ACI 369.1M-17

An ACI Standard

Standard Requirements for Seismic Evaluation and Retrofit of Existing Concrete Buildings (ACI 369.1M-17) and Commentary

Reported by ACI Committee 369

American Concrete Institute
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Reported by Committee 369

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PREFACE

This standard provides retrofit and rehabilitation criteria for reinforced concrete buildings based on results from the most recent research on the seismic performance of existing concrete buildings. The intent of this standard is to provide a continuously updated resource document for modifications to Chapter 10 of ASCE 41-17, similar to how the National Earthquake Hazards Reduction Program (NEHRP) Recommended Seismic Provisions produced by the Federal Emergency Management Agency (FEMA) (FEMA 450) have served as source documents for the International Building Code (IBC) and its predecessor building codes. Specifically, this version of ACI 369.1M serves as the basis for Chapter 10, "Concrete," of ASCE 41-17.

This standard should be used in conjunction with Chapters 1 through 7 of ASCE 41-17. Chapter 1 of ASCE 41-17 provides general requirements for evaluation and retrofit, including the selection of performance objectives and retrofit strategies. Chapter 2 of ASCE 41-17 defines performance objectives and seismic hazards. Chapter 3 of ASCE 41-17 provides the requirements for evaluation and retrofit, including treating as-built information and selecting the appropriate screening procedures. Chapter 4 of ASCE 41-17 summarizes Tier 1 screening procedures, while Chapters 5 and 6 summarize Tier 2 deficiency-based procedures and Tier 3 systematic procedures for evaluation and retrofit, respectively. Chapter 7 of ASCE 41-17 details analysis procedures referenced in ACI 369.1M, including linear and nonlinear analysis procedures, acceptance criteria, and alternative methods for determining modeling parameters and acceptance criteria. Chapter 8 of ASCE 41-17 provides geotechnical engineering provisions for building foundations and assessment of seismic-geologic site hazards. References to these chapters can be found throughout the standard. The design professional is referred to FEMA 547 for detailed information on seismic rehabilitation measures for concrete buildings. Repair techniques for earthquake-damaged concrete components are not included in ACI 369.1M. The design professional is referred to FEMA 306, FEMA 307, and FEMA 308 for information on evaluation and repair of damaged concrete wall components.

This standard does not provide modeling procedures, acceptance criteria, and rehabilitation measures for concrete-encased steel composite components. Future versions will provide provision updates for concrete moment frames and will add provisions for concrete components and systems omitted in the present version of the standard.

ACI 369.1M-17 was adopted September 22, 2017, and published February 2018.

CONTENTS

INTRODUCTION

Earthquake reconnaissance has clearly demonstrated that existing concrete buildings designed before the introduction of seismic design codes in the 1980s are more vulnerable to severe damage or collapse when subjected to strong ground motion than concrete buildings built after that period. Seismic rehabilitation of existing buildings where new components are added or existing components are modified or retrofitted with new materials, or both, can be used to mitigate the risk to damage in future earthquakes. Seismic rehabilitation is encouraged not only to reduce the risk of damage and injury in future earthquakes, but also to extend the life of existing buildings and reduce using new materials in the promotion of sustainability objectives.

It is not possible to codify all problems encountered in the process of performing the seismic evaluation and retrofit of reinforced concrete buildings, nor is the intent of the standard to do so. The standard provides a basic framework for modeling and evaluation of structures that reflects the latest information available from researchers and practicing engineers, so that seismic evaluation and retrofit can be performed with a consistent set of criteria. Many provisions in the standard rely on the use of sound engineering judgement for their implementation. The commentary of the standard provides references that describe in detail the implementation of methodologies adopted in the standard.

Keywords: acceptance criteria; building; deformation-controlled; dynamic analysis; earthquake; force-controlled; modeling parameters; nonlinear analysis; retrofit; seismic evaluation.

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STANDARD

CHAPTER 1—GENERAL

1.1—Scope

This standard sets forth requirements for the seismic evaluation and retrofit of concrete components of the seismic-force-resisting system of an existing building. These building standard requirements apply to existing concrete components, retrofitted concrete components, and new concrete components. Provisions of this standard do not apply to concrete-encased steel composite components.

Chapter 2 specifies data collection procedures for obtaining material properties and performing condition assessments. Chapter 3 provides general analysis and design requirements for concrete components. Chapters 4 through 9 provide modeling procedures; component strengths; acceptance criteria and retrofit measures for cast-in-place and precast concrete moment frames; concrete frames with masonry infills; cast-in-place and precast concrete structural walls; and concrete braced frames. Chapters 10 through 12 provide modeling procedures, strengths, acceptance criteria, and retrofit measures for concrete diaphragms and concrete foundation systems.

COMMENTARY

C1.1—Scope

These standard requirements were developed based on the best knowledge of the seismic performance of existing concrete buildings at the time of publication. These requirements are not intended to restrict the licensed design professional from using new information that becomes available before the issuance of the next edition of this standard. Such new information can include tests conducted to address specific building conditions.

This standard provides short descriptions of potential seismic retrofit measures for each concrete building system. The licensed design professional, however, is referred to FEMA 547 for detailed information on seismic retrofit measures for concrete buildings. Repair techniques for earthquake-damaged concrete components are not included in this standard. The licensed design professional is referred to FEMA 306, FEMA 307, and FEMA 308 for information on evaluation and repair of damaged concrete wall components.

Concrete-encased steel composite components behave differently from concrete sections reinforced with steel reinforcement. Concrete-encased steel composite components frequently behave as over-reinforced sections. This type of component behavior was not represented in the data sets used to develop the force-deformation modeling relationships and acceptance criteria in this standard, and is not covered in this standard. Concrete encasement is often provided for fire protection rather than for strength or stiffness and typically lacks transverse reinforcement. In some cases, the transverse reinforcement does not meet detailing requirements in AISC 360. Lack of adequate confinement can result in lateral expansion of the core concrete, which exacerbates bond slip and undermines the fundamental principle that plane sections remain plane.

Testing and analysis used to determine acceptance criteria for concrete-encased steel composite components should include the effect of bond slip between steel and concrete, confinement ratio, confinement reinforcement detailing, kinematics, and appropriate strain limits.

To preserve historic buildings, exercise care in selecting the appropriate retrofit approaches and techniques for application.

STANDARD

CHAPTER 2—MATERIAL PROPERTIES AND CONDITION ASSESSMENT

2.1—General

Mechanical properties of materials shall be obtained from available drawings, specifications, and other documents for the existing building in accordance with the requirements of ASCE 41-17, 3.2. Where these documents fail to provide adequate information to quantify material properties, such information shall be supplemented by materials testing based on requirements of Chapter 2. Material properties of existing concrete components shall be determined in accordance with 2.2. The use of default material properties based on historical information is permitted in accordance with 2.2.5. A condition assessment shall be conducted in accordance with 2.3. The extent of materials testing and condition assessment performed shall be used to determine the knowledge factor as specified in 2.4.

COMMENTARY

C2.1—General

Chapter 2 identifies properties requiring consideration and provides requirements for determining building properties. Also described is the need for a thorough condition assessment and use of knowledge gained in analyzing component and system behavior. Personnel involved in material property quantification and condition assessment should be experienced in the proper implementation of testing practices and the interpretation of results.

When modeling a concrete building, it is important to investigate local practices relative to seismic design. Specific benchmark years can be determined for the implementation of earthquake-resistant design in most locations, but caution should be exercised in assuming optimistic characteristics for any specific building. Particularly with concrete materials, the date of original building construction significantly influences seismic performance. Without deleterious conditions or materials, concrete gains compressive strength from the time it is originally cast and in place. Strengths typically exceed specified design values (28-day or similar). In older construction, concrete strength was often very low (less than 21 MPa) and it was rarely specified in the drawings. Early adoptions of concrete in buildings often used steel reinforcement with relatively low strength and ductility, limited continuity, and reduced bond development. Continuity between specific existing components and elements, such as beams, columns, diaphragms, and shear walls, can be particularly difficult to assess because of concrete cover and other barriers to inspection.

Properties of welded wire reinforcement for various periods of construction can be obtained from the Wire Reinforcement Institute (2009).

Documentation of the material properties and grades used in component and connection construction is invaluable and can be effectively used to reduce the amount of in-place testing required. The licensed design professional is encouraged to research and acquire all available records from original construction, including photographs, to confirm reinforcement details shown on the plans.

Further guidance on the condition assessment of existing concrete buildings can be found in the following:

a) ACI 201.1R, which provides guidance on conducting a condition survey of existing concrete structures

b) ACI 364.1R, which describes the general procedures used for the evaluation of concrete structures before retrofit

c) ACI 437R, which describes methods for strength evaluation of existing concrete buildings, including analytical and load test methods

2.2—Properties of in-place materials and components

2.2.1 *Material properties*

C2.2—Properties of in-place materials and components

C2.2.1 *Material properties*

STANDARD

2.2.1.1 *General*—The following component and connection material properties shall be obtained for the as-built structure:

a) Concrete compressive strength

b) Yield and ultimate strength of nonprestressed and prestressed steel reinforcement, cast-in-place and post-installed anchors, and metal connection hardware

Where materials testing is required by ASCE 41-17, 6.2, the test methods to quantify material properties shall comply with the requirements of 2.2.3. The frequency of sampling, including the minimum number of tests for property determination, shall comply with the requirements of 2.2.4.

2.2.1.2 *Nominal or specified properties*—Nominal material properties, or properties specified in construction documents, shall be taken as lower-bound material properties. Corresponding expected material properties shall be calculated by multiplying lower-bound values by a factor taken from Table 1 to translate from lower-bound to expected values. Alternative factors shall be permitted where justified by test data.

Table 1—Factors to translate lower-bound material properties to expected strength material properties

Material property	Factor
Concrete compressive strength	1.50
Steel reinforcement tensile and yield strength	1.25
Connector steel yield strength	1.50

2.2.2 *Component properties*—The following component properties and as-built conditions shall be established:

a) Cross-sectional dimensions of individual components and overall configuration of the structure

b) Configuration of component connections, size, embedment depth, type of anchors, thickness of connector material, anchorage and interconnection of embedments, and the presence of bracing or stiffening components

COMMENTARY

C2.2.1.1 *General*—Other material properties and conditions of interest for concrete components include:

a) Tensile strength and modulus of elasticity of concrete

b) Ductility, toughness, and fatigue properties of concrete

c) Carbon equivalent present in the steel reinforcement

d) Presence of any degradation such as corrosion or deterioration of bond between concrete and reinforcement

The extent of effort made to determine these properties depends on availability of accurate, updated construction documents and drawings; construction quality and type; accessibility; and material conditions. The analysis method selected—for example, linear static procedure (LSP) or nonlinear static procedure (NSP)—might also influence the testing scope. Concrete tensile strength and modulus of elasticity can be estimated based on the compressive strength and may not warrant the damage associated with any extra coring required.

The sample size and removal practices followed are referenced in FEMA 274, C6.3.2.3 and C6.3.2.4. ACI 228.1R provides guidance on methods to estimate the in-place strength of concrete in existing structures, whereas ACI 214.4R provides guidance on coring in existing structures and interpretation of core compressive strength test results. Generally, mechanical properties for both concrete and steel reinforcement can be established from combined core and specimen sampling at similar locations, followed by laboratory testing. Core drilling should minimize damage to the existing steel reinforcement.

C2.2.2 *Component properties*—Component properties are required to properly characterize building performance in seismic analysis. The starting point for assessing component properties and condition is retrieval of available construction documents. A preliminary review should identify primary gravity and seismic-force-resisting elements and systems and their critical components and connections. If there are no drawings of the building, the licensed design professional should perform a thorough investigation of the

STANDARD

c) Modifications to components or overall configuration of the structure

d) Most recent physical condition of components and connections, and the extent of any deterioration

e) Deformations beyond those expected because of gravity loads, such as those caused by settlement or past earthquake events

f) Presence of other conditions that influence building performance, such as nonstructural components that can interact with structural components during earthquake excitation

2.2.3 *Test methods to quantify material properties*

2.2.3.1 *General*—Destructive and nondestructive test methods used to obtain in-place mechanical properties of materials identified in 2.2.1 and component properties identified in 2.2.2 are specified in this section. Samples of concrete, reinforcement, and connector steel shall be examined for physical condition, as specified in 2.3.2.

When determining material properties with the removal and testing of samples for laboratory analysis, sampling shall take place in primary gravity and seismic-force-resisting components in regions with the least stress.

Where 2.2.4.2.1 does not apply and the coefficient of variation is greater than 20 percent, the expected concrete strength shall not exceed the mean less one standard deviation.

2.2.3.2 *Sampling*—For concrete material testing, the sampling program shall include the removal of standard cores. Core drilling shall be preceded by nondestructive location of the steel reinforcement, and core holes shall be located to avoid damage to or drilling through the steel reinforcement. Core holes shall be filled with concrete or grout of comparable strength having nonshrinkage properties. If nonprestressed steel reinforcement is tested, sampling shall include removal of local bar segments and installation of replacement spliced material to maintain continuity of the reinforcing bar for transfer of bar force unless an analysis confirms that replacement of the original components is not required.

Removal of core samples and performance of laboratory destructive testing shall be permitted to determine existing concrete strength properties. Removal of core samples shall use the procedures included in ASTM C42/C42M. Testing shall follow the procedures contained in ASTM C42/C42M, ASTM C39/C39M, and ASTM C496/C496M. Core strength shall be converted to in-place concrete compressive strength by an approved procedure.

Removal of bar or tendon samples and performance of laboratory destructive testing shall be permitted to determine existing steel reinforcement strength properties. The tensile yield and ultimate strengths for reinforcing and prestressing steels shall follow the procedures included in ASTM A370. Reinforcement samples that are slightly damaged during removal are permitted to be machined to a round bar as long as the tested area is at least 70 percent of the gross area of the original bar. Prestressing materials shall meet the supple-

COMMENTARY

building to identify these elements, systems, and components as described in 2.3.

C2.2.3.2 *Sampling*—ACI 214.4R and FEMA 274 provide further guidance on correlating concrete core strength to in-place strength and provide references for various test methods that can be used to estimate material properties. Chemical composition can be determined from retrieved samples to assess the condition of the concrete. Section C6.3.3.2 of FEMA 274-97 provides references for these tests.

When concrete cores are taken, care should be taken when patching the holes. For example, a core through the thickness of a slab should have positive anchorage by roughening the surface and possibly dowels for anchorage. For that case, the holes should be filled with concrete or grout and the engineer should provide direction for filling the hole so that the added concrete or grout bonds to the substrate.

The steel reinforcement system used in the construction of a specific building is usually of uniform grade and similar strength. One grade of reinforcement is occasionally used for small-diameter bars, such as those used for stirrups and hoops, and another grade for large-diameter bars, such as those used for longitudinal reinforcement. In some cases, different concrete design strengths or classes are used. Historical research and industry documents contain insight on material mechanical properties used in different construction eras (2.2.5). This information can be used with laboratory and field test data to gain confidence in in-place strength properties. Undamaged steel reinforcement can be reduced to a smooth bar if the samples meet the requirements of ASTM A370, excluding the limitations of Annex 9. This