Post-tensioned slabs on ground are easier with shrinkage-compensating concrete

Makes single-step post-tensioning possible

By Robert J. Gulyas
Marketing Director, Special Products
Medusa Cement Company
Cleveland, Ohio

Post-tensioned concrete slabs on ground are coming into use to prevent cracking, particularly when built on expansive soils. Post-tensioning usually is a two-step process. The common practice is to lightly post-tension the slabs at an early age to prevent early shrinkage cracking. At a later age, when concrete strength is high enough, the full post-tensioning load is applied. The procedure is costly in labor because it requires that the post-tensioning be done twice.

If expansive cement is used, however, it is possible to eliminate the first post-tensioning operation and enjoy another advantage as well—freedom from the early cracking that sometimes occurs in the two-step process.

Most post-tensioned slabs on ground are cast with side forms. Post-tensioning steel is usually nonbonded tendons. Soon after the concrete is cast it begins to shrink. It may also contract thermally. But the subgrade restrains the slab from moving freely, so tensile stresses begin to build up. These increase rapidly enough at the beginning to soon exceed the tensile strength, and the slab cracks. The problem is compounded by the restraint offered by any thickened edges and interior thickened sections.

When the concrete reaches its specified early compressive strength, usually in 3 to 7 days, the steel tendons are tensioned and the compressive force is transferred to the concrete. Unfortunately, cracks often occur earlier than this strand tensioning, usually in placements of slabs as large as 40 by 60 feet.(1)* This circumstance can introduce the further complication that the cracks may not close properly during post-tensioning either because the fractured pieces become mismated or because the relatively low forces applied to the concrete (about 50 psi(2) net compression) are not enough to overcome the subgrade friction. (The amount of this friction depends on the thickness and length of the slab and the texture of the subgrade or subbase.) Thus prestressed slab-on-ground applications may develop cracks both before and after tensioning unless modifications are made.

Full early stressing is not practical because of the low early compressive strength of high-slump concrete. Consequently, partial post-tensioning is advocated, for example 1500 psi(3) at 24 hours and full stressing later, when adequate compressive strength has developed, for example within 3 to 7 days.

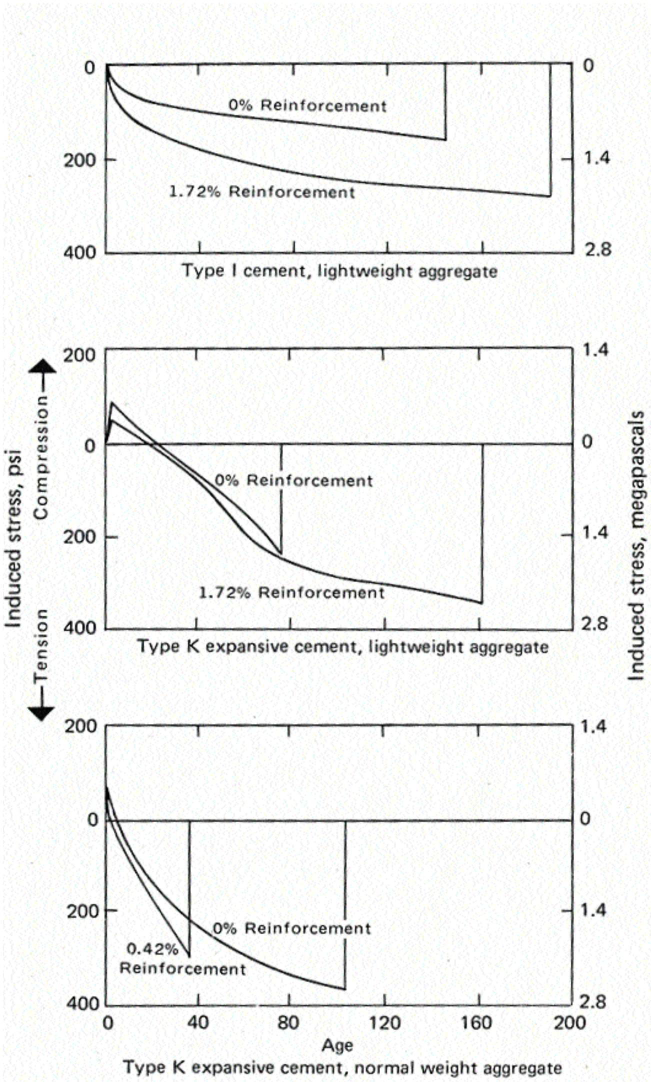
Opportunity offered by expansive cement

Expansive cement can be used to make shrinkage-compensating concrete, eliminate the possibility of early shrinkage cracking and make the first post-tensioning operation unnecessary. Such a slab actually undergoes a controlled increase in volume as it is curing. Inasmuch as the slab is cast against a form or existing concrete, external edge restraint plus subgrade restraint restricts the concrete expansion. Since the tendons are not yet post-tensioned and bonded they do not offer any restraint. The existing restraint is entirely external and nonresilient.

When shrinkage-compensating concrete is used for post-tensioned slabs, no internal reinforcement is required to provide restraint, unlike the customary uses of expansive cements. While expansion takes place the concrete develops internal compression up until the point of maximum expansion, which occurs in 3 to 9 days. The concrete undergoes no tensile stress before this time and it can develop an early temporary compression of 50 psi(2) without any internal reinforcement, as shown in the figure.

When the concrete reaches its specified strength, the tendons are tensioned. The concrete slab goes into compression and shortens. But it contains no drying shrink-

* Numbers in parentheses refer to metric equivalents listed with this article.



Stresses in slabs with full external restrain (Adapted from Reference 1)

age cracks that must close in the process. The need for the preliminary partial tensioning step is eliminated.

External restraint

If the side forms are removed, special provision for external restraint must be made on the day of slab casting. Normally slabs are cast against previously placed slabs on one or two edges. External restraint is present at these edges.

On the other slab edges, perimeter restraint is achieved by the edge of the slab form and stakes, or even internal mild perimeter steel. Forty to 60 percent of the expansion occurs within the first 8 to 32 hours and the compression buildup occurs simultaneously. Additional compression can develop afterward if the forms are kept in place, or if the slab is bounded by an adjacent slab cast earlier, or even if the slab is bounded by a slab cast soon enough afterward.

Even if the restraint is insufficient to produce 50 psi[2] compression, minor restraint would produce some compression, for example 10 to 25 psi.[4]

High water requirement of expansive cements

In most slab-on-ground applications, especially in residential work, use of overly wet mixes is an unfortunate fact of life. In conventional portland cement concrete, high shrinkage rates, low strength and low durability result. A benefit of shrinkage-compensating concrete is that slabs can be cast at a slump of 6 inches[5] or more rather than the 2- to 4-inch[6] range without the adverse effects of shrinkage. This is because the excess water of convenience is tied up to form ettringite, a compound that requires a great amount of water of hydration.

Reference 2, in its Figure 3.4, shows that the following expansions can be expected in shrinkage-compensating concretes all made with the same amount of expansive cement but at three different water-cement ratios:

Water-cement ratio	Maximum expansion, percent
0.49 (low-slump)	0.136
0.54	0.170
0.57 (high-slump)	0.184

In the same reference Figure 3.3 shows that at an age of 7 days the following expansions were obtained for different expansive cement contents:

Cement content, pounds per cubic yard	Cement content, kilograms per cubic meter	Expansion, percent
450	265	0.128
550	325	0.160
700	415	0.246
900	535	0.313

Control differences

The only added requirement in the control of a shrinkage-compensating concrete mix is control of slump loss, which is similar to that of structural lightweight concrete. This is accomplished by adding 10 to 15 percent more water at the batch plant, according to the instructions of ACI 223 (Reference 3), to obtain a 7- to 8-inch[7] slump in order to be able to place shrinkage-compensating concrete at about a 6-inch[8] slump.

Placement patterns

With post-tensioned shrinkage-compensating concrete, placement patterns are recommended that provide as much external restraint against expansion as would otherwise be provided internally by reinforcing steel. If pour strips are used for tensioning purposes, their edge forms should be left in place until the post-tensioning force is applied.

Placement of one slab directly against the other for restraint is encouraged to minimize the use of pour strips. It eliminates the double bulkhead and the necessary through-reinforcement on at least one edge of the pour strip. Tensioning can be done at those edges of the slab that are on the perimeter of the floor.

Special note: plastic shrinkage cracking

Precautions have to be taken against plastic shrinkage cracking, which can occur during finishing operations. These are well covered in Chapter 5 of ACI 223-77.

Shrinkage-compensating concrete should be cured as soon as finished. The potential level and rate of expansion of shrinkage-compensating concrete is a function of the curing efficiency. In conventional portland cement concrete curing efficiency influences drying shrinkage while in shrinkage-compensating concrete, expansion rate is influenced as well.

References

(1) Russell, Henry G., Design of Shrinkage-Compensating Concrete Slabs, Bulletin RD034D, Research and Development Laboratories. Portland Cement Association, Skokie, Illinois 1975

(2) ACI Committee 223, "Expansive Cement Concretes—Present State of Knowledge," ACI Journal, August 1970, pages 583-610.

(3) Recommended Practice for the Use of Shrinkage-Compensating Concrete, (ACI 223-77), American Concrete Institute, Detroit, Michigan 1977.

(4) Nagataki, Shigeyoshi, and Yoneyama, Koichi, "Studies on Continuously Rein forced Concretes and Prestressed Concrete Pavements Made with Expansive Cement Concrete," Klein Symposium on Expansive Cement Concrete, SP-38, American Concrete Institute, Detroit, Michigan, 1973, pages 131-163.

Metric equivalents

(1) 12 by 18 meters
(2) 0.3 megapascal
(3) 10 megapascals
(4) 0.07 to 017 megapascal
(5) 150 millimeters
(6) 50- to 200-millimeter
(7) 175- to 200-millimeter
(8) 150-millimeter

PUBLICATION #C790117