener

Spyros Tsoukantas, not only for carrying out such useful and ambitious work and for imparting it through this valued report, but also because they have committed themselves to a further study of how to upgrade existing structures, including structures possibly damaged by earthquakes, that were built when practice was less qualified.

U.S. design and construction practice for precast concrete structures was used as basis throughout the preparation of this report. Nothing in here is contrary to U.S. practice. This report has been approved by the Technical Activities Council of the Precast/Prestressed Concrete Institute (PCI) as a joint *fib*-PCI publication.

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1 Introduction

1.1 General

The technology of prefabrication in buildings has been in use for more than half a century and is spreading considerably and successfully every day throughout the world.

Experience in earthquakes has shown generally good behaviour, even in regions of high seismicity, in precast structures if they are properly designed and built. In particular, precast frame systems, which are very commonly used for one-story industrial buildings, combine their capacity for high resistance with a strong attenuation of the seismic action because of a long period of natural vibration and a large capacity for ductile deformation. Most of the precast buildings that suffered excessive damage with partial or total collapse were built using ill-conceived conceptual designs, inadequate structural schemes and load paths and/or the poor detailing of connections between structural elements, as well as between structural and 'non-structural' elements, such as claddings and heavy infills.

In general, for all types of structures and structural systems, good behaviour under seismic situations depends on the following fundamental elements:

- overall design
- construction details of the structure

Good seismic design depends on the experience and skills of the designer and the state of knowledge at local and international levels in terms of theory, analytical/numerical and experimental observations, and design guidelines and codes at the time of design. In general terms, knowledge of current 'best practice' is required. This often goes beyond the prescriptions contained in the latest codes. Design codes, standards or by-laws, in fact and by definition, set 'minimum' requirements. It is up to the owner to discuss requirements with the engineer and the other parties involved so as to set the desired design targets, which may be higher than the code requires, and to investigate options and solutions to achieve them in a cost-effective manner. Ultimately, it is best to be mindful of Professor Tom Paulay's dictum: Earthquakes do not read the code. Earthquakes seem to be particularly effective at showing up the hidden structural weakness of a system - the so-called weakest link in the chain.

Good construction depends on the experience, skills, available equipment and so on of the construction company as well as adequate supervision and inspection to ensure that all design details are properly implemented.

In the particular case of precast construction (when compared to monolithic construction) additional design rules, concepts, code provisions and building procedures and details are required to provide a level of safety under seismic actions that is equal to or better than those for cast-in-situ construction. Furthermore, given the peculiarities and recognized advantages of precast construction, such as high quality control, speed of erection, modular construction, it is essential to have an integrated and collaborative approach from the owner and the design and construction teams. A precast structure is, in general, less forgiving than its cast-in-situ counterpart in terms of tolerances and post-design on-site modifications of any kind. Hence, the entire building system has to be looked at holistically rather than at a component level. At the same time, specific attention needs to be paid to the final detailing of each connection between elements in order to guarantee the expected performance, while maintaining ease of constructibility.

1.2 Scope

This bulletin is mainly addressed to engineers who are involved in the design, construction and/or production of precast buildings. It is also intended for civil engineers and architects who want to become acquainted with the main principles of design, detailing and construction, and in general, the behaviour of different precast structural systems under seismic actions.

The scope is broad and does not focus on design issues. Precast construction under seismic conditions is treated as a whole. The main principles of the seismic design of different structural systems, their behaviour and their construction techniques are presented through rules, construction stages and sequences, procedures and details. The purpose is to allow precast structures to be built in seismic areas that comply with the fundamental performance requirements of collapse prevention and life safety in major earthquakes and limited damage in more frequent earthquakes.

The content of this bulletin is largely limited to conventional precast construction and although some information is provided on the well-known technology of PRESSS (jointed-ductile dry connections), this latter solution is not covered in detail. A systematic description of PRESSS technology may be found in the PRESSS Design Handbook (NZCS, 2010) and other publications.

Detailed information about the seismic design of precast-concrete building structures may be found in *fib* Bulletin 27 (2003), while the design and behaviour of structural connections for precast-concrete buildings is thoroughly dealt with in *fib* Bulletin 43 (2008).

The general overview in this bulletin of alternative structural systems and connection solutions that are available for achieving desired performance levels intends to provide engineers, architects, clients and end-users in general with a better appreciation of the wide range of applications that modern precast-concrete technology can have in various types of construction, from industrial to commercial as well as residential. Lastly, the emphasis on practical aspects, from conceptual design to connection detailing, aims to help engineers rid themselves of the habit of blindly following prescriptive design codes and instead to return to basic principles in order to achieve a more robust understanding and thus greater control of the seismic behaviour of the structural system as a whole, as well as of its components and individual connections.

1.3 Key features

The key features outlined in this bulletin include:

- Basic principles of seismic design with particular reference to precast structures
- Role of connections and their relationship to selected behaviour factors q (as used in the Eurocode or, as per other codes, ductility factors μ or reduction factors R)
- Basic principles of conceptual design
- Description of hinged and moment-resisting frame systems, including jointed systems and construction details of beam-to-column connections
- General information about and details of column-to-foundation, beam-to-beam and column-to-column connections
- General information about precast large-panel-wall systems and construction details
- General information about wall-frame systems (dual systems) and construction details
- General information about the seismic behaviour of floor systems (diaphragm action)
- General information about and construction details of precast double wall systems
- General information about and construction details of precast cell systems

Design examples are also given using both the more traditional 'force-based design' (FBD) approach and the emerging 'displacement-based design' (DBD) approach, for comparison.

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