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Technical Blog

Strength or Stiffness: Which is More Important for Reinforcement of Nominal Slabs-on-Ground?

In past WRI technical blog entries we have discussed WWR usage in slabs-on-ground. Our focus in this entry is on what we refer to as “nominal slabs-on-ground”, or “slabs reinforced for crack-width control” as described in ACI 360R-10 Guide to Design of Slabs-on-Ground.

Nominal slabs are characterized by the following approach, with information referenced directly from ACI 360:

1. Slab thickness is selected based on prevention of flexural cracks that would arise as a result of externally-applied loads, with calculations based on the assumption of an uncracked and unreinforced slab (Section 8.1).
2. Reinforcement may be specified to improve the performance of the slab, with benefits including limitation of shrinkage crack width, use of wider joint spacing intervals, providing flexural strength and stability at cracked sections (Section 8.1), and load transfer across joints (Section 7.1).
3. Providing uniform support conditions is extremely important for serviceable slab performance (Section 4.5.2).
4. Reinforcement required for crack-width control is a function of joint spacing and slab thickness (Section 8.3).
5. Bars or welded wire reinforcement are used to provide flexural strength at a cracked section. In this case, and for slabs of insufficient thickness to carry the applied loads as an unreinforced slab, the reinforcement required for flexural strength should be sized by reinforced concrete theory as described in ACI 318. Using the methods in ACI 318 with high steel reinforcement stresses, however, may lead to unacceptable crack widths (Section 3.2.2).
6. Cracking, joint instability, and surface character problems are considered slab serviceability issues and not relevant to the general integrity of the building structure (Section 7.1).

With the above in mind, and assuming that a nominal slab-on-ground is constructed on a properly designed subgrade and is of a thickness proportioned to preclude flexural cracking due to external loads, the reinforcement placed therein is largely used for improvement of the slab’s serviceability. As such, the reinforcement’s most common positioning would be proximate to the slab’s exposed upper surface in order to best mitigate the propagation of shrinkage crack widths that impact serviceability.

While strength of the reinforcement is of course an important attribute to ensure the material does not fracture or fail, for nominal slabs a more relevant consideration is the reinforcement’s available stiffness that is relied upon to resist tensile strains associated with the opening of shrinkage cracks. The reinforcement’s cross-sectional area and its Modulus of Elasticity (MOE) are attributes that play a central role in the effectiveness of reinforcement used to control shrinkage crack width, as it is these two attributes (along with the length of the reinforcement) that define its axial stiffness. The larger the magnitude of the reinforcement’s axial stiffness, the more effective it can be in “stitching” crack widths and preventing excessive propagation.

A good example of the acknowledgment of the role played by a reinforcement material’s stiffness can be found in Appendix A of ACI 440.1R-15 *Guide for the Design and Construction of Structural Concrete with Fiber-Reinforced Polymer Bars*. Two separate equations are used therein to determine reinforcement areas using the "Subgrade Drag Method."

For steel reinforcement:

$$A_s = \frac{\mu L w_{slab}}{2 f_{s,\text{allow}}}$$

Where:

A_s = cross-sectional area of steel reinforcement per lineal foot, in2

μ = coefficient of subgrade friction = 1.5

L = distance between joints in slab, ft

w_{slab} = dead weight of the slab, psf

$f_{s,\text{allow}}$ = allowable stress in the steel reinforcement, commonly taken as 0.67 to 0.75x yield strength, psi

And for FRP reinforcement:

$$A_{f,sh} = \frac{\mu L w_{slab}}{2x\,(0.0012\ x\ E_f)}$$

$A_{f,sh}$ = cross-sectional area of FRP reinforcement per lineal foot, in2

μ = coefficient of subgrade friction = 1.5

L = distance between joints in slab, ft

w_{slab} = dead weight of the slab, psf

E_f = MOE of the FRP reinforcement, psi
(as noted in ACI 440.1R-15, at the allowable stress range noted for steel, the strain in the steel reinforcement is approximately 0.0012; this same strain is implemented for FRP).

If we look at a very simplistic calculation assuming a 4-inch thick slab of normal-weight concrete (150 pcf) with a 15-foot joint spacing, the above equations yield the following when comparing 70 ksi WWR to a GFRP reinforcement with an MOE of 9,500,000 psi:

Required area of steel reinforcement = 0.012 in^2 per foot
Required area of GFRP reinforcement = 0.049 in^2 per foot

While very rudimentary (and perhaps somewhat obsolete by today's slab-on-ground design standards), the results of the Subgrade Drag Method as utilized above are helpful in illustrating that, for a defined level of crack control reinforcement comprised of steel material, an equivalent area of GFRP material will be significantly larger. This is predicated on the fact that the MOE of GFRP is so much smaller than that of steel.

For nominal slabs-on-ground that are designed for "non-structural" shrinkage and temperature effects, the specified reinforcement arrangement is likely not going to be driven by the available tensile strength of the reinforcement itself, as the large crack widths that would correspond to the high stress levels at which a reinforcement is approaching fracture would be untenable for the serviceability of the slab. Reinforcement will instead be proportioned to control crack widths, and the stiffness of the reinforcement – in the form of its cross-sectional area and Modulus of Elasticity – becomes the primary consideration. In this scenario, high strength is not a substitute for stiffness.