

## ‘Super’ Tech Superstructures

From idea to ribbon cutting and beyond, technological breakthroughs are revolutionizing bridge superstructures.

**N**ew technologies – both active and passive, mechanical and electronic, as-built or retrofitted – are revolutionizing how bridge superstructures are designed, built, protected and maintained.

Bridges have almost nothing in common with roadways, except they abut each other, are used by vehicles, and have the same ownership. It's the same with conventional bridge superstructures as opposed to bridge piers and footings; they are joined to each other but largely function independently, with their own design, maintenance and rehab needs.

That's why new “super” technologies for superstructures deserve an independent look, as bridge superstructure life-cycle performance is impacted by the quality and implementation of bearings, deck surfaces, monitoring systems, sealants, coatings, abutment and joint systems, reinforcing steel, drainage systems, seismic reinforcement, and much more.

### Managing Superstructure Life Cycles

The life-cycle management of bridges and superstructures is so important that the Federal Highway Administration (FHWA) has launched an Exploratory Advanced Research (EAR) program project, *Development and Demonstration of Systems-Based Monitoring Approaches for Improved Infrastructure Management Under Uncertainty*. It describes a next-generation, integrated, structural-monitoring framework to boost reliability of bridge assessments, and is now underway at the University of Central Florida and Lehigh University.

Effectively managing bridge maintenance, repair and replacement requires a deeper understanding of how these complex structures and their components respond to environmental conditions, increasing traffic loads, and to events such as earthquakes, floods, fires and collisions.

FHWA's EAR program focuses on long-term, high-risk research with a high payoff potential.

“Our knowledge of how structures behave over time under a wide range of environmental and load conditions is broad but incomplete,” says Hamid Ghasemi, of FHWA's Office of Infrastructure Research and Development. “This research is pursuing a structural monitoring framework that can accommodate the collection, integration and analysis of monitoring data to better predict bridge performance. The goal is to provide the best information possible to inform decisions about further testing, repairs and reconstructions.”

The project is unique: in the variety, location and number of sensors it utilizes; in its “global” approach to monitoring structural, mechanical and electrical components; in the sheer amount of data that could be collected, integrated and effectively analyzed; and finally, in new methods of quantifying uncertainties in making decisions about a structure's reliability and load-carrying capacity.

The framework project will integrate bridge and superstructure data from a broad array of sources for analysis and future research, including historical data. In an attempt to characterize a bridge's reliability, it will define safety and serviceability performance expectations for individual structural components and structural systems. And it will develop reliable 3D finite element models that can be constantly updated with new data.

### Sensors Generate Data

In this project, using state-of-the-art data mining and analysis techniques, bridge superstructure information generated during the design, construction and maintenance of structures can be integrated with continuously updated data from a network of monitoring sensors.

Common monitoring technologies (e.g., sensors for strain, temperature, displacement, tilt, vibration) are being used, as well as technologies that are newer or not traditionally used in bridge monitoring (e.g., video imaging, infrared sensing, pressure gauges and microphones).

In particular, the use of sensor data in structural health monitoring shows great promise in the laboratory



# Bridges to the Future

## New-generation technology behind new generation superstructures

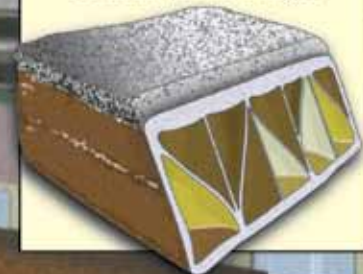


Most new bridge designs minimize deck joints. But where joints appear, watertight deck joint systems reduce substructure damage due to drainage of chloride-contaminated melt water, but metal plates and angles must be anchored



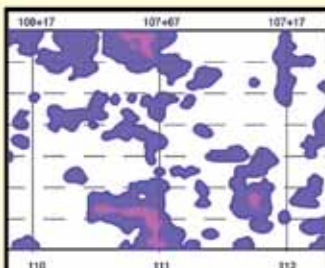
Precast full-depth deck panels can be a cost-effective alternative for long-life bridge decks and can speed construction

Fiber-reinforced polymer (FRP) honeycomb bridge decks represent a new generation of so-called plastic bridges



Superstructure-mounted sensors can collect measurements such as bridge deck acceleration, temperature changes

and crack opening displacement data for real-time inspection or planned maintenance and rehabilitation



Ground penetrating radar (GPR) for bridge decks provides detailed maps of concrete condition and rebar depth for each of the decks, without coring or lane closures



As quake-induced displacements occur primarily in the bearings, a new kind of bearing – a three-pendulum seismic isolation bearing – can reduce lateral loads and shaking movements transmitted to the structure





▲ A precast, prestressed panel is placed on I-287 ramp in New Jersey.

Photo courtesy of FHWA

and in real-life implementation for predicting the load-carrying capacity of bridges, says FHWA.

The project's technologies, algorithms and methods have been tested in physical test beds in laboratories and now are being implemented on a mid-size steel bridge near Ft. Lauderdale, Fla., with support from the Florida DOT, District 4. This one-year demonstration under real-world conditions will allow investigators to evaluate and refine the framework under a full annual cycle of weather and traffic conditions.

It's hoped the research will lead to significant cost-efficiencies in managing transportation structures, while also reducing the cost of information processing and analysis through automated data collection and evaluation processes. And in pursuit of the goals of FHWA's *Highways for Life* program, the structural health monitoring framework should advance performance-based condition assessment of transportation infrastructure in general, and superstructures in particular.

## GPR for Superstructures

The same radar technology used in mobile applications to conduct

real-time, nondestructive analysis of pavements below their surface also is used to survey the condition of bridge decks.

Such electronic analysis replaces the time-honored, acoustic chain-drag process in which hand-held chains are bounced against the surface of the deck, and the users listen for a dull sound where voids exist, which are marked on graph paper. While effective, that process is strictly subjective and lacks the precision that modern bridge and pavement management systems require. For example Geo-physical Survey Systems, Inc.'s *Bridge Scan* is a GPR system designed specifically for bridge condition assessment and analysis, and for accurately determining concrete cover over rebar on new structures.

*BridgeScan* results are provided in a simple ASCII file format for simple integration with a variety of programs. Results also automatically accommodate for the bridge skew angle, which provides for an accurate representation of the bridge data.

Such systems are used for bridge deck condition assessment, measurement of the thickness of the bridge

deck, determination of concrete cover depth on new structures, location of metallic and non-metallic targets, and detection of voids.

## Prefabricated Units

The use of prefabricated bridge components now goes beyond simple precast, prestressed, post-tensioned I-beams and box girders, to complete deck systems which are placed by crane – often at night, as traffic must be halted on the pavements beneath – and which are speeding bridge reconstructions across the country.

Whether made of high-strength concrete, or glass or carbon fiber-reinforced polymer configurations, prefabricated bridge elements and systems offer advantages for the owning agency, says FHWA. They may be manufactured on-site or off-site, under controlled conditions, and brought to the job location ready to install according to FHWA.

Prefab components are a good idea, according to FHWA's *Highways for Life* program. They may be of better quality because they are plant-cast in a controlled environment; they permit better inspection of materials and finished product before being incorporated into the project; their use minimizes disruptions to the traveling public; they greatly reduce the time of construction; they contribute to a safer work environment; they have less of an impact on the environment; and they are cost-effective as more is done with less.

"Traffic and environmental impacts are reduced, constructability is increased, and safety is improved because work is moved out of the right-of-way to a remote site, minimizing the need for lane closures, detours and use of narrow lanes," FHWA says.

"Prefabrication of bridge elements and systems can be accomplished in a controlled environment without concern for jobsite limitations, which increases quality and can lower costs," FHWA adds. "Prefabricated bridge elements especially tend to reduce costs where use of sophisticated techniques would be needed for cast-in-place, such as long water crossings or higher structures like multi-level interchanges."





▲ **A precast panel is placed on the Eastern Ave. overpass (top) during District of Columbia DOT's workshop on precast panels in bridge construction in July 2010.**

**A prefabricated superstructure section of concrete deck on steel girders (bottom) is placed on the Creek Road overpass above I-295 in New Jersey.**

*Photos courtesy of FHWA*

On July 20, 2010, in the District of Columbia, the FHWA conducted an accelerated bridge construction workshop using prefabricated bridge components. There, the D.C. DOT was reconstructing its Eastern Avenue Bridge over Kenilworth Avenue using prefabricated components for the pier and superstructure.

Innovative traffic management plans such as the utilization of the service roads *in lieu* of closing lanes on the main line Kenilworth Avenue were

intended to reduce the traffic queuing during construction. The project had a "no-excuse" completion clause of finishing the project within 320 days, and completion was scheduled for October 2010. The contractor was Fort Myer Construction Corp., and the precast sections were manufactured by the Fort Miller Corp.

The project also featured geosynthetic reinforced soil (GRS). Along with precast components, use of GRS can provide a fast, cost-effective bridge support method using alternating layers of compacted fill and sheets of geotextile reinforcement to provide bridge support, said Jim McMinimee, principal engineer, Applied Research Associates, Inc.

GRS, says McMinimee, eliminates the approach slab or construction joint at the bridge-to-road interface, reduces construction time with a complete bridge in about 10 days, costs 25- to 30-percent less than standard pile-capped abutments, results in construction that is less dependent on weather conditions, and provides a flexible design and a bridge that is easier to maintain, built with common equipment and materials.

Nontraditional superstructure construction materials still need to be monitored, the Utah DOT maintains. Utah has been researching methods and products to extend the lives of its bridge decks to match the service life of the entire bridge.

Currently, Utah bridges are designed to a 75-year design life, but the decks are requiring replacement after 30 to 40 years, the state says. Deck replacement projects increase the life-cycle cost of the structure, as well as adding to user delays.

In response, Utah DOT decided to evaluate glass fiber-reinforced polymer (GFRP) reinforcing bars as an alternative to steel rebar in bridge decks, even though there is no significant amount of research regarding precast concrete panels for bridge decks totally reinforced with GFRP bars, says Chris P. Pantelides, Ph.D., S.E., University of Utah Civil & Environmental Engineering Department; Jim Ries, graduate student, University of Utah; and Rebecca Nix, S.E., Utah DOT Structures,



in their September, 2010 report, *Health Monitoring of Precast GFRP-Reinforced Bridge Deck Panels*.

In this application, GFRP reinforcing bars were used in place of traditional epoxy-coated steel rebar in both mats of reinforcing in the deck of the Beaver Creek Bridge on U.S. 6 in rural Utah. The bridge is a single-span creek crossing with access for wildlife passage. The overall span length is 88 feet 2 inches. The girders are AASHTO Type IV prestressed beams.

The deck was constructed using precast deck panels mildly post-tensioned in the longitudinal direction. The bridge was constructed in two phases, which required a closure pour between the east- and west-bound lanes. Pantelides, Ries and Nix believe that this may be the largest bridge utilizing GFRP bars in precast deck panels.

Two GFRP reinforced precast concrete panels were monitored during construction, lifting and placement using electrical strain gauges. In addition, the two panels are being monitored during post-tensioning, truck load testing and long-term using vibrating wire strain gauges. The bridge deck deflections relative to the two diaphragms connecting the prestressed concrete girders were monitored using linear variable differential transformers.

Finally, the absolute deflection of the girders at midspan during a static truck load test and the dynamic performance of the girders during a dynamic truck load test were monitored using surveys and accelerometers.

During the summer of 2009, construction began on Beaver Creek Bridge. The preconstruction phase focused on instrumentation and monitoring of two precast concrete deck panels. These panels each were instrumented with 28 electrical strain gauges, to be used during the lifting and transport of the panels. These gauges were attached to both the top and bottom GFRP mats.

Also, the two panels each were instrumented with four vibrating wire strain gauges, placed in the longitudinal direction of the bridge. These gauges were used to record strains induced by post-tensioning, as well as the change in strain due to creep and

shrinkage and for long-term monitoring.

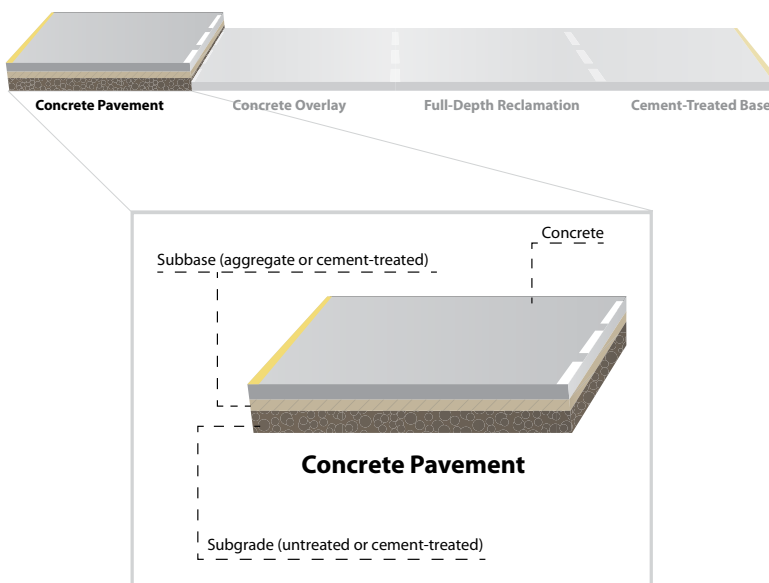
The relative deflection from the bottom of the bridge deck to the top of the steel diaphragms that join the prestressed girders was measured using six linear variable differential transducers, placed above diaphragms. Six single-axis accelerometers were at-

tached at the midspan of each girder to measure vertical acceleration of the girders.

All instrumentation data was collected by an electronic data acquisition system at an appropriate sampling rate. The monitoring of the lifting of the precast panels was achieved wirelessly

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▲ **Survey vehicle collects subsurface bridge deck data** at normal driving speed without requiring lane closures. The system includes dual 1 GHz air coupled horn antennas, and an electronic distance-measuring instrument providing position data as the GPR data is collected. After collection, the data are analyzed for deck deterioration according to ASTM D6087-08 using proprietary software.

*Photo courtesy of Infrasonics, Inc.*

using a modem. During the truck load test, the data was also recorded using a modem. For the long-term monitoring, the modem is connected with a cell phone and is continuously sending data through a secure cell phone connection to the University of Utah.

## Static and Dynamic Tests

A truck load test was carried out at the bridge in September of 2009, which included both static and dynamic tests. The researchers observed:

- The GFRP bars withstood normal handling at the precast yard and placement without any major problems. In addition, the light weight of the bars made them easy to carry and easier to place. The precast panels were also lighter and easier to transport to the bridge.
- The panels were lifted at the precast yard and transported to the bridge using straps, employing a four-point lift using two different lifting configurations, one at the precast yard and one at the bridge. From strain measurements, it was found that

the flexural design method used is very conservative; no cracks larger than hairline cracks were observed during lifting.

- The relative deflections between the bridge deck and the west diaphragm were measured during the static tests. The magnitude of the relative deflections was found to be very small and shows that the bridge deck and the girders have good composite action.

"From the tests carried out for the precast concrete bridge deck panels reinforced with GFRP bars, it is clear that this is a viable construction method," the authors report. The bridge was opened to traffic on October 2, 2009. Long-term monitoring of the bridge is continuing, and a second static and dynamic truck load test series is planned for the future.

## Vermont Explores Jointless Bridges

In general, due to the problems inherent in bridge joints – such as joint deterioration due to superstructure segment movement, and their pro-

pensity to let chloride-laden meltwater drip onto bridge substructures, thus encouraging rebar corrosion – so-called "jointless" bridge superstructure designs have gained favor with state DOTs in recent years.

Jointless bridges – also called integral abutment bridges – have a superstructure that is cast integrally with the substructure, eliminating costly expansion joints and bearings, according to Chad Allen, geotechnical engineer for the Vermont Agency of Transportation (VTrans), Montpelier, Vt.

VTrans had used jointless bridge designs since the late 1970s, but in 1999, the agency formed an Integral Abutment Committee (IAC) to codify a measured, analytical and multidisciplinary approach to jointless bridge design and construction, Allen says.

VTrans has constructed several jointless bridges in the past decade, finding the structures more advantageous than conventional abutment bridges. Advantages of jointless bridges can include, according to Allen:

- **Reduced environmental impacts.** Abutments farther from the stream banks minimize the effects on stream water, and a longer superstructure allows more room below for wildlife passages.
- **Lower construction costs.** Placement of abutments farther away from the stream often eliminates the need for cofferdam construction.
- **A more rapid construction schedule.** With integral abutment bridges, fewer piles need to be driven.
- **Elimination of costly future repairs, which can affect users.** "Without the need for expansion joints and bearings," Allen says, "costly, complicated and time-sensitive maintenance activities are eliminated."

Nonetheless, VTrans engineers often have struggled with how best to approach the design of jointless bridges, because no quantitative data are available, and the American Association of State Highway and Transportation Officials (AASHTO) offers

no specific guidelines for integral abutment design, he says.

"Without fully-developed design guidelines and construction plans and specifications, the benefits of jointless bridges may not be fully realized," says Allen.

### Monitoring Jointless

To better understand how jointless bridges perform, VTrans initiated a research project, *Performance Monitoring of Jointless Bridges*, to gain a thorough understanding of how jointless bridges respond to thermal movements, and to dead and live loads in a northern climate.

"The primary research objectives were to provide VTrans engineers with the knowledge and quantitative data to design and construct cost-effective, efficient, safe, reliable and low-maintenance structures," Allen says.

This ongoing project has three phases. Phases I and II, completed by Wiss, Janney, Elstner Associates in 2002, included a formal literature search and the development of an instrumentation plan. VTrans applied the information and knowledge gained from the research to develop design guidelines, contract plans and specifications, and has used the documents to build several integral abutment bridges since 2002.

Now, the 2010 *VTrans Structures Manual* will include guidelines and procedures for integral abutment design developed from the Phase I research. "With the application of the Phase I research findings, integral abutment bridges have become the preferred structures at VTrans," Allen says.

For Phase III, the University of Massachusetts-Amherst is conducting research, which includes modifications to the Phase II instrumentation plans, installation and monitoring of instrumentation, data analysis and reduction, and preparation of a final report. Phase III should be completed in February 2013.

The Phase III research involves three bridges: a straight bridge with a 141-foot span in Middlesex; a 121-foot-long bridge with a 15-degree skew in East Montpelier; and a curved-girder, two-span continuous structure

with 11.25 degree of curvature and a total length of 226 feet in Stockbridge.

Instrumentation on these bridges includes pile and girder strain gauges, earth pressure cells, displacement transducers, inclinometers, tiltmeters and thermistors – devices used to measure temperature differences.

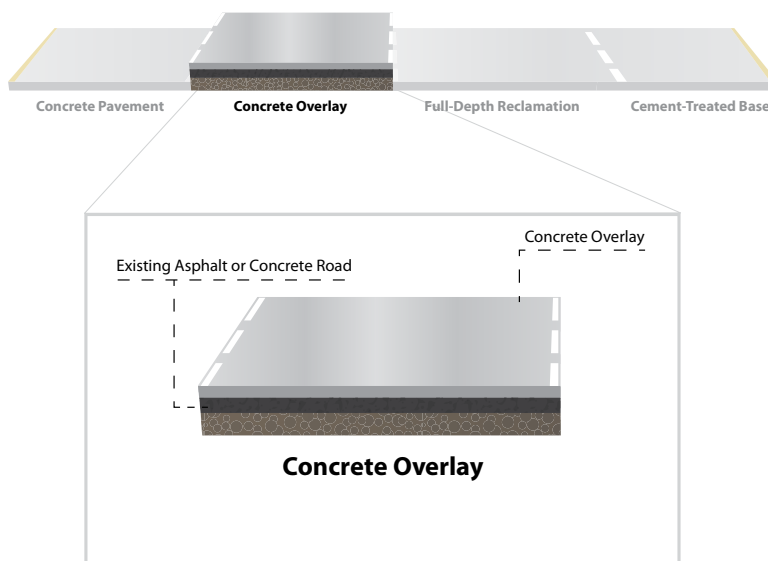
"Tangible economic benefits [of this

research] include reductions in maintenance and construction costs," says Allen. "The construction cost savings result from eliminating cofferdams and from using less concrete and reinforcing steel in the substructure and superstructure."

The integral abutments, he says,

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▲ **At a University of California-Berkeley demo.** (top) triple pendulum isolators (twin stainless steel facing concave devices with 'pendulum') above the bridge column bents allow the bridge superstructure to move with a seismic event.

*Photo courtesy of Pacific Earthquake Engineering Research Center at Berkeley.*

**Crack meters in reference pile enclosures** (bottom) measure the longitudinal and lateral displacements on East Montpelier Bridge in Vermont.

*Photo courtesy of Vermont Agency of Transportation*

have a typical height that is less than that of a conventional abutment, reducing the quantity of excavation and backfill materials. In addition, integral abutments require fewer piles for support than do conventional abutments. Indirect benefits include savings from a more rapid construction schedule, which decreases user costs; fewer environmental impacts, such as less sediment pollution of streams; and better access under the bridge for wildlife passage, because the structures are longer.

## Berkeley's New Seismic Bearings

In May 2010, the University of California-Berkeley demonstrated three new permutations of seismic bearings that could radically change how bridge superstructures are protected in case of an earthquake.

Over 100 engineers, researchers, media representatives and members of the public were on hand to witness a demonstration of a new isolated bridge system at the PEER Earthquake Simulator Laboratory at the university's Richmond Field Station.

In this new bridge system, as displayed in the lab, all three bridge segments were supported using seismic isolators, and utilized the new *Segmental Displacement Control Isolation System*, which was being tested for the first time.

In the new approach that was displayed, the movement of the three isolated bridge segments is constrained so that the bridge's road centerline remains continuous without residual offsets, thus improving driver safety, minimizing the need to realign the different segments following an earthquake and minimizing damage to the joints provided between segments along the bridge. This is achieved using special **lockup guides** between the bridge segments, **triple pendulum isolators** above the bridge column bents, and **linear isolation bearings** at the ends of the bridge.

"We have designed a new system for bridges to go through an earthquake in a safe manner, yet remain open and functioning for the public following a very large earthquake," says Stephen Mahin, director, Pacific Earthquake Engineering Research Center at Berkeley.

"We normally divide a bridge [superstructure] into segments," Mahin says. "Each of the segments are like people in a line; if you have 10 people in a line, each person will be moving sideways or out of phase. We are trying to keep everybody in a line, so that white line down the road will be continuous, and they stay in line."

That's done with the different types of newly-designed seismic bearings or appurtenances, all manufactured by Earthquake Protection Systems, Inc., Vallejo, Calif.

Triple pendulum isolators are placed at the top of the bridge columns or pier caps, and control the maximum displacement of the bridge superstructures. They have three different pendulum mechanisms that sequentially engage as shaking increases.

"The triple pendulum isolator has a spherical bowl [negative concavity] inside, which allows the device to move back and forth, and roll like a pendulum," Mahin says. "But the surface inside is coated with Teflon, so instead of simply rolling, it moves with a bit of friction." It's topped with a matching concave half that permits the "pendulum" within to rotate, but also move sideways.

The adjacent bridge superstructure segments also must move in unison, and "lock-up guides" allow the bridge

to move while guided in longitudinal and transverse displacements. The connection is rigid in both the vertical and transverse directions, but can rotate around its vertical axis, thus the guides keep the bridge deck and centerline continuously aligned during and after earthquake shaking.

Finally, linear isolators are used at bridge abutments. They allow unidirectional sliding in the longitudinal direction along a Teflon-lined surface, says UC-Berkeley.

They are allowed to rotate 360 degrees around the vertical axis, 12 degrees about the x and y axes, and have no tension capability.

"Our tests exceeded our expectations, and we look forward to doing some actual analysis of the bridge so we can be more confident in our findings, and come up with some recommendations for future bridge designs," says Mahin.

## High-Performance Deck Sealants

When it comes to the wearing surface of the superstructure, high-performance deck sealants protect decks and ensure longer bridge lives. And the improved technology of value-added products is making that work easier and more environmentally acceptable.

For example, in summer 2010, the 33,000-square-foot Trout Creek Bridge in Wawarsing, Ulster County, N.Y., was sealed in just two days.

Because of watershed concerns at Rondout Creek Reservoir on County Road 77, the New York Department of Environmental Protection (NYDEP), New York City Water Authority and Ulster County Department of Public Works wanted a product that would eliminate all possible leakage into the public water supply.

Through New York Department of Transportation past experience, and testing by the NYDEP, *Sealate* (T-70/MX-30) deck sealant from Transpo Industries was the product chosen for this environmentally-sensitive project. Its fast cure time enabled FAHS Construction Group of Binghamton, N.Y., to fill and seal all cracks in the deck in

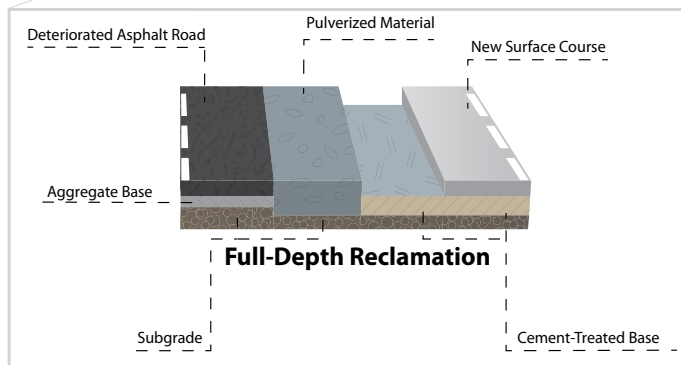
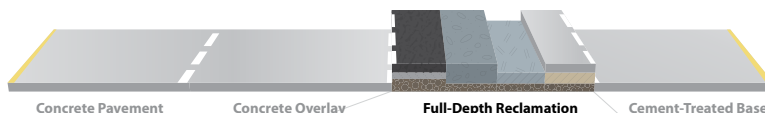
the quick turn-around time required.

Sealate is a specially-formulated, high-molecular-weight, methacrylate-penetrating crack healer/sealer for use on concrete surfaces and bridge decks. The material's very low viscosity allows it to penetrate deep into cracks, the maker says. When fully cured, it

restores over 50 percent of the original strength of the concrete across the crack.

Sealate features low-cost, easy application, and is a maintenance/preservation material with water and corrosive-resistant features, according to Transpo. ♦

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