Allen Face has written an excellent article series titled “That Pesky Moisture Gradient, Parts 1–5,” discussing the function of water in a concrete mix, as well as the benefits and consequences thereof. The article is written from the materials perspective of concrete with
emphasize on mix water and how it works in the hydration process and its impact on the finished product—concrete slabs. As with any good article, it plants the seeds for follow up articles, particularly, how can the “The Big Three Concrete Problems” be dealt with in an easy and economical way. Face identifies what he calls the “Big Three” concrete-related problems pertaining to slabs: shrinkage cracking, slab edge curling, and delamination.

The first two, shrinkage cracking and slab edge curling, can be eliminated by using shrinkage-compensating concrete. The third problem, delamination, is very often more of a finishing problem than a concrete materials problem, but still, occurrence rates can be reduced with the use of shrinkage-compensating concrete. Shrinkage-compensating concrete is a specialty concrete created by mixing a component into a standard concrete mix.

The reference document, as published by the American Concrete Institute, Farmington Hills, Mich., is ACI 223R-10 “Guide for the Use of Shrinkage-Compensating Concrete.” ACI 223R-10 introduces two new concepts that are revolutionizing the concrete industry. First is the use of Type G cementitious material added to a standard concrete mix—this technique is user friendly and much more economical than the previous methods of using shrinkage-compensating cement. Second is the recognition of a new method of creating the expansion mechanism, which is designated as Type G. Type G components are transparent in the concrete mix meaning a concrete contractor can place Type G shrinkage-compensating concrete using his regular placement, finishing, and curing procedures. Combining these two new concepts means Type G components provide all the benefits of shrinkage-compensating concrete while allowing the contractor to maintain standard practices and a competitive price.

**Cracking**

Eliminating, or greatly reducing, shrinkage cracking is the reason shrinkage-compensating concrete was developed. Face identifies excess water in the concrete, or more precisely the loss of this excess water, as the cause of drying shrinkage. Mix water contributes to the
problems in four ways: self desiccation, absorption into the base material, bleed water, and evaporation. Although Face’s article is very meticulous and accurate in describing what happens during the hydration and initial curing processes from a material standpoint, it stops short of providing guidance on how to prevent or remedy the big three problems.

As concrete cures, it shrinks. If the concrete was completely free to shrink, shrinkage cracks would not develop. Although this free body analysis is excellent for textbook explanations, it cannot be totally achieved in actual field construction. Real-world concrete is restrained from shrinking by such things as internal reinforcing steel, and external restraint from subgrade friction. When the curing concrete is restrained, the shrinkage stresses develop until they equal or exceed the developing tensile strength of the concrete. Then shrinkage cracking occurs to relieve these restrained internal shrinking stresses.

Shrinkage-compensating concrete creates an expansion mechanism in the curing concrete that counteracts, or compensates, for the anticipated shrinkage. As the expansion mechanism is forming in the curing concrete, it is being restrained by the same factors, but in the opposite direction, that restrain the drying shrinkage. Reinforcing steel, fabricated bars, mats, or fibers are the primary restraining devices used today. This restraint prevents the physical expansion of the curing concrete thereby transforming the expansion forces into compressive forces in the concrete. During subsequent curing the shrinkage stresses counteract and relieve the expansive stresses, present as compressive stresses, in the curing concrete. The two opposing forces, expansion and shrinkage, compensate and neutralize each other as the concrete returns to its as-placed volume as shown in Fig. 4.1 of ACI 223R-10. The upper curve in Fig. 4.1 shows the expansion followed by the shrinkage of shrinkage-compensating concrete. Note the curve remains at or above the as-cast volume of the concrete and the concrete is never in the negative or shrinkage region of the graph. The lower curve shows conventional portland cement concrete with a small initial expansion followed by shrinkage that extends well below the as-cast volume of the concrete. It is during this shrinkage phase that shrinkage cracking appears.
Designing a concrete mix with an expansion slightly greater than the anticipated drying shrinkage will assure that the concrete will compensate for the shrinkage stresses and a slight residual compressive stress will remain in the concrete. Because the concrete does not go into tension, shrinkage cracking is eliminated.

**Curling**

A concrete mix contains water for hydration of the cement plus water of convenience to aid in the placement and finishing procedures. This excess water of convenience rises to the surface as bleed water and evaporates, or settles to the subgrade by the forces of gravity. Interior floor slabs usually are placed on a vapor barrier that exacerbates the problem by trapping water at or near the bottom of the slab. The top surface of the slab dries at a faster rate than the rest of the slab with the rate of drying slowing with the increase in depth, and moisture content, of the slab. This differential drying results in the top of the slab shrinking more as it cures resulting in upward curling of the slab edges. This curling force is two directional on the surface resulting in accentuated curling at the corners. Shrinkage-compensating concrete can eliminate these forces resulting in elimination of edge curling and a state-of-the-art floor.

There are two inherent primary characteristics of shrinkage-compensating concrete that contribute to eliminating slab curing. First, because tension stresses never form during the shrinkage phase, contraction joints are not needed and can be eliminated. Eliminating the contraction joints means there are no joint edges to curl. It also means that the time, labor cost, and material cost of installing the contraction joints can be eliminated resulting in a savings for the project. Second, because the concrete is compensating for its shrinkage the expansion counters the shrinkage and the top surface never goes into tension, thereby eliminating the forces that cause edge curling. Stated differently, at the same time that the concrete is shrinking, the expansion mechanism is forming and the two forces neutralize each other eliminating the forces that cause edge curling at expansion and construction joints.
Restraint is the key element initiating shrinkage cracking and it is also the key element making shrinkage-compensating concrete work. Steel reinforcing is the most common, but not the only, means of providing restraint. As the concrete is curing, it also is bonding to the reinforcing. As the expansion mechanism is forming, it is restrained by the reinforcement transforming a large portion of the expansive forces into compressive forces in the concrete. Without this restraint, the curing concrete would be free to expand and the resulting expansion would be greater than the normal expansion for conventional portland cement concrete. Therefore, it is critical that reinforcing be placed in accordance with the guidelines contained in ACI 223R-10. As a rule of thumb, for most concrete slabs on grade, temperature steel placed at the top of the slab with the minimum coverage required by ACI 318 will meet the requirements of ACI 223 and result in a high-quality economical concrete slab in which the “big three” problems are eliminated or greatly reduced.

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