Concrete solutions to aging bridges

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In the Civil Infrastructure Testing and Evaluation Lab at Cato Park, Farshad Rajabipour prepares to add aggregate (crushed rock) to a concrete mixer. The aggregate is dark because it has been soaked in water, one step in a new practice of internal curing of concrete to improve its strength, durability and service life. Credit: Curtis Chan

According to the Pennsylvania Department of Transportation (PennDOT), this state leads the nation in the number of bridges classified as "structurally deficient."

That's probably not a surprise to most residents who've done any driving throughout the commonwealth. Our 25,000 state-owned bridges are aging—their average age is over 50 years—and in need of repair. Civil engineer Farshad Rajabipour and his colleagues are working on solutions.

Rajabipour, together with Aleksandra Radlinska and Gordon Warn, all Penn State civil engineering faculty, are researching methods for enhancing the maintenance and durability of civil infrastructure—including anything made of concrete, from bridges to roads to buildings.

"We are looking at improved maintenance practices, specifically how to reduce cost while improving safety and longevity," says Rajabipour. "Conventionally, we have not done much preventive care of our infrastructure, until we see potholes or more significant signs of damage and failure. Then we have to do repairs out of urgency. The better approach is one of preventive maintenance, which will save money, reduce traffic, and improve the longevity of bridges and roads. It's similar to health care for people—preventive measures can make you healthier and extend your life."

Rajabipour explains that steel rebar corrosion and concrete cracking, among other factors, contribute to infrastructure degradation over time. He and his students work to understand and predict how those damages happen so they can be prevented.

Engineer Farshad Rajabipour examines a concrete prism being used to study the alkali-silica reaction, which is a major cause of deterioration in concrete structures. Behind him, each white bucket holds four such prisms at high humidity and a temperature of 38 degrees Celsius (about 98 degrees Fahrenheit). Researchers measure expansion of the prisms over time and remove slices of them every few months for microscopic examination. Credit: Curtis Chan

"Let's say you have a bridge that is five years old," says Rajabipour. "That bridge has a certain bill of health—a certain extent of damage—and we want to predict what its health will be 10 to 20 years down the road. Should we do any maintenance treatment now, and what should that treatment include to have a better, safer, and longer-lasting bridge in the future?"

In a cooperative effort with PennDOT, the researchers are evaluating 220 bridges in Pennsylvania, forecasting the extent of cracking over time and working to optimize the type and timing of maintenance. By collecting and analyzing data on maintenance that's been done over the last 15 years, they can determine the costs and benefits of performing maintenance immediately, as opposed to waiting another few years. Most importantly, they are working to come up with an optimum maintenance schedule to help PennDOT determine which bridges must be repaired this year, next year, and further into the future and to get the most benefit out of the limited maintenance dollars available.

As well as concrete maintenance and durability issues, Rajabipour and his colleagues explore options for making concrete a greener and more environmentally friendly material. Simply put, Rajabipour says, concrete is "a formable, manmade rock that is made of natural stone particles or aggregates, such as sand or gravel, that are glued together."

The glue is a mixture of Portland cement and water, which react chemically and harden. Portland cement is relatively cheap and is produced using some of the world's most abundant resources. At the same time, it is the most energy-intensive and environmentally negative element of concrete, Rajabipour explains. To make traditional Portland cement, limestone, sand and clay are ground up and heated to a high temperature (1,450 degrees Celsius or 2,600 degrees Fahrenheit), creating a cement powder that is highly reactive with water. This process uses a lot of energy and releases large amounts of carbon dioxide into the atmosphere. In fact, it is estimated that more than 5 percent of total human-generated carbon dioxide emissions is the result of cement production.

With funding from the National Science Foundation, Rajabipour and his colleagues and students are working to produce new cements that perform as well as Portland cement, while providing significant energy savings and environmental benefits. For example, they are studying recycled materials, such as ground glass bottles, and industrial byproducts, such as iron blast furnace slag and coal combustion residue (fly ash and gypsum), to produce new cements.

Samples of a new low-energy, low- CO_2 concrete made using coal combustion ash instead of Portland cement. The samples are in an environmental chamber that allows researchers to vary the temperature and humidity in order to study the concrete’s shrinkage and propensity to crack. Credit: Curtis Chan

"When you're using recycled and waste materials, you're likely doing something that's good for the environment," Rajabipour says, "but at the same time you don't want it to come at the expense of longevity and performance. Portland cement has been around for about 200 years. We know a lot about its properties and performance. But in the case of alternative cements, we have made a brand new material and we know little about its long-term quality. It doesn't mean this material won't be as good or better, it's just that we don't know yet. And we don't have enough time or money to study these materials for another century or two to see if they're good enough."

To address this problem, the researchers are starting to use computer simulations to predict how materials will behave over a long period of time. They are performing what Rajabipour calls "virtual experiments" that simulate and accelerate the aging process for concrete. They use computer modeling to figure out the best recipe for combining different ingredients and processing or cooking materials to make an optimum cement and to determine how concretes made from these cements will perform over several decades of service life.

Civil engineer Farshad Rajabipour inspects a tube filled with concrete. The steel frame holding the specimen allows him to measure changes in length of a sealed sample over time. He and his colleagues are working to produce new, environmentally friendly cements with great strength and durability. Credit: Curtis Chan

Over the years, Rajabipour has developed close relationships with members of the local and national construction industry. He collaborates with groups such as the Pennsylvania Aggregate and Concrete Association, a consortium of concrete producers in the state, and the Pennsylvania Coal Ash Research Group, a consortium of electric power producers.

"The electric power industry is very supportive of research on how we can use byproducts of burning coal," Rajabipour says. "We continue to explore how we can use those products in a beneficial way, as opposed to putting them into landfills or impoundments. It's a valuable working relationship—we're the go-to place for the industry when they need basic or applied research to solve a practical problem."

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