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Precast/Prestressed Concrete Institute

# Seismic Design of Precast/Prestressed Concrete Structures

By Ned Cleland, Ph.D., P.E. and S. K. Ghosh, Ph.D.

Second Edition



**SEISMIC DESIGN OF  
PRECAST/PRESTRESSED  
CONCRETE STRUCTURES**

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Ned Cleland, Ph.D., P.E.  
S. K. Ghosh, Ph.D.



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## FORWARD



Successful design of precast/prestressed concrete projects involves an integration of system, connections, and components to satisfy functional, environmental, and aesthetic requirements. In this manual, the focus is on the environmental requirements imposed by earthquakes.

Precast concrete is commonly perceived as a derivative of monolithic cast-in-place concrete. Precast concrete components, such as columns, beams, and slabs, are easily recognized as plant-cast variants of their monolithic cast-in-place concrete counterparts. The assembly of these components, however, uses connections that are not common to traditional cast-in-place concrete construction. The development of precast concrete over more than 50 years results in systems that are typically quite different from monolithic systems.

During the early development of the precast concrete industry, the requirements for earthquake resistance were not considered a major aspect of the environmental considerations in much of the United States. As the use of these materials grew in importance, the effect of the lack of attention to earthquake resistance was seen as a limitation to growth. The issue was taken up in earnest in an Applied Technology Council workshop in 1981, and the proceedings of that workshop were published as ATC-8. The issue was further addressed in 1982 in PCI Technical Report No. 2, *Connections for Precast Prestressed Concrete Buildings Including Earthquake Resistance*, by L. D. Martin and W. J. Korkosz and in 1985 in PCI Technical Report No. 5, *Design of Connections for Precast Prestressed Concrete Buildings for the Effects of Earthquake*, by D. V. Cough. These publications provided recommendations for solutions, but also raised more questions, which provoked two and a half decades of research, including the 10-year PRESSS research program.

Meanwhile, profound changes have taken place in the seismic design provisions of building codes. The introduction of the NEHRP Provisions into the east coast model codes in the early 1990s caused serious attention to be focused on earthquake-resistant design beyond the west coast. This has been followed by consolidation of the three regional model codes into the International Building Code, which has required some compromise in “code culture” that used to reflect regional differences. Generally, the east coast codes were based on the principle that if something is not specifically prohibited, then it is permissible. In the west, the code has been based on the principle that if the law or code does not specifically permit something, then it is prohibited. The merger in codes faces the inherent conflict of these principles.

The current requirements for earthquake-resistant design in ACI 318 were developed in the context of monolithic cast-in-place concrete construction. This results in some prescriptive requirements that are not wholly applicable to or appropriate for precast concrete construction. Recent updates to ACI 318 have included new provisions that do recognize the special characteristics of precast construction, but these were largely developed in the context of emulating comparable monolithic construction.

Most seismic design is based on equivalent static forces that represent a simplification of actual dynamic behavior. However, the dynamic behavior itself cannot be ignored. Energy dissipation is a key principle guiding detailing in Chapter 21. In general, precast mechanical connections do not provide the energy-dissipating capacity of monolithic construction, but jointed precast construction also varies in rigidity and period, so that overall energy demand is less.

Although PCI has sponsored and promoted millions of dollars worth of seismic research and published dozens of papers on seismic subjects in its *PCI Journal*, it has not published a collective work on the seismic design of precast structures in over 20 years. The first edition of this manual was developed to fill that need.

The intent of this manual is to provide current information on precast design within the context of the code requirements for seismic design, ongoing research, and the authors’ opinions about appropriate practice. It must be emphasized that this manual, although sponsored by PCI, does not represent a consensus recommended practice. It represents opinions of the authors concerning some ways in which precast design may be carried out to conform to code requirements and to perform acceptably under seismic effects. The methods and procedures

discussed and illustrated here are not a substitute for the sound professional judgment of engineers familiar with both earthquake effects and precast concrete construction.

The manual is not a textbook. For the various styles or classifications of precast lateral force-resisting systems, the code and behavior requirements are reviewed and then applied to realistic examples to illustrate their application. Hopefully, the manual will provide the engineer with acceptable ways of applying the seismic design provisions of ACI 318-05, ASCE 7-05, and IBC 2006 to precast concrete structures.

Some errors, almost certainly, will be found. PCI and the authors would be grateful to any reader who would bring any errors or inconsistencies to our attention. Suggestions for alternative methods or improvements are also welcome.

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# CHAPTER 1

## INTRODUCTION

### 1.1 OVERVIEW

The purpose of this publication is to assist in the design of precast concrete structures using the seismic design provisions of the 2006 edition of the *International Building Code (IBC)*.<sup>[1.1]</sup> The seismic design provisions of the IBC are discussed in detail below and are illustrated in subsequent chapters of this publication with examples of typical building and parking structures located in regions of low, moderate, and high seismic hazard and founded on different types of soil. In the examples, structural members are designed and detailed according to Chapter 19 of the IBC, which is based primarily on *Building Code Requirements for Structural Concrete (ACI 318-05)* and Commentary (*ACI 318R-05*),<sup>[1.2]</sup> with a few modifications.

The IBC is issued by the International Code Council (ICC), a nonprofit organization established in 1994. The three former model code bodies—Building Officials and Code Administrators International Inc. (BOCA), International Conference of Building Officials (ICBO), and the Southern Building Code Congress International Inc. (SBCCI)—were the founding members of the ICC. The first edition of the IBC, dated 2000, was the culmination of years of cooperative effort by committees representing the three model code bodies and other organizations. The 2000 IBC was followed by a 2001 supplement, a 2002 accumulative supplement, and then the 2003 IBC. The 2003 edition in its turn, has been followed by a 2004 supplement and then the 2006 IBC.

Chapter 16 of the IBC addresses the design requirements for various types of loads and design load combinations. The ASCE standard *Minimum Design Loads for Buildings and Other Structures* <sup>[1.3]</sup> (ASCE 7-05) is the basis of all provisions related to nonseismic forces. The seismic design provisions of the 2006 IBC are also those of ASCE 7-05, which in turn are based on the 2003 NEHRP Provisions.<sup>[1.4]</sup>

Throughout this publication, section numbers from the 2006 IBC are referenced as illustrated by the following: Section 1613 of the 2006 IBC is denoted as IBC 1613. Similarly, section references from ASCE 7-05 and ACI 318-05 appear, for example, as ASCE 6.5 and ACI 21.2, respectively.

### 1.2 NATURE OF EARTHQUAKE MOTION

Ground motion resulting from earthquakes presents unique challenges to the design of structures. The forces that a structure must resist in an earthquake result directly from the distortions caused by the motion of the ground that supports it. The response — magnitude and distribution of forces and displacements — of a structure resulting from such ground motion is influenced by the properties of the structure and its foundation, as well as the character of the exciting motion.

Earthquakes produce large-magnitude forces of short duration that must be resisted by a structure without causing collapse and preferably without significant damage to the structural members. Lessons from past earthquakes and research have provided technical solutions that will minimize loss of life and property damage associated with earthquakes. For materials such as concrete that lack inherent inelastic deformability or ductility, a critical part of the solution is to provide special detailing of the reinforcement to assure a ductile response to lateral forces. Inelastic deformability is the ability of a structure to sustain gravity loads as it deforms laterally beyond the stage where the deformations are recoverable, that is, beyond the stage where no residual deformations remain in a structure once the earthquake motion subsides. Irrecoverable deformations, also called residual deformations, are associated with damage, while recoverable deformations are associated with no damage.

Figure 1.1 illustrates a simplified representation of a building during an earthquake. As the ground on which the building rests is displaced, the base of the building moves with it. However, the inertia of the building mass resists this motion and causes the building to suffer a distortion (greatly exaggerated in the figure). This distortion wave travels along the height of the structure. The continued shaking of the base causes the building to undergo a complex series of oscillations.