

## CODE

**9.2.6** — Required strength  $U$  for other than compression-controlled sections, as defined in 10.3.3, shall be multiplied by the following environmental durability factor ( $S_d$ ) in portions of an environmental engineering concrete structure where durability, liquid-tightness, or similar serviceability are considerations. In the case of shear design, this factor is applied to the excess shear strength carried by shear reinforcement only. This durability factor shall not be used for designs using service loads and permissible service load stresses. For applicable use of the environmental durability factor ( $S_d$ ) in conjunction with load combinations that include earthquake loads, see Section 21.2.1.8.

$$S_d = \frac{\phi f_y}{\gamma f_s} \geq 1.0 \quad (9-8)$$

where  $\gamma = \frac{\text{factored load}}{\text{unfactored load}}$

and where  $f_s$  is the permissible tensile stress in reinforcement as given below:

**9.2.6.1** — Flexural stress: See 10.6.4.

**9.2.6.2** — Direct and hoop tensile stress in normal environmental exposures

$$f_s = 20,000 \text{ psi}$$

**9.2.6.3** — Direct and hoop tensile stress in severe environmental exposures

$$f_s = 17,000 \text{ psi}$$

**9.2.6.4** — Shear stress carried by shear reinforcement in normal environmental exposures

$$f_s = 24,000 \text{ psi}$$

**9.2.6.5** — Shear stress carried by shear reinforcement in severe environmental exposures

$$f_s = 20,000 \text{ psi}$$

## COMMENTARY

not more than 96 percent of the nominal ultimate strength of the prestressing steel. This compares well with the maximum attainable jacking force, which is limited by the anchor efficiency factor.

**R9.2.6** — In environmental engineering concrete structures, durability and long-term service life are paramount. The resulting stresses in nonprestressed reinforcement using normal building code load factors are higher than would be desirable in environmental engineering concrete structures. The intent of the environmental durability factor is to reduce the effective stress in nonprestressed reinforcement under service load conditions, such that stress levels are considered to be in an acceptable range for control of cracking. The environmental durability factor in Eq. (9-8) will vary with individual load combinations and with applicable  $\phi$  factors (for example, flexure versus shear). As a conservative simplification, the  $\phi$  factor may be taken as the maximum  $\phi$  factor (0.90) in Eq. (9-8).

The limitation of  $S_d \geq 1.0$  is to ensure that the strength requirements of 318 are always met as a minimum regardless of crack control considerations. This limitation will likely control where bars of relatively low yield strength are used.

In effect, for tension-controlled sections and shear strength contributed by reinforcement, Eq. (9-8) eliminates the effects of code-prescribed load factors and  $\phi$  factors and applies an effective load factor equal to  $f_y/f_s$  with  $\phi$  factors set to 1.0. Thus, where the environmental durability factor is applicable in these types of sections, the following design procedure will achieve the same results:

1. Multiply the unfactored loads by a uniform load factor equal to  $f_y/f_s$  ( $\geq 1.0$ );
2. Use a value of 1.0 for applicable design  $\phi$  factors.

The normal load factors would still be applicable to some design conditions, such as shear strength from concrete and compression-controlled members.

**R9.2.6.1** — Required flexural strength  $\geq S_d U$ .

**R9.2.6.2 and R9.2.6.3** — Required strength in direct and hoop tension  $\geq S_d U$ .

Some designers prefer to use a maximum steel stress equal to 14,000 psi for hoop tension. This practice is based on an earlier version of the PCA publication, "Circular Concrete Tanks without Prestressing."<sup>9.7</sup>

**R9.2.6.4 and R9.2.6.5** — Shear stress carried by the shear reinforcing is defined as the excess shear strength required in addition to the design shear strength provided by the concrete  $\phi V_c$

$$\phi V_s \geq S_d (V_u - \phi V_c)$$

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**9.2.7** —  $S_d$  shall be taken as 1.0 for the flexural design of compression-controlled sections, all prestressed reinforcement, and post-tensioned anchorage zone reinforcement, regardless of exposure.

## 9.3 — Design strength

**9.3.1** — Design strength provided by a member, its connections to other members, and its cross sections, in terms of flexure, axial load, shear, and torsion, shall be taken as the nominal strength calculated in accordance with requirements and assumptions of this code, multiplied by the strength reduction factors  $\phi$  in 9.3.2 and 9.3.4.

**9.3.2** — Strength reduction factor  $\phi$  shall be as follows:

**9.3.2.1** — Tension-controlled sections as defined in 10.3.4.....0.90

**9.3.2.2** — Compression-controlled sections, as defined in 10.3.3:

- (a) Members with spiral reinforcement conforming to 10.9.3.....0.70
- (b) Other reinforced members.....0.65

For sections in which the net tensile strain in the extreme tension steel at nominal strength is between the limits for compression-controlled and tension-controlled sections,  $\phi$  shall be permitted to be linearly increased from that for compression-controlled sections to 0.90 as the net tensile strain in the extreme tension steel at nominal strength increases from the compression-controlled strain limit to 0.005.

Alternatively, when Appendix B is used, for members in which  $f'_y$  does not exceed 60,000 psi, with symmetric reinforcement, and with  $(h - d' - d_s)/h$  not

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**R9.2.7** — The environmental durability factor is taken equal to 1.0 for compression controlled sections because by definition, their steel strains are less than or equal to 0.002 per 10.3.3, and therefore have low tensile steel stress levels and minimal concern for cracking.

## R9.3—Design strength

**R9.3.1** — The design strength of a member refers to the nominal strength calculated in accordance with the requirements stipulated in this code multiplied by a strength reduction factor  $\phi$ , which is always less than one.

The purposes of the strength reduction factor  $\phi$  are: (1) to allow for the probability of understrength members due to variations in material strengths and dimensions; (2) to allow for inaccuracies in the design equations; (3) to reflect the degree of ductility and required reliability of the member under the load effects being considered; and (4) to reflect the importance of the member in the structure.<sup>9,8,9,9</sup>

In the ACI 318-02 code, the strength reduction factors were adjusted to be compatible with the ASCE 7-98<sup>9,10</sup> load combinations, which were the basis for the required factored load combinations in model building codes at that time. These factors are essentially the same as those published in Appendix C of the ACI 318-95, except the factor for flexure/tension controlled limits is increased from 0.80 to 0.90. This change is based on past<sup>9,8</sup> and current reliability analyses,<sup>9,11</sup> statistical study of material properties, as well as the opinion of the committee that the historical performance of concrete structures supports  $\phi = 0.90$ .

**R9.3.2.1** — In applying 9.3.2.1 and 9.3.2.2, the axial tensions and compressions to be considered are those caused by external forces. Effects of prestressing forces are not included.

**R9.3.2.2** — Before the 2006 edition, the code specified the magnitude of the  $\phi$ -factor for cases of axial load or flexure, or both, in terms of the type of loading. For these cases, the  $\phi$ -factor is now determined by the strain conditions at a cross section, at nominal strength.

A lower  $\phi$ -factor is used for compression-controlled sections than is used for tension-controlled sections because compression-controlled sections have less ductility, are more sensitive to variations in concrete strength, and generally occur in members that support larger loaded areas than members with tension-controlled sections. Members with spiral reinforcement are assigned a higher  $\phi$  than tied columns because they have greater ductility or toughness.

For sections subjected to axial load with flexure, design strengths are determined by multiplying both  $P_n$  and  $M_n$  by the appropriate single value of  $\phi$ . Compression-controlled and tension-controlled sections are defined in 10.3.3 and