

Acceptance Criteria for Moment Frames Based on Structural Testing (ACI 374.1-05) and Commentary

An ACI Standard

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This document defines the minimum experimental evidence deemed adequate to validate the use, in regions of high seismic risk or in structures assigned to satisfy high seismic performance or design categories, of weak beam/strong column moment frames not in conformance with Chapter 18 of ACI 318-14. This document consists of both a Standard and a Commentary that is not part of the ACI 318-14 Standard and Commentary. The document

ACI Committee 374 adopted ACI T1.1/T1.1R-01 as ACI 374.1-05 on October 12, 2005. ACI T1.1/T1.1R-01 superseded ACI ITG/T1.1-99 and became effective March 9, 2001.

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has been written in such a form that its various parts can be adopted directly into Sections 2, 3, 18.1, and 18.2 of ACI 318-14 and the corresponding sections of the Commentary of ACI 318-14. Among the subjects covered are requirements for: procedures that shall be used to design test modules; configurations for those modules; test methods; test reports; and determination of satisfactory performance.

The Commentary describes some of the considerations of the Innovation Task Group (1) in developing this Standard. The section numbering for the Commentary is the same as that for the Standard, with numbers preceded by an "R" and the text in italics to distinguish them from the corresponding section numbers of the Standard.

The Commentary references documentary evidence, additional to the references of Chapter 18 of the ACI 318-14 Commentary, that supports this Standard. Consistent with the approach of ACI 318-14, no comparison is made between research results for test modules conforming to ACI 318-14 with those for modules that, although not conforming to ACI 318-14, do conform to this Standard. Such comparisons, both experimental and analytical, are available in the references of the Commentary.

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

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INTRODUCTION

For seismic design, 18.2.1.7 in ACI 318-14 specifies 18.2.1.7 that "a reinforced concrete structural system not satisfying this chapter shall be permitted if it is demonstrated by experimental evidence and analysis that the proposed system will have strength and toughness equal to or exceeding those provided by a comparable reinforced concrete structure satisfying this chapter." This Standard defines the minimum experimental evidence that shall be provided in order to validate the use, in regions of high seismic risk or for structures assigned to satisfy high seismic performance or design categories, of a weak beam/strong column moment frame not conforming to the requirements of Chapter 18 of ACI 318-14.

Consistent with the ACI 318-14 requirement for analysis, this Standard specifies that, before the testing mandated by the Standard, a design procedure shall have been developed for prototype frames having the generic form for which acceptance is sought and that design procedure shall be used to

proportion the test modules. Further, the Standard assumes that the prototype frames have forms that are essentially regular, having no significant physical discontinuities in plan or in vertical configuration or in their lateral-force-resisting systems, and that the frames conform to some, but not all, of the requirements of ACI 318-14, Chapter 18. Such frames might, for example, involve use of precast elements, precast-prestressed elements, post-tensioned reinforcement, or combinations of those elements and reinforcement. Prescriptive requirements for moment frames constructed with such elements are not included in ACI 318-14. Such frames might also, for example, use alternate methods, other than those specified in Chapter 18, for force transfer through beam-column joints.

The provisions of this Standard are intended to supplement the provisions of Chapter 18 of ACI 318-14 and not to supplant them.

1.0—Notation

Only notation additional to that in ACI 318-14 is defined.

E_{max} = maximum lateral resistance of test module determined from test results (forces or moments)

E_n = nominal lateral resistance of test module determined using specified geometric properties of test members, specified yield strength of reinforcement, specified compressive strength of concrete, a strain compatibility analysis for flexural moment strength, and a strength reduction factor ϕ of 1.0

E_{pr} = probable lateral resistance of test module determined using actual geometric and material properties of test members, an analysis for probable flexural moment strength of beams based on strain compatibility and including strain-hardening effects in the reinforcement, and a strength reduction factor ϕ of 1.0

λ = column overstrength factor used for test module

θ = drift ratio

β = relative energy dissipation ratio

R1.0—Notation

Only symbols used in this Commentary that are additional to those in Section 2.1 of ACI 318-11 and ACI T1.1-01 are defined in the following:

A_h = area of hysteresis loop

E_1, E_2 = peak lateral resistance for positive, negative, loading for third cycle of loading sequence

f_l = factor on live load defined in R2.6

h = height of column of test module, in. or mm

K, K' = initial stiffness for positive, negative, loading for first cycle

θ_1, θ_2 = drift ratios at peak lateral resistance for positive, negative, loading for third cycle of loading sequence

θ'_1, θ'_2 = drift ratios for zero lateral load for unloading at stiffnesses K, K' from peak positive, negative, lateral resistance for third cycle of loading sequence (Fig. R2.4)

Δ = lateral displacement, in. or mm. See Fig. R2.1

Δ_a = allowable story drift, in. or mm. See Table 12.12-1 of ASCE/SEI 7-10

2.0—Terminology

2.1 Drift ratio—Angular rotation under load of the column chord of the test module with respect to the beam chord, where the chords are the straight lines connecting the centroidal axes of the points of contraflexure in the beam and the column, respectively, or the centroidal axis at the point of contraflexure to the centroid of the beam-column joint in the case where a member extends on one side of the joint only.

R2.1 Where a column exists on both sides of the joint, its chord is defined by the line joining the loading (or support) points. The same is true for a beam that exists on both sides of the joint. If a column or beam exist on one side of the joint only, then the chord is defined by the line joining the end loading (or support) point and the joint centerline.

The drift ratio θ concept is illustrated in Fig. R2.1 for an exterior column-beam module. The position of the module at the start of testing, with its self-weight only acting, is indicated by broken lines. The module is pin supported at A and roller supported at D. The self weight is taken by vertical reactions V_{AD} and V_{DD} . That weight, however, also causes a twisting about the centroid B of the joint so that opposing horizontal reactions, H_{AD} and H_{CD} , develop. Under self weight alone, the pin at C must be constrained to lie on the centroidal axis of the column that passes from C through B to A. That chord is the vertical reference line for drift measurements. The setup also constrains the chord joining the centroid of the joint B and the centroid of the section at D to be horizontal.

For acceptance testing, a lateral force H_{CE} is applied to the column through the pin at C and results in the specimen taking up the deformed shape indicated by solid lines. The lateral force causes reactions H_{AL} at A and V_{DL} at D. The column at C displaces laterally by an amount Δ . The chord defining the reference axis for the beam, however, remains horizontal. The drift ratio is the angular rotation of the column chord with respect to the beam chord and for the setup shown equals Δ/h where h is the column height and equal to the distance between the pin at A and that at C.

2.2 Moment frame—Space frame in which members and joints resist forces through flexure, shear and axial force.

2.3 Overstrength factor—Ratio of the sum of the nominal flexural strengths of the columns at their interfaces with the joint to the sum of the nominal flexural moment strengths of the beams at their interfaces with the same joint.

R2.3 The column overstrength factor λ should be selected so that λE_n is greater than the probable lateral resistance E_{pr} . It is to be expected that the maximum lateral resistance of the test module E_{max} should be similar to E_{pr} . In 18.7.3.2 of ACI 318-14, the ratio of the sum of the moments at the faces of the joint, corresponding to the nominal flexural strengths of the columns framing into that joint, to the sum of the moments at the faces of the joint, corresponding to the nominal flexural strengths of the beams framing into that same joint, must exceed 1.2. Further, in T-beam construction, where the slab is under tension under moments at the face of

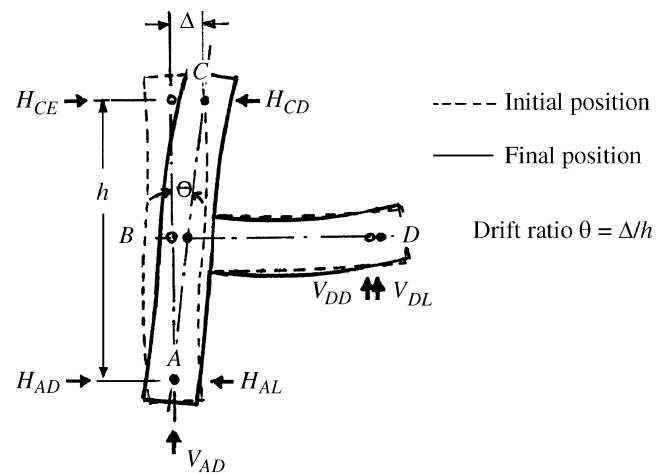


Fig. R2.1—Deformations of exterior column-beam test mod-

the joint, slab reinforcement within an effective width defined in 6.3.2 of ACI 318-14 must be assumed to contribute to the flexural strength if the slab reinforcement is developed at the critical section for flexure. Hence the λ specified here is a comparable quantity to, but is not the same quantity as, the 1.2 value specified in ACI 318-14. For application of this Standard, the column overstrength factor is to be specified in the design procedure and, when the contribution of the reinforcement in the slab is considered, the requirement of 18.7.3.2 of ACI 318-14 must be met. There is, however, no requirement to provide a slab on the test module.

Moment strengths should take into account simultaneous application of axial force and direction of loading. The axial forces on the beam and the column should be those causing the largest and the smallest moment strength possible, respectively. Most beams, however, will have zero axial force and for most columns the smallest strength will also be for zero axial force. Directional effects require that the sign of any column axial force and beam bending moments be consistent. For example, for an end joint, column tension effects need only be considered in combination with beam positive moment strength.

Where prestressing steel is used in frame members the stress f_{ps} in the reinforcement at nominal and probable lateral resistance shall be calculated in accordance with 20.3.2 and 22.3.2 of ACI 318-14.

2.4 Relative energy dissipation ratio—Ratio of actual to ideal energy dissipated by test module during reversed cyclic response between given drift ratio limits, expressed as the ratio of the area of the hysteresis loop for that cycle to the area of the circumscribing parallelograms defined by the initial stiffness during the first cycle and the peak resistance during the cycle for which the relative energy dissipation ratio is calculated. See 9.1.3.

R2.4 The relative energy dissipation ratio concept is illustrated in Fig. R2.4 for the third cycle to the drift ratio of 0.035. For Fig. R2.4, it is assumed that the test module has exhibited different initial stiffnesses, K and K' , for positive and negative lateral forces and that it produced peak resistances for the third cycle for the positive and negative