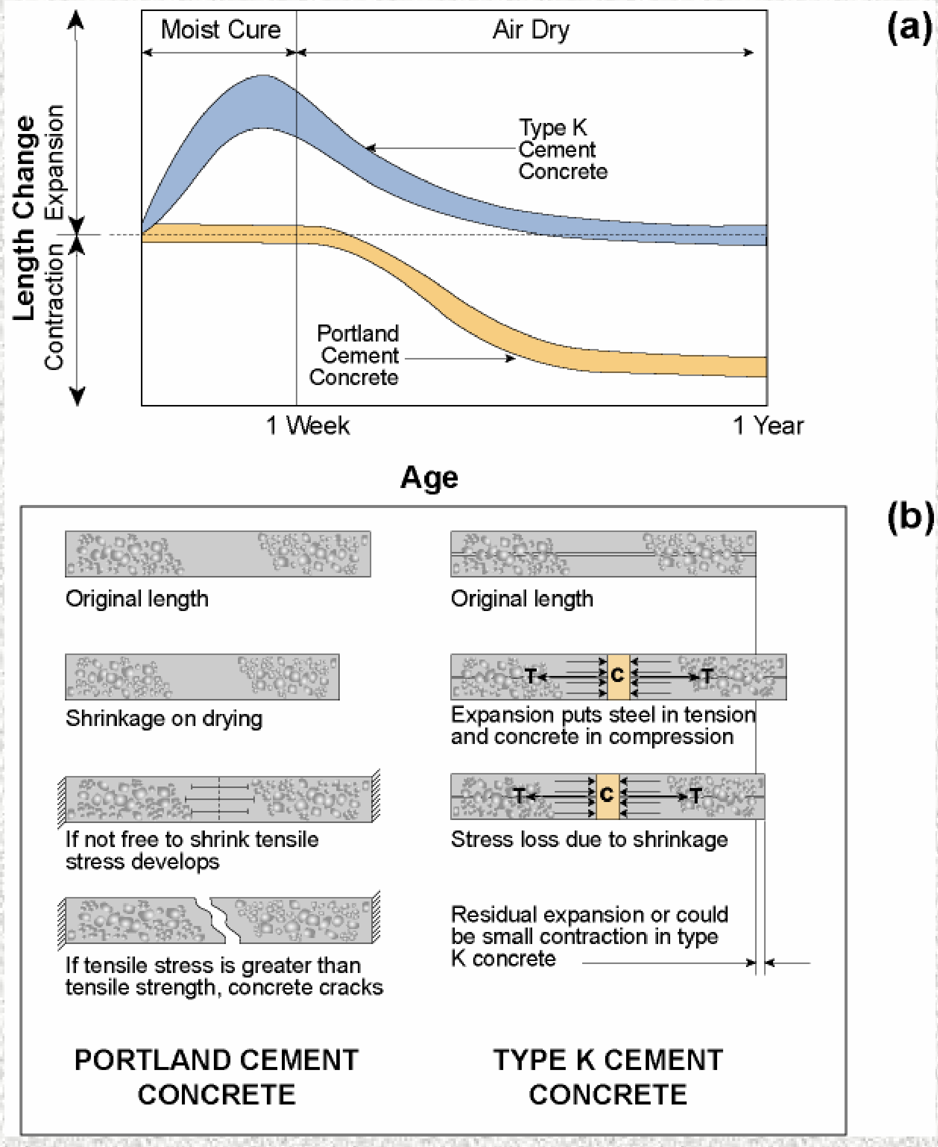
Expansive Cements



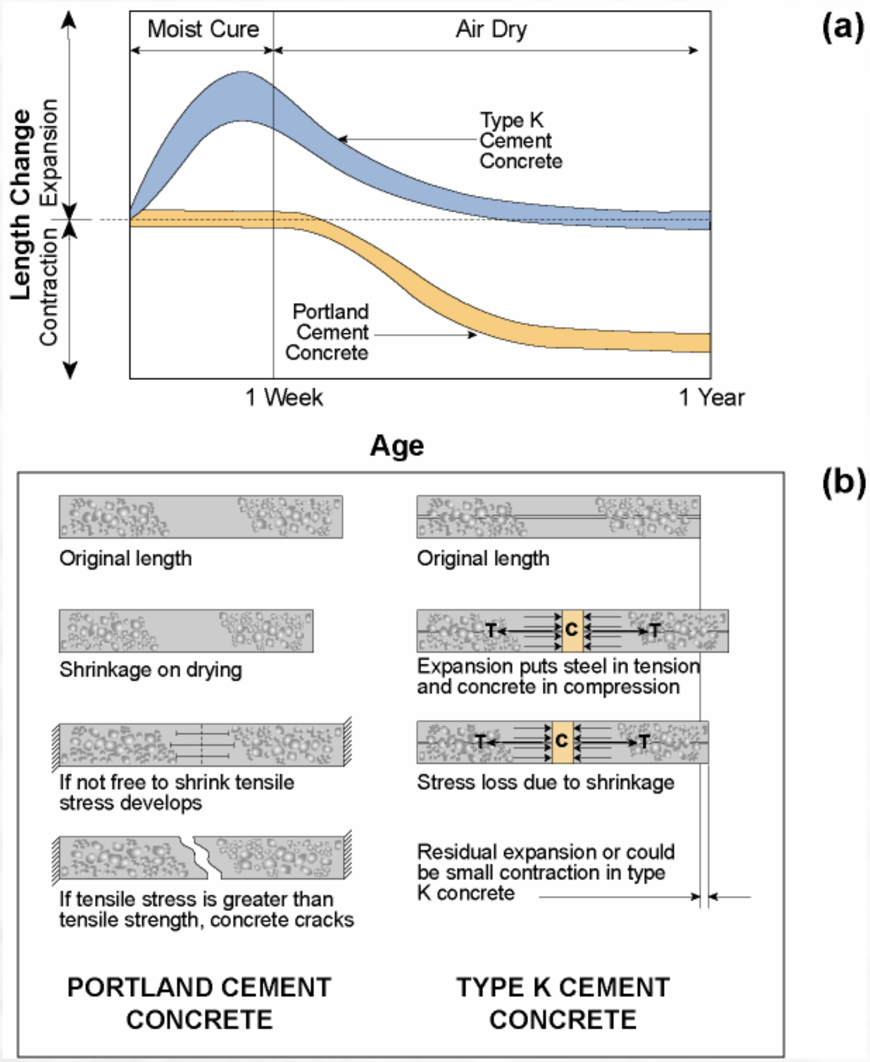
Introduction

- *Expansive cements* are hydraulic cements which, unlike portland cement, expand during the early hydration period after setting.
- When the magnitude of expansion is small but usually adequate to offset the tensile stress from restrained drying shrinkage, the cement is known as *shrinkage compensating*.
- When the magnitude of expansion is large, the cement is called *self-stressing* and can be used for the production of chemically prestressed concrete elements.

Definition

- **Shrinkage-compensating concrete** is an expansive cement concrete which, when properly restrained by reinforcement of other means, will expand an amount equal to or slightly greater than the anticipated drying shrinkage.
- Because of the restraint, compressive stresses will be induced in the concrete during expansion. Subsequent drying shrinkage will reduce these stresses.

Graphically



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Type M expansive cement

- Mixture of portland cement, calcium aluminate cement (with CA is the principal compound), and calcium sulfate.

$$CA + 3C\bar{S} + 2CH + 30H \rightarrow C_6A\bar{S}_3H_{32}$$

Type S expansive cement

- Composed of a very high CA portland cement (approximately 20% CA) and large amounts of calcium sulfate.

$$C_3A + 3C\bar{S} + 32H \rightarrow C_6A\bar{S}_3H_{32}$$

Type O expansive cement

- Initially developed by the Onoda Cement Company of Japan, the expansive portland cement deriving its expansion from hard-burnt CaO

Type expansive cement

- Developed originally by Alexander Klein of the University of California at Berkeley in the 1960s, the sulfoaluminate-type clinker is a modified portland cement clinker.

$$C_4A_3\bar{S} + 8C\bar{S} + 6CH + 90H \rightarrow 3C_6A\bar{S}_3H_{32}$$

Materials and Mix Proportions

- The same basic materials and methods necessary to produce high-quality portland cement concrete are required to produce satisfactory results in the use of shrinkage-compensating concrete.
- Additional care is necessary to provide continuous moist curing for a least 7 days after placement in order for the expansion to develop, and the structural design must be such as to ensure adequate expansion to offset subsequent drying shrinkage.

Cement Content

- To assure adequate expansion and restraint when Type K cement is being used, it is recommended to have a minimum cement content of 515 lb/yd (305 kg/m) concrete with a minimum 0.15 percent reinforcement.

Water content and w/c

- A slightly higher water-cement ratio may be used in shrinkage-compensation concrete for achieving the same strength level.
- Due to the relatively large amount of water needed for ettringite formation, and the water-imbibing property of ettringite, approximately 10 percent additional water may be used with a Type K expansive cement concrete, without strength impairment, in order to produce a consistency similar to that of a Type I portland cement concrete having the same cement content.

Admixtures

- Calcium chloride, excessive amounts of fly ash and other pozzolans, and some water-reducing agents tend to reduce expansion by causing an imbalance between the rate of ettringite formation and the rate of strength development in the concrete.

TYPICAL MIX PROPORTIONS

Mix proportions (no admixtures were used)	
Type K cement	588 lb/yd^3
Coarse aggregate (1 in., max.)	1790
Fine aggregate	1287
Water	312
Water-cement ratio	0.53
Properties	
Slump	4¾ in.
Specified compressive strength	4000 psi
Average 28-day strength	6034 psi

Workability

- Because of the water-imbibing characteristic of ettringite, which forms in relatively large quantities during very early stages of hydration, the concrete mixtures tend to be stiff but highly cohesive.
- The use of a somewhat higher water-cement ratio than recommended by the standard w/c-strength relationships for normal portland cement concrete is permitted with expansive cements for achieving a reasonable consistency.

Workability

- Compared to portland cements, the ettringite-forming expansive cements are quick setting and prone to suffer rapid slump loss.
- However, they show excellent workability.
- These properties can be anticipated from the large amounts of ettringite formed and the water-imbibing characteristic of the ettringite.

Slump

- Slumps in the range of 100 to 150 mm are recommended for most structural members, such as slabs, beams, reinforced walls, and columns.
- Because it is more cohesive or "fat" than portland cement concrete and has less tendency to segregate, the Type K shrinkage-compensating concrete is reported to be especially suitable for placement by pumping.

Slump loss

- Slump loss under hot (concrete temperatures 32C or higher) and dry conditions is more serious a problem in shrinkage-compensating concrete than in normal portland cement concrete.
- As a result of slump loss, excessive retempering of concrete on the job site will not only reduce the strength but also the expansion, which defeats the purpose for which the concrete is used.
- At higher than 17 to 29 C ambient temperatures, unless the concrete is cooled, both the amount of ettringite formed and the rate of its formation may be large enough to cause severe slump loss and quick setting.

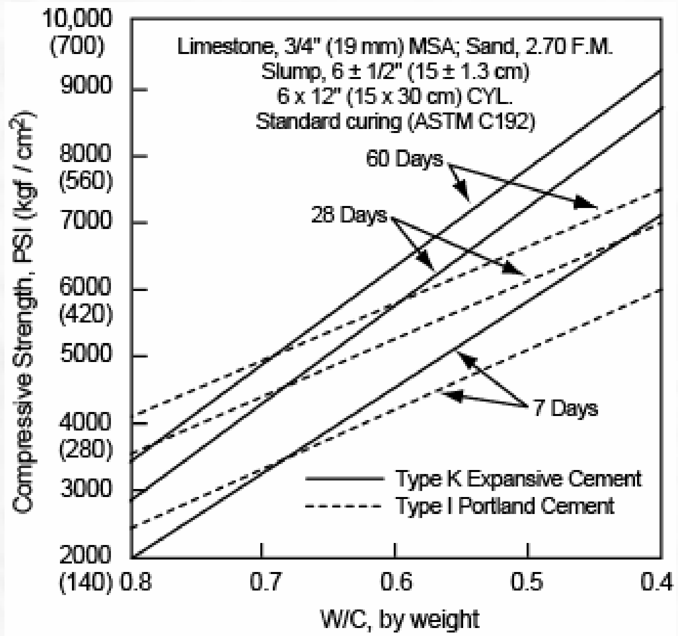
Plastic shrinkage

- Because of lack of bleeding and quicker stiffening and setting of concrete under hot, dry, and windy conditions, plastic shrinkage cracking is another problem for which extra precautions must be taken when using the shrinkage-compensating concrete.
- When fresh concrete is likely to be in contact with an absorptive surface, the base should be thoroughly saturated by soaking it the evening before placement.
- Special precautions should be taken to avoid placement delays at the job site when using ready-mixed concrete.
- For slabs, fog spraying or covering the surface with wet blankets soon after placement is desirable in order to prevent rapid moisture loss.

Strength

- The development of compressive, tensile, and flexural strength in shrinkage-compensating concrete is generally influenced by the same factors as portland cement concrete.

Effect of w/c and cement type



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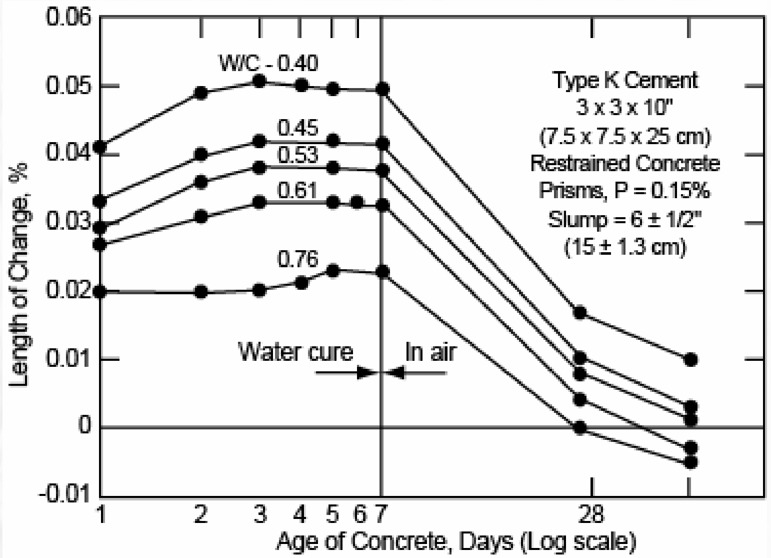
Effect of water-cement ratio on expansion



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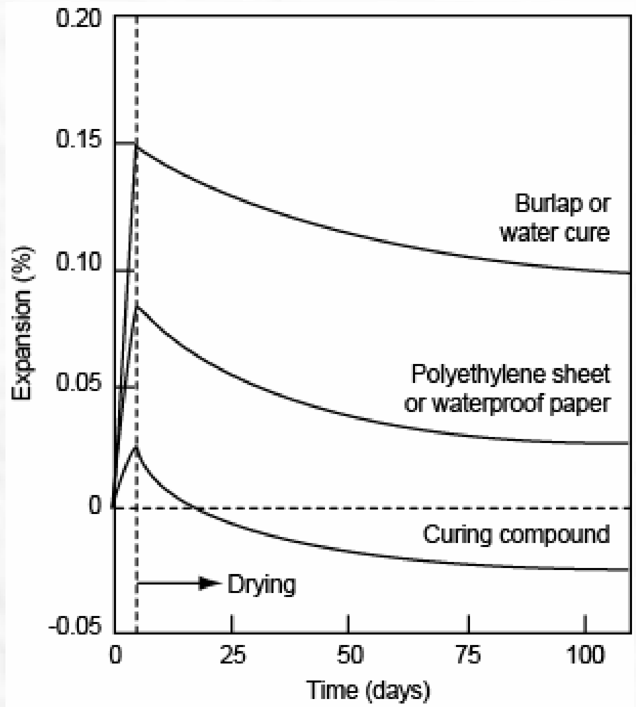
Effect of curing conditions on expansion



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Frost resistance

- Air-entraining admixtures are as effective with shrinkage-compensating concrete as with portland cement concrete in providing freeze-thaw and deicer salt durability.

Durability

- The restrained expansion of concrete, lack of bleeding, and little or no microcracking by drying shrinkage, the shrinkage-compensating concrete provides a more dense and essentially impermeable mass than does portland cement concrete of an equivalent water-cement ratio in the range 0.4 to 0.6.
- Laboratory and field experience has shown that Type K cement concretes possess a significantly higher resistance to abrasion, erosion, and chemical attack by aggressive solutions.

Sulfate Resistance

- Type K shrinkage-compensating cements made with blending ASTM Type II or Type V portland cement show excellent durability to sulfate attack because they contain little reactive alumina or monosulfate after hydration.

Comparisons

Type of property	Characteristics of shrinkage-compensating concrete relative to portland cement concrete of similar water-cement ratio
Workability	
Consistency	Stiffer
Cohesiveness	Better
Time of set	Quicker
Strength	Better
Impermeability	Better
Drying shrinkage	Similar
Creep	Similar
Elastic modulus	Similar
Overall dimensional stability	Better
Durability	
Resistance to abrasion	Better
Resistance to erosion	Better
Resistance to sulfate attack	Similar to Type V portland cement concrete[a]
Resistance to frost action	Similar when equivalent air entrainment present

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Applications

Type of structure	Owner and location	Pertinent facts	Observations
Airport pavement	Love Field, Dallas, Texas	Taxiway 1 (1969) Taxiway 2 (1972) Each taxiway is in excess of 2 km (1 mile) in length and consists of three 7.6-m (25-ft) lanes reinforced with welded wire fabric providing 0.12% and 0.06% steel in longitudinal and transverse directions.	Existing portland cement pavement has joints spaced 15 m (50ft) with cracks midway between them. The Type K concrete pavement, which had joints spaced 23 and 38m (75 and 125 ft), has only occasional cracks between joints.

Applications

Type of structure	Owner and location	Pertinent facts	Observations
Parking structure	O'Hare International Airport, Chicago, Illinois	Completed in 1972 10,000 automobile six-level structure 92,000 m³ (120,000 yd³) Type K concrete. Type K concrete used in combination with post-tensioning for low maintenance design.	Decks are divided by columns into bays of multiple pan-and-beam construction. Each bay consist of 46 cm (12-18 in.) deep pans with a relatively thin 11-cm (4½-in.) slab overhead. The shrinkage-compensating concrete section has an excellent inspection rating after 5 years of heavy traffic.

Applications

Type of structure	Owner and location	Pertinent facts	Observations
Office building and parking structure	Los Angeles World Trade Center, Los Angeles, California	Completed in January 1974. A six-level modular parking structure supporting the building superstructure and 10-story tower. 11 x 10^6 kg (12,000 tons) of Type K cement and 41,000 m^3 (53,000 yd^3) Type K concrete. Mix designs based on structural requirements ranged from 280 to 350 kgf/m^2 (4000 to 5000 psi)	The six-level parking structure contained 513 precast table-type modules each $15m^3$ (20 yd^3) with cast-in-place slabs pumped into the structure at the site. The precast table modules sit on cast-in-place pedestals into which are embedded the post-tensioning cables. The tower is supported by the parking structure. The structure used natural and lightweight aggregate (seven different mix designs) because of unique structural design.

Applications

Type of structure	Owner and location	Pertinent facts	Observations
Cold-storage warehouse	Meijer Frozen Foods, Lausing, Michigan	Completed in October 1975. Temperature range –23 to + 4ºC (-10 to + 40ºF). Type K shrinkage compensating concrete slabs subjected to both drying shrinkage and thermal contraction associated with a cold storage warehouse 8900 m^2 (96,000 ft^2).	This project was used to compare slab design theory with onsite analysis of concrete expansion and shrinkage. Field measurements were made to determine center and edge slab movement under a variety of restraint and temperature conditions.

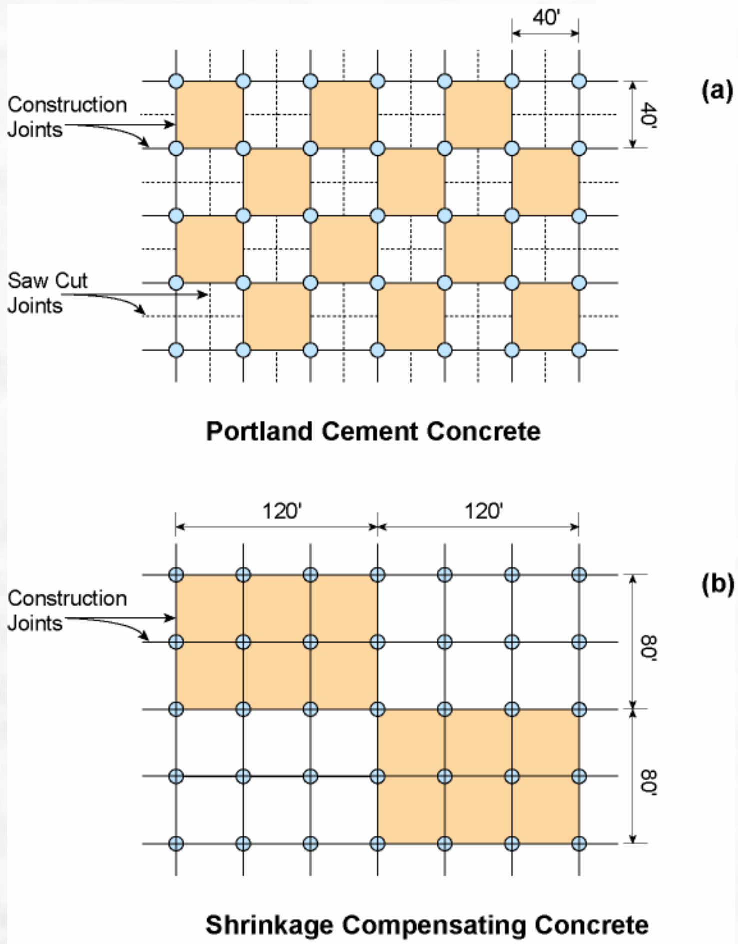
Applications

Type of structure	Owner and location	Pertinent facts	Observations
Industrial warehouse, slabs on grade	J. C. Penney Co. 1.Lenexa, Kansas	Completed in November 1976. 186,000m² (2 million ft²) under roof 24 x 36m (80x120 ft) placement (no sawed joints); 15 cm (6 in.) thick; 4 x 4-W4 x W4 4000 psi concrete (12,000 tons) of Type K cement.	A Type I or II portland cement concrete design would call for 28 km (16.7 miles) of construction joints and an additional 28 km (16.7 miles) of sawed joints. Slab size limited to 12 x 12m (40 x 40 ft) placements. Type K shrinkage compensating concrete 24x36m (80 x 120 ft) placements allow only 11 km (6.6 miles) of construction joints and no intermediate sawed joints. Slab in excellent condition.

Applications

Type of structure	Owner and location	Pertinent facts	Observations
	2.Reno, Nevada	Completed in December 1977. 139,000 m² (1.5 million ft²) under roof. Design same as Kansas $8x10^6$ kg (9000tons) Type K cement.	Slabs at final inspection were free of any cracks (first placement on 7/6/77). Contractor averaged 1670 m² (18,000 ft²) per day over entire project.

Constructions joints



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