CHAPTER 24 — STRENGTH EVALUATION OF EXISTING STRUCTURES

For convenience of the voters, the approved code provisions are shown.

This ballot is on the commentary, shown in boxes.
Sub C balloted and approved the proposed commentary

Underline and strikethrough highlighted in yellow designate changes from the LB12-4 version

24.1 — Scope

24.1.1 — This chapter provides minimum requirements for the strength evaluation of existing structures by analytical means or by load testing <20.1.1> <20.1.3>

R24.1.1 — Chapter 24 does not cover load testing for the approval of new design or construction methods. Provisions of Chapter 24 may be used to evaluate whether a structure or a portion of a structure satisfies the safety requirements of this 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 structure has deteriorated, 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, Chapter 24 provides guidance for investigating the safety of the structure. Chapter 24 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. [1][2][3][4]

24.2 — General

24.2.1 — 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. < 20.1.1>

R24.2.1 — 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 a load test is described as part of the strength evaluation process, it is desirable for all parties involved to come to an agreement about 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. [5][6][7]

24.2.2 — 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 24.3. <20.1.2>
**R24.2.2** — 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.

**24.2.3** — 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 24.4. <20.1.3>

**R24.2.3** — 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.

**24.2.4** — 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 24.4.5, the structure or part of the structure is permitted to remain in service for a time period specified by the licensed design professional. If deemed necessary by licensed design professional, periodic re-evaluations shall be conducted. <20.1.4>

**R24.2.4** — For a deteriorating structure, the acceptance provided by the load test may not be assumed to be without limits in terms of time 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 periodic inspection program continues, is to limit the live load to a level determined to be appropriate. 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. [9]

**24.3** — Analytical strength evaluation

**24.3.1** — Verification of as-built condition

**R24.3.1.1** — Dimensions of members shall be established at critical sections. <20.2.1>

**R24.3.1.1** — Critical sections for different load effects, such as moment, shear force, and axial force, etc., 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. For example, deterioration could define a critical section, should be consistent with those defined elsewhere in the code. [11][12][13][14]
24.3.1.2 — 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. <20.2.2>

R24.3.1.2 — For investigating individual members, the amount, size, arrangement, and location should be determined at the critical sections for of reinforcement or tendons, or both, designed to resist applied load should be determined at the critical sections. Nondestructive investigation methods are generally acceptable. In large structures, determination of these data for approximately 5 percent of the reinforcement or tendons in each critical region may suffice if these measurements confirm the data provided in the available drawings. [15][17][18][19]

24.3.1.3 — If required, an estimated equivalent $f_{c}'$ shall be based on analysis of results of cylinder tests from the original construction or tests of cores removed from the part of the structure where strength is in question. <20.2.3>

R24.3.1.3 — 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 214.4R20.1 and rely on statistical analysis techniques. The procedures described are only appropriate where the determination of an equivalent $f_{c}'$ is necessary for the strength evaluation of an existing structure and should not be used to investigate low cylinder strength test results in new construction, which is considered in 22.5.6. The number of core tests may depend on the size of the structure and the sensitivity of structural safety to concrete strength. Guidance on estimating equivalent $f_{c}'$ from original cylinder data can be found in reference 24.XX. In cases where the potential deficiency involves flexure only, investigation of concrete strength can be minimal for a lightly reinforced section ($\rho f_{y} / f_{c} \leq 0.15$ for rectangular section). [20][21][22]

24.3.1.4 — The method for obtaining and testing cores shall be in accordance with ASTM C42. <20.2.3>

24.3.1.5 — The properties of reinforcement are permitted to be based on tensile tests of representative samples of the material in the structure. <20.2.4>

R24.3.1.5 — The number of tests required depends on the uniformity of the material within the structure and is best should be determined by the licensed design professional responsible for the evaluation. [25]

24.3.2 — Strength reduction factors

24.3.2.1 — If dimensions, size and location of reinforcement, and material properties are determined in accordance with 24.3.1, it is permitted to increase $\phi$ from the design values elsewhere in this Code, however $\phi$ shall not exceed the values in Table 24.3.2.1. <20.2.5>

Table 24.3.2.1 — Maximum permissible strength reduction factors

<table>
<thead>
<tr>
<th>Strength Classification</th>
<th>Transverse reinforcement</th>
<th>Maximum permissible $\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexure, Tension</td>
<td>All cases</td>
<td>1.0</td>
</tr>
</tbody>
</table>
### Axial, or both Controlled

<table>
<thead>
<tr>
<th>Compression Controlled</th>
<th>Spirals*</th>
<th>0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td></td>
<td>0.8</td>
</tr>
</tbody>
</table>

| Shear, Torsion, or both |          | 0.8 |

| Bearing                 |          | 0.8 |

Note: * Spirals shall satisfy 14.6.3, 14.7.4.4, and 21.7.6

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**24.4 — Strength evaluation by load test**

**24.4.1 — General**

* Load tests shall be conducted in a manner that provides for safety of life and the structure during the test. <20.7.1>*

* Safety measures shall not interfere with the load test or affect the results. <20.7.2>*

* 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. <20.3.3>*

* 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):<16.10.1>*

1. Test loads shall be applied only when calculations indicate the isolated precast member will not fail by compression or buckling. <16.10.1.1>

2. 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 member with the test load in accordance with 24.4.2. <16.10.1.2>*

**24.4.2 — Test load arrangement and load factors**

* Test load arrangements shall be selected to maximize the deflection, load effects, and stresses in the critical regions of the members being evaluated. <20.3.1>*
Add definition of $T_t$—total test load, lb, Chapter 24

R24.4.2.1—Load arrangement

It is important to apply the load at locations so that its 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 carry some of the load, the test load should be adjusted to ensure sufficient forces act on the critical region of the members being evaluated placed to develop effects consistent with the intent of the load factor.

[42][43][44][45]

Sub C proposes to define “load effects” in the commentary:

“load effects” will be defined in the commentary to this section to include bending moments, shear forces and axial forces. Acceptance criteria in 24.4.5 consider deflections, not rotations, so “rotations” has been deleted. [46][47][48][49][50][51][52]

24.4.2.2 — The total test load, $T_t$, including dead load already in place shall be at least the greatest of (a), (b), and (c): <20.3.2>

(a) $T_t = 1.15D + 1.5L + 0.4(L_r$ or $S$ or $R)$ (24.4.2.2a)
(b) $T_t = 1.15D + 0.9L + 1.5(L_r$ or $S$ or $R)$ (24.4.2.2b)
(c) $T_t = 1.3D$ (24.4.2.2c)

R24.4.2.2 — Load intensity

The required load intensity follows the load test practice in ACI 318-11. 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. These test loads are considered appropriate for designs using the load combinations of Chapter 7 and strength reduction factors of Chapters 9, 17, and 18, and 25. [53][54][55][56][57][58][59][60][61][63][64][65]

24.4.2.3 — It is permitted to reduce $L$ in 24.4.2.2 in accordance with the General Building Code. <20.3.2>

24.4.2.4 — The load factor on the live load $L$ in 24.4.2.2(b) shall be permitted to be reduced to 0.45 except for parking structures, areas occupied as places of public assembly, or areas where $L$ is greater than 100 lb/ft$^2$. <20.3.2>

24.4.3 — Test load application

24.4.3.1 — Total test load, $T_t$, shall be applied in at least four approximately equal increments. <20.4.2>

R24.4.3.1 — Inspecting the area of the structure subject to test loading for signs of distress after each load increment is advisable. See also R24.4.5.1. [66]
24.4.3.2 — Uniform $T_i$ 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 of the test load shall be avoided. <20.4.3>

R24.4.3.2 — 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, arching would result in reduction of the load on the slab near the midspan of the slab. [68]

24.4.3.3 — After the final load increment is applied, $T_i$ shall remain on the structure for at least 24 hours unless signs of distress, as noted in 24.4.5, are observed. <20.4.4>

24.4.3.4 — After all response measurements are recorded, the test load shall be removed as soon as practical. <20.4.5>

24.4.4 — Response measurements

24.4.4.1 — 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. <20.4.1>

24.4.4.2 — The initial value for all applicable response measurements shall be obtained not more than 1 hour before applying the first load increment. <20.4.1>

24.4.4.3 — A set of response measurements shall be recorded after each load increment is applied and after $T_i$ has been applied on the structure for at least 24 hours. <20.4.4>

24.4.4.4 — A set of final response measurements shall be made 24 hours after $T_i$ is removed. <20.4.6>

24.4.5 — Acceptance criteria

24.4.5.1 — The portion of the structure tested shall show no spalling or crushing of concrete, or other evidence of failure. <20.5.1>

R24.4.5.1 — A general acceptance criterion for the behavior of a structure under the test load is that it does not show evidence of failure. 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 is satisfactory. However, exact accurate prediction or measurement of crack widths in reinforced 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. [70][71][72][73][75][76][77][78][79][80]

24.4.5.2 — Members tested shall not exhibit cracks indicating imminent shear failure. <20.5.3>

R24.4.5.2 — Forces are transmitted across a shear crack plane by a combination of 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. [81]

24.4.5.3 — 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 mid-length of the crack. <20.5.4>

R24.4.5.3 — The intent is to make the personnel in charge of the test assess the structural implication of observed inclined Inclined cracks that may lead to brittle failure of members without transverse reinforcement. Assessment of all inclined cracks is advisable where transverse reinforcement is not present. [84][85][86][87][88][89][90][91][92]

24.4.5.4 — In regions of anchorage and lap splices of reinforcement, short inclined cracks or horizontal cracks along the line of reinforcement shall be evaluated. <20.5.5>

R24.4.5.4 — 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. [93]

24.4.5.5 — Measured deflections shall satisfy either equation (24.4.5.5a) or (24.4.5.5b). <20.5.2>

\[ \Delta_1 \leq \frac{h^2}{20,000h} \]  
(24.4.5.5a)

\[ \Delta_r \leq \frac{\Delta_1}{4} \]  
(24.4.5.5b)

Revise Chapter 2 definitions:

\[ \Delta_1 = \text{maximum deflection, during first load test, measured 24 hours after application of the full test load} \]

\[ \Delta_r = \text{residual deflection measured 24 hours after removal of the test load. For the first load test, residual deflection is measured relative to the position of the structure at the beginning of the first load test. For the second load test, residual deflection is measured relative to the position of the structure at the beginning of the second load test.} \]
R24.4.5.5 — The deflection limits for the test in 24.4.5.5 and for the retest option in 24.4.5.3 follow ACI 318-11. 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. In the case of a very stiff structure, however, the 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 is less than \( \frac{\varepsilon_i^{1/2}}{t_v/20,000} \). The residual deflection is the difference between the initial and final (after load removal) deflections for the load test or the repeat load test.

24.4.5.6 — If 24.4.5.5 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. <20.5.2>

24.4.5.7 — Portions of the structure tested in the second load test shall be considered acceptable if

\[
\Delta_r \leq \frac{\Delta_2}{5} \quad (24.4.5.7)
\]

In Chapter 2, change the definition to “\( \Delta_2 \) = maximum deflection, during the second load test, measured 24 hours after application of the full test load. Deflection is measured relative to the position of the structure at the beginning of the second load test.”

24.5 — Reduced load rating

24.5.1 — If the structure under investigation does not satisfy conditions or criteria of 24.3 or 24.4.5, the structure shall be permitted for use at a lower load rating, based on the results of the load test or analysis, if approved by the building official. <20.6>

R24.5.1 — Provision for lower load rating

Except for load tested members that have failed under a test (refer to 24.4.5.5), 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. [119][120][121]

New Commentary Reference
24.XX - Bartlett, F.M., “Using Historical Cylinder Data for Structural Evaluation, SP284-5”, Special Publication 284, American Concrete Institute, 2012