

ACI 550.3-13

**Design Specification
for Unbonded Post-Tensioned
Precast Concrete Special Moment
Frames Satisfying ACI 374.1
(ACI 550.3-13) and Commentary**

An ACI Standard

Reported by Joint ACI-ASCE Committee 550



American Concrete Institute®



First Printing
November 2013

American Concrete Institute®
Advancing concrete knowledge

Design Specification for Unbonded Post-Tensioned Precast Concrete Special Moment Frames Satisfying ACI 374.1 and Commentary

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at www.concrete.org/committees/errata.asp. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

ISBN: 978-0-87031-850-4

Design Specification for Unbonded Post-Tensioned Precast Concrete Special Moment Frames Satisfying ACI 374.1 (ACI 550.3-13) and Commentary

An ACI Standard

Reported by Joint ACI-ASCE Committee 550

Harry A. Gleich, Chair

Larbi M. Sennour, Secretary

Te-Lin Chung
Ned M. Cleland
Thomas J. D'Arcy
William K. Doughty
Alvin C. Ericson
Neil M. Hawkins
Augusto H. Holmberg
L. S. Paul Johal
Jason J. Krohn

Emily B. Lorenz
Kenneth A. Luttrell
Vilas S. Mujumdar
Frank A. Nadeau
Clifford R. Ohlwiler
Lance Osborne
Victor F. Pizano-Thomen
Jose I. Restrepo
Sami H. Rizkalla

Mario E. Rodriguez
Joseph C. Sanders
Edith G. Smith
John F. Stanton
P. Jeffrey Wang
Cloyd E. Warnes
Subcommittee Members
Satyendra Ghosh
Suzanne Dow Nakaki

This Standard defines requirements that may be used to design special hybrid moment frames composed of discretely jointed precast concrete beams post-tensioned to concrete columns. After a major earthquake, these hybrid moment frames should exhibit minimal damage in beam-column regions and negligible permanent displacements. Hybrid moment frames do not satisfy the prescriptive requirements of Chapter 21 of ACI 318-11 for frames of monolithic construction. According to 21.1.1.8 of ACI 318-11, their acceptance requires demonstration by experimental evidence and analysis that the frames have strength and toughness equal to or exceeding those provided by comparable monolithic reinforced concrete frames that satisfy the prescriptive requirements of Chapter 21. This Standard describes the requirements that the licensed design professional may use to demonstrate, through analysis, that such frames have strength and toughness at least equal to those of comparable monolithic frames. This Standard is a revision of the ACI T1.2 Standard.

In this Standard, consistent with the format of ACI 318, the word "Section" is not included before a reference to a section of ACI 318. To more clearly designate a section of this Standard, however, the word "Section" is used before any reference to a section of this Standard. Consistent with the format of ASCE/SEI 7, the word "Section" is also included before a reference to a section of ASCE/SEI 7.

Keywords: drift ratio; earthquake-resistant design; energy dissipation; moment frame; post-tensioning; precast concrete; prestressed concrete; test module; toughness.

CONTENTS

CHAPTER 1—GENERAL, p. 3

- 1.1—Introduction, p. 3
- 1.2—Scope, p. 4
- 1.3—Structural drawings, p. 6
- 1.4—Units, p. 6

CHAPTER 2—NOTATION AND DEFINITIONS, p. 7

- 2.1—Notation, p. 7
- 2.2—Definitions, p. 8

CHAPTER 3—REFERENCED STANDARDS, p. 10

CHAPTER 4—MATERIALS, p. 11

- 4.1—General, p. 11
- 4.2—Ducts, p. 11
- 4.3—Energy-dissipating reinforcement, p. 11
- 4.4—Prestressing strands and tendons, p. 11

ACI 550.3-13 supersedes T1.2-03, was adopted August 8, 2013, and was published November 2013.

Copyright © 2013, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

R4—MATERIALS, p. 11

- 4.5—Interface grout, p. 12
- 4.6—Grout for anchorage of energy-dissipating reinforcement, p. 12

CHAPTER 5—FRAMING SYSTEM REQUIREMENTS, p. 13

- 5.1—General, p. 13
- 5.2—Strength, p. 13
- 5.3—Drift, p. 13
- 5.4—Moment frame characteristics, p. 14
- 5.5—Distribution of moment frames within structures, p. 15
- 5.6—Moment frame-floor slab interactions, p. 16

CHAPTER 6—DESIGN REQUIREMENTS FOR BEAMS OF MOMENT FRAMES, p. 17

- 6.1—Prestress, p. 17
- 6.2—Beam design, p. 17

CHAPTER 7—REQUIREMENTS FOR BEAM-COLUMN INTERFACES OF MOMENT FRAMES, p. 19

- 7.1—General, p. 19
- 7.2—Prestress force, p. 19
- 7.3—Interface grout, p. 19
- 7.4—Energy-dissipating reinforcement, p. 20
- 7.5—Nominal flexural strength, p. 20
- 7.6—Probable flexural strength, p. 20
- 7.7—Anchorage of energy-dissipating reinforcement, p. 23
- 7.8—Distribution of flexural reinforcement, p. 25

CHAPTER 8—FRAME JOINTS, p. 26

- 8.1—General, p. 26

R9—COMMENTARY REFERENCES, p. 27

- Authored references, p. 27

CODE**COMMENTARY****CHAPTER 1—GENERAL****R1—INTRODUCTION AND SCOPE****1.1—Introduction**

For regions of high seismicity, 21.1.1.8 of ACI 318-11 permits the use of structural systems that do not meet the prescriptive requirements of Chapter 21 if certain experimental evidence and analysis are provided. The intent of ACI 374.1 is to define the minimum evidence required when attempting to validate the use of weak-beam, strong-column special moment frames in accordance with 21.1.1.8 of ACI 318-11.

Before acceptance testing can be undertaken, ACI 374.1 requires that a design procedure be developed for prototype moment frames having the generic form for which acceptance is sought, and that procedure be used to proportion the test modules. ACI 550.3-13 defines the requirements to be used for one specific type of moment frame that does not fully satisfy the prescriptive requirements of Chapter 21 of ACI 318-11. This moment frame has been validated for use in regions of high seismicity under ACI 374.1 and ACI 318. The moment frame uses precast concrete beams that are post-tensioned to precast or cast-in-place concrete columns. The columns are continuous through the joints and the beams each span a single bay. This Standard describes the frame as hybrid because it combines post-tensioned and precast concrete construction and combines the use of deformed reinforcement that is designed to yield with unbonded post-tensioning tendons that are designed to remain essentially elastic during the design basis earthquake (DBE).

In this specific type of hybrid frame, the post-tensioning tendons are unbonded. Horizontal reinforcing bars grouted in ducts located in the columns and in the top and bottom of the beams, and described in this Standard as energy-dissipating reinforcement, provide additional continuity between the beams and the columns, and additional moment strength to the beams. Those bars dissipate energy as they yield alternately in tension and compression during an earthquake.

A key feature of this system is that the grouted bars are deliberately debonded for a short distance in the beam adjacent to the beam-column interface to reduce the high cyclic strains that would otherwise occur at that location. Consequently, during an earthquake, the beams and columns displace essentially as rigid bodies with deformations occurring primarily at the beam-column interface as the beam rocks against the column.

A second key feature is that post-tensioning allows the columns to be built without the permanent corbels normally found in precast concrete construction. The post-tensioning has two purposes. First, the friction induced by the post-tensioning transfers vertical shears at the interface between beam and column for both gravity and lateral loadings. Second, with the post-tensioning deliberately designed to remain essentially elastic during the DBE, the post-tensioning forces the moment frame to return to its undeformed position following the DBE.

R1.1—Introduction

Laboratory studies (Stone et al. 1995; Hawkins and Ishizuka 1988; Priestley 1996; Priestley and MacRae 1994; Palmieri et al. 1996; Nakaki et al. 1999; Priestley et al. 1999; Day 1999) have shown that precast or prestressed concrete moment frames can provide safety and serviceability levels, during and after an earthquake, that meet or exceed performance levels required by 21.1.1.8 of ACI 318-11. To achieve such performance levels, the precast or prestressed concrete moment frames should be carefully proportioned and detailed. This Standard is based on the studies reported by Stone et al. (1995), Hawkins and Ishizuka (1988), Priestley and MacRae (1994), Priestley (1996), Nakaki et al. (1999), Priestley et al. (1999), and Day (1999). It contains the minimum requirements for ensuring that one type of precast and prestressed concrete moment frame can sustain a series of oscillations into the inelastic range of response without critical decay in strength or excessive story drifts. Further, that frame should show only minimal or no damage in beam-column joint regions and no permanent displacements after the oscillations cease.

A typical interior frame for this seismic-force-resisting system is illustrated in Fig. R1.1. Details for a vertical longitudinal section of the beam as it passes through the column are shown in Fig. R1.1(b), and details for cross sections of the beam at the column face (Section B) and on the centerline of the column (Section C) are shown in Fig. R1.1(c). The frame is composed of multistory columns to which single-bay precast concrete beams are connected. Except for possible yielding at the column bases, the interfaces between the precast beams and the continuous columns are the only locations where yielding of the reinforcement (nonlinear action location) occurs in the frame during a major earthquake. Crossing each interface are three deliberately debonded reinforcement elements: post-tensioned strands that extend the full length of the frame in the direction of its plane; and top and bottom deformed bar energy-dissipating reinforcement that is anchored by grouting in ducts preformed in the beam and column. The length over which the energy-dissipating reinforcement is debonded in the beam adjacent to the connection is selected deliberately to provide the desired design level of overall performance. Cheok et al. (1996) describes the development of a rational basis for the design procedures for a frame with equal strength for the top and bottom partially debonded energy-dissipating reinforcement and central post-tensioning tendons that remain elastic during a major earthquake. Stanton and Nakaki (2002) describe design guidelines for the same frame system using an iterative step-by-step procedure and displacement-based design procedures. Hawileh et al. (2006) provide nondimensional, noniterative, simplified design procedures for that same system for either displacement-based or force-based design procedures. Where force-based design procedures are used,

CODE**COMMENTARY**

Under earthquake loading, the special moment frames described in this Standard are intended to behave differently than monolithic frames. Most of the deformations of the frames occur from the opening and closing of the joint at the interface between the precast beam and the column. Consequently, with the detailing procedures described in this Standard, damage during a major earthquake is limited in extent, confined essentially to the joint filler material, and is readily repairable after the earthquake. By contrast, monolithic frames designed to Chapter 21 of ACI 318-11 can suffer significant cracking, crushing, and spalling in the plastic hinging regions of the beam, the beam-column joint, or both, and repair can be costly. Further, monolithic special moment frames designed to Chapter 21 of ACI 318-11 may show permanent lateral deformations following a DBE, whereas the special moment frames described in this Standard do not.

The preceding paragraphs define the key characteristics of hybrid frames. The detailing requirements described in this Standard are for one specific type of special hybrid moment frame with:

- a) Equal moment strengths for the top and bottom energy-dissipating reinforcing bars that cross the interface between the precast beam and column;
- b) Post-tensioning tendons that are unbonded from anchor to anchor and concentrically located within the cross section of the beam.

Special moment frames with unequal moment strengths for the top and bottom energy-dissipating reinforcing bars, and with amounts, location, and bonding of the post-tensioning tendons that differ from those described in this Standard, can be proportioned to have performance characteristics similar to the frames described in this Standard. However, research investigations additional to those completed to date, and modifications of the requirements described in this Standard, are needed before prescriptive provisions for the design of such frames can be formulated.

1.2—Scope

1.2.1 This Standard defines requirements for a certain type of hybrid special moment frame composed of precast concrete beams jointed at their connections to columns that are continuous past those joints. Whereas these frames do not satisfy all of the prescriptive requirements of 21.5 through 21.7 of ACI 318-11, analyses, tests, and reporting requirements in accordance with ACI 374.1 have established dependable and predictable strength, energy dissipation, stiffness, and drift capacities for characteristic beam-column configurations of the frames described in this Standard. Such special moment frames are permitted for structures assigned to SDC D, E, or F in accordance with 21.8.4 of ACI 318-11.

1.2.2 The intended user of this Standard is a licensed design professional experienced in earthquake-resistant design and precast concrete design and construction.

ASCE/SEI 7 and ACI 318-11 in combination permit the use of R , C_d , and Ω_o values for special hybrid moment frames designed in accordance with this Standard, which are the same as the R , C_d , and Ω_o values for monolithic cast-in-place moment frames designed in accordance with 21.5 through 21.7 of ACI 318-11.