Open Beauty, Hidden Strength

Despite deep soft soil conditions, a replacement bridge was built quickly by using geofoam as an approach embankment fill.

By Gwendolynn I. Lewis, Steven Gibbs, and Kevin Dusenberry

The 117-ft long York Bridge across the Sammamish River was a necessary but drab link in the road system of suburban Seattle. However, the 50-year old bridge was structurally deficient (with cracked concrete and rusting reinforcing steel) and functionally obsolete, posing hazards such as substandard sight distances and at-grade crossings with heavily used riverbank trails. Co-owners King County and the City of Redmond decided to replace the structure with a seismically sound bridge designed to meet current standards for vehicular and pedestrian traffic, and to eliminate conflicts with trail users. In the process, they also managed to improve the river as both a natural habitat and a recreational resource. And they did it beautifully.

Geofoam was cut with a heated wire. **Photo by John Livzey.**

To meet the safety objectives, the replacement bridge would be 103 ft longer, 16 ft wider, and 15 ft higher than the original structure, allowing the riverbank trails to pass underneath. The $12-million project budget, nearly half of which was funded by the federal government's Highway Bridge Rehabilitation and Replacement Program, included rebuilding, widening, and raising the elevation of 1,400 ft of approach roadways. A major challenge arose when the geotechnical investigation consultant, HWA GeoSciences (www.hongwest.com), determined that the ground consisted of highly compressible soils—primarily peat. The condition was particularly problematic on the west approach, where the soft soil was up to 195 ft deep.

Soft soil problems are commonly solved by over-excavating the roadbed to remove a predetermined amount of the highly compressible material, and replacing it with lightweight fill material to minimize settlement of the remaining subsurface soil. Subsequently adding a temporary overburden of material exceeding the weight of the planned road effectively compacts the fill and subbase, but the process can require lengthy consolidation times when the soft layers are thick. The material and labor for placing and removing the overburden also add to the project cost.

In the York Bridge case, the depth of the peat and the extra weight associated with raising the roadway height made this process impractical for two reasons. "If excavation had been pursued, the preloading time would have driven this project into three construction seasons, which would increase construction costs significantly," says Rachel Speer, project engineer for King County Road Services.

The other reason the compaction process would be impractical on the west approach was that an existing 20-ft deep, six-ft diameter sanitary sewer line would be covered by the new roadway embankment. The designers predicted that the settlement due to compaction would be great enough to break the sewer line. Moving the sewer would be excessively expensive and time consuming.

The ideal solution would be to build up the roadway approach with a material so lightweight that it would add virtually nothing to the burden on the supporting soil. Expanded polystyrene (EPS) blocks make that possible. According to the Federal Highway Administration (FHWA), the material weighs only one to two lb/cu ft. Most regular soils weigh roughly 120 lb/cu ft,

Assembly of the geofoam on the west approach embankment was likened to "putting together a giant, three-dimensional jigsaw puzzle." **Photo by John Livzey.**

A six-in. thick reinforced concrete slab was poured on top of the geofoam to protect it from solvents and provide lateral support for concrete panels intended to cover the embankment. **Photo by John Livzey.**

and even the commonly used lightweight fill materials are 20 to 30 times heavier than EPS blocks. Known as geofoam, these blocks have proven their effectiveness on widely publicized projects such as the reconstruction of Interstate 15 in Salt Lake City. FHWA, which provides information and training for geofoam use on road projects, reports that it has been used in at least 20 states.

Although King County had not previously used geofoam, the city had. "Other cities in the area have been using it," says Ron Grant, P.E., construction division manager for Redmond. "It's available, and it's environmentally sensitive as well." In fact, since geofoam is not biodegradable, it imposes no adverse effects on soil and groundwater quality. Furthermore, the Geofoam Research Center at Syracuse University (http://geofoam.syr.edu) reports that the manufacture of geofoam does not involve any gases known to be environmentally harmful.

Construction Sequence

The sequence of constructing the west approach embankment began with removing enough of the existing soil to equal the weight of the geofoam blocks that would be used to increase the road's elevation. The first layer of the new construction consisted of geogrid soil reinforcement topped with six in. of compacted sand to provide drainage and facilitate leveling. On top of this level surface, the geofoam blocks were stacked up to nine ft high, stopping three ft below finished grade. The blocks—which were typically 2.5 ft high, four ft wide, and eight ft long—were stacked in alternating directions so no seams ran continuously through the layers. When all of the geofoam was in place, a six-in. thick reinforced concrete structural load distribution slab was constructed on top to distribute live loads evenly to the geofoam, protect the geofoam from solvents that could damage it, and provide lateral support for concrete panels that would cover the faces of the embankment. A gravel base and the final asphalt pavement were placed on top of the load distribution slab.

Working with geofoam was new to most of the people involved with the York Bridge replacement. "There was a learning curve that kept cropping up as we went along," says Dee Gilmore, resident engineer for King County. "It never really stopped during the three months it took to place the geofoam." For example, stockpiling the blocks was different from mounding typical fill material. Stacks of the blocks had to be kept covered to protect them from sunlight's ultraviolet rays, and to keep the wind from scattering them.

Another skill the workers had to develop was cutting the geofoam to

Geofoam was cut by two men using an electrically heated wire about five ft long.
Photo by John Livzey.

achieve the desired roadbed slope and crown, and to fit the material around storm drain pipes and manholes. "These are well-trained carpenters who were putting it in," says Gilmore, "so they're used to running a tape measure and figuring out what size piece they need for any given area." The workers cut the blocks with an electrically heated wire about five ft long, with a handle at each end. After marking the desired cutting lines on the white block with black marker or chalk, two workers would each hold one of the handles, pull the wire tight, and guide it along the lines. With practice, they learned the best setting on the hot wire's rheostat control and the proper speed at which to move the wire through the block.

Workers also cut trenches in the blocks to contain utility conduits. Some trial and error was involved in figuring out what to fill the trench with after the conduit was placed in it. "We ended up using [expanded polystyrene] packing peanuts," Gilmore says. "Any other material caused the geofoam to displace, and we couldn't keep it in its alignment."

Another challenge was that the blocks tended to slide as they were being stacked. "We had to run rebar down through some of the edge pieces to make sure that as we were stacking layers we didn't knock them out of whack," says Gilmore. "It was like putting together a giant, three-dimensional jigsaw puzzle."

"I think that in the future you're going to find a lot of roadway beds being supported by geofoam whenever there are settlement issues," says Kiva Lints, P. E., bridge project engineer with the Bellevue, WA, office of design consultant DMJM Harris (www.dmjmharris.com). "Contractors are going to have to learn to deal with it and figure out how to bid it. And it's going to take awhile for the engineering side to come up with the best way to show details in the plans. We need to give the contractors flexibility in doing what they need and want to do, without requiring a lot of extra changes."

When designing a project using geofoam, engineers must also evaluate the potential for flooding. "You have to make sure that flood waters won't come up high enough to allow the buoyancy of the geofoam to actually float the road," Lints says. "The last thing you need is to have your roadway floating a couple of feet above your bridge. If there are floating concerns, then you've got to anchor it somehow." At this site, the designers determined that the weight of the gravel, pavement, and concrete walls and sidewalks would be sufficient to keep the geofoam from floating.

The design team worked closely with the owners and the contractor, Mowat Construction (www.mowatco.com) to solve geofoam installation challenges. For example, the original design specified segmental mechanically stabilized earth (MSE) walls to cover the sides of the geofoam embankment. Straps would anchor five-ft square panels into the geofoam, with the weight of the embankment above securing the anchors. The contractor, however, preferred using full-height precast concrete panels for the retaining walls for ease and speed of construction. To accommodate this change, the engineers decided to connect the tops of the walls to the load distribution slab that capped the geofoam embankment.

A further challenge was that one of the retaining walls would be directly above the large, deep sewer line. "The retaining walls are designed to bear on the ground, and that's a significant amount of weight," Lints says. "In order to mitigate some of that weight, we put a two-ft by six-ft block of geofoam under the wall. When we evaluated the weight of the soil we were taking out and the weight of the panel itself, it balanced out pretty closely."

In all, the project used nearly 6,000 cu yd of geofoam supplied by ACH Foam Technologies (www.achfoam.com). Building the west approach road embankment out of geofoam effectively eliminated destructive settlement and saved about one year of construction time. "In this particular situation, I think it was about the only option we had," Lints says. "I would highly recommend the geofoam for similar situations where there are settlement issues—but not if you have other alternatives." In fact, geofoam was not used on the east roadway approach to the York Bridge. The peat and other soft soils were not as deep on that approach, and limiting settlement was not as critical since there was no buried sewer line.

Instead, the east embankment was built using conventional fill material and structural earth retaining walls. Settlement still had to be taken into account, however, as the contractor's proposed construction sequence called for bridge support piles to be driven before the embankment was built. After the fill was placed and it began to settle, it would create friction against the piles and exert down-drag forces on them. The contractor had to compensate for these forces by driving the piles to a larger load-carrying capacity. "It was a significant load," Lints recalls, "from a quarter to half of the initial design load, so it did result in significant additional driving effort."

More Challenges

Constructing wider, longer, higher approach-road embankments was one of the major challenges of the York Bridge replacement; designing the actual bridge was another. It had been decided that the bridge would be supported by an arch. "Redmond has a few other arched bridges, so we wanted to preserve the continuity of the bridges that go across the Sammamish River," Speer explains.

Structurally, the new bridge is a four-span precast concrete W42G girder bridge with a shallow, cast-in-place arch and inclined columns supporting the two center spans. "Typically when you design an arch, most of it is in compression," explains Lints. "This one is not entirely in compression because it's so flat. In addition, the foundations for the arch are somewhat flexible because the sloped piles go 100 to 150 ft down through soft soil before reaching good bearing material. "The flexibility of the support at the foundation level meant that our arch wasn't a true arch anymore," he says. "It was somewhat an arch and somewhat a beam."

Aesthetic considerations further increased the complexity of the bridge design. Both King County and Redmond designated the new bridge to receive funds from their One Percent for Art programs. A nationwide search for an artist culminated in the selection of Cliff Garten, whose studio is in Venice, CA. Garten worked with the design engineers to refine the geometry of the arch so it would coordinate with nearby bridges and be aesthetically pleasing. Some of the other elements he designed, such as decorative railings, could simply be bolted on after the bridge was built, but other elements were integral to the structure's design.

For instance, the artist envisioned large horizontal bulbouts on the deck. Beginning at the west end of the bridge, the six-ft wide north sidewalk gradually bows out over the river until it is 14 ft wide, then decreases to six-ft wide at the center of the bridge. Then the ten-ft wide south sidewalk bows out to 18 ft and back in until it reaches the east end of the bridge. This makes the bridge unsymmetrical, further complicating the structural analysis. "I did an analysis that modeled all the beam elements as typical stick elements," Lints says, "and modeled the deck itself with finite elements to represent the weight distribution on the bridge." The design team's full analysis determined not only the details of the bridge's physical components, but the stages of construction as well. Rather than building the whole bridge and then releasing all the falsework, it was necessary to build the arch and then progressively load the arch with weight before making the deck continuous across it.

"One of the reasons this project was undertaken was that the old bridge was seismically deficient," Grant says. "But as of now, if there's anywhere in the city you want to be during a seismic event, underneath that bridge would be a very safe place."

The artistic elements made the analysis challenging, but they make the bridge a beautiful structure from both the roadway level and from the trail level below. That is significant because the trail is part of a 27-mile long regional trail system extending from Redmond into Seattle. The portion in the vicinity of the York Bridge consists of a paved trail on the east bank of the river for pedestrians, skaters, and bicyclists, and an unpaved trail on the west bank for equestrians and runners.

Before this project, both trails came up for at-grade crossings of the street, which carries an average of 6,000 vehicles per day. Conflicts arose on weekdays, when commuters used both the

Cliff Garten, an artist from Venice, CA, worked with design engineers to provide the bridge's aesthetic touches. **Photo by John Livzey.**

Clear separation of the trail running below from the bridge itself makes recreational activities safer for pedestrians, skaters, and bicyclists. **Photo by John Livzey.**

trails and the road, and on weekends, when recreational use dominates. Three facilities located adjacent to the bridge site contribute to recreational roadway traffic: a major golf course, a robotic airplane field, and a 16-field soccer complex that attracts 250,000 people a year. “Being a regular user of the area trails, it’s exciting to see that the trails are now going under the bridge as opposed to hitting the roadway right at the crest where the bridge was,” Speer says. “We had to scurry across to avoid being hit.”

While the new bridge configuration eliminates conflicts between trail and road users, the project has also improved trail access by incorporating paved ramps leading down from the road. Access to the river has also been improved by constructing a paved parking lot and a kayak launch point consisting of a 12-ft wide, 32-ft long arrangement of flat-faced basalt boulders that step down to the water.

Enhancement of the water quality was another major component of this project. As currently configured, the Sammamish River is actually an artificial construction. In the mid-1960s, the U.S. Army Corps of Engineers channeled the natural meandering stream into a straight, riprap-lined canal designed to control flooding and conserve agricultural land. This slough achieved its stated purpose, but the slow-moving water and the lack of vegetation resulted in an oxygen-poor environment for salmon and other native fish. “In hindsight, we’ve all learned that that was a very bad idea,” Lints says. “Now, whenever projects are undertaken along the slough, they usually require some work to mitigate the residual impacts of that design.”

Formulating an acceptable mitigation plan was complicated by the number of stakeholders, which included city, county, and state agencies as well as the Corps of Engineers and the Muckleshoot Indian tribe. Ultimately, 22 permits were required. One of the initial tasks was to determine all of the different requirements imposed by the various agencies to assemble a set of design specifications that would meet the highest criteria of each agency.

“We are trying to restore the river to a habitat that would be successful for fowl, wildlife, and fish,” Grant says. He explains that the primary mitigation strategy entailed placing large woody debris in the water. “Old trees and their root wads provide pools for the fish, and also provide higher ground for ducks to stand on.”

“For the most part, the logs are 30 to 40 ft long, and about two-thirds of each one is embedded in the bank of the river,” Gilmore says. Because of permit restrictions, all work in the river—including log placement as well as removal of the old bridge—had to be done early in the project, in August 2005. “We had some 100-year rains last winter,” Gilmore reports. “The river and Sammamish Lake flooded to an extent that really put the log installation to the test. If they were ever going to cut loose and float downstream, they would have done it last year.”

Strategically placing woody debris in the river may have been the primary habitat enhancement measure, but the design of the new bridge and approach road also had a positive environmental impact. Using geofoam blocks for building the approach road embankments limited muddy runoff into the river by minimizing the amount of excavation and eliminating placement and removal of compaction-inducing overburden. Also, the new bridge is designed to channel rain water runoff into bioswales that filter the water before it enters the river.

The new York Bridge was opened to traffic in November 2006. “A two-lane bridge with that short of a span generally wouldn’t take us a year and a half to build,” Gilmore says. “But this one has far more to it than that, what with the geofoam and the trail ramps and the complicated structure itself. This has probably been the most interesting project of my 30-plus years in construction.” GE

Ms. Lewis, CPM, is the project manager for King County, a co-owner of the York Bridge and the lead agency on the project. Mr. Gibbs, PE, is the project manager for the City of Redmond, the other co-owner of the York Bridge.