ACI 360R-06 Brings Slabs on Ground Design into the 21st Century

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ACI Committee 360, Design of Slabs on Ground, recently completed a comprehensive update of their 360-92 document. All chapters from the existing document were extensively rewritten and new chapters were added on fiber reinforcing, slabs in refrigerated buildings, and structural slabs.

Figure 1: A perfect world – an industrial shell building ready for slab installation

General Considerations

Over the past fourteen years, there has been a broad increase of the industry's ability to place and finish high quality surfaces that are, at least initially, flat and level. The key drivers have been the Face Flatness and Levelness Numbering System for evaluating the surface, the laser screed, pan floats and early entry dry cutting saws. These developments permit the placing, finishing, and surface tolerance control of high quality floors at significantly higher daily production rates than in the past.

A serviceable slab is almost always defined by reference to only the exposed surface: a flat, level, dense finished surface with stable joints and limited cracking. However, the slab must be capable of supporting the applied loads by bearing on the ground. ACI Committee 302 (Construction of Concrete Floors) concentrates on the construction techniques required to achieve such a surface. ACI Committee 360 concentrates on the design considerations to achieve a stable platform for the serviceable surface.

The Committee's goal is to provide guidance for designers in planning, analyzing, specifying, and detailing slabs on ground which will provide the expected serviceability under the anticipated loadings and conditions of use. For a successful solution, it should be noted that even the best design requires reconciliation with the actual means, methods, materials and site conditions.

Design Choices

With an eye to these expectations, ACI 360R-06 presents four basic design choices:

1. Unreinforced concrete slab
2. Slabs reinforced to limit crack widths
3. Slabs designed to minimize cracking
   - o Shrinkage compensating concrete
   - o Post-tensioned
4. Structural slabs

These choices are each developed in specific chapters, preceded by general considerations, soil support system requirements and jointing options.

It is important to frame any design discussion with the acknowledgement that ACI considers slabs on ground as non-structural. Slabs on ground are generally modeled as an elastic slab supported by a field of linear springs. Stresses from applied loads can be calculated using this or similar models. Slab on ground design should result in sufficient strength to support the loads applied to the finished surface. Of course, an adequate soil support system is critical to the performance of the slab.

Slabs on ground are typically designed as unreinforced sections. The moment and shear stresses are calculated in working stress, and an appropriate safety factor against first cracking (Modulus of Rupture) is applied to determine the required section modulus and thickness. The first three design choices all use this approach. Under choice three, post-tensioned slabs evaluate the net tensile stress including the effective p-t compression, while shrinkage compensating concrete allows extended joint spacing independent of slab thickness.

The reason for the stress limiting approach to slab design is *serviceability*. Reinforced concrete is designed as a cracked section, but cracking of slabs on ground is generally contrary to Owner expectations.

Slabs on ground, working stress, section modulus — nothing could be simpler — right? Browse on, gentle reader.

The second choice only adds reinforcing steel to *limit* crack widths. The presence of reinforcing does *not* prevent cracking. Such reinforcing has negligible effect prior to cracks forming. The goal is to limit crack widths when and if cracking occurs.

The use of reinforcement to limit crack width received significant attention from the Committee. In the previous edition, the Subgrade Drag Formula provided a ready solution for using reinforcement to extend the contraction joint spacing. This formula yielded very low reinforcing ratios (suggesting the ubiquitous use of 6 x 6 x 10/10 welded wire fabric). The formula considers only subgrade friction, but the industry now recognizes the primary role warping (curling) plays in slab cracking.

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Figure 2: Subgrade restraint has been the focus of concern in the past

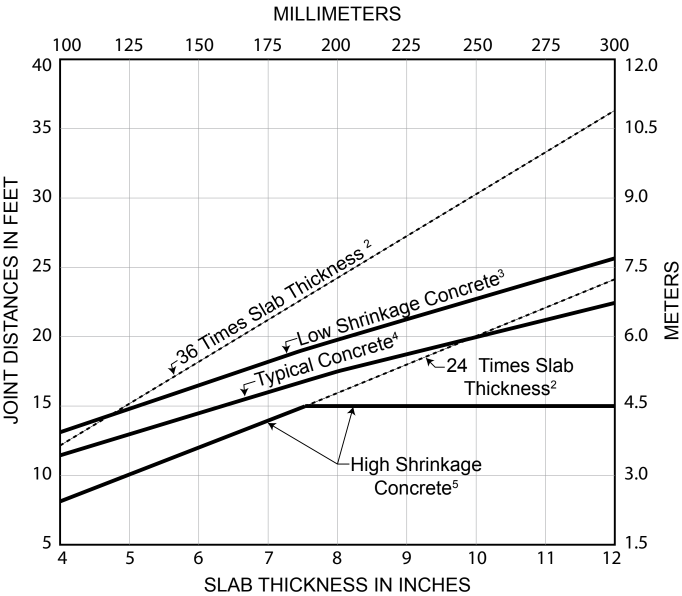

Fig. 5.6 Recommended joint spacing for unreinforced slabs

NOTES:

1. Joint spacing recommendations based on reducing the curling stresses to minimize mid-panel cracking (Walker-Holland 2001). See discussion in Section 5.2 for joint spacing for aggregate interlock.
2. Join spacing criteria of 36 and 24 times the slab thickness which has been utilized in the past is shown for reference.
3. Concrete with an ultimate dry shrinkage strain of less than 520 millionths placed on a dry base material.
4. Concrete with an ultimate dry shrinkage strain of 520 to 780 millionths placed on a dry base material.
5. Concrete with an ultimate dry shrinkage strain of 780 to 1100 millionths placed on a dry base material.

Figure 3: © 2006 ACI, reprinted by permission (This is referenced as new Figure 5.6 in this article)

While the formula seems rational within limits, the Committee has concluded that there are currently no valid criteria for selecting reinforcement to extend the joint spacing in slabs on ground. Joint spacing effectively should be selected on the basis of slab thickness only.

A new Figure, 5.6, (*see Figure 3*) is introduced recommending joint spacing based on slab thickness and anticipated concrete mix shrinkage characteristics. Specific mix shrinkage data is generally not available. Without valid data, high shrinkage should be assumed.

Other Reinforcing Considerations

Reinforcement can also be provided to maintain a nominal moment strength if unintended cracking does occur. A little belt and suspenders, but possibly reasonable insurance. Another option is to provide significant continuous steel at a ratio of about 0.50%. Properly designed and located, continuous reinforcing should produce acceptable tight, fine cracking at close spacing, and contraction joints may be effectively eliminated.

A new alternative discussed in ACI 360R-06 is to provide relatively light reinforcing continuous through the contraction joints. This concept is introduced in the *joint chapter* as a method of stabilizing the contraction joints, not to limit crack widths.

The issue of joint stability also received significant attention. Unreinforced slabs are usually divided into panels by contraction joints. Load transfer across contraction joints is accomplished by either aggregate interlock or load transfer devices, such as smooth steel dowels. Aggregate interlock can be lost if shrinkage is excessive or if all joints don't activate (by not cracking under every saw cut, for example), leading to accumulated movement at widely spaced joints.

Conventional wisdom has been that, when reinforcing is used, it should be discontinued at the contraction joints. The concern here was that the reinforcing could "blind" the slab to the presence of the sawn joint and cracking would occur away from the saw cut. The use of light reinforcing (0.10%), *not more*, *not less*, is presented. This reinforcing, while continuous through the contraction joints, is provided only to hold the activated joints in effective contact for load transfer. If properly positioned, even light reinforcing would provide some resistance to crack widening. However, to reiterate, joint spacing should follow Figure 5.6.

Fiber Reinforcing

The new chapter on fiber reinforced slabs on ground provides useful insights on using fibers to enhance slab performance. Fine monofilament fibers (denier less than 100) are useful in controlling bleed water channel formation and plastic shrinkage. They have limited effect after the concrete takes initial set.

Macropolymeric fibers (denier greater than 1000) help control cracking due to drying shrinkage. Steel fibers can increase impact resistance and other properties.

In general, the Committee believes that fibers should be treated as an enhancement. The notion that fibers contribute to ductility was resisted. Fibers typically fail by progressive bond failure. This may mimic tensile ductility, but would not justify extending joint spacing or reducing slab thickness. Further research and development may build better confidence in this area.

The structural slab chapter, while brief, draws attention to the requirement that load bearing elements must bear on foundations. Slabs on ground can be designed as foundations; however the design criteria would then be mandated by ACI 318 (Building Code Requirements for Structural Concrete). This can be a gray area and the chapter is intended to draw attention to the issue and act as a placeholder for future elaboration.

Conclusion

The new 360 document reflects current research and analysis, addresses significant changes in design thinking, and embraces new materials and technologies. For industrial applications, slabs on ground are the working surface for all activities. As someone said, "The roof only leaks when it's raining — a floor problem is there all day, every day."

Design should provide adequate thickness. Joints should be closely spaced with adequate provision for load transfer — *or* joints should be minimized by shrinkage compensating concrete or eliminated by post-tensioning or heavy continuous reinforcing. And finally, the design must be reconciled with the actual means, methods, materials and site conditions of the project.▪

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