Introducing InspirArch™

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Inspiring Bridge Innovation through High Performance Composites

University of Maine’s Advanced Structures and Composites Center has spent the last decade taking arch bridge design and construction to a higher level. Using high-performance lightweight Fiber Reinforced Polymer (FRP) material, they have created a solution for short and medium span bridges that is recognized as one of the great new civil engineering innovations. The composite arch has already improved infrastructure deficiencies on roadway projects in more than twenty locations in the Northeast and Midwest United States.

Under a recent partnership between their spin-off company, Advanced Infrastructure Technologies, Inc. (AIT), and The Reinforced Earth Company (Terre Armée Group), the bridge system is fully-engineered and delivered on-site as InspirArch™. It combines the new composite arch innovation with a longstanding and thriving innovation, Reinforced Earth® Mechanically Stabilized Earth (MSE) retaining walls. The result is an efficient bridge solution with a 100-year design life.

InspirArch will accommodate a wide range of bridge geometries and site conditions, from the straight-forward to complex. The profile of the arch tube is custom-designed and fabricated to meet the geometry requirements of the bridge. They can be easily configured to allow for a skewed bridge alignment.

The materials and construction sequence are ideal for short to medium span bridges, especially when considering remote locations and accelerated bridge construction. The FRP arch units and decking are lightweight and can be installed with hand labor. The tubes are essentially pre-fabricated concrete formwork and reinforcement.

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InspirArch structures consist of five major steps:

1. **FRP arch tube units are secured to cast-in-place concrete footing rebar on both ends of the bridge.**
2. **Cast-in-place concrete footings are poured.**
3. **FRP decking is installed along the top of the arch units.**
4. **Concrete is pumped into the top of the arch units.**
5. **MSE spandrel walls and wing walls are installed to create the roadway grade.**
Continued from cover...

Originally known as Bridge-in-a-Backpack™, the composite arch bridge system was developed with military applications in mind, due to its lightweight and easily mobilized material. Other agencies have quickly recognized the value of the solution when applied to the Nation’s badly needed infrastructure upgrades.

The American Association of State Highway and Transportation Officials (AASHTO) has completed a review of the composite arch system and published, “AASHTO LRFD Guide Specifications for Design of Concrete-filled FRP Tubes for Flexural and Axial Members.”

The Federal Highway Administration has played an active role in the research and exploration of the use of FRP, and specifically the use of composites in bridge construction.

In addition to receiving an innovation award in 2011 from the American Society of Civil Engineers (ASCE), the composite arch system has been recognized as a “gamechanger” in ASCE’s 2017 Infrastructure Report Card.

InspirArch has proven to be the high-performance innovation needed to provide long-lasting upgrades to our transportation infrastructure.

Heavy Haul MSE Walls Provide Industrial Site Infrastructure

The Marcellus and Utica shale formations, which extend across southern New York, northern and western Pennsylvania, western Maryland, eastern Ohio and almost all of West Virginia, offer a plentiful supply of ethane, a natural gas liquid and a primary raw material in the production of plastics. To be usable, however, ethane’s large molecules must first be “cracked”, or broken apart, and its carbon and hydrogen atoms rearranged to form first ethylene, then polyethylene, which is delivered from the cracking process in the form of pellets.

Polyethylene pellets are the primary feedstock in the fabrication of products ranging from food packaging and containers, to automotive components, garden furniture and the absorbent beads in baby diapers, meaning there is substantial demand for this shale gas end product.

On the banks of the Ohio River, about 30 miles northwest of Pittsburgh in Potter Township, PA and immediately adjacent to the interchange of I-376 and SR 18, Shell Chemicals is building an ethane cracker. It’s the first large petrochemical facility built outside the Gulf Coast region in 20 years, and allows Shell to take advantage of not only the vast regional supply of ethane, but also the more than 70% of North American polyethylene customers who are within a 700-mile radius of Pittsburgh. Meeting market demand for its planned annual production of 1.76 million tons of polyethylene pellets requires substantial upgrades to on-site transportation infrastructure to assure that Shell’s workers have unimpeded site access and that its product gets offsite and to market efficiently and timely. These upgrades – along with the requisite construction cost-effectiveness – are being achieved in part using Reinforced Earth® MSE structures for portions of the nearly 400-acre site development.

Previously home to a zinc smelter, site environmental remediation and grading required significant hauling of excavated soil to prepare for cracker construction. In addition, the site is traversed by both SR 18 and a rail line, requiring several bridges, retaining walls, and even

Belfast, ME - photo courtesy of AIT

Ellsworth, ME - photo courtesy of AIT
some traffic maintenance actions to accommodate ongoing rail operations (Fig. 1). Therefore, a “heavy haul” bridge was built to carry the West Haul Road over the relocated rail line and its sidings, as well as over SR 18 (Fig. 2). This road then connects on grade to SR 18’s new alignment, providing permanent access to the cracker plant site. Elsewhere on the site another bridge was required to carry the East Loop Road, a primary internal roadway, over the railroad and highway. Additionally, a 2,000-foot long, up to 36 feet tall “Wall B” supports the East Loop Road where it runs parallel and close to the railroad before reaching the bridge. These structures were all designed to support heavy industrial vehicle loading.

Designer Jacobs Engineering Group (Houston, TX) selected Reinforced Earth MSE structures for Wall B and the four bridge abutments. Following standard Pennsylvania DOT (PennDOT) procedure, the bridges were designed with “mixed” MSE abutments – meaning the bridge seats are supported on piles which extend down through the MSE structures.

**High Loads**
MSE retaining walls and bridge abutments at an industrial site like this one often are required to carry much higher loads than would be the case along a typical highway, and Jacobs Engineering specified particularly high construction and operational loads for the West Haul Road bridge, the East Loop Road (on top of Wall B) and the East Loop Road bridge. Where a typical PennDOT highway MSE wall will be designed for 3 feet of live load surcharge, the walls on this site were designed for over 14 feet. These loads produced not only higher tensile stress in the steel reinforcing strips of these three structures, but also higher pullout forces on the reinforcing strips. Similar to increasing both the number of rebars and their development length in a reinforced concrete structure, these Reinforced Earth walls used more reinforcing strips per panel to carry the tensile load, as well as longer strips to provide more embedment length for resisting pullout.

**Bridge Piles**
At the abutments, piles were driven prior to wall erection, which is standard practice to prevent pile-driving damage to installed reinforcements. Corrugated metal pipe sleeves protect the piles from downdrag forces that may be caused by compaction and settlement (Fig. 3). Of course, the sleeves also increase the effective diameter of the piles, which can add to the degree of skewing of reinforcing strips (Fig. 4).

**Skewing Strips**
Skewing strips up to 15° from perpendicular to the panels is consistent with normal design parameters, while skewing in excess of 15° requires situation-specific calculations. Where large-angle skewing is necessary to be able to clear obstructions, reinforcement connection points on the panels may be shifted, or additional reinforcements may be added, to maintain an even distribution of reinforcements throughout the soil mass.

**Crash Wall**
Three of the four abutments — the north abutment on the West Haul Road bridge and both abutments on the East Loop Road bridge — required cast-in-place reinforced concrete crash walls (Fig. 5) due to the rail lines passing under the bridges. A crash wall is intended to deflect a derailed train, much as a Jersey barrier does for errant vehicles on a highway, while also distributing impact forces to minimize the risk of rolling stock damaging the MSE wall face. Crash wall rebar (Fig. 6) is tied to the panels using threaded anchors, tightened into ferrule loops embedded in the panel face approximately every 15 to 18 inches vertically and horizontally.
that form the abutment faces, wingwalls and approach walls. Working through
general contractor Trumbull Energy
Services (Pittsburgh), subcontractor
Mascaro Construction (Pittsburgh)
installed the structures, which consist
of 5-foot by 10-foot precast concrete
panels and galvanized steel reinforcing
strips.

Two wire-faced TerraTrel® MSE walls
were also required at the Shell site. The
original rail line location was just north
of the planned West Haul Road bridge
and directly in the path of that bridge’s
approach embankment. To maintain rail
traffic during bridge construction, Jacobs
called for the north abutment wingwalls
to temporarily terminate about 55 feet
behind the abutment face. One wire
wall provided the needed temporary
support to allow the abutment to be
completed and the bridge deck installed
over the relocated highway and railroad.
Once these relocated facilities were
open to traffic, the remaining 148 feet
of the Reinforced Earth wingwall was
completed, including installation of
a slip joint (Fig. 5) at the junction with
the first-constructed portion of the wall,
permanently burying the wire facing.

The remaining wire wall was constructed
to establish necessary grade separation
for a parking lot for Shell’s craft workers.
Located in a sloped area west of the
main cracker site, this wire wall balances
cuts and fills. It is 34 feet high through
most of its 550-foot mid-section, with
long wing walls folded back roughly 90°
to support worker driveways and the
shuttle bus loop serving several parking
areas.

Reinforced Earth MSE structures played
a key role in the site development for the
Shell ethylene cracker outside Pittsburgh.
Requiring only a graded soil foundation
and a simple, unreinforced concrete
leveling pad under precast facing
panels, MSE structures evenly distribute
applied loads to the foundation soils
and offer contractors a rapid and simple
construction process. For Shell and other
industrial owners, using Reinforced
Earth mechanically stabilized earth
structures is an important component of
economical and timely site development.
A Reduction in Excavation and Backfill for a Tennessee Road Widening Project

The bottom line is safety, and that was especially true for approximately 12 miles of SR 16/US 41A between Shelbyville and Tullahoma, about 80 miles southeast of Nashville. This corridor was studied in the mid-1990s by Tennessee Department of Transportation (TDOT) for possible operating deficiencies. TDOT determined that the projected 60% traffic growth by the mid-2010s would lead to more accidents and lower overall safety on what was, essentially, a 2-lane country highway.

The recommended solution was “… increasing the number of lanes; increasing lane structure and shoulder widths …,” to be accomplished through a series of 4 contracts. The recently completed third contract, for 2.2 miles from SR 276 to Rippy Road, was constructed by Highways, Inc. of Cookeville, TN.

As it heads northwest from Tullahoma, SR 16/US 41A passes through rolling and hilly terrain typical of central Tennessee. In many areas the highway winds along the side of a hill, with the terrain sloping up from the edge of one shoulder and down from the other. Toward the midpoint of the project, Shipman Creek closely parallels 41A, with Shipman Creek Road running between the creek below and 16/41A high above.

Addressing this narrow right-of-way, TDOT’s contract plans called for a contractor-designed retaining wall to support the widened highway above Shipman Creek Road. Special Provision 624, which governed this wall, allowed an MSE wall. The general contractor selected RECo to provide the design. While averaging 35 feet tall, almost two thirds of the wall’s 2,007-foot length is 45 to 50 feet high – a structurally significant wall to be sure.

A typical MSE wall has uniform-length reinforcements from top to bottom and a 70% aspect ratio (aspect ratio = B/H; where B = soil reinforcement length and H = wall height). TDOT’s overall stability analysis resulted in a minimum 80% aspect ratio, accounting for a 3:1 slope rising above the wall and the (TDOT-specified) assumed friction angle of 25° for the retained fill behind the MSE structure. The combination of the 3:1 slope and the 25° retained fill increased the lateral earth pressure on the MSE structure, pushing the aspect ratio to 90% to achieve sliding stability (Fig. 1a).

Long stretches of the wall required a strip length between 40 and 44 feet, which caused two major problems. First, the cost of the quantity of excavation and backfill, and second, the proximity of the excavation to the existing road, which needed to carry traffic during construction. The issue was further exacerbated by TDOT’s requirement for major undercut and replacement to improve bearing capacity and minimize the settlement due to the weight of the wall.

Not surprisingly, even the lowest bid significantly exceeded TDOT’s budget, so the department requested cost-reducing proposals to avoid rebidding. Retaining wall excavation was clearly a major cost item, so Highways, Inc. asked RECo for help in reducing those quantities. The physical and economic results were dramatic.

In preparing his bid, the contractor had elected to use the same granular material (38° friction angle) for both the reinforced backfill and the retained material behind the MSE structure (Fig. 1b). Using the same material (and, therefore, the same design properties) for both the retained and the select fill is allowed by TDOT if...
Foundation undercut and replacement with “graded solid rock”. The required undercut depth varied between 4 feet and 15 feet along the length of the wall. The bottom of the undercut extended a distance of half of the depth both in front of and behind the base width of the MSE wall, with 1:1 side slopes. As explained by Highways, Inc.’s Project Manager, Lance Roach, the excavation width (front to back) required by the undercut pushed farther back into the hillside than did even the excavation to achieve a 1:1 slope behind the as-bid reinforcing strips.

Comparing as-bid (uniform) and as-redesigned (uneven) strip lengths at a typical cross section where the wall is 47.5 feet high, the as-bid bottom strips are 42 feet long while the uneven-design bottom strips are only 23 feet – a 45% reduction. Rising from the base of the wall, uneven strip lengths increase approximately every 10 feet vertically in the following increments: 23 feet, 26 feet, 30 feet, 35 feet, and 41 ft. Always remaining shorter than the as-bid uniform length of 42 feet.

As a result, the 1:1 slope from the back of the strips (to accommodate the 38° granular material in the retained zone) required substantially less cutting and filling than would have been required for the backslope to accommodate the as-bid design. A tremendous cost savings resulted from reducing the strip length by nearly half at the bottom of the wall, and the longer strip lengths rising up the wall easily fit within the 1:1 slope. Wall construction became more economical and faster, and the project was saved from rebidding.

This was Highways, Inc.’s third project with a Reinforced Earth MSE wall. Facing the risk of losing the job to rebidding, The Reinforced Earth Company and the contractor found a solution that saved money, saved time and, literally, saved the project. As Mr. Roach put it, “The wall portion of the project couldn’t have gone better … we would use RECo again in a heartbeat.”

MSE wall section with a 90% aspect (base to height) ratio, and undercut dimensions according to the wall footprint.

The Contractor opted to use select backfill in the retained backfill zone, as long as it extended to the 1:1 line required by TDOT.

The reduction of earth pressure due to using higher shear strength MSE select backfill in the retained zone allowed for trapezoidal (uneven reinforcement length) design, per FHWA. The result was reduced excavation and undercut.
At GeoFrontiers 2017 in March, a panel session was held to discuss the topic of design responsibility and roles on MSE projects. To provide varying perspectives of the industry, the panel members included MSE wall suppliers, an MSE wall builder (Slaton Bros.), a geotechnical engineer (The Collin Group, Ltd.), and a government owner (FHWA). The lengthy Q/A with other members of the industry in attendance provided great discussion. Important outcomes included the acknowledgement of a different dynamic between public and private projects, the need to bring knowledge to other contributing professionals such as architects and land civil engineers, and of course the need for clear lines of responsibility in order to achieve a successful and safe project. Below is The Reinforced Earth Company’s recommendation for the ideal responsibility hierarchy. Feel free to contact us if you would like to join in on the conversation.

**MSE Wall Project Hierarchy**

**Owner**
Sets contract structure and selects PE(s), QA, and Contractor (Hierarchy/Entities may change)

**Contractor**
Builds the walls

**MSE Wall Supplier/Designer**
Internal stability
Preparation of wall drawings and details

**Geotechnical**
Subsurface and seismic definition
External / global stability

**Civil**
Grading
Drainage
Erosion

**Structural**
Integrate walls into other structural elements, e.g. bridges

**Coordinating Professional Engineer(s)**
Quality Assurance Authority
Monitors construction

Collaboration and approvals (communicated through Contractor)

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Visit us at these upcoming summer events:

- **CA Construction Expo**
  - July 20
  - Anaheim, CA

- **SASHTO**
  - August 12
  - Norfolk, VA

- **Western Bridge Engineers**
  - September 6
  - Portland, OR

- **AREMA**
  - September 17
  - Indianapolis, IN

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CONTACT US to discuss making your next project a success

12001 Sunrise Valley Dr., Ste 400
Reston, VA 20191

800-446-5700

ContactUs@reinforcedearth.com

reinforcedearth.com