CHAPTER 27—STRENGTH EVALUATION OF EXISTING STRUCTURES

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27.1—Scope

27.1.1 Provisions of this chapter shall apply to strength evaluation of existing structures by analytical means or by load testing.

27.2—General

27.2.1 If there is doubt that a part or all of a structure meets the safety requirements of this Code and the structure is to remain in service, a strength evaluation shall be carried out as required by the licensed design professional or building official.

27.2.2 If the effect of a strength deficiency is well understood and it is practical to measure the dimensions and determine the material properties of the members required for analysis, an analytical evaluation of strength based on this information is permitted. Required data shall be determined in accordance with 27.3.

27.2.3 If the effect of a strength deficiency is not well understood or it is not practical to measure the dimensions and determine the material properties of the members required for analysis, a load test is required in accordance with 27.4.

27.2.4 If uncertainty about the strength of part or all of a structure involves deterioration, and if the observed response during the load test satisfies the acceptance criteria in 27.5 or 27.6 for the selected load test procedure, the structure or part of the structure is permitted to remain in service for a time period specified by the licensed design professional. If

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R27.1—Scope

R27.1.1 Provisions of this chapter may be used to evaluate whether a structure or a portion of a structure satisfies the safety requirements of the Code. A strength evaluation may be required if the materials are considered to be deficient in quality, if there is evidence indicating faulty construction, if a building will be used for a new function, or if, for any reason, a structure or a portion of it does not appear to satisfy the requirements of the Code. In such cases, this chapter provides guidance for investigating the safety of the structure. This chapter does not cover load testing for the approval of new design or construction methods. Acceptance of alternative materials or systems is covered in 1.10.

R27.2—General

R27.2.2 Strength considerations related to axial load, flexure, and combined axial load and flexure are well understood. There are reliable theories relating strength and short-term displacement to load in terms of member dimensional and material data. To determine the strength of the structure by analysis, calculations should be based on data gathered on the actual dimensions of the structure, properties of the materials in place, and all pertinent details. Additional guidance on evaluation of existing structures is provided in ACI PRC-437 and Chapter 6 of ACI CODE-562-25.

R27.2.3 If a load test is to be conducted as part of the strength evaluation process, it is desirable for all parties to agree on the region to be loaded, the magnitude of the load, the load test procedure, and acceptance criteria before any load tests are conducted. If the safety concerns are related to an assemblage of members or an entire structure, it is not feasible to load test every member and section. In such cases, it is appropriate that an investigation plan be developed to address the specific safety concerns.

If the shear or bond strength of a member is critical in relation to the doubt expressed about safety, a test may be the most efficient solution to eliminate or confirm the doubt. A test may also be appropriate if it is not feasible to determine the material and dimensional properties required for analysis, even if the cause of the concern relates to flexure or axial load. Wherever possible and appropriate, the results of the load test should be supported by analysis.

R27.2.4 For a deteriorating structure, acceptance provided by the load test is, by necessity, limited in terms of future service life. In such cases, a periodic inspection program is useful. A program that involves physical tests and periodic inspection can justify a longer period in service. Another option for maintaining the structure in service, while the

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deemed necessary by the licensed design professional, periodic reevaluations shall be conducted.	periodic inspection program continues, is to limit the live load to a level determined to be appropriate in accordance with 27.2.5. The length of the specified time period between inspections should be based on consideration of: a) the nature of the deterioration; b) environmental and load effects; c) service history of the structure; and d) scope of the periodic inspection program. At the end of a specified time period, further strength evaluation is required if the structure is to remain in service. With the agreement of all concerned parties, procedures may be devised for periodic testing that do not necessarily conform to the loading and acceptance criteria specified within this chapter.
27.2.5 If the structure under investigation does not satisfy conditions or criteria of 27.3, 27.5, or 27.6, the structure shall be permitted for use at a lower load rating, based on the results of the load test or analysis, and if approved by the building official.	**R27.2.5** Except for load tested members that have failed under a test (refer to 27.4.5), the building official may permit the use of a structure or member at a lower load rating that is judged to be safe and appropriate on the basis of the strength evaluation.
27.3—Analytical strength evaluation	**R27.3—Analytical strength evaluation**
27.3.1 *Verification of as-built condition*	**R27.3.1** *Verification of as-built condition*
27.3.1.1 As-built dimensions of members shall be field-verified at critical sections.	**R27.3.1.1** As-built dimensions at critical locations requiring field verification are those dimensions necessary to quantify the performance at those sections. Critical sections for different load effects, such as moment, shear force, and axial force, are locations where stresses caused by such effects reach their maximum value and as further defined for various member types in the Code. Additionally, critical sections may be defined by specific conditions in the structure being evaluated, such as localized member deterioration.
27.3.1.2 Locations and sizes of reinforcement shall be determined by measurement. It shall be permitted to base reinforcement locations on available drawings if field-verified at representative locations to confirm the information on the drawings.	**R27.3.1.2** If investigating individual members, the amount, size, arrangement, and location of reinforcement designed to resist applied load should be determined at the critical sections. Nondestructive investigation methods are generally acceptable. In structures with many critical sections, the frequency of measurements may be reduced if the field measurements are consistent.
27.3.1.3 If required, an estimated equivalent f_c' shall be based on analysis of results of cylinder tests from the original construction, tests of cores removed from the structure, or both sets of data. Original cylinder data and core test data shall be representative of the area of concern.	**R27.3.1.3** Guidance on estimating equivalent f_c' from original cylinder data can be found in Bartlett (2012). ACI Committee 214 has developed two methods for determining an equivalent f_c' from cores taken from an existing structure. These methods are described in ACI PRC-214.4 and rely on statistical analysis techniques. The procedures should not be used to investigate low cylinder strength test results in new construction, which is considered in 26.12.4. The number of core tests may depend on the size of the structure and the sensitivity of structural safety to concrete strength.
27.3.1.4 The method for obtaining and testing cores shall be in accordance with ASTM C42.	

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27.3.1.5 The properties of reinforcement are permitted to be based on tensile tests of representative samples of the material in the structure.

27.3.2 *Strength reduction factors*

27.3.2.1 If dimensions, size, and location of reinforcement, and material properties are determined in accordance with 27.3.1, it is permitted to increase ϕ from the design values elsewhere in this Code; however, ϕ shall not exceed the limits in Table 27.3.2.1.

Table 27.3.2.1—Maximum permissible strength reduction factors

Strength	Classification	Transverse reinforcement	Maximum permissible ϕ
Flexure, axial, or both	Tension controlled	All cases	1.0
	Compression controlled	Spirals[1]	0.9
		Other	0.8
Shear, torsion, or both			0.8
Bearing			0.8

[1]Spirals shall satisfy 10.7.6.3, 20.2.2, and 25.7.3.

27.4—Strength evaluation by load test

27.4.1 Load tests shall be conducted either monotonically in accordance with 27.5 or cyclically in accordance with 27.6.

27.4.2 Load tests shall be conducted in a manner that provides for safety of life and the structure during the test.

27.4.3 Safety measures shall not interfere with the load test or affect the results.

27.4.4 The portion of the structure subject to the test load shall be at least 56 days old. If the owner of the structure, the contractor, the licensed design professional, and all other involved parties agree, it shall be permitted to perform the load test at an earlier age.

27.4.5 A precast member to be made composite with cast-in-place concrete shall be permitted to be tested in flexure as a precast member alone in accordance with (a) and (b):

(a) Test loads shall be applied only when calculations indicate the isolated precast member will not fail by compression or buckling.

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R27.3.1.5 The number of tests required depends on the uniformity of the material within the structure and should be determined by the licensed design professional responsible for the evaluation.

R27.3.2 *Strength reduction factors*

R27.3.2.1 The strength reduction factors are larger than those defined in Chapter 21. These increased values are justified by the use of field-obtained material properties and actual in-place dimensions.

R27.4—Strength evaluation by load test

R27.4.1 The monotonic load test procedure is recommended if the strength of the structure being evaluated may be limited by the concrete strength or the expected structural failure is controlled by shear or reinforcement development.The sustained load applied during the monotonic test allows greater time for widening and propagation of cracks, creep, and slip of reinforcement, as compared with the cyclic procedure.

R27.4.4 Other involved parties may include building officials, concrete subcontractors, and persons with a future interest in the structure.

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(b) The test load, when applied to the precast member alone, shall induce the same total force in the tensile reinforcement as would be produced by loading the composite concrete member with the test load in accordance with 27.4.6.

27.4.6 *Test load arrangement and load factors*

27.4.6.1 Test load arrangements shall be selected to maximize the load effects in the critical regions of the members being evaluated.

27.4.6.2 The total test load T_t, including dead load already in place, shall be at least the greatest of (a), (b), and (c):

(a) $T_t = 1.0D_w + 1.1D_s + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$ (27.4.6.2a)
(b) $T_t = 1.0D_w + 1.1D_s + 1.0L + 1.6(L_r \text{ or } S \text{ or } R)$ (27.4.6.2b)
(c) $T_t = 1.0D_w + 1.1D_s + 1.0L + 1.6(L_r \text{ or } S \text{ or } R)$ (27.4.6.2c)

27.4.6.3 It is permitted to reduce L in 27.4.6.2 in accordance with the general building code.

27.4.6.4 The load factor on the live load L in 27.4.6.2(b) shall be permitted to be reduced to 0.5 except for parking structures, areas occupied as places of public assembly, or areas where L is greater than 100 lb/ft^2.

27.4.6.5 Unless documentation or tests are available to confirm the density of normalweight concrete used in the structure, the density shall be taken as 150 lb/ft^3. For other types of concrete materials, the density shall be determined based upon test results or from other documentation.

27.5—Monotonic load test procedure

27.5.1 *Test load application*

27.5.1.1 Total test load T_t shall be applied in at least four approximately equal increments.

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R27.4.6 *Test load arrangement and load factors*

R27.4.6.1 It is important to apply the load at locations so the effects on the suspected deficiency are a maximum and sharing of the applied load with unloaded members is minimized. In cases where it is shown by analysis that adjoining unloaded members will help resist some of the load, the test load should be adjusted to produce appropriate load effects in the critical region of the members being evaluated.

R27.4.6.2 Test loads were changed in ACI CODE-318-19 to be consistent with the requirements in ACI CODE-437.2 for tests on a portion of a structure and for statically indeterminate structures. The test load separates the dead load into self-weight dead load and the superimposed dead load on the structure during the load test. ACI PRC-437.1 provides additional discussion of test loads for concrete structures.

R27.4.6.3 The live load L may be reduced as permitted by the general building code governing safety considerations for the structure. The test load should be increased to compensate for resistance provided by unloaded portions of the structure in question. The increase in test load is determined from analysis of the loading conditions in relation to the selected pass/fail criterion for the test.

R27.4.6.5 Documentation to support a different unit weight may include test results showing concrete unit weight during placement or measured unit weight of concrete core samples. For other types of concrete materials (such as lightweight concrete), the unit weight should be determined based upon concrete core test results or other documentation. The calculation of D_w may include determination of the weight of bonded concrete materials, such as a topping slab to be placed on precast members, not present during a load test. D_s may also include the weight from structural framing members.

R27.5—Monotonic load test procedure

R27.5.1 *Test load application*

R27.5.1.1 Inspecting the area of the structure subject to test loading for signs of distress after each load increment is advisable (refer to R27.5.3.1).

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27.5.1.2 Uniform T_t shall be applied in a manner that ensures uniform distribution of the load transmitted to the structure or portion of the structure being tested. Arching action in the test load apparatus shall be avoided.

27.5.1.3 After the final load increment is applied, T_t shall remain on the structure for at least 24 hours unless signs of distress, as noted in 27.5.3, are observed.

27.5.1.4 After all response measurements are recorded, the test load shall be removed as soon as practical.

27.5.2 *Response measurements*

27.5.2.1 Response measurements, such as deflection, strain, slip, and crack width, shall be made at locations where maximum response is expected. Additional measurements shall be made if required.

27.5.2.2 The initial value for all applicable response measurements shall be obtained not more than 1 hour before applying the first load increment.

27.5.2.3 A set of response measurements shall be recorded after each load increment is applied and after T_t has been applied on the structure for at least 24 hours.

27.5.2.4 A set of final response measurements shall be made 24 hours after T_t is removed.

27.5.3 *Acceptance criteria*

27.5.3.1 The portion of the structure tested shall show no spalling or crushing of concrete, or other evidence of failure.

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R27.5.1.2 Arching refers to the tendency for the load to be transmitted nonuniformly to the flexural member being tested. For example, if a slab is loaded by a uniform arrangement of bricks, arching of bricks in contact would result in reduction of the load on the slab near the midspan of the slab.

R27.5.3 *Acceptance criteria*

R27.5.3.1 Evidence of failure includes distress (cracking, spalling, or deflection) of such magnitude and extent that the observed result is obviously excessive and incompatible with the safety requirements of the structure. No simple rules have been developed for application to all types of structures and conditions. If sufficient damage has occurred so that the structure is considered to have failed that test, retesting is not permitted because it is considered that damaged members should not be put into service even at a lower load rating.

Local spalling or flaking of the compressed concrete in flexural members related to casting imperfections need not indicate overall structural distress. Crack widths are good indicators of the state of the structure and should be observed to help determine whether the structural strength and behavior are satisfactory. However, accurate prediction or measurement of crack widths in structural concrete members is not likely to be achieved under field conditions. It is advisable to establish criteria before the test relative to the types of cracks anticipated; where the cracks will be measured; how they will be measured; and approximate limits or criteria to evaluate new cracks or limits for the changes in crack width.

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27.5.3.2 Members tested shall not exhibit cracks indicating imminent shear failure.

27.5.3.3 In regions of members without transverse reinforcement, structural cracks inclined to the longitudinal axis and having a horizontal projection greater than the depth of the member shall be evaluated. For variable-depth members, the depth shall be measured at the midlength of the crack.

27.5.3.4 In regions of anchorage and lap splices of reinforcement, short inclined cracks or horizontal cracks along the line of reinforcement shall be evaluated.

27.5.3.5 Measured deflections shall satisfy:

$$\Delta_r \leq \frac{\Delta_1}{4} \qquad (27.5.3.5)$$

27.5.3.6 If the maximum deflection measured during the test, Δ_1, does not exceed the larger of 0.05 in. or $\ell_t/2000$, the residual deflection requirements in 27.5.3.5 shall be permitted to be waived.

27.5.3.7 If 27.5.3.5 or 27.5.3.6 is not satisfied, it shall be permitted to repeat the load test, provided that the second load test begins no earlier than 72 hours after removal of externally applied loads from the first load test.

27.5.3.8 Portions of the structure tested in the second load test shall be considered acceptable if:

$$\Delta_r \leq \frac{\Delta_2}{5} \qquad (27.5.3.8)$$

27.6—Cyclic load test procedure

27.6.1 A cyclic load test in accordance with ACI CODE-437.2 shall be permitted to be used to evaluate the strength of an existing structure.

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R27.5.3.2 Forces are transmitted across a shear crack plane by aggregate interlock at the interface of the crack that is enhanced by clamping action of transverse reinforcement and by dowel action of stirrups crossing the crack. The member is assumed to be approaching imminent shear failure when crack lengths increase to approach a horizontal projected length equal to the depth of the member and concurrently widen to the extent that aggregate interlock cannot occur, and as transverse stirrups, if present, begin to yield or display loss of anchorage so as to threaten their integrity.

R27.5.3.3 Inclined cracks may lead to brittle failure of members without transverse reinforcement. Assessment of all inclined cracks is advisable where transverse reinforcement is not present.

R27.5.3.4 Cracking along the axis of the reinforcement in anchorage zones may be related to high stresses associated with the transfer of forces between the reinforcement and the concrete. These cracks may be indicators of impending brittle failure of the member if they are associated with the development of main reinforcement. It is important that their causes and consequences be evaluated.

R27.5.3.5 If the structure shows no evidence of failure, recovery of deflection after removal of the test load is used to determine whether the strength of the structure is satisfactory.

R27.5.3.6 In the case of a very stiff structure, errors in measurements under field conditions may be of the same order as the actual deflections and recovery. To avoid penalizing a satisfactory structure in such a case, recovery measurements are waived if the maximum deflection does not exceed the larger of 0.05 in. or $\ell_t/2000$.

R27.6—Cyclic load test procedure

R27.6.1 Cyclic load testing involves the cyclic application and removal of load to a structure or structural element. The cyclic load test protocol described in ACI CODE-437.2 involves the application of increasing levels of load to a structure in repeated load cycles. The measured load-deformation response of the structure is used to evaluate the

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27.6.2 Acceptance criteria for cyclic load test results shall be in accordance with ACI CODE-437.2.

27.6.3 If a member fails a cyclic load test, it shall be permitted to retest the member or structure in accordance with ACI CODE-437.2. It shall be permitted to waive the maximum deflection limit (ℓ_t/180) in ACI CODE-437.2 that precludes a retest.

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performance of the tested element. The acceptance criteria for the cyclic test are based upon deviation of the load deformation response from linear elastic behavior, permanency of deflections during each cycle of the load test, and recovery of deflection after completion of the load test.

R27.6.3 ACI CODE-437.2 precludes a retest if the member exceeds a maximum deflection limit of ℓ_t/180 (Section 6.4.4.2 in ACI CODE-437.2-13). For consistency with the monotonic testing protocol, this limit is waived.

Notes