ARTICLE REPRINT
Public Works Magazine *June 2009*

KOMPONENT

STICK TOGETHER

Special cements impact durability and speed in building and repairing concrete bridges and decks

The Theodore Roosevelt Bridge in Washington, D.C. is being repaired with Rapid Set® latex modified concrete.
Photos: CTS Cement Manufacturing Corp.

"

Concrete shrinks as it dries and hardens, forming shrinkage cracks, which provide a path for chloride ions to reach the reinforcing steel.

Most of the approximately 350,000 concrete bridges in the United States have concrete decks that develop avoidable premature cracking due to initial shrinkage soon after the pour. While the useful life of concrete can exceed 50 years, outdoor installations frequently do not achieve that. Obviously, the cement used in concrete can have a lasting impact on the life span of new concrete bridge decks. One growing solution is the use of Type K cement for new bridge construction and rapid hardening cement for repairs and new overlays. Proven, yet still underspecified, these special cements can help extend the useful life cycle of concrete bridge decks.

A good portion of the approximately $8 billion spent annually repairing, rehabilitating, strengthening, and waterproofing bridge decks is allocated for deck repair. However, using concrete products that help make the concrete more durable in the first place, such as shrinkage-compensated concrete for new construction, could eliminate much of the need for deck repair.

Because bridge decks are exposed top and bottom, they ice up faster in the winter and often are treated with deicing salts and/or other aggressive chemicals to keep the surface free of snow and ice. Concrete shrinks as it dries and hardens, forming shrinkage cracks, which provide a path for chloride ions to reach the reinforcing steel.

Concrete has a pH of about 11 to 13. Upon contact with such a highly alkaline material, reinforcing steel develops a passivating film that protects it against corrosion. However, from bleeding of excess water, chlorides can enter the concrete via cracks and water channels. If this happens, the protective film may be destroyed, which in turn allows corrosion to begin.

The products of corrosion take up a greater volume than the constituents. An internal pressure develops, eventually leading to cracking and spalling of the concrete cover above the steel. This reduces the bond and anchorage of the steel to the concrete,

The Theodore Roosevelt Bridge in Washington, D.C. is being repaired with Rapid Set® latex modified concrete.
Photos: CTS Cement Manufacturing Corp.

> *There is a solution to the problem: a shrinkage-compensating cement that can offset the tensile stresses caused by shrinkage.*

negatively impacting the structural properties of the deck and its contribution to the bridge structure. To minimize the need for early bridge repair, that corrosion must be prevented.

While suitable for many applications, when used for roads and bridges, portland cement concrete (PCC) has one limitation that contributes to need for repairs: it shrinks as it dries. Shrinkage is the bane of longevity of a reinforced concrete bridge deck because it leads, eventually, to corrosion of the reinforcing steel.

Although some shrinkage is due to formation of hydration products, most results from the bleeding of excess water. Portland cement requires a water-cement (w/c) ratio of only about 0.22 for complete hydration. However, the ability to place the concrete where it needs to go requires about twice that. The bleeding of the excess water is a loss of some volume and leaves voids both in the mass and in surface channels.

As the PCC hardens and shrinks, tensile stresses develop caused by restraint from reinforcing steel, forms, aggregate interlock, and other factors. While the concrete is still relatively fresh, the tensile strength is practically negligible and therefore cracks develop as a result of the shrinkage stresses.

Research conducted recently at the University of Kansas supports the conclusion that cracks in concrete are the major source of entry of chlorides. Test results show that at cracks, the average chloride concentration at a depth of 3 inches can exceed the corrosion threshold (1 pound/cubic yard) of uncoated reinforcing steel within one year. After two years, the threshold will be exceeded in most decks. Yet away from cracks, at a depth of 3 inches, the chloride concentration is less than the corrosion threshold even after a dozen years. The research also showed that chloride concentration increases as the bridge deck ages.

PROVEN SOLUTION

Using shrinkage-compensating cement can extend the useful service life of concrete. The most effective way to help ensure durable concrete bridge decks is to eliminate cracking of the concrete from drying shrinkage that results in tensile stresses during a time when the concrete still has little or no tensile strength. There is a solution to this problem: a shrinkage-compensating cement that can offset the tensile stresses caused by shrinkage.

Although this cement initially costs somewhat more than the portland cements predominately used for concrete bridges and bridge decks, the lower life-cycle cost due to reduced maintenance and repair over the long run would more than compensate for any increased construction costs.

The cement was invented when a manufacturer combined an expansive component with portland cement. This caused the concrete to expand slightly initially, but then, as the concrete bond-ed to the reinforcing steel, tensioned the steel. This tension (as per Newton's third law of motion that every action has an equal and opposite reaction) placed the concrete in compression.

In compression, the concrete can resist the tensile stresses from shrink-age. When the concrete later shrinks, the compression is relieved. However, at the same time, the concrete has developed enough tensile strength to resist the tensile stresses put upon it from shrinkage. The combination of this innovative expansive component and portland cement is called a shrinkage-compensating cement, which is recognized in ASTM C 845 as Type K cement. Concrete containing Type K cement is called shrinkage-compensating concrete.

Though shrinkage-compensating concrete requires slightly more water than PCC to hydrate the expansive material, it does not bleed, so there are no water channels to the surface. The combination of no cracks and no bleed water channels results in low chloride permeability and, therefore, longer life.

Over the past four decades, shrinkage-compensating concrete has been used in millions of cubic yards of concrete with excellent results in a broad range of installations. Although it cannot guarantee total freedom from cracking, any cracking will be less frequent and less severe.

For example, since 1988, all bridges under the auspices of the Ohio Turnpike Commission have Type K concrete decks for their new bridges and replacements. Since then, several states have adopted use of Type K cement for bridge decks, including Michigan, Indiana, and Pennsylvania. And, in 1995, a new bridge was built in Barstow, Calif., using Type K.

Shrinkage-compensating concrete is also cost-effective and a smart choice for large flat slabs, such as in warehouses, office buildings, and parking structures. Areas up to 50,000 square feet can be installed without saw-cutting any control joints. The only joints required are construction joints, and the floors stay flat and curl-free. The use of the material in walls enables extended joint spacing and broad, virtually crack-free concrete surfaces.

MINIMIZE FUTURE CORROSION

When it comes to repairing crack-damaged bridge decks, there are effective products that can reduce the permeability of PCC bridge decks in order to minimize chloride-induced corrosion of the reinforcing steel. One such product is latex; added to PCC, the concrete is almost impermeable.

While latex-modified PCC (LMC) is quite impermeable, it requires several days to gain sufficient strength to be able to sustain traffic. With Type III cement (LMC-HE) it still requires one to two days before the roadway can be returned to use.

Rapid-hardening cement overcomes this limitation, as it sets and gains strength very rapidly. Developed specif-ically to capitalize on a different chemistry that allows it to set quickly, when rapid-hardening cement combines with water (hydrates), it forms crystalline compounds much faster than compounds in portland cement form when

Rapid Set® cement is being used for he overlay of he 79-year-old Lewis and Clark Bridge over the Columbia River between Washington and Oregon.

EXTEND CONCRETE'S SERVICE LIFE … FOR LESS

The specially blended cement required for rapid-hardening cement concrete (LMC-VE) costs four times as much as Type I/II cements used in conventional latex-modified portland cement concrete (LMC) overlays. Type III cement (LMC-HE) carries a cost 20% higher than Type I/II cements used in the conventional LMC overlays. The higher cement prices increase the cubic yard cost of the concrete by approximately $90/cubic yard and $7/cubic yard respectively. But these added costs are more than compensated by the substantial savings in traffic control costs. The costs for traffic control for LMC-VE overlays and for epoxy overlays are the same. For example, DOTs spending $5 million annually on deck rehabilitation can save as much as $1.25 million each year by using LMC-VE overlays. LMC-VE and LMC-HE overlays can run approximately 25% less than conventional LMC overlays.

THE ADVANTAGES OF RAPID-HARDENING CEMENT ARE THREE-FOLD:

1. Completed overlays can open to traffic in three hours. An overlay installed overnight causes less inconvenience to the public even the very next morning. It has been found that the initial higher material cost is more than offset by the reduction in traffic control costs incurred for more extended closure.

2. Rapid-hardening cement shrinks less and is more resistant to harsh chemical environments than portland cement (e.g., sulfates and reactive aggregates).

3. Additives are available that allow for extended mixing and transport times, which can be convenient for high-volume applications or other applications where time of application is a consideration (a longer lead time is desirable).

combined with water. It shrinks less and gains strength faster than portland cement and therefore gets traffic back on the road in less time.

Rapid-hardening cement has been used widely for bridge deck overlays with excellent results. For example, it enabled a contractor a few years ago to speed through refurbishing of much of the surface of the Lewis and Clark Bridge, which dates from 1929 and connects the communities of Rainier, Ore., and Longview, Wash. Although some sections of the deck had to be completely replaced, requiring partial closures for 18 months, the Washington State DOT (WSDOT) was keen on keeping bridge closures to a minimum. By using 450 cubic yards of rapid-hardening cement concrete (LMC-VE) for a 1575-foot length of overlay during one weekend, WSDOT saved at least nine days of closure as compared with traditional slower-setting concrete.

A few years ago, rapid-hardening cement was also used for resurfacing the main interstate bridge connecting Interstates 70, 64, and 55 across the Mississippi River in downtown St. Louis and passing near the Cardinals' baseball stadium. The Missouri DOT was concerned that the surface repairs not disrupt major league baseball. The fast set time of the cement enabled start and completion of the entire resurfacing job between Friday evening and noon Sunday, a time frame in which there were no home games. The contractor was successful in hitting an inside-the-time-frame home run.

Since 1998 rapid-hardening cement has been used in several states around the country in approximately 100 bridge deck overlays. It has also been used in buildings, tunnels, bridges, chemical plants and on highways and at airports when time is critical. While concrete generally is specified essentially as a commodity product, selecting a specific product mix with an eye to its features and benefits can increase the service-ability and longevity of the project.

Ed Rubin is a concrete consultant and was one of the developers of shrinkage-compensating cement (Type K) and concrete. He is a consultant to CTS Cement Manufacturing Corp.

Original publication: Rubin, E., PE, FACI. (2009, June). Stick Together. Public Works Magazine, 39-41.

"It shrinks less and gains strength faster than portland cement and therefore gets traffic back on the road in less time.