joints. The PCA (2001) provides considerations for the effectiveness of shear transfer at joints.

7.3.1 *Steel dowels*—Steel dowels are the most effective means to provide effective load transfer and to ensure adjacent curled joint edges deflect together. Refer to Chapter 6 for a discussion of different doweling approaches.

When dowels are installed across a joint, the slab edges abutting the joint may still curl and deflect when loaded, but they do so in unison. When the wheel reaches the joint, no significant relative vertical displacement between the panels is encountered, and the impact loads imposed on the edges are greatly reduced.

7.4—Maximum joint spacing

Assuming the subgrade is relatively free from abrupt changes in elevation, such as that caused by uncorrected wheel rutting, the tensile stresses created in the shrinking panel by subgrade frictional restraint are relatively minor in comparison to curling-induced stresses. These higher curling stresses are likely the principal cause of shrinkage cracking in most unreinforced concrete floor slabs (Walker and Holland 1999).

In general, joint spacing should not exceed the spacing in Fig. 6.6 and as discussed in Chapter 6. Refer to Chapter 14 for discussion on how joint spacing affects curling-induced stress.

CHAPTER 8—DESIGN OF SLABS REINFORCED FOR CRACK-WIDTH CONTROL

8.1—Introduction

The thickness of slabs-on-ground should be selected to prevent cracking due to external loadings as discussed in Chapter 7. Slab thickness calculations should be based on the assumption of an uncracked and unreinforced slab. Reinforcement may be used in slabs-on-ground to improve performance of the slab under certain conditions. These reinforcement benefits include:

- Limiting shrinkage crack width;
- Use of longer joint spacings than unreinforced slabs; and
- Providing flexural strength and stability at cracked sections.

Reinforcement will not prevent cracking, but will actually increase crack frequency while reducing crack widths. Properly proportioned and positioned, reinforcement limits crack widths such that the cracks should not affect slab serviceability. The appearance of cracks for this slab type should, however, be discussed with the owner so that the owner has the expectation that cracks will possibly occur.

8.2—Thickness design methods

The inclusion of reinforcement, even in large quantities, has very little effect on the uncracked strength of the slab. The PCA, WRI, and COE thickness design methods described in Chapter 7 may all be applied to the design of reinforced slabs-on-ground by ignoring the presence of the reinforcement.

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. 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.

CHAPTER 9—DESIGN OF SHRINKAGE-COMPENSATING CONCRETE SLABS

9.1—Introduction

This chapter deals with shrinkage-compensating concrete slabs made with cement conforming to ASTM C845. The design procedure differs significantly from that for conventional concrete with ASTM C150/C150M portland cement and blends conforming to ASTM C595.

When concrete dries, it contracts or shrinks and when it is wetted again, it expands. These volume changes with changes in moisture content are an inherent characteristic of hydraulic-cement concrete. ACI 224R discusses this phenomenon in detail. Volume changes also occur with temperature changes.

Shrinkage-compensating concrete is expansive cement concrete that, when restrained by the proper amount of reinforcement or other means, will expand an amount equal to or slightly greater than the anticipated drying shrinkage. Subsequent drying shrinkage reduces the expansion strains, but ideally, a residual compressive stress remains in the concrete, thereby minimizing shrinkage cracking and curling. Sections 9.1.1 and 9.1.2 explain how shrinkage-compensating concrete differs from conventional concrete with respect to volume changes.

9.1.1 *Portland-cement and blended-cement concrete*—The shortening of cement and blended-cement concrete due to shrinkage is restrained by reinforcement and friction between the ground and the slab. This shortening occurs at an early age, and the friction can cause concrete tension restraint stress in excess of its early tensile strength, thereby cracking the slab.

As drying shrinkage continues, cracks open wider. This may present maintenance problems, and when the crack width exceeds 0.025 in. (0.6 mm), aggregate interlock (load transfer) becomes ineffective. Refer to Section 6.2 for additional information on aggregate interlock. Cracking due to shrinkage restraint can be minimized by closer joint spacing or post-tensioning, or crack widths can be minimized with additional distributed reinforcement.

9.1.2 *Shrinkage-compensating concrete compared with conventional concrete*—Shrinkage-compensating concrete is used to limit cracking and curling. Shrinkage-compensating concrete is made with cement conforming to ASTM C845 rather than ASTM C150/C150M or C595/C595M. Therefore, the volume change characteristics are different. Shrinkage-compensating concrete undergoes an initial volume increase during the first few days of curing, and then undergoes drying shrinkage. The drying-shrinkage characteristics of shrinkage-compensating concrete are similar to those of portland-cement concrete. The drying shrinkage of shrinkage-compensating concrete is affected by the same factors as portland-cement concrete. These include water content of the concrete mixture, type of aggregate used, aggregate gradation, and cement content. The water content influences the expansion during curing and subsequent shortening due to drying shrinkage. Figure 9.1 illustrates the typical length-change characteristics of shrinkage-compensating and portland-cement concrete prism specimens tested in accordance with ASTM C878/C878M (ACI Committee 223 1970).

In shrinkage-compensating concrete, the expansion is restrained by the bonded reinforcement, which causes tension in the reinforcement. As a result of this expansive strain causing tension in the reinforcement, compression develops in the concrete to oppose this tension. These stresses are relieved over time by drying shrinkage and creep. It is intended that the restrained expansion be greater than the resultant long-term shrinkage, as shown in Fig. 9.2, so the concrete remains in compression. The minimum recommended amount of concrete expansion for slabs-on-ground, measured in accordance with ASTM C878/C878M, is 0.03%.

9.2—Thickness determination

For a shrinkage-compensating concrete slab-on-ground, the determination of the slab thickness is similar to that used for other slab-on-ground design methods. The PCA, WRI, and COE methods are all appropriate. Refer to Chapter 7 and Appendixes 1, 2, and 3. Appendix 5 illustrates other design considerations specific to shrinkage-compensating concrete.

9.3—Reinforcement

9.3.1 *Restraint*—An elastic type of restraint, such as that provided by internal reinforcement, should be provided to develop shrinkage compensation. Other types of restraint such as adjacent structural elements, subgrade friction, and integral abutments, are largely indeterminate, and may provide either too much or too little restraint. Subgrade frictional coefficients in the range of 1 to 2 have been used with acceptable results. High restraint, however, induces a high compressive stress in the concrete but provides little shrinkage compensation. To reduce subgrade frictional restraint, which allows easier expansion, two sheets of polyethylene have been used successfully. Subgrade frictional coefficients as low as 0.20 have been measured (Timms 1964) for two sheets of polyethylene in the laboratory. Due to the construction variations in the base, however; a more realistic subgrade friction value of 0.30 for two sheets of polyethylene is likely and recommended for projects with

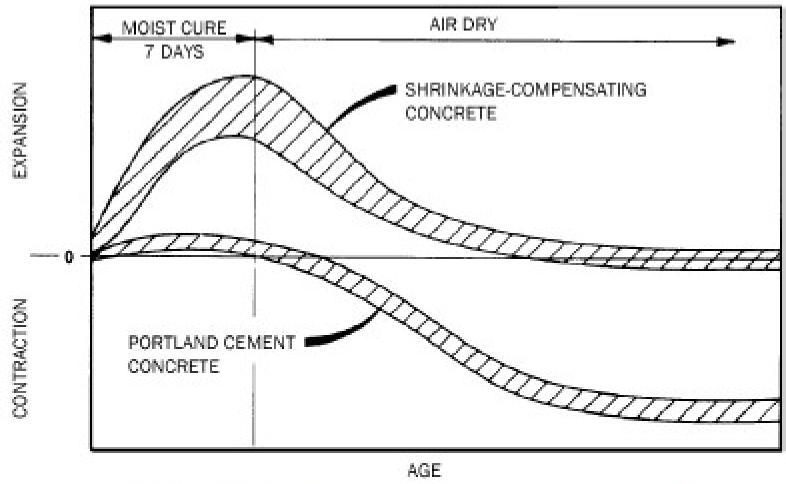

Fig. 9.1—Typical length change characteristics of shrinkage-compensating and portland-cement concretes (ACI Committee 223 1970).

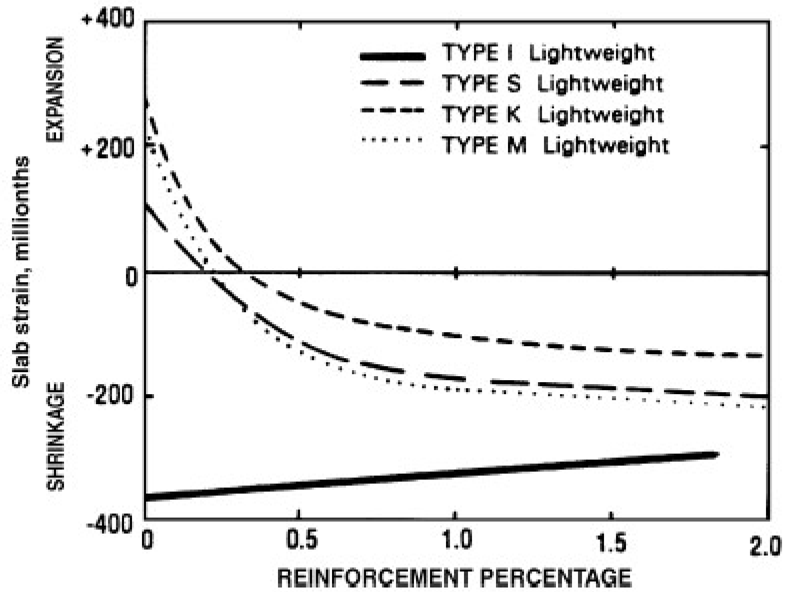

Fig. 9.2—Effect of reinforcement on shrinkage and expansion at 250 days (Russell 1980).

smooth and level bases. Wherever possible, the designer should specify the reinforcement recommended in ACI 223.

9.3.2 *Minimum reinforcement*—A minimum ratio of reinforcement area to gross concrete area of 0.0015 should be used in each direction that shrinkage compensation is desired. This minimum ratio does not depend on the reinforcement yield strength. When procedures outlined in ACI 223 are followed, however, a reinforcement ratio of less than 0.0015 may be used.

9.3.3 *Effect of reinforcement location*—The position of the steel is critical to both slab behavior and internal concrete stress. ACI 223 recommends positioning reinforcement 1/3 of the depth from the top. The top reinforcement balances the restraint provided by the subgrade and provides elastic restraint against expansion. Exercise caution when using smaller percentages of reinforcement because small-gauge bars and wires may be more difficult to position and maintain in the top portion of the slab. Use lower reinforcement percentages with stiffer, more widely spaced reinforcement such as ASTM A497/A497M, deformed wire reinforcement ASTM A615/A615M, ASTM A996/A996M, and ASTM A706/A706M deformed bars.