Highway Panel Replacement—CSA Concrete in California

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In general, the U.S. highway system dates from the 1940s and 1950s. Some of these original pavements exist 60 years later. Needless to say, our Nation's transportation infrastructure is in great need of improvements. According to the American Society of Civil Engineers' "2009 Report Card for America's Infrastructure," our roads earn a D-minus, with 33 percent of the nation's major roads in "poor or mediocre condition." Repair solutions must be cost-efficient, easy to implement, and long-lasting.

The last 10 years have seen considerable growth in the use of proprietary and special repair cements for concrete pavements. Many of these products lend themselves to "fast track" construction techniques that allow reopening to traffic within 12 hours or less. These products achieve high early strengths by accelerating the portland cement hydration process for both Type I and Type III cements or through alternative cementitious reactions that include alkali-activated aluminosilicate cements, sulfoaluminate based cements, or magnesium phosphate cements. These products are typically labeled as "cementitious" because their chemical reactions are inorganic, unlike the organic chemical reactions fundamental to epoxies and polymeric concretes. Unfortunately, most of these products are difficult to work with or uneconomical.

The perfect material for highway panel replacement would be (1) cost effective, (2) easy to work with, and (3) have very early strength for early opening to traffic. The time required for a concrete mixture to achieve a minimum compressive strength influences the timing of opening a repaired road to service. Zia et al. (*1*) applied a criterion for a minimum compressive strength of 13.8 MPa (2,000 lbf/in^2) in 6 hours for very early strength (VES) high-performance concrete. This paper discusses the use of a VES calcium sulfoaluminate concrete to meet these challenges and its use in the State of California.

PROPRIETARY TESTING PROGRAM

In the last 10 years, more than 20 proprietary very early strength (VES) materials have been tested at Donald G. Fears Structural Engineering Laboratory at the University of Oklahoma. These materials included aluminosilicate cements, sulfoaluminate based cements, magnesium phosphate cements, epoxy based cements and gypsum based cements. In general the materials tested compare poorly in comparison to VES I and VES III. These are state-of-the-art, Type I and Type III, very early strength (VES) concrete mix designs developed at the University of Oklahoma and adopted by the Oklahoma Department of Transportation (*2*,*3*,*4*).

One of the few exceptions is a VES mix built around a calcium-sulfoaluminate-based (CSA-based) cement. Table 1 presents the VES CSA mix proportions. Figure 1 illustrates the early age

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compressive strength gain for this VES concrete with variable initial temperature conditions. In this test, for the first 24 hours the samples were subjected to a water bath with temperatures ranging from 4.4 °C to 43.3 °C (40 °F to 110 °F). After 24 hours, the samples were dry-cured in an environmental chamber at 23°Celsius (73.4°F) and 50 percent humidity. With the exception of the 4.4 °C (40° F) mix and 43.3 °C (110° F) mix, all of the samples met the strength requirement to open a road to traffic of 20.7 MPa (3000 lbf/in^2) at 3 hours. These two exceptions met the requirement by 6 hours. The ASTM C 666 freeze–thaw durability in essentially 100 at 300 cycles and shows negligible visual damage. Performing the ASTM C 1202 Rapid Chloride Permeability Test on this material at 28 days rates this material's permeability as "very low," with 760 coulombs passing.

Table 1
Very Early Strength Mix Proportions

Ingredient	**Amount for 1 m^3 (1 yd^3)**
Calcium sulfoaluminate cement	390 kg (658 lb)
#57, Coarse aggregate	989 kg (1667 lb)
River sand, fine aggregate	867 kg (1462 lb)
Water	156 L (262 lb)
High range water reducer (polycarboxylate)	2.5 L (66 ozs)

Note: Water amount assumes aggregate is at saturated surface dry condition.

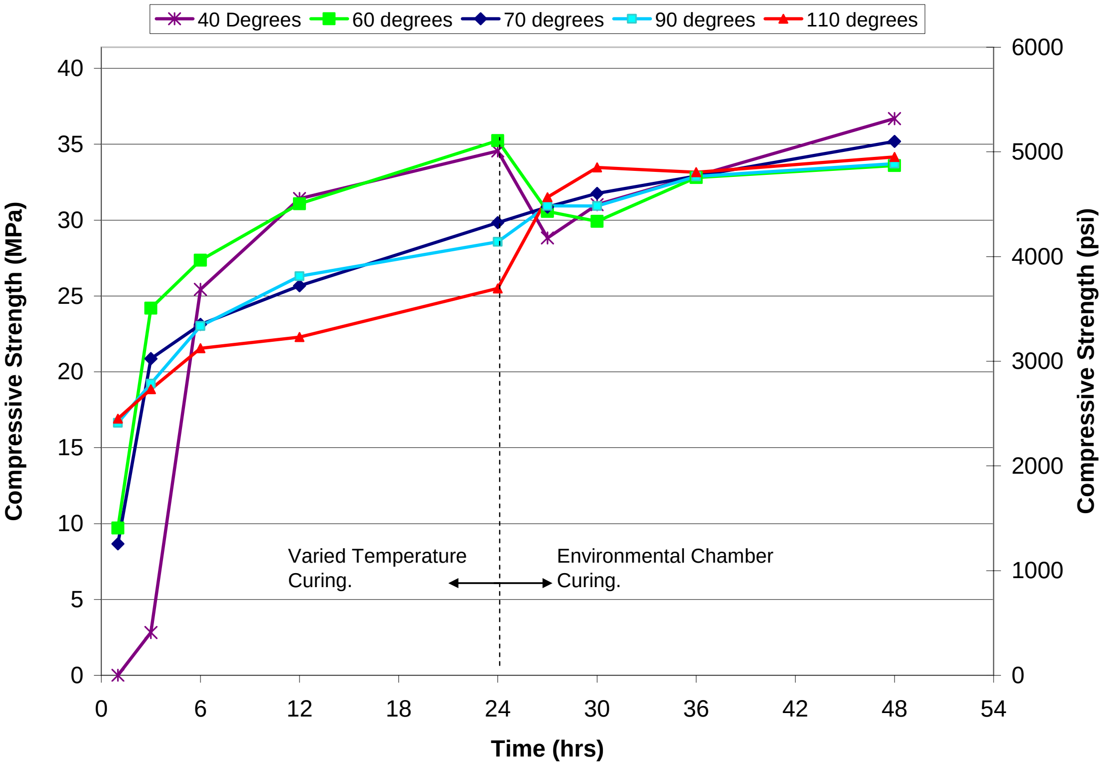

Figure 1. Early age strength gain for very early strength calcium sulfoaluminate concrete with changes in temperature.

The CSA VES mix typically used in California gains structural strength in approximately 1 hour at standard placement temperatures and has superior durability and low shrinkage. Due to its chemistry, it is resistant to sulphate and alkali–silica reactivity attack. The 1-year flexural strength of this typical pavement mix design is 7.7 MPa (1,120 lbf/in^2), while the 1-year compressive strength is 71.6 MPa (10,390) lbf/in^2.

USE OF CALCIUM SULFOALUMINATE CEMENTS BY CALTRANS

California's Department of Transportation (Caltrans) has been using a VES CSA-based concrete for highway panel replacement since 1994. The average concrete panel in the State of California is 3.7 m wide, 4.6 m long, and 230 mm thick (12 ft wide, 15 ft long, and 9 in. thick). From 1994 to 2008 Caltrans replaced approximately 70,000 highway panels, an equivalent of approximately 322 lane-km (200 lane-mi), using this VES material. In total, over 267,600 m^3 (350,000 yd^3) of VES CSA-based concrete has been used for highway panel replacement in California since 1994.

The replacement process is fairly simple. In California, perimeter sawcutting is allowed up to 2 days prior to the removal process. At the time of replacement, the panels can then be sawed into smaller sections for removal by a nonimpact method in an attempt to preserve the base material. In southern California, dowel bars, tie bars, or dowel baskets are not generally encountered during the removal and replacement process. The Special Provisions do mention sawing through tie bars or dowel bars before the concrete slabs are removed.

A bond breaker is required and must be one of the following:

1. Curing paper ASTM C-171, white.
2. Polyethylene film ASTM C-171 minimum thickness 6mm, white opaque.
3. Paving asphalt, Grade PG 64-10.
4. Curing compound.

Joints for pavement 8 in. (203 mm) thick shall have a minimum depth of 2.75 in. (70 mm) to D/3 in. (76 mm) (D = pavement thickness). Commercial quality polyethylene flexible expansion foam, 0.25 in. (6 mm) thick is placed to full depth along all joint faces.

Generally an ASTM C-309, Type II, Class B, resin based, white pigmented curing compound is used.

The highway panel is lifted out with minimal disturbance to the base. If the base needs repair, it is simple to remove the questionable material and then move on to the next step, placing the very early strength concrete. Filling the void left by the questionable base with high-quality VES CSA-based concrete. This process solves a poor base problem in a timely manner, maintaining the high production quantities required. It also achieves a superior pavement in this troubled area since the section properties of the pavement are improved due to the pavement's increased thickness. The remaining steps are similar to any concrete process, finishing and opening to traffic. Figures 2 through 5 outline this process.

Figure 2. Damaged highway panel being removed.

Figure 3. Mobile Mixer placing very early strength (VES) concrete.

Figure 4. Finishing the panel.

Figure 5. Panels open to traffic.

The average volume of VES CSA concrete produced in an 8-hour lane closure is 134 m^3 (175 yd^3). This is enough to replace a total of 35 typical highway panels. Placing this material can be achieved by batching in a ready-mix plant or a mobile (Volumetric) mixer. The highest yardage of VES CSA produced in a single night using a ready-mix plant is 776 m^3 (1015 yd^3) in a 10-hour production run. This is enough to replace a total of 203 typical highway panels. The highest volume of VES CSA produced in a single night using mobile (Volumetric) mixers is 381 m^3 (498 yd^3) in a 6-hour production run. This is enough to almost replace 100 typical highway panels.

COMPARISON TO PRECAST SYSTEMS

In general there are a number of additional requirements for recast panels that the VES CSA system does not have to deal with:

1. Transporting two panels per flat bed to the job site.
2. Crane and crane operator to unload panels.
3. Base sand that has been laser-screeded and compacted prior to receiving panel.
4. Tying panels together and grouting tie cable pockets.
5. Waiting for grout to obtain strength.
6. Limited production capacity.

Additionally, Smith (*5*) and Kohler et al. (*6*) mention the use of nonplanar warped slabs cast to the three-dimensional geometry required at the location they are placed. This type of panel increases the complexity and cost of the planning, manufacturing, coordination, and installation phases.

In general, the precast systems to date are require more time and are less cost efficient than the VES CSA system. The shortest time from production of the concrete to opening to traffic for the VES CSA system is 48 minutes, with the average being a little over an hour. The average production per shift is 35 typical highway panels, with approximately 1 panel completed every 14 minutes.

While the average cost of a VES CSA system highway panels in 2007 was $2,716, the reported cost of precast panels have run between $7,000 and $24,000 dollars per highway panel. Table 2 by Muench et al. (*7*) lists the panel replacement projects in Washington (both rapid and not). Muench et al. mention that the costs in Table 2 “indicate that for a longer construction schedule (the Spokane project involved just over 20 days of lane closure for panel replacement), replacement costs can be between $2,500 and $10,00 per panel, while for rapid construction those costs can increase to the $18,000 to $25,000 range.” They went on to mention that their paper “assumes that a reasonable cost per panel replaced is $20,000” because “future panel replacement projects are likely to use rapid construction.”

Table 2
Comparison of Panel Replacement Costs (Muench et al. (*7*)

Panel Replacements	Rapid?	Cost ($)[a]	Lane-mi	Panels Replaced No.	Panels Replaced Percent	Rounded Cost/Panel ($)
Tacoma, WA (2006)	Yes	735,000	10.4	29	0.79	25,300
Federal Way, WA (2006)	Yes	1,000,000	11.4	54	1.35	18,500
Bellingham, WA (2003)[b]	No	660,000	13.2	265	5.70	2,500
Vancouver, WA (2006)	No	1,600,000	16.5	233	4.01	7,000
Spokane, WA (2007)	No	300,000	11.1	36	0.92	8,000

1 mi = 1.61 Km

a. Costs are approximate because of difficulties in separating panel replacement work from other work on single contracts, differences in costs betweeen geographic locations, and differences in complexity and urgency of work.

b. The contractor lost a substantial amount of money on the Bellingham job. Therefore, the rounded cost per panel, while reasonably accurate for this job, is probably too low to use for future estimating.

COMPARISON TO ASPHALT PANEL REPLACEMENT

For years, the prevailing mindset was that asphalt is cheaper than concrete. However, the reverse is actually true in today's changing marketplace. The days of inexpensive asphalt have come to an end, in part due to rising petroleum prices and an overall shortage of asphalt in the United States. The U.S. asphalt shortage is so severe that currently the country is undersupplied by about 24,000 barrels of asphalt a day, a figure that is expected to jump to 257,000 barrels a day by 2012, according to San Antonio-based NuStar Energy L.P., a producer of asphalt (*8*).

Table 3 is a direct comparison of panel replacement in Southern California districts where asphalt was used to make repairs in 2007. The eight Caltrans contracts include a total of 2,249 panels. The average price for the VES CSA system was $2,703.39 per panel, and the average price for the asphaltic concrete was $2,789.37. In a direct comparison of initial cost, asphalt was found to cost more than VES CSA concrete, which was found to offer an average initial cost savings of $85.98 per panel or $193,369.02 dollars overall on these contracts. When the contracts are compared within their district, the average initial cost savings is approximately $300 per panel.

The longevity of the VES CSA concrete accounts for few, if any, repairs over the lifespan of the roadway. If life-cycle costs are compared, and the longevity of VES CSA concrete when compared to asphalt is factored into the economic question, the advantage of CSA concrete is even more evident.

Many people hold a perception that VES concrete is difficult to use. In this case, the reverse is true. Research at the University of Oklahoma has shown that the VES CSA system is much more forgiving than typical VES concretes. CSA has a high theoretical optimum water-to-cementitious materials ratio of 0.47, which means it is extremely pourable and placeable, easier in some cases to install than asphalt. And since all the water is used in the hydration process, shrinkage is extremely small. In addition, fast-setting materials such as VES CSA cement can be extremely user-friendly due to (1) the advances in admixtures available today, which have helped to increase the material's working time, and (2) advancements in the clinkering process and production quality control of CSA cements available in the United States, which have helped improve batching characteristics.

Table 3
Initial Cost Comparison of 2007 Caltrans Contracts

Contract #	Location	Material	# Panels	Cost / Panel ($)
03-0C7704	03-PLA-80-R66.3/68.5	Rapid Setting Concrete	272	2,295.00
01-457704	01-MEN-101-R31.6/R33.7	Rapid Setting Concrete	133	2,715.75
05-491904	05-SLO-1-L16.7/18.1	Rapid Setting Concrete	209	3,155.63
06-0G6204	06-KER-5-62.0/82.5	Rapid Setting Concrete	198	2,640.00
04-269604	04-CC-24-R0.1/R8.3	Rapid Setting Concrete	993	2,731.05
		Total	1,805	
		Average Cost per Panel		$ 2,703.39
06-0F5004	06-KER-14-R17.9/T22.0	Asphaltic Concrete	128	3,387.75
04-447204	04=ALA-92-6.8/8.2	Asphaltic Concrete	34	3,407.63
04-4A6104	04-SOL-80-22.0/30.6	Asphaltic Concrete	282	2,443.22
		Total	444	
		Average Cost per Panel		$2,789.37

Environmental Considerations

Environmental sensitivities are among the forefront of today’s building and construction topics, and here VES CSA again excels over asphalt for numerous reasons. First, the production process uses less fuel and is able to utilize alternative fuel sources such as industrial byproducts. By relying on waste materials for production, VES CSA actually helps reduce the carbon footprint of other production processes.

Like other concrete products, VES CSA does not have the rain or water runoff concerns that asphalt has. After a rain, no oils come to the surface of VES CSA that could then seep into the water supply.

Another environmental benefit is that as a concrete product, VES CSA helps minimize the urban heat island effect. This phenomenon occurs in cities, where asphalt is the primary building material for roads and parking lots. The black surfaces absorb heat and raise temperatures in these areas, so that the city experiences an increased demand for electricity to cool homes and buildings. Brownouts and blackouts then become more likely as energy demand soars. On the other hand, concrete is reflective, helping to keep temperatures down; concrete roadways help minimize such an urban heat island effect.

The durability of VES CSA makes it a greener choice in that fewer, if any, repairs are required over the course of the pavement’s lifespan. Concrete, in general, is an extremely durable product, and VES CSA is no exception. According to the American Concrete Pavement Association (ACPA), most pavements are placed with a targeted design life of 20 years, but concrete pavements typically last much longer. There are well-documented cases of heavily trafficked concrete pavements that have performed for more than 40 years. On the other hand, most asphalt pavements last less than 20 years, and recent modifications to asphalt mixes due to the increased efficiency of the cat-cracking process, which has reduced the amount of heavy molecular weight organic compounds in asphaltic oils, have shortened the product's life span even more.

What is more, the cement industry has reduced the amount of energy required to produce the product by 30 percent and is committed to reducing this figure by another 10 percent by the year 2020. All materials are readily available in the United States, and the production does not rely on the importing of oil. Adding to concrete's green appeal is the material's recyclability and reusability. According to the ACPA, routinely old concrete is crushed, steel components are removed and recycled, and the crushed concrete is used for roadbed materials, stormwater management, aggregate in new concrete mixtures, and also some nonpaving applications. Concrete is 100 percent recyclable and reusable.

As contractors look for ways to create a competitive advantage and transportation departments look for long-term, high-value solutions, the VES CSA system proves to be one such means of doing so. This CSA-based cement allows paving costs to be kept at a minimum, while roads can open in shorter times.

CONCLUSIONS

Caltrans has placed over 70,000 highway panels using CSA concrete, an equivalent of approximately 322 lane-km (200 lane-mi) since 1994. It is easy to work with and requires a minimum of equipment. It can be successfully produced at a batch plant or Volumetric mixer. It provides VES, which minimizes a project's impact on traffic. CSA concrete provides a cost-effective solution for highway panel replacement.

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