

ACI T1.2M-03
ACI T1.2RM-03

**Special Hybrid Moment Frames
Composed of Discretely Jointed
Precast and Post-Tensioned
Concrete Members (T1.2M-03) and
Commentary (T1.2RM-03)**

Reported by ACI Innovation Task Group 1
and Collaborators



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Special Hybrid Moment Frames Composed of Discretely Jointed Precast and Post-Tensioned Concrete Members

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**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

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Special Hybrid Moment Frames Composed of Discretely Jointed Precast and Post-Tensioned Concrete Members

An ACI Standard

Reported by ACI Innovation Task Group 1 and Collaborators

Innovation Task Group 1

Norman L. Scott
Chair

Neil M. Hawkins
Secretary

Michael E. Kreger

James R. Libby

Robert F. Mast

Leslie D. Martin

Collaborators

Geraldine S. Cheok

Suzanne Nakaki

John F. Stanton

S. K. Ghosh

M. J. Nigel Priestley

Dean E. Stephan

H. S. Lew

Joseph C. Sanders

William C. Stone

David C. Seagren*

*Deceased.

This document defines requirements that may be used to design special hybrid moment frames composed of discretely jointed precast concrete beams post-tensioned to concrete columns. Such frames are suitable for use in regions of high seismicity or for structures assigned to satisfy high seismic performance or design categories. After a major seismic event, that moment frame can be expected to exhibit minimal damage in beam-column regions and negligible permanent displacements. Such moment frames do not satisfy the prescriptive requirements of Chapter 21 of ACI 318M-99 for frames of monolithic construction. According to Section 21.2.1.5 of ACI 318M, 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 document describes the requirements that the designer may use to demonstrate, through analysis, that such frames have strength and toughness at least equal to those of comparable monolithic frames.

Among the subjects covered in this standard are requirements for:

- 1. Materials, and especially the special reinforcement that is debonded in the beam adjacent to the beam-column interface;*
- 2. The framing system, and especially the roles of the post-tensioning tendons, the special reinforcement, and the floor slab; and*
- 3. The beams of the moment frame, and especially their required prestress force level, the contribution of the special reinforcement to their probable moment strength, and the calculation of that strength.*

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The commentary describes some of the issues addressed by the Innovation Task Group and Collaborators in developing the standard.

The commentary references documentary evidence, additional to the references of ACI T1.1R-01 and Chapter 21 of ACI 318RM, that supports this standard. No comparison is made, however, either within the body of this standard or in its commentary, of the performance of test modules satisfying the prescriptive requirements of ACI 318M with modules that, although not satisfying the prescriptive requirements of ACI 318M, satisfy this standard. Such comparisons, both experimental and analytical, are available in the references cited in the commentary.

Keywords: drift ratio; energy dissipation; hybrid construction; lateral resistance; moment frame; post-tensioning; precast concrete; prestressed concrete; seismic design; test module; toughness.

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- 7.1—General

1.0—Introduction

1.1 Foreword—For regions of high seismicity, Section 21.2.1.5 of ACI 318M 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 T1.1-01/T1.1R-01, “Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary,” is to define the minimum evidence required when attempting to validate the use of weak-beam strong-column special moment frames in accordance with Section 21.2.1.5.

Before acceptance testing can be undertaken, ACI T1.1-01 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 T1.2-03 defines the requirements to be used for one specific type of moment frame that does not satisfy the prescriptive requirements of Chapter 21 of ACI 318M, but can be validated for use in regions of high seismicity under ACI T1.1-01. 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 a hybrid frame because it combines post-tensioned and precast concrete construction and because it combines the use of ordinary reinforcement

that is designed to yield with unbonded post-tensioning tendons that are designed to remain elastic.

In this specific type of hybrid frame, the post-tensioning tendons are unbonded and designed to remain elastic during an earthquake. Horizontal reinforcing bars grouted in ducts located in the columns and in the top and bottom of the beams, and described in this document as special 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 in order 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 the 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 elastic during a major seismic event, the post-tensioning forces the moment frame to return to its undeformed position following the event.

Under seismic loading, the special moment frames described in this document 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 seismic event is limited in extent, confined essentially to the joint filler material, and can be readily repaired after the earthquake. By contrast, monolithic frames designed to Chapter 21 of ACI 318M 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 318M may show permanent lateral deformations following a major seismic event whereas the special moment frames described in this document should not.

The preceding five 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 strength for the top and bottom energy-dissipating reinforcing bars that cross the interface between the precast beam and column; and
- (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 strength 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 document, can be proportioned to have performance characteristics similar to the frames described in this document. However, research investigations additional to those completed to date, and modifications of the requirements described in this document, are needed before prescriptive provisions for the design of such frames can be formulated.

Development of the frame described in this standard was made possible by the combined efforts of the National Institute for Standards and Technology (NIST); the University of California, San Diego; the University of Washington, Seattle; and the University of Illinois at Urbana-Champaign; the American Concrete Institute (ACI); the Precast/Prestressed Concrete Institute (PCI); numerous dedicated individuals; and the financial support of Charles Pankow Builders, Ltd., ACI's Concrete Research and Education Foundation, and Dywidag Systems International.

1.2 Scope

1.2.1 This document defines requirements for a certain type of special hybrid moment frame composed of precast concrete beams jointed at their connections to columns that are continuous past those joints. While these frames do not satisfy all of the prescriptive requirements of Sections 21.3 through 21.5 of ACI 318M, analyses and tests and reporting requirements in accordance with ACI T1.1-01 have established dependable and predictable strength, energy dissipation, stiffness, and drift capacities for characteristic beam-column configurations of the frames described in this document.

1.2.2 The requirements described in this document are for special hybrid moment frames with:

1. Equal moment strength for the top and bottom energy-dissipating bars (special reinforcement) that cross the interface between the precast beam and column; and
2. Post-tensioning tendons that are unbonded from anchor to anchor and concentrically located within the cross section of the beam.

1.2.3 All precast and reinforced concrete components and systems for the moment frames, and the associated gravity load frames, shall be designed to satisfy the requirements of ACI 318M except as modified by this document.

1.2.4 The special inspection requirements of Section 1.3.5 of ACI 318M shall be satisfied for all precast and reinforced concrete components and systems for the special moment frames.

2.0—General

2.1 Notation

- A_j = effective cross-sectional area within a joint, mm²; Section 21.5.3.1 of ACI 318M
- A_{ps} = area of post-tensioning tendons crossing beam-column interface, mm²
- A_s = area of special top reinforcement crossing beam-column interface, mm²
- A'_s = area of special bottom reinforcement crossing beam-column interface, mm²
- A_{vc} = area of closed hoops or spirals within a distance s_{vc} , mm²

- b = width of compression face of precast beam, mm
- C = compression force when probable flexural strength M_{pr} acts at interface, N
- c = distance from extreme compression fiber of grout pad to neutral axis at beam-column interface, mm
- d = distance from extreme compression fiber of grout pad at interface to centroid of special tension reinforcement, mm
- d_b = bar diameter of special reinforcement, mm
- E = load effects of earthquakes, or related internal moments and forces
- f'_c = specified compressive strength of concrete, MPa
- f_{prs} = stress in post-tensioning tendons when stress in special reinforcement is f_u , MPa
- f_{pu} = specified tensile strength of post-tensioning tendons, MPa
- f_{py} = specified yield strength of post-tensioning tendons, MPa
- f_{se} = effective stress in post-tensioning tendons (after allowance for all prestress losses), MPa
- f_u = specified tensile strength of special reinforcement crossing beam-column interface, MPa
- f_{vcy} = specified yield strength of closed hoops or spirals, MPa
- f_y = specified yield strength of special reinforcement, MPa
- h = overall thickness of the precast beam of a moment frame, mm
- h_p = dimension of a column in the direction of the post-tensioning tendon, mm
- ℓ_d = development length in tension for a straight deformed reinforcing bar, mm
- L_{clear} = clear span measured face-to-face of columns, mm
- L_u = length over which special reinforcement crossing beam-column interface is deliberately debonded, mm
- L_{ups} = length associated with a given interface over which post-tensioning tendon is unbonded, mm
- M_{pr} = probable flexural strength at a beam-column interface of a precast concrete beam of moment frame, N-mm
- M_{prs} = contribution of post-tensioning reinforcement to M_{pr} , N-mm
- M_s = contribution of special reinforcement to M_{pr} , N-mm
- N_u = effective post-tensioning force, $A_{ps}f_{se}$, N
- s_{vc} = spacing of transverse reinforcement surrounding special reinforcement development length, mm
- V_c = nominal shear strength provided by concrete, N
- V_D = shear force due to unfactored dead load, N
- V_L = shear force due to unfactored live load, N
- V_n = nominal shear strength, N
- V_u = factored shear force at section, N
- α_b = coefficient quantifying the effective additional debonded length for special reinforcement at probable flexural strength
- β_1 = factor defined in Section 10.2.7.3 of ACI 318M
- Δ_{prs} = elongation of post-tensioning tendon at probable flexural strength, mm
- Δ_s = elongation of special reinforcement at probable flexural strength, mm
- ϵ_f = strain in special reinforcement at its fracture

ϵ_{prs} = strain in post-tensioning tendon when stress in special reinforcement is f_u
 ϵ_{se} = strain in post-tensioning tendon due to effective prestress only (after allowance for all losses)
 ϵ_{su} = strain in special reinforcement at elongation Δ_s
 ϵ_u = strain in special reinforcement at its tensile strength f_u
 ϕ = strength reduction factor
 λ = overstrength factor for column
 μ = coefficient of friction
 θ_m = maximum inelastic response drift ratio capacity

2.2 Definitions

The following definitions, additional to those of Section 21.1 of ACI 318M and of ACI T1.1-01, shall apply:

Nonlinear action location—Interface where end of precast beam of moment frame meets column face.

Reinforcement, ordinary—Reinforcement conforming to Section 3.5 of ACI 318M, excluding prestressing tendons.

Reinforcement, prestressing—Post-tensioned tendons that cross the interface between precast beam and column and conform to [Section 3.4](#).

Reinforcement, seismic—Reinforcement that conforms to Section 21.2.5 of ACI 318M.

Reinforcement, special—Reinforcement (nonprestressed) that crosses the interface between the precast beam and the column, is debonded for a specified length in the beam adjacent to the beam-column interface and conforms to [Section 3.3](#).

2.3 Drawings—Drawings of the moment frames shall show all features of the work, including those details essential for satisfactory seismic performance of the frame. Essential details include: debonding the special reinforcement that crosses beam-column interfaces; anchoring the special reinforcement and tendons within beams and columns; and developing floor slab-frame interactions that conform to those assumed in the design documents.

2.4 Referenced standards

American Concrete Institute (ACI)

318M-99 Building Code Requirements for Structural Concrete

T1.1-01 Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary

ASTM International

A 370-96 Test Methods and Definitions for Mechanical Testing of Steel Products

A 416-96 Standard Specification for Steel Strand, Uncoated Seven Wire for Prestressed Concrete

A 706-96 Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

C 1107-97 Specification for Packaged Dry, Hydraulic Cement Grout (Nonshrink)

International Building Council (IBC)

IBC 2000 International Building Code

These publications may be obtained from these organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428

International Code Council
5203 Leesburg Pike, Suite 708
Falls Church, VA 22041-3401

3.0—Materials

3.1 General—All materials and material tests shall conform to the requirements of ACI 318M except as specified in this standard.

3.2 Ducts—Ducts, including those for special reinforcement, shall conform to the requirements of ACI 318M, Section 18.17.

3.3 Special reinforcement

3.3.1 Special reinforcement shall have rib deformation heights, yield strength, and an ultimate elongation equal to or exceeding those required by ASTM A 706.

3.3.2 Unless specific test data on the stress-strain properties of the special reinforcement are obtained before design and construction, the stress-strain properties shall conform to ASTM A 706. For that latter case, the tensile strength shall be taken as the specified minimum tensile strength f_u . The strain ϵ_u at the tensile strength shall be taken as a strain 0.02 less than the strain at the minimum elongation specified in ASTM A 706 for the given bar size.

3.3.3 Where properties are based on test data as permitted by Section 3.3.2, the stress-strain properties of the special reinforcement for each bar size used in the moment frame shall be obtained from tension tests specified in ASTM A 706. The average strain ϵ_u of that reinforcement at its average tensile strength f_u shall be obtained. Averages shall be based on the results of a minimum of three tension tests for each bar size for every steel heat used for the moment frame.

3.4 Prestressing strands and tendons

3.4.1 In moment frames meeting the requirements of this document, post-tensioned prestressing strand tendons shall be used at nonlinear action locations, and pretensioned prestressing reinforcement shall be permitted in precast concrete flexural members.

3.4.2 Prestressing strand shall conform to ASTM A 416.

3.4.3 Prestressing strands shall be permitted to resist earthquake-induced forces, provided the strain in the strands does not exceed 0.011 at the limiting drift ratio of 0.035 specified in ACI T1.1-01.

3.4.4 Anchorages shall withstand, without failure, a minimum of 50 cycles of a loading for which the load in each cycle is varied between 40 and 80% of the minimum specified tensile strength of the prestressing strand or the post-tensioning tendon.