Before a deteriorating bridge from the 1930s could be removed in downtown St. Louis, project designers had to devise a way to fill in the 30 ft deep excavation beneath the ground-level structure without imposing lateral loads on adjacent buildings. The novel solution involved using blocks of lightweight expanded polystyrene near the buildings and traditional soil fill within the rest of the excavation.


The newly refinished, earthquake-resistant facility of North Tucker Boulevard, which is today's new commercial development as a new McDonald's restaurant, eliminates the safety concerns that plagued the former roadway. B Fixing had been used to block certain problematic portions of the former roadway.

CONSTRUCTED IN DOWNTOWN St.
Louis in 1931, the North Tucker Boulevard Bridge facilitated the movement of vehicular and pedestrian traffic along North Tucker Boulevard while a passenger railway operated within a 30 ft deep trench beneath it. However, by the mid-1950s passenger rail service had ended along the route. By the early 1980s nearly all rail activity had ceased at the site, and today there is no rail service at all along the route. During the past 20 years the North Tucker Boulevard Bridge has undergone significant deterioration and has required numerous repairs. Faced with safety concerns and the prospect of additional costly repairs, the City of St. Louis decided to remove the bridge, backfill the excavation to ground level, and support the roadway at grade. Because of the proximity of several vulnerable buildings, the project designer—HDB Engineering, Inc., of Omaha, Nebraska—recommended filling in the trench with a combination of expanded polystyrene (EPS) and soil fill. Also known as geofoam, the lightweight EPS would be used adjacent to the buildings so as to avoid imposing lateral loads on the structures. A 6 ft thick soil layer would be placed on top of the EPS fill to accommodate buried utilities and support tree growth.

Because the site is situated within the New Madrid Seismic Zone, the response of the EPS and soil to strong ground motions was a significant element of the design. The project design had to address numerous other challenges as well,
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The most significant problem areas of the bridge were adjacent to the expansion joints, along the curb lines, and along the sidewalks on each side of the bridge deck. This deterioration was mainly from decaying salts and chemicals that were used during winter months and drained through the expansion joints and leached through construction joints in the deck. This corrosive solution then attacked the unprotected steel superstructure, a process exacerbated not only by the dampness of the area beneath the bridge but also by connection details that did not allow proper drainage or easy inspection of the U-shaped connections referred to as expansion pocklers that were used to support the beams while allowing thermal movement at the expansion joints.

The substructure units typically comprised cast-in-place concrete foundations supporting steel frame beams consisting of columns and main cross-girders. The steel columns and lateral bracing of the beams were typically found to be in good condition. While minor corrosion on the columns was found, there was no significant section loss. Some of the girders still had an intact catenary span, although most had visible rust. The main steel cross-girders of the frame beams supporting expansion joints all exhibited differing degrees of corrosion. Most of these girders were heavily painted on the expansion side, and half of them showed additional minor corrosion on the fixed side. At the worst joints, the girders showed evidence of significant section loss. The steel expansion pocklers were filled with dirt and nux, which stopped salt-saturated water. Several of the pocklers also exhibited significant section loss.

The city had made numerous repairs to the bridge, primarily in the 1990s. Major repairs largely consisted of removing and replacing severely deteriorated portions of stringers near the expansion joints. In more severe cases, the entire beam and expansion pocklers were replaced. In addition to other extensive repairs, the city installed temporary staging for several reasons: to support the existing structure and prevent detrimental displacement of the bridge deck. This temporary support also provided a cost-effective approach to keep the bridge functional during the repair work.

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In late 2007, St. Louis' Board of Public Service hired HDR as the prime consultant to conduct a feasibility study to develop options for removing the North Tucker Boulevard Bridge and installing in the railroad excava-
tion. The scope of the project was to provide design services for the demolition and removal of the North Tucker Boulevard Bridge and to restore the Railway embankment profile without damaging the exiting buildings and utilities. To achieve this goal, several challenges and impediments had to be overcome. The primary design criterion was to provide a solution that would offer a 100-year design life. Given the presence of buildings immediately adjacent to the proposed roadway embankment, careful earthwork, inspections, maintenance, and repairs would be difficult or impossible without removing large portions of the embankment.

Three additional design criteria were specified:

- Restrict the lateral movement of the EPS and soil system.
- Maintain the bearing pressure on the native soil within allowable values (typically less than 2,500 psi).
- Predict the stresses and strains of the EPS so that the response of the materials would remain elastic.

To meet these criteria, the project was divided into three phases:

1. Exclusive use of temporary staging for several reasons: to support the existing structure and prevent detrimental displacement of the bridge deck.
2. Temporary support also provided a cost-effective approach to keep the bridge functional during the repair work.
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constituted of a mixture of clay with pieces of brick, concrete, moment, slag, and glass—along with gravel, limestone, sand, and gravel—in varying proportions. The rubble was probably a waste product from the construction and demolition of the buildings along either side of the street. Rubble was also present in the soil samples from other locations and chunked beneath the bridge.

The natural soils at the site consist primarily of residual deposits comprising loam and clay, denoted as respectively CL and CH in ASTM International's standard D2487-11 (Standard Practice for Classification of Soils for Engineering Purposes: Unified Soil Classification System). The soils exhibited standard penetration resistance N values of 0 to 1 blow per foot. Moisture contents in the natural soil ranged from 18 to 49 percent, the higher values corresponding to the fine clays. Unconfined compression tests on the soil samples yielded undrained shear strengths ranging from 0.3 kPa to 5 kPa per square foot.

With its extremely light weight of 1 to 2 pcf, EPS is ideal for use in an embankment in which minimal consolidation settlement of existing soft clay foundation soils is desired.
values of $T_y$ were calculated along the alignment using methods discussed by Bertlett and Lawson and the methodology described in a February 2004 report entitled 'A Technical Note on Calculating the Fundamental Period of an EPS-Black-Grafain Embankment', by John S. Harvath, Ph.D., P.E., a professor of civil engineering at Manhattan College. The values were calculated using the corresponding height, width, and elastic properties of the EPS embankment.

Ultimately, it was concluded that the highest embankment section of about 50 ft controlled the design because this section produced the highest inertial forces within the embankment and the lowest factors of safety against basal sliding. The corresponding $T_y$ value for the controlling section is about 0.97 second, and the associated horizontal acceleration is 0.18g. These values were used as the horizontal inertial accelerations in the limit equilibrium stability analyses.

The computed yield acceleration for the critical embankment section was estimated from the SLOPE/W analyses to be 0.17g. Therefore, Newmark sliding block displacement analyses were performed to estimate the permanent deformation for the design earthquake event. Using the computed acceleration at $T_y$ for the design event and the estimated yield acceleration, the estimated permanent deformation of the maximum height embankment section ranged from 1.7 to 1.8 in. To minimize the effect of the seismic load transfer, a synthetic compressible inclusion product was incorporated into the design between the embankment and the existing buildings. The synthetic inclusion provided predictable and consistent mechanical behavior that was useful in increasing the seismic stability of the embankment.

HDR submitted the feasibility study to the city in January 2009. Meanwhile, the project was selected to receive federal funding through the American Recovery and Reinvestment Act of 2009. As a result of the federal funding, final design for the project was subject to a tight schedule that began in early April 2009 with the notice to proceed. Preliminary plans were due that July, while right-of-way plans had to be completed by September. Final approved plan documents had to be submitted in December 2009. The Missouri Department of Transportation allocated construction funds for the project in February 2010.

Because of the accelerated schedule associated with the federal funding, the project was divided into two phases. Properties included in the second phase had substantial right-of-way concerns that could not be addressed under the design schedule. This article has dealt with the first phase, for which construction began in March 2010 and was substantially completed by the fall of 2011. The second phase, which involved a separate design and was awarded to a different contractor, is still under construction.

The Gentleman Construction Co., Inc., of Eureka, Missouri, served as the contractor for the first phase, which involved several critical tasks, beginning with the relocation of affected utilities before the start of demolition. The existing steel bridge then had to be demolished and removed without affecting the adjacent buildings or impeding safety at the work site. The EPS blocks, which were provided by Versa-Ad, Inc., of Fredericktown, Missouri, were then shaped and placed to fit around intermediate surfaces. The EPS material was placed simultaneously with the adjoining soil fill as the embankment elevation increased. The 6 in. thick concrete load distribution slab was then placed over the limits of the EPS fill. This slab distributes high point loads and protects the EPS from petroleum products. Next came placement of the 6 ft thick layer of additional soil fill above the concrete load distribution slab to facilitate tree plantings and make it possible to install utilities in the future. Finally, the roadway base and pavement were placed. All told, the first phase cost $16.6 million.

Because it is a lightweight soil alternative, EPS is typically used when excessive settlement is anticipated. For this project, two factors supported the use of EPS. First, the ability of vertically stacked EPS blocks to support loads immediately adjacent to the existing buildings without inducing lateral loads on the buildings. The second was the relatively maintenance-free nature of the EPS material over the long term. Even though EPS and the techniques for installing it are relatively new to the construction industry, the project contractor quickly learned how to shape and place the material. The contractor praised the material, especially the fact that it could be placed quickly by a relatively small crew. On this project, the general limiting factor was how much material could be delivered to the site, as physical factors limited the number of trucks that could bring in material at one time. Of course, use of EPS will be limited by its high cost relative to conventional fill materials, which, depending on density, typically costs just $10 to $20 as much as EPS. But as the North Texas Boulevard project illustrates, in certain unique applications EPS provides a clear advantage over typical fill material and other structural systems.


*Justin Anderson, P.E., M.ASCE, is a geotechnical engineer in the Lexington, Kentucky, office of HDR Engineering, Inc., which has its headquarters in Omaha, Nebraska. Patrick Papad, P.E., M.ASCE, is a senior geotechnical engineer in the firm's Omaha office, and Karen Kraus, P.E., M.ASCE, is a senior bridge engineer in the St. Louis office. This article is based on a paper presented at Geo-Congress 2013, a conference sponsored by ASCE and its Geo-Institute and held March 3–6 in San Diego.*