the Construction Specifier

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Concrete Floor Slabs

Writing a specification that mitigates project risk

by Nigel K. Parkes

More than any other component, a facility's concrete slab-on-ground can render the biggest risk to designers for long-term client retention and potential litigation. As the floor is the platform for work in an industrial, warehouse, or retail environment, its serviceability can significantly impact the building owner's and/or tenant's efficiency and profitability.

A 2003 survey conducted by Metzger/McGuire found only 25 percent of facility owners agreed their floors were in good or excellent condition.[1] While the performance of a slab-on-ground primarily results from its design, the quality of its construction is also a factor. With multiple variables and potentially conflicting guidance from industry publications, the challenge of delivering a good concrete slab-on-ground is exacerbated by its construction in sometimes unpredictable conditions, often with limited oversight by the designer due to time and cost constraints. Even with the utmost confidence in a contractor's ability to provide a quality installation, design professionals must provide clear specifications. That is, each point must be qualified by either a measurable performance specification or clearly constructible prescriptive details and notes.

In an attempt to mitigate design execution risk, designers often try to specify every aspect and component of a floor slab's structure. The opportunities to use measurable performance specifications, as well as this approach, can cloud the delineation of responsibility between designer and contractor. Further, the litany of information provided by vendors of proprietary products can increase the likelihood of conflicting information in a specification.

Alternatively, some designers attempt to lessen risk by relying heavily on industry standards and guides, while omitting the contractor's core requirements. Most concrete slab-on-ground designs are not contemplated in American Concrete Institute (ACI) 318, *Building Code Requirements for Structural Concrete*. Other relevant industry guides are written in non-mandatory language and cover numerous designs and detail alternates. Specifications that state "the requirements of any given guide or standard should be followed," without noting specific aspects, can lead to confusion, conflict, and possibly litigation. If a designer wishes to use information contained in industry guides, it is safer to insert specific text in the specification and put it into mandatory language.

Every building owner's requirements are unique and specifications must be customized to meet those needs. This article clarifies some of the more confusing and frequently problematic aspects of a concrete slab-on-grade specification.

Understand the client's needs

Before deciding on a design methodology or specific details to use, the design professional should gather as much information from the owner or tenant as possible. The following are some key criteria to be ascertained.

Loads to be carried

Static loads must be understood, specifically their types and location in the facility. If loads include racks, then the typical and maximum loads applied should be determined. Owners often draw information from their racking company's trade literature and provide the designer with the maximum allowable loads, rather than those expected from their pallets of product and/or materials. This can result in over-designing a slab and the ensuing unnecessary additional costs.

Important elements of determining dynamic loads include the equipment type (*e.g.* fork trucks, carts) and the frequency in which they move about the facility. The type of equipment should be described using the rated and expected use capacity, wheel type, size and composition, and tolerances required for it to function at full speed. Characteristics of vehicular traffic greatly impact numerous design decisions, including the surface tolerance, finish, resistance to wear (*i.e.* abrasion), joint details for load transfer, joint-filling, and/or sealing requirements.

Wet curing covers are becoming popular. This curing method is the optimal way to cure a slab and increase abrasion resistance.

Abrasion resistance

In cases where a client is building a particular type of facility for the first time, abrasion resistance may be difficult to ascertain. However, estimates can be made based on the type of wheels on equipment and load repetitions with documented assumptions related to the building's main purpose. For example, a high-volume distribution center open around the clock will probably have a greater instance of moving materials around and therefore, a greater need for abrasion resistance compared to a manufacturing facility with limited hours of operation.

Aesthetics

The arbitrary nature of aesthetics can often lead to misunderstanding and disagreement. Referring to existing facilities as a guide is often the best means of establishing a desired look. Surface finish or texture, color, and curing methods can affect aesthetics considerably. Additionally, the required abrasion resistance can sometimes conflict with the desired look, which may require the designer to advise the building owner on the limitations of certain finishes.

Previous problems

The best assessment of an owner's expectation can be found by looking at his or her existing facilities. If the client is a first-time facility owner, then accompanying the owner on tours of other buildings can prove extremely useful.

often greatly exceeded.

Specified far less frequently, but equally important, is flexural strength. Most designers assume a relationship between compressive and flexural strength in their slab-on-ground designs. Given its importance, specifying flexural strength directly may reduce the frequency of over-designed concrete mixes. The standard test method for flexural strength is ASTM International C 78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-point Loading).*

Budget

Based on an owner's performance criteria, more than one design may be a valid option. However, the cost of these alternatives could vary significantly, especially considering initial construction and lifecycle costs.

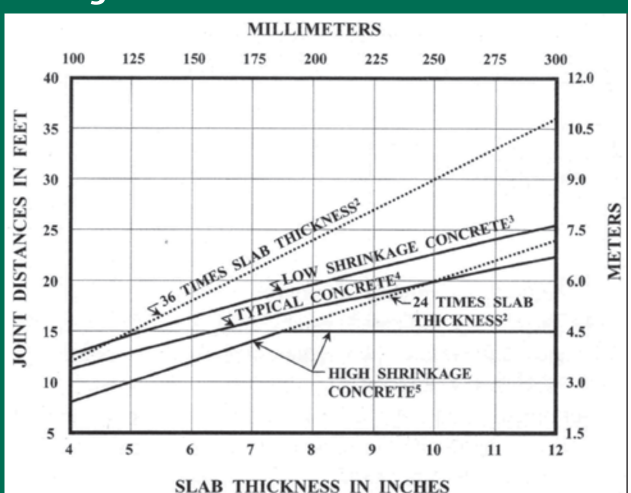
Performance-based specifications

Whenever standardized testing exists, performance-based specifications are preferred. However, where this is not the case, prescriptive specifications are recommended to ensure delivery of the intended slab-on-ground.[2] If the designer must go the prescriptive route, it is critical to clearly identify specific requirements with sufficient information regarding the means, methods, and products to accomplish the desired results. The following are some of the most important, yet confusing, criteria of a concrete flatwork performance-based specification.

Concrete strength

Compressive strength is perhaps the most clearly defined and used test regarding materials for concrete slab construction. However, it is perhaps one of the least important factors in achieving a durable floor. In fact, the specification of a high compressive strength concrete can be counterproductive. Increasing the concrete's compressive strength by specifying higher quantities of cement generally increases drying shrinkage and, therefore curling. For this reason, the latest edition of ACI 302, *Guide for Concrete Floor and Slab Construction*, reduces the recommended compressive strength for floor classes '4,' '5,' and '6' (*i.e.* light to heavy industrial vehicular traffic use) to 24,132 kPa (3500 psi).[3] Since the compressive strength is often the only tested quality of a concrete mix, ready-mix suppliers err on the side of caution, meaning minimal strength requirements are often greatly exceeded.

Figure 1 ACI 360R-06



New recommendations for joint spacing significantly reduce the number of random cracks.

Figure courtesy American Concrete Institute

Drying shrinkage

Concrete's drying shrinkage rate directly affects the required joint spacing.[4] Higher drying shrinkage increases the propensity for excessive curling, random cracking, and wide joint openings. The result leads to reduced load transfer effectiveness and joint filler performance and, consequently, increased potential for joint spalling. Drying shrinkage can be tested using the standard test method outlined in ASTM C 157, *Standard Test Method for Length Change of Hardened Hydraulic-cement Mortar and Concrete*. This allows design professionals to specify a measurable value rather than a prescriptive mix. ACI 360R-06, *Design of Slabs On Ground*, provides ranges of dry shrinkage strain relative to the recommended joint spacing.[5]

Joint spacing

A slab's joint spacing is calculated by dividing the column spacing into even portions without exceeding the maximum spacing dictated by the drying shrinkage. The traditional rule of thumb of 24 to 36 times the slab depth has been replaced in ACI 360R-06 by more realistic and safer guidelines (Figure 1). The new recommendations for joint spacing can significantly reduce the number of random cracks experienced, particularly in deeper slabs.

Surface tolerance

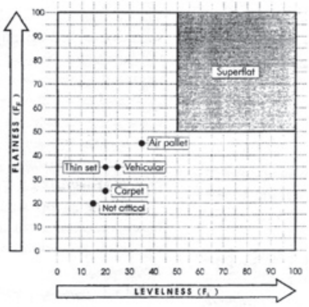
The use of the FF/FL number system for measuring surface flatness and levelness (both slab and base) and to control slab thickness is now common. (The method of testing is defined in ASTM E 1155-96/01, *Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers*). Each surface should be specified using two FF/FL numbers, that is, the overall and minimum local FF/FL numbers. The best method of assessing an owner's requirement is based on their existing floors or secondarily referring to ACI guides (Figure 2).[6]

The majority of contractors have learned which placing and finishing techniques achieve certain specified F numbers. If the floor's flatness tolerance is expected to have a significant effect on the performance of vehicular equipment, then designers should consider specifying tolerance measurement from joint to joint, rather than a 0.6 m (2 ft) envelope of all joints, which is common practice. ACI guides indicate testing should be

Figure 2 Floors and F-numbers

CONCRETE FLOOR AND SLAB CONSTRUCTION

FLATNESS/LEVELNESS TYPICAL USE GUIDE



SLABS ON GROUND

Composite Overall Flatness (F_F)	Composite Overall Levelness (F_L)	Typical Use	Typical Class
20	15	Noncritical: mechanical rooms, non-public areas, surfaces to have raised computer flooring, surfaces to have thick-set tile, and parking structure slabs	1 or 2
25	20	Carpeted areas of commercial office buildings or lightly-trafficked office/industrial buildings	2
35	25	Thin-set flooring or warehouse floor with moderate or heavy traffic	2, 3, 4, 5, 6, 7, or 8
45	35	Warehouse with air-pallet use, ice or roller rinks, gymnasium floors[4]	9
>50	>50	Movie or television studios	3 or 9

SUSPENDED SLABS

Composite Overall Flatness (F_F)	Composite Overall Levelness (F_L)	Typical Use	Typical Class
20	15[2] or N/A	Noncritical: mechanical rooms, non-public areas, surfaces to have raised computer flooring, surfaces to have thick-set tile, and parking structure slabs	1 or 2
25	20[1] or N/A	Carpeted areas of commercial office buildings or lightly-trafficked office/industrial buildings	2
35	20[2] or N/A	Surfaces to receive thin-set flooring	2, 3, or 4
45	35[3]	Ice or roller rinks, gymnasium floors[4]	3
>50	>50[1,3]	Movie or television studios	3 or 9

NOTES

1. Multi-directional quality of this level requires grinding of joints.
2. Levelness F-number only applies to level slabs shored at time of testing.
3. This levelness quality on a suspended slab requires a two-course placement.
4. All elevation samples should fall inside a 1/2 in. deep envelope.

The use of F-numbers is now common. The above comes from the American Concrete Institute (ACI) ACI 302.1R-04, Guide for Concrete Floor and Slab Construction.

Figure courtesy American Concrete Institute

conducted within 72 hours of a specific placement and completion. Therefore, the designer should consider curling's possible effect on finished tolerances. In those rare cases where F numbers are not achieved, acceptable remedies should be included in the specification. These would generally address grinding the surface to achieve the required flatness specification or financial penalties. However, in unusual circumstances, more extreme remedies (*e.g.* slab removal and replacement) may be appropriate.

Abrasion resistance

ASTM C 779, *Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces*, provides standards for testing abrasion resistance. Given these are costly laboratory-based methods, a useful alternative can be an instrument such as the Chaplin Abrasion Tester, as it can be employed on-site.[7] A performance specification for wear resistance can be established by specifying the maximum depth of wear at 28 days or more for the floor class (per ACI 302.1R-04) being designed using Table 20.1 (Figure 3).

This approach can significantly reduce potential conflict between owners and contractors over expectations and results. Second only to the F number testing for tolerance compliance, it also provides an opportunity to differentiate between qualified contractors.

More important than the concrete strength and aggregates used is the contractor's ability to provide a hard-troweled, smooth finish, as well as the application of a good curing method. Wet curing covers are becoming commonplace due to their effectiveness, consistency, environmental factors, more prevalent polymer coatings and toppings, and the quality of results. Due to its importance, the curing method and product should be stipulated in the specification.

Soil support system

One of the largest sources of restraint to a slab's normal drying shrinkage is induced by its contact with the base. Designers should specify the acceptable range of the modulus of subgrade reaction and the method of measurement using ASTM D 1196, *Standard Test Methods for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components for use in Evaluation and Design of Airports and Highway Pavements*, based on soil classification or one of the other methods identified in ACI 360R-06.[8]

Base friction can be reduced with the introduction of a compacted and rolled stone base. The designer can specify all bases be proof-rolled with a fully loaded concrete or dump truck, and require proper repair of rutting or pumping be performed both before and during the concrete placement. Rutted bases often go untended in conventionally reinforced designs because the rebar mat prevents the contractor from bringing a roller compactor back in to straighten grades during the placement. The restraint caused by uneven, rutted bases can significantly contribute to the number of random cracks experienced.

Prescriptive-based specifications

If a performance-based specification cannot be found for an important element of the design of a slab-on-ground, then the designer must resort to one of the following prescriptive-based criteria.

Figure 3 Table 20.2: American Classification of Wear Resistance

Class	Use	Usual traffic	Maximum wear depth*
1	Exposed concrete in offices, houses, shops, and institutions	Feet	0.80 mm (0.031 in)
2	Covered concrete in offices, houses, shops, and institutions	Construction vehicles	0.80 mm (0.031 in)
3	Toppings in non-industrial buildings	Feet	0.80 mm (0.031 in)
4	Institutions and retail stores	Foot and light vehicles	0.40 mm (0.016 in)
5	Medium-duty factories and warehouses	Pneumatic tires, soft plastic tires	0.20 mm (0.008 in)
6	Heavy-duty factories and warehouses	Heavy industrial, impact	0.10 mm (0.004 in)
7	Bonded toppings in heavy-duty factories and warehouses	Hard tires and heavy loads	0.05 mm (0.002 in)
8	Unbonded toppings	As for classes 4–6	0.40–0.10 mm (0.016–0.004 in)
9	Superflat floors	Hard plastic tires in defined paths	0.10 mm (0.004 in)

**From standard test with Chaplin abrasion test.*

Table courtesy George Garber's *Design and Construction of Concrete Floors* (Halsted Press, 1991).

Surface finish

The concrete surface finish is the most arbitrary specification point and generally described by the last piece of finishing equipment to be used. Consequently, the placement of a test panel is recommended to ensure all parties agree on the finish. The test panel should be left in place for comparison with the final product.

Joint details

As a result of curling and spalling under vehicular traffic, joints are the most prolific problem with concrete slabs-on-ground. Curling (or warping) is an extended process occurring in all slabs-on-ground—it is not primarily the contractor's fault. Generally, only 60 to 80 percent of the curling will have occurred one year after the slab has been poured. Curling cannot be eliminated except under highly unusual conditions where there is no moisture or thermal gradient between the slab's top and bottom or when special designs are used. Examples of these special designs include shrinkage-compensating concrete or post-tensioning with the tendon heights adjusted to restrain the curl.

A significant drawback in the slab thickness design methodologies outlined in current ACI guides is all three methods assume the slab remains in full contact with the ground and curl-induced stresses are not considered. The three acceptable design methodologies from the Portland Cement Association (PCA), the Wire Reinforcement Institute (WRI) and the U.S. Army Corps of Engineers (USACE) are outlined in ACI 360R-06. Each of these methods seeks to avoid live load-induced cracks through the provision of adequate slab cross-section by using an acceptable safety factor against rupture. The edge effect is reduced by the introduction of positive load transfer at joints; as a result, specifications for joints (construction and saw-cut contraction) subject to vehicular traffic, heavy loads, or both should include load transfer devices.[8]

Load transfer device specifications

Dowel geometry should be taken into account in load transfer device specifications to minimize bearing stress on the concrete and avoid inducing restraint from either misalignment or restriction of the adjacent panels' lateral movement.[9]

There are generally four types of dowels—round, square, rectangular plate, and tapered plate. Caution should be exercised with the specification of round dowels due to the difficulty of installing them straight and without creating a void around them. The lack of allowance for the lateral movement of adjacent slabs is also a consideration. To mitigate this with square and rectangular plate dowels, the designer should specify the vertical sides as having compressible foam attached via a secure device (*e.g.* clip).

Dowel details are calculated using the dynamic and static loading requirements and include the diameter or cross-sectional area, length, spacing, and acceptable range of distance from the joints' intersection. Tapered plate dowels can be placed within 152.4 mm (6 in.) of the joint intersection because of the allowance for lateral movement inherent in their geometry, eliminating the inducement of restraint at the slab corner.

All dowels should be smooth, deburred, and sawn to prevent inducement of restraint to the slab's horizontal movement. Additionally, the use of a thinly controlled bond-breaker, preferably factory-applied, is recommended.

Ideally, construction joints are formed with full-depth bulkheads of wood or metal placed at the proper elevation. Stakes and support should be placed to keep the bulkheads straight, true, and rigid during the entire placing and finishing procedure to avoid joint spalling and the creation of key ways.[10] Fully welded basket assemblies should be used in saw-cut contraction joints to maintain the alignment of the dowels at the mid-point of the slab. Shipping wires for baskets do not need to be cut.

Internal vibration is required for the area around any embedment, including load transfer devices, to ensure complete consolidation.

Joint filler or sealant

Industrial floors should be filled, rather than sealed. Any filler flexible enough to expand substantially will deflect under hard-wheeled fork truck traffic, therefore exposing the joint to deterioration. A designer may want to specify the construction joints be saw-cut 25.4 mm (1 in.) deep, providing a platform to hold the joint filler. Construction and saw-cut contraction joints should be filled full saw-cut depth.

Joint armoring

If a client has either no tolerance for joints or no budgetary constraints, a jointless slab design such as shrinkage-compensating concrete or a post-tensioned slab should be recommended. In such cases, it is critical to specify load transfer devices that allow for differential shrinkage of adjacent slab casts and armored joints at the construction joints. This prevents the only remaining joints from spalling and becoming maintenance issues. These armored joints should be manufactured from cold-rolled steel bars to ensure a straight edge to finish against at the same elevation as the slab surface.

Reinforcement

Among owners, there is a common misconception reinforcement prevents cracking. In truth, reinforcement restrains movement resulting from slab shrinkage and can actually increase the number of random cracks experienced, particularly at wider joint spacing.[11] Reinforcement is for crack-width control, but it is costly and cumbersome to install. If reinforcement is in the slab design, then it is critical to specify it:

- be placed above mid-depth, but low enough so the saw cut will not cut the reinforcement;
- is discontinued at least 50.8 mm (2 in.) from each joint;
- does not 'extend' the joint spacing, which is advised against in ACI 360R-06, unless it is clearly justifiable based on the individual circumstances; and
- is chaired at the specified elevation and not walked in or pulled up.

Doing so may avoid additional random cracking and may help the reinforcement hold the cracks tight at the top of the slab, rather than the bottom.[12]

Using a strategic reinforcement design mitigates design execution risk and delivers a more durable slab-on-ground.

Conclusion

When concrete flatwork specifications are inaccurate or incomplete, the designer, contractor, and owner pay the price in the form of damaged reputation and reduced profitability through lost productivity, slab/

equipment repairs, and litigation costs. The most common concrete flatwork failures are spalled joints, random cracking, and low wear resistance. All three issues can be significantly reduced, if not eliminated, with the controlled application of a clearly written specification.

The adoption of performance specifications for minimum strengths, drying shrinkage rates, and abrasion resistance, along with clearly defined prescriptive specifications of surface texture, means designers can leave contractors and their ready-mix suppliers to develop suitable mix designs to produce the desired results.

Current ACI guides offer valuable information that can be used to update old specifications and mitigate a designer's professional liability, but references to the adoption of the guides in their entirety should be avoided as they encompass too many options.

Notes

[1] See www.metzgermcguire.com.

[2] If a standard test is available, then a value can be specified and its result measured for compliance. If it is not, then any value given is arbitrary and often leads to argument. Prescriptive specifications provide more direction, often outlining the 'means and methods' required to accomplish a given quality of standard.

[3] See the 2004 *Guide for Concrete Floor and Slab Construction,* American Concrete Institute (ACI) 302.1R-04.

[4] See the 2006 *Design of Slabs-on-Ground,* American Concrete Institute 360R-06.

[5] See note 4.

[6] See note 3.

[7] See George Garber's *Design and Construction of Concrete Floors* (Elsevier, 2006).

[8] See note 4.

[9] See note 4.

[10] See Wayne W. Walker and Jerry A. Holland's "Performance-based Dowel Design," in the January 2007 issue of *Concrete Construction.*

[11] See note 3.

[12] See Gregory Scurto, David Scurto, et al's "Cost-effective Slabs-on-Ground," in the May 2004 issue of *Concrete International.*

Additional Information

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Abstract

In big box retail, industrial, and manufacturing facilities, one of the areas most prone to failure is the slab. When concrete slabs-on-ground fail, the owner pays in facility downtime and costly repairs; and the designer risks potential litigation for the firm. In this article, readers will learn how to use latest industry guidelines to design more serviceable slab and mitigate risk for the designer and owner.