## Slab-on-Ground Reinforcement per ACI 360

ACI 360 “Guide to Design of Slabs-on-Ground” is a common reference utilized by design professionals to establish basic guidelines for the reinforcement of slabs-on-ground. In this blog we will spotlight ACI 360 provisions that are relevant to defining reinforcement in slabs-on-ground, and will explore potential overlap with ACI 318.

***Soil Support Systems for Slabs-on-Ground***
**ACI 360-10 Section 4.1**

*The design of slabs-on-ground to resist moments and shears caused by applied loads depends on the interaction between the concrete slab and the supporting materials. Properties and dimensions of the slab and the supporting materials are important in the design of a slab-on-ground. The support system should be of acceptable uniform strength and not easily susceptible to the effects of climatic changes. Slab-on-ground failures can occur because of an improper support system.*

*The slab support system consists of a subgrade, usually a base, and sometimes a subbase.*

The importance of proper specification and preparation of supporting materials upon which a slab-on-ground is constructed cannot be overstated. Simply put, if the subsurface is inadequate, the slab-on-ground is far more likely to perform poorly and be prone to failure, regardless of the type and placement of the reinforcement therein.

Project contract documents should clearly define the slab-on-ground design criteria. This includes design load magnitude and arrangement and minimum supporting material load response requirements (which are often presented in terms of a minimum required modulus of subgrade reaction), as well as details related to slab-on-ground concrete composition, thickness, reinforcement, terminations and transitions, tolerances, finishing and curing, and testing requirements.

It is critical that the design professional of record provide sufficient structural performance-related information to inform the geotechnical engineer’s recommendations for the composition and preparation of the supporting materials. These geotechnical recommendations, in turn, provide the contractor with information necessary for construction corresponding to the structural design intent.

***Reinforcement Placement***
**ACI 360-10 Section 3.2.2 Slabs reinforced for crack-width control**

*Bar and wire reinforcement should be stiff enough to be accurately located in the upper 1/3 of the slab.*

**ACI 360-10 Section 3.2.3 Slabs reinforced to prevent cracking** *(for shrinkage-compensating concrete slabs)*

*To limit the initial slab expansion and to prestress the concrete, reinforcement is distributed in the upper 1/3 of the slab. Such reinforcement should be rigid and positively positioned.*

**ACI 360-10 Section 6.2** *(reinforcement for enhanced aggregate interlock across joint)*

*Place the reinforcement above mid-depth but low enough that the sawcut will not cut the reinforcement.*

**ACI 360-10 Section 8.3** *(reinforcement for crack-width control only)*

*For slabs that will not be exposed to view, or where appearance is not important, the reinforcement should be located as close to the slab top surface as possible while maintaining minimum concrete cover over the reinforcement. For slabs that will be exposed to view and the surface appearance is important, consideration should be given to specifying sufficient cover to minimize possible bar shadowing and subsidence cracking longitudinally over the reinforcement (Babaei and Fouladgar 1997; Dakhil and Cady 1975). A common practice is to specify that the steel have 1.5 to 2 in. (38 to 51 mm) cover from the top surface of the concrete to the bar to minimize the bar shadowing and subsidence cracking.*

**ACI 360-10 Table 3.1** *(slabs continuously reinforced with deformed bars or welded-wire reinforcement mats)*

*…continuous reinforcement placed near the top of the slab…*

WRI's Technical Blog titled "Thoughts on WWR Placement", is found in the link below:

https://wirereinforcementinstitute.org/technical-resources/technical-blog-and-case-studies/thoughts-wwr-placement

The WRI strongly encourages the reader to review the above-noted technical blog for a better understanding of WRI's position on the topic of WWR placement and related placement tolerance.

With the above in mind, it is clear that ACI 360 does not define explicit requirements for WWR placement, as it is – again – by definition a "guide" to design slabs-on-ground. Still, the recommendations therein are a reasonable starting point, and are worth consideration by the design professional of record unless on a project-specific basis there are underlying attributes of the project's slab design intent that are not appropriately captured.

***Reinforcement Amount***
**ACI 360-10 Section 6.1.3 Sawcut Vertical Joints**

*For unreinforced slabs-on-ground and for slabs only reinforced for limiting crack widths, other than continuously reinforced with more than 0.5% of steel by cross-sectional area, Figure 6.6 provides recommendations for joint spacing.*

**ACI 360-10 Section 6.2 Load-Transfer Mechanisms**

*Enhanced aggregate interlock depends on a combination of the effect of a small amount of deformed reinforcement continued through the joint and the irregular face of the cracked concrete at joints for load transfer. The continuation of a small percentage of deformed reinforcement (0.1% of the slab cross-sectional area) through sawcut contraction joints in combination with joint spacings (ACI 360 Fig. 6.6), has been used successfully by some designers to provide load-transfer capability without using dowels.*

**ACI 360-10 Section 8.3 Reinforcement for crack-width control only**

*Reinforcement required for crack-width control is a function of joint spacing and slab thickness. To eliminate sawcut contraction joints, a continuous amount of reinforcement with a minimum steel ratio of 0.5% (PCA 2001) of the slab cross-sectional area in the direction where the contraction joints are eliminated is recommended.*

Contraction joints, also known as weakened-plane joints or control joints, are features intended to help in mitigating random distributions of wide cracks that would otherwise occur in unreinforced expanses of concrete slab, as well as to manage panel edge curling. A contraction joint is meant to separate horizontally, effectively behaving as an intentional but controlled crack through the slab depth. Contraction joints are created through the application of partial-depth saw cuts into the top surface of the slab, in turn prompting the drying slab to crack along the resulting weakened plane as it volumetrically shrinks.

ACI 360 provides recommendations on maximum spacings of contraction joints in unreinforced slabs. The guide also provides guidance on load-transfer devices that should be deployed at these joints, as the utility of a space can be significantly impacted if at joint locations there occurs a differential vertical displacement of one slab panel relative to the next. Per ACI 360, the goal of load-transfer devices is to force the concrete on both sides of a joint to deflect approximately equally when subjected to load. This, in turn, helps to prevent damage to an exposed slab edge when subjecting the joint to wheel traffic while also maintaining a reasonably flush slab transition within a tolerance that is acceptable for the supported traffic and equipment utility.

A key attribute of a load-transfer device is its ability to provide the aformentioned “bridging” effect against differential vertical displacement without resisting the inherent need for the joint itself to open horizontally. One method that can achieve this combined behavior is the use of “enhanced aggregate interlock”, wherein a small amount of deformed reinforcement is continued through the joint. This reinforcement, applied at a small percentage (0.1% of the slab cross-section), allows for sufficient horizontal separation of the joint while at the same time keeping the irregular faces of the concrete slab on each side of the crack in close enough contact for the joint to remain vertically stable.

Theoretically then, and in the absence of larger areas of reinforcement needed between joint locations to resist localized effects of moment and shear, it is feasible for a slab-on-ground to be reinforced with 0.1% steel throughout its expanse, provided the reinforcement is positioned within the slab at a depth where it is not being interrupted by the saw cuts.

So what does 0.1% continuous reinforcement look like? See the WWR examples tabulated below for designer consideration.

| **Slab Thickness (inches)** | **Required Steel Area ($in^2/ft$)** | **Example Welded Wire Reinforcement** |
|---|---|---|
| 4.0 | 0.048 | 4x4 W1.7/W1.7 ←→ 12x12 D4.8/D4.8 |
| 5.0 | 0.060 | 8x8 D4.0/D4.0 ←→ 12x12 D6.0/D6.0 |
| 6.0 | 0.072 | 8x8 D4.8/D4.8 ←→ 12x12 D7.2/D7.2 |
| 6.5 | 0.078 | 8x8 D5.2/D5.2 ←→ 12x12 D7.8/D7.8 |
| 7.0 | 0.084 | 8x8 D5.6/D5.6 ←→ 12x12 D8.4/D8.4 |
| 7.5 | 0.090 | 8x8 D6.0/D6.0 ←→ 12x12 D9.0/D9.0 |
| 8.0 | 0.096 | 6x6 D4.8/D4.8 ←→ 9x9 D7.2/D7.2 |

The row shown in yellow includes an approximated “light-gauge” WWR mat style, while rows shown in green are steel areas that match the required steel area precisely.

Note that there exist a multitude of other WWR style combinations that can achieve a designer’s specified steel area beyond those tabulated above.

And what if contraction joints are not desired at all? ACI 360 states that the joints can be eliminated if a continuous amount of 0.5% reinforcement is provided. See the WWR examples tabulated below for designer consideration.

| **Slab Thickness (inches)** | **Min. Req’d Steel Area ($in^2/ft$)** | **Example Welded Wire Reinforcement** |
|---|---|---|
| 4.0 | 0.24 | 10x10 D20.0/D20.0 |
| 5.0 | 0.30 | 8x8 D20.0/D20.0 |
| 6.0 | 0.36 | 6x6 D18.0/D18.0 |
| 6.5 | 0.39 | 6x6 D18.5/D18.5 |
| 7.0 | 0.42 | 6x6 D21.0/D21.0 |
| 7.5 | 0.45 | 6x6 D22.5/D22.5 |
| 8.0 | 0.48 | 5x5 D20.0/D20.0 |

Again, note that there exist a multitude of other WWR style combinations that can achieve a designer’s specified steel area beyond those tabulated above.

Depending on the project parameters and limitations, an efficient and cost-effective method of specifying WWR for a slab-on-ground is for the designer to specify the required steel area itself (in conjunction with a prescriptive minimum and maximum wire spacing). This broad-based information in turn allows the WWR manufacturer to derive the ideal combination of wire size and spacing that suits both the design intent and the economy of production within their plant.

***Using ACI 318 for slab-on-ground design***

**ACI 360-10 Section 3.2.2 Slabs reinforced for crack-width control**

*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.*

**ACI 360-10 Section 3.2.4 Structural slabs**

*Structural plain and reinforced slabs that transmit vertical loads or lateral forces from other portions of the structure to the soil should be designed in accordance with ACI 318. Using the methods in ACI 318 with high steel reinforcement stresses, however, may lead to unacceptable crack widths.*

ACI 318-19 itself states in Section 1.4.8 that it *"does not apply to design and construction of slabs-on-ground, unless the slab transmits vertical loads or lateral forces from other portions of the structure to the soil."*

Essentially, then, for a slab-on-ground to fall entirely under the purview of ACI 360, it would need to be – by way of intentional isolation / separation - perfectly independent of the superstructure and substructure (i.e., foundation) load paths to ground.

In practice, achieving said isolation is far easier said than done. Because many slabs-on-ground have an inherent interaction with adjoining / abutting elements of the superstructure and substructure (for example, at the building's perimeter boundary and at interior vertical transitions such as pits and cheek walls), these slabs must be designed with various ACI 318 strength and connectivity provisions in mind.

ACI 360 goes on to list other slab-on-ground scenarios that would ultimately require ACI 318 provisions to be applied:

- Storage rack columns that support the building roof structure
- Mezzanine posts supported by the slab-on-ground
- Load-bearing walls supported by the slab-on-ground
- Perimeter building walls tied to the slab-on-ground to resist lateral and vertical loads
- Pre-engineered metal building columns vertically supported by the slab-on-ground or that use the slab to resist lateral loads

But this creates for the designer somewhat of a dilemma: procedurally, upon completing a design in accordance with ACI 318, how does one validate that a serviceability attribute like slab cracking is being controlled to a level anticipated by the prescriptions of ACI 360? Crack widths at the levels calculated within ACI 318, while appropriate for serviceability considerations of structural elements, may not be acceptable for the intended utility and/or aesthetic of a slab-on-ground otherwise intended to perform within the constraints of ACI 360 guidelines. It is possible that a slab-on-ground design characterized by 0.18% reinforcing steel (an amount defined in ACI 318 to be the minimum for both shrinkage & temperature effects as well as for flexural strength) underperforms from an industrial floor serviceablity perspective.

For a design scenario in which ACI 318 provisions must be applied, one possible approach is to consider utilizing the ACI 360 0.50% steel reinforcement threshold as a minimum reinforcement limit. The degree to which this provision is applied across the expanse of the slab-on-ground would of course require close consideration by the designer, however, as there could be select instances in which the corresponding amount of steel reinforcement – significantly higher than the 0.18% minimum - is unconservative from the standpoint of a particular application's tension-controlled behavior and desired ductile response.

Keep in mind that the prescriptions and guidelines discussed herein are just starting points for the slab-on-ground design process. The design professional of record, in conjunction with the end user, is ultimately responsible for establishing acceptance criteria for a particular slab-on-ground application, and the designer in turn must deploy the appropriate case-specific analytical method(s) to derive and detail a solution that satisfies both strength and serviceability.

It is possible – if not probable – that more complex designs are informed by both ACI 360 and ACI 318. It is the designer who is left to decide how best to balance provisions from both references in a culminating slab-on-ground design. In any case, welded wire reinforcement is a code-compliant structural solution that is manufactured with design versatility and ease of installation in mind.

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*For more information visit www.wirereinforcementinstitute.org.*

*References:*

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)", American Concrete Institute, Farmington Hills, MI, 2019 (Reapproved 2022)

2. ACI Committee 360, "Guide to Design of Slabs-on-Ground (ACI 360R-10)", American Concrete Institute, Farmington Hills, MI, 2010