CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES AND COMMENTARY (ACI 350-06)

REPORTED BY ACI COMMITTEE 350

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10.6.2 — Distribution of flexural reinforcement in two-way slabs shall also meet the requirements of 13.3. For the application of 10.6.4, slabs with an aspect ratio (long span to short span) not greater than 2.0 shall be considered as two-way members and slabs with an aspect ratio greater than 2.0 shall be considered as one-way members.

10.6.3 — Flexural tension reinforcement shall be well distributed within maximum flexural tension zones of a member cross section as required by 10.6.4.

10.6.4 — The calculated stress f_s in reinforcement closest to a surface in tension at service loads shall not exceed that given by Eq. (10-4) and (10-5) and shall not exceed a maximum of 36,000 psi:

10.6.4.1 — In normal environmental exposure areas as defined in 10.6.4.5

$$f_{s,\,max} = \frac{320}{\beta\sqrt{s^2 + 4(2 + d_b/2)^2}} \qquad (10\text{-}4)$$

but need not be less than 20,000 psi for one-way and 24,000 psi for two-way members.

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control cracking. For protection of reinforcement against corrosion, and for aesthetic reasons, many fine hairline cracks are preferable to a few wide cracks.

Control of cracking is particularly important when reinforcement with a yield strength in excess of 40,000 psi is used. Current good detailing practices will usually lead to adequate crack control even when reinforcement of 60,000 psi yield is used.

Extensive laboratory work[10.12-10.14] involving deformed bars has confirmed that crack width at service loads is proportional to steel stress. The significant variables reflecting steel detailing were found to be thickness of concrete cover and the area of concrete in the zone of maximum tension surrounding each individual reinforcing bar.

Crack width is inherently subject to wide scatter, even in careful laboratory work, and is influenced by shrinkage and other time-dependent effects. The best crack control is obtained when the steel reinforcement is well distributed over the zone of maximum concrete tension.

R10.6.2 — For the purposes of design of environmental engineering concrete structures, no distinction is made between one-way and two-way elements with the exception of minimum stress levels for two-way members with aspect ratios less than or equal to 2.0. Two-way members with an aspect ratio greater than 2.0 have moment and shear diagrams at the midpoint along the long span that are basically indistinguishable from a one-way slab. Based on this observation, two-way members with aspect ratios greater than 2.0 are considered to be one-way members for the purposes of crack control. Crack width prediction in two-way elements is not as well defined as one-way elements; however, the intent of the design practice for environmental structures is to control stress levels to limits shown to control corrosion effectively rather than predict crack widths with any precision.

R10.6.3 — Several bars at moderate spacing are much more effective in controlling cracking than one or two larger bars of equivalent area.

R10.6.4 — This section replaces the z factor requirements of the 2001 code edition. The maximum allowable stresses are now specified directly as a function of bar spacing.[10.15] The figures R10.6.4(a) through R10.6.4(d) are plots of Eq. (10-4) and (10-5) including the simplifications of Sections 10.6.4.3 and 10.6.4.4 and limitations for one- and two-way members. β is defined as the ratio of distances to the neutral axis from the extreme tension fiber and from the centroid of the main reinforcement. These figures may be used to select an allowable stress based on a maximum bar spacing to be used in bar selection.

Crack widths in environmental structures are highly variable. In previous codes, provisions were given for distribution of reinforcement that were based on empirical equations using

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10.6.4.2 — In severe environmental exposure areas as defined in 10.6.4.5

$$f_{s,\,max} = \frac{260}{\beta\sqrt{s^2 + 4(2 + d_b/2)^2}} \qquad (10\text{-}5)$$

but need not be less than 17,000 psi for one-way and 20,000 psi for two-way members.

10.6.4.3 — In Eq. (10-4) and (10-5) it shall be permitted to use the value 25 for the term $4(2 + d_b)^2$ as a simplification.

10.6.4.4 — The strain gradient amplification factor shall be given by

$$\beta = \frac{h - c}{d - c} \qquad (10\text{-}6)$$

where c is calculated at service loads. In lieu of this more precise calculation, it shall be permitted to use β equal to 1.2 for $h \geq 16$ in. and 1.35 for $h < 16$ in. in Eq. (10-4) and (10-5).

10.6.4.5 — For liquid retention, normal environmental exposure is defined as exposure to liquids with a pH greater than 5, or exposure to sulfate solutions of 1000 ppm or less. Severe environmental exposures are conditions in which the limits defining normal environmental exposure are exceeded.

10.6.4.6 — Calculated flexural stress in reinforcement at service load f_s (in ksi) shall be computed as the unfactored moment divided by the product of steel area and internal moment arm.

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a calculated maximum crack width of 0.010 in. for normal environmental exposure. The current provisions for spacing are intended to limit surface cracks to a width that is generally acceptable in practice, but may vary widely in a given structure.

The role of cracks in the corrosion of reinforcement is controversial. Research[10.16,10.17] shows that corrosion is not clearly correlated with surface crack widths in the range normally found with reinforcement stresses at service load levels. Although a number of studies have been conducted, clear experimental evidence is not available regarding the crack width beyond which a corrosion danger exists. Environmental engineering concrete structures have traditionally performed well using quality concrete, as defined by this code, using adequate compaction, limiting maximum bar stresses, and equally distributing more smaller bars rather than few larger bars on tension faces.

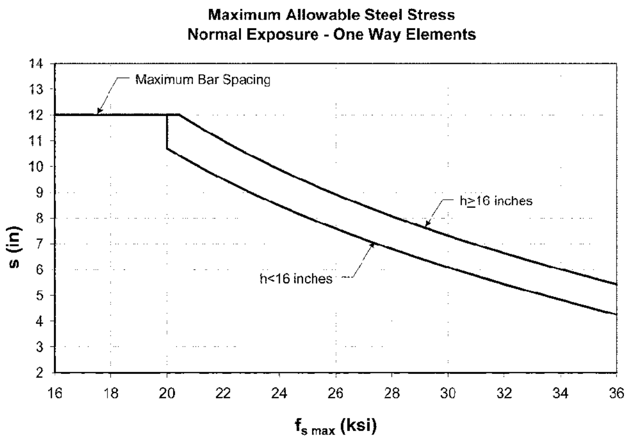

Fig. R10.6.4(a)—Maximum allowable steel stress, normal exposure—one-way elements.

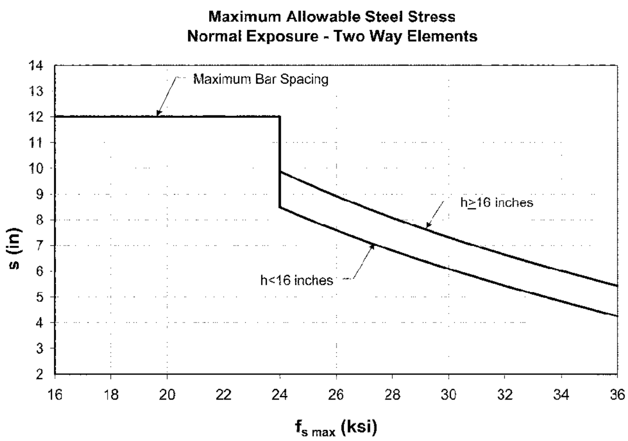

Fig. R10.6.4(b)—Maximum allowable steel stress, normal exposure—two-way elements.