CODE

19.2.2.1 It shall be permitted to calculate E_c in accordance with (a) or (b):

(a) For values of w_c between 1440 and 2560 kg/m^3

$$E_c = w_c^{1.5} 0.043 \sqrt{f'_c} \text{ (in MPa)} \quad (19.2.2.1.a)$$

(b) For normalweight concrete

$$E_c = 4700 \sqrt{f'_c} \text{ (in MPa)} \quad (19.2.2.1.b)$$

19.2.2.2 It shall be permitted to specify E_c based upon testing of concrete mixtures to be used in the Work in accordance with (a) through (c):

(a) Specified E_c shall be used for proportioning concrete mixtures in accordance with 26.4.3.
(b) Testing to verify that the specified E_c has been achieved shall be conducted, and results shall be provided with the mixture submittal.
(c) Test age of measurement of E_c shall be 28 days or as indicated in the construction documents.

19.2.3 *Modulus of rupture*

19.2.3.1 Modulus of rupture, f_r, for concrete shall be calculated by:

$$f_r = 0.62\lambda \sqrt{f'_c} \quad (19.2.3.1)$$

where the value of λ is in accordance with 19.2.4.

COMMENTARY

R19.2.2.1 Equations in 19.2.2.1 provide an estimate of E_c for general design use. Studies leading to the expression for E_c of concrete are summarized in Pauw (1960), where E_c is defined as the slope of the line drawn from a stress of zero to 45 percent of the compressive strength using the stress-strain curve of the concrete. This definition is slightly different than the definition in ASTM C469. ASTM C469 defines E_c using 40 percent of the compressive strength.

The modulus of elasticity is sensitive to a number of variables including aggregate type, concrete constituents, mixture proportions, bond between paste and aggregate, and the age of the concrete. This sensitivity, coupled with the inherent variability in the properties of the constituent materials and quality control exercised during construction, can result in differences between measured and calculated values for deflection, drift, periods of vibration, and other quantities that depend on E_c. Refer to ACI 435R for more information on the use of E_c, especially when used in deflection calculations.

Modulus of elasticity determined by calculation using the Code equations has been shown to be appropriate for most applications based on many years of use. For some applications, however, these equations may not provide sufficiently accurate estimates of actual values. Larger differences between measured and calculated values of E_c have been observed for high-strength concrete ($f'_c > 55$ **MPa**), lightweight concrete, and for mixtures with low coarse aggregate volume, as can occur with self-consolidating concrete. Refer to ACI 363R, ACI 213R, and ACI 237R for more information.

R19.2.2.2 For any project, E_c used for design may be specified and verified by testing. Design conditions that are sensitive to the value of E_c may warrant testing. Examples include applications where deflections are critical, tall buildings or similar structures for which axial deformation or lateral stiffness impact performance, and where estimation of E_c is important to acceptable vibration or seismic performance.

In cases where an unintended change of stiffness may have an adverse effect on the design, such as for some seismic applications, the licensed design professional may choose to specify a range of acceptable values of E_c at a specified test age. If a range of values of E_c is specified, details of a testing program and acceptance criteria should be provided in the construction documents.

The licensed design professional may choose to specify laboratory testing of E_c at multiple ages. It should be recognized that the development of E_c over time cannot be controlled with precision.