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Ultra-high hybrid wire and concrete-faced Mechanically Stabilized Earth bridge abutments

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ABSTRACT: Hybrid Reinforced Earth® abutments support a two-span highway bridge crossing a mine haul road in Arizona, USA. Concrete abutments were physically impractical and economically impossible at this 24m height, while a four-span bridge would have required massive, expensive earthmoving. Bridge loads are supported by spread footings bearing on the Reinforced Earth backfill. The superstructure's adjacent 1.4m deep precast box girders have an asphalt wearing surface, making the bridge easy to disassemble when the highway is relocated after the 10 year life of the mine. These unique abutments have a hybrid facing of Reinforced Earth precast concrete panels and TerraTrel® galvanized wire mesh facing, all connected to galvanized steel strip reinforcements. Exposed to impact, the lower 9m has 180mm thick precast facing. The upper 15m, with TerraTrel wire facing, directly supports the abutment footings. This hybrid Reinforced Earth design using TerraTrel solved an otherwise economically unsolvable problem.

1 BACKGROUND

Improvements in mining technology have made recovery of lower-grade ores more economical, resulting in the opening or reopening of sections of many mines. This change in economics required the relocation of a state highway that passes through a major open-pit mine property in Arizona, in the southwestern United States. The nearly 2 km relocation traverses hilly terrain to avoid the new mine pit, requiring the highway to cross a haul road located in a deep ravine. A 24 m high, two-span bridge was required and Reinforced Earth® technology, utilizing a hybrid facing of both precast concrete and wire (Figure 1), was selected for the abutments and wing walls. This selection was based on several factors, including:

- Temporary Structure – The expected economic life of the new mine pit is 10 years, after which the highway will be relocated to its original alignment and the bridge will be torn down.
- Ease of Construction/Dismantling – Reinforced Earth is a modular mechanically stabilized earth (MSE) retaining wall system that uses a low volume of manufactured components and a high volume of (in this case) readily available on-site backfill. Fabricated materials are shipped and erected easily and inexpensively compared to alternatives like cast-in-place concrete. After the anticipated 10-year service life, abutment dismantling will be almost as easy as was the original construction.
- Settlement Tolerance – The bridge site is underlain by mine dump (waste rock previously used as backfill) of varying size, density and depth. Since differential settlement was possible between abutments and pier, or within the individual abutments, the modular nature of Reinforced Earth structures and their ability to deform without failure were significant benefits.
- Economics – Economy is always required, especially for temporary structures. Both the extremely high structural dimensions and the high standards of public safety (as compared to the sometimes lesser requirements for purely industrial-use structures) were economically met by the hybrid Reinforced Earth abutments without compromising either safety or quality. Indeed, no other abutment construction system was seriously considered due to the extreme requirements of this site.

2 GEOTECHNICAL CONDITIONS AND DESIGN

2.1 *Influence of mine dump foundation material*

Borings revealed that granitic bedrock underlay the bridge site at depths varying from 7 m to 26 m. Above the bedrock, almost to the ground surface, was mine dump (generally coarse waste rock) having a relative density ranging from medium to extremely dense. The variations in both density and thickness of the mine dump layer, and the previous

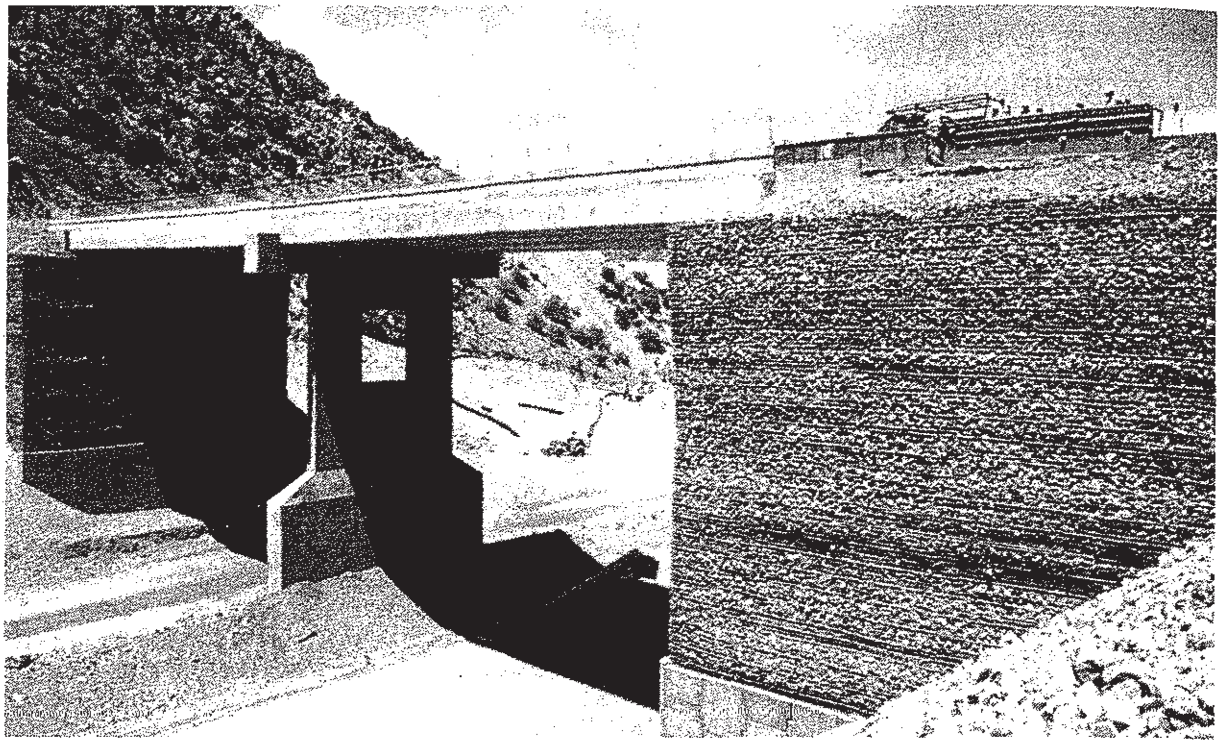

Figure 1. Hybrid Reinforced Earth concrete and wire-faced abutments.

observations of 5-10 cm of subsidence at other locations where the existing road is underlain by the same material, suggested the proposed 24 m high Reinforced Earth abutments (and the reinforced concrete pier) could experience some movement. The geotechnical report emphasized the development of stable and reliable foundation support for the complete bridge structure, including the pier and both abutments, by reducing the effect of mine dump-induced subsidence.

2.2 *Designing to accommodate mine dump*

Due not only to the heavy load to be imposed by the ultra-high Reinforced Earth structures, but also to the anticipated subsidence of the mine dump, the geotechnical engineer required a 6 m thick geogrid-reinforced MSE mat beneath the abutments and pier. The primary purposes of the mat were to:

- Provide uniform bearing for the Reinforced Earth abutments and the pier through removal, then replacement as engineered fill, of some of the dump material,
- Distribute stresses over an area wider than the abutment and pier footprints, reducing contact pressure on the untreated mine dump material below and reducing subsidence,
- Reduce the chance that any subsidence of the deep, untreated dump material would reach the ground surface, and
- Provide damping and resist settlement caused by mining activity-induced vibrations.

Mat design called for excavation of approximately 7.5 m of mine dump followed by placement of 21 layers of biaxial geogrid alternating with 0.3 m thick compacted backfill. The backfill was crushed and/or screened excavated mine dump, processed to a dense-graded granular consistency. The top of the mat was the foundation elevation for the Reinforced Earth abutment walls.

2.3 *Anticipated settlement*

Settlement was estimated based on immediate elastic compression of both the reinforced fill in the MSE mat and the mine dump beneath the mat. Under each bridge abutment, settlement was estimated at 5-9 cm, except in areas with bedrock directly beneath the MSE mat, where expected settlement was on the order of 2 cm. The pier settlement estimate was 1-2.5 cm. Estimated differential settlement between abutments and pier was 1-8 cm. Settlement calculations assumed the elastic compression discussed above and did not estimate either long-term subsidence or settlement of reinforced fill within the Reinforced Earth abutments themselves.

3 STRUCTURE ECONOMICS AND DESIGN

As indicated above, the abutment design had to meet both the rigorous safety requirements of public highway structures and the equally stringent demands for economy in temporary industrial structures. These combined requirements, plus the remote project site, made MSE walls and their prefabricated materials the natural choice. The specific choice of Reinforced Earth was made by the low bidder, from among three alternates acceptable to the Arizona Department of Transportation (DOT), in a design-build contract awarded and paid for by the mine owner. The structure and roadway design met state design and construction standards.

3.1 *Temporary-structure economics vs. traditional design requirements*

The initial design concept for the Reinforced Earth abutments used traditional precast concrete facing. When questioning by the owner revealed a $200,000 saving by using the Terratrel wire facing instead, state approval of this approach was sought. The temporary nature of the bridge and its remote location, with no public access to the abutment faces themselves (the haul road under the bridge is private mine property, minimizing risk of accidental damage or vandalism from the public), justified using the wire facing. The owner realized there was still a risk to the physical integrity of the abutment facings, however, from mine truck traffic under the bridge, meaning the full 24 m height could not be wire facing.

The haul road vehicle mix would include heavy trucks carrying ore and spoil from the mining pit, with the attendant risk of large boulders being thrown against the wall face. Such impact or abrasion could damage the wire facing, forcing the owner to reconsider using precast panels for the lower portion of the walls. It was decided the precast would rise to an elevation 7.5 m above the proposed haul road surface (9 m above foundation elevation), with the remaining 15 m height to be constructed of wire facing. Acceptance of this revised plan by the Arizona DOT resulted in the world's first hybrid Reinforced Earth facing system.

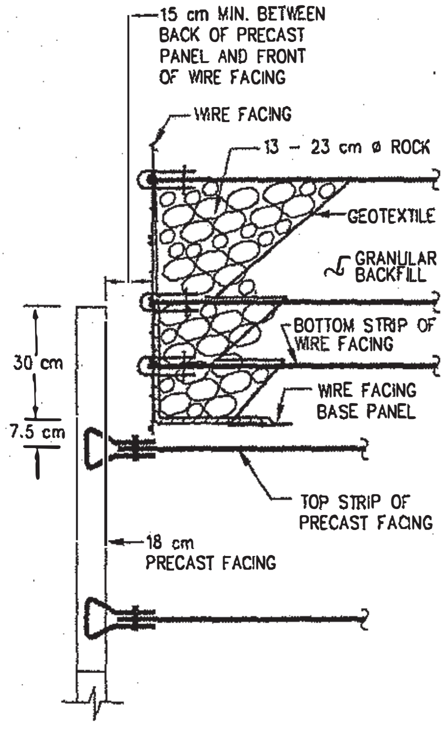

Figure 2. Embedment of wire facing and clearance between precast panel and wire facings

3.2 *Design changes due to hybrid facing*

The decision to use a hybrid facing forced two design changes, even as it provided a net economic benefit. The two changes together lengthened the bridge by 60 cm, using up a small portion of the savings from changing to the hybrid system. The first change was to embed the wire facing 30 cm below the top of the concrete panels to protect the bottom of the wire wall from erosion.

To create this embedment, the wire facing was positioned 15 cm behind the back of the concrete facing and 30 cm below the concrete panel's top, putting the wire only 7.5 cm above the topmost reinforcing strip of the concrete panel (Figure 2).

Along the wingwalls, where the finished grade on the wall face grade climbed above the top of the and avoid loss of backfill at the transition (Figure 3). The extra 15 cm setback (per abutment) of the wire faces relative to the precast faces lengthened the bridge by 30 cm.

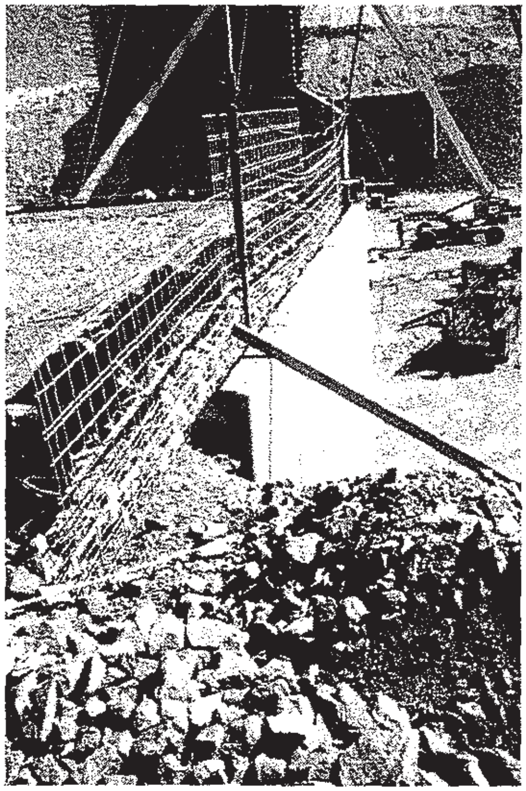

Figure 3. Transition from precast concrete to wire facing. Note finish grading to be required to protect bottom of wire facing.

The second change occurred at the bridge footings on top of the Reinforced Earth walls. To limit bearing pressure forces transmitted into the precast panels, normal clearance between the front of the footing and the back of the panels is at least 15 cm. Because of the flexibility of the wire facing system used on this project, however, a 30 cm bridge footing setback was required at each abutment (Figure 4), adding another 30 cm to the bridge length.

3.3 *Reinforced Earth abutment design*

The bridge design conformed to the requirements of AASHTO (American Association of State Highway and Transportation Officials) and the Arizona DOT. Accordingly, the bridge live load for design was 96.2 kN/m (2-lane roadway, AASHTO HS 20-44 loading with no reduction allowed). The bearing pressure under the bridge seat was 163.7 kPa, well below the allowable of 191.5 kPa. Based on the subsurface conditions and the depth to bedrock, seismic design used an Arizona- and AASHTO-recommended horizontal acceleration of 0.05g.

Since all construction would be done with crushed rock from mining operations, backfill properties were very favorable for Reinforced Earth design. Whereas the normal assumed angles of internal friction for select backfill, random backfill and foundation soil are, respectively, 34°, 30° and 30°, the design benefited substantially because all three angles of internal friction were 36°.

The North abutment was 4.5 m higher than the south abutment and had a maximum bearing pressure at its foundation of 765.5 kPa. As originally designed, the maximum horizontal stress within the reinforced soil at the bottom of the north abutment was 191.5 kPa, requiring 14 reinforcing strips per panel. Each strip carried a tensile force of 30.3 kN, as close as possible to the strip's allowable tension of 32 kN. Strip length was 18.3 m. (By comparison, south abutment loads were slightly lower, with a bearing pressure of 727.7 kPa, resulting in a bottom-layer strip density of 13 per panel and a strip length of 17.1 m.)

North abutment design had to be revised when excavation for the MSE mat revealed bedrock in the lower 5.5 m of the wall was much closer to the wall face than had been anticipated. This condition would have required substantial blasting and removal of rock to make room for the 18.3 m long reinforcing strips, unless that length could be reduced. A review of the calculations showed that the lower 8 layers of strips could be shortened to 13.1 m without affecting the internal safety factors of the wall, although this increased the applied bearing pressure almost 23% (from 765.5 kPa to 940.7 kPa). The changes in reinforcing strip length and bearing pressure were reviewed and approved by the geotechnical engineer.

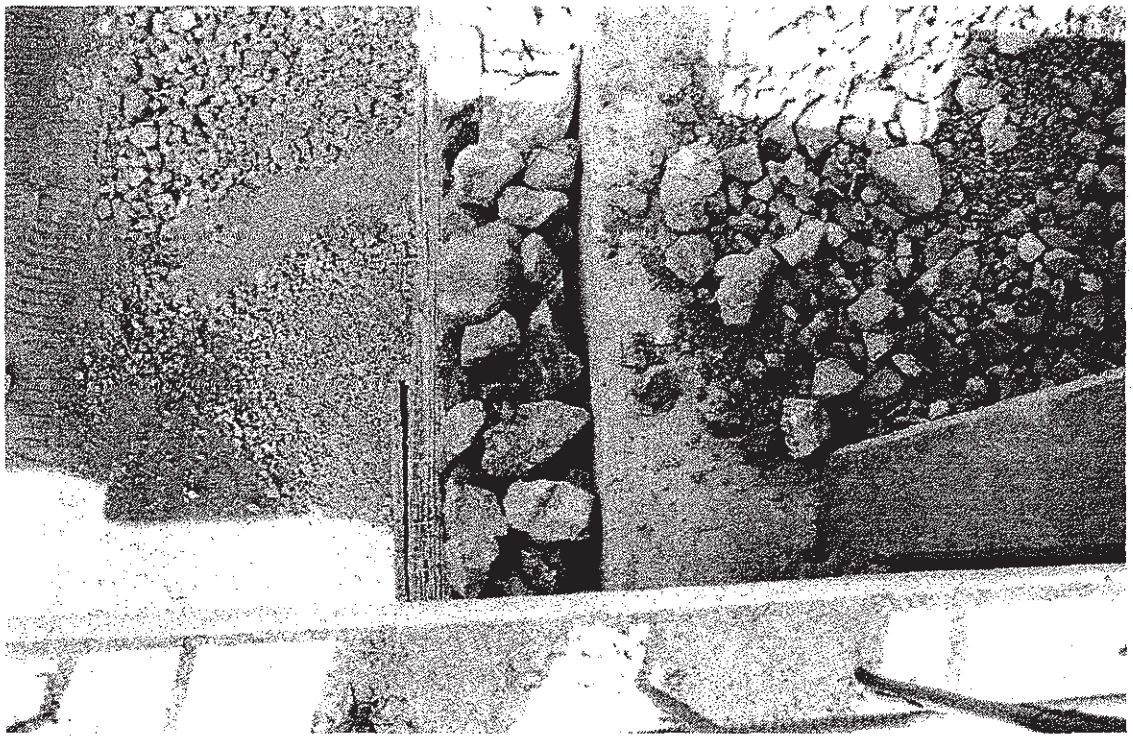

Figure 4. Looking down on front of bridge seat. Note clearance behind wire facing, top of precast panel walls below. Bridge deck is in foreground.

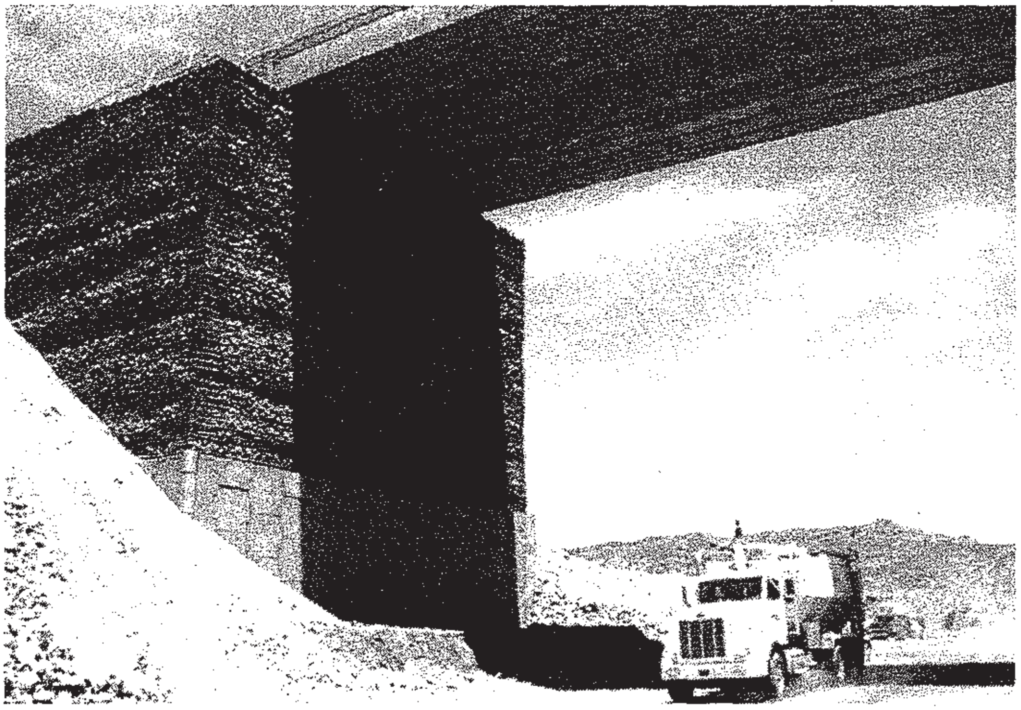

Figure 5. Completed hybrid Reinforced Earth abutment.

4 CONSTRUCTION

Manufactured materials were delivered to the project site in late December 1999, and the abutment walls were substantially complete by April 2000. The precast panel facings were installed on a customary 15 x 30 cm unreinforced concrete leveling pad, with the Terratrel wire facings founded on the backfill of the concrete panel walls. When wall construction began, the superstructure box girders were already in fabrication, making wall alignment and plumbness critical to insure proper girder fit. The plumbness issue dominated field quality control during the whole wall erection phase of the project.

Each Terratrel wire facing panel sits immediately behind the wire facing panel below, so the thickness of the panel itself automatically creates a nearly 1.5 % batter in the wall unless measures are taken to compensate. For a pair of 15 m high wire walls, 1.5 % batter of both walls potentially puts the tops of the two abutment faces almost 0.5 m farther apart than intended. Indeed, field checks revealed this was happening, forcing crews to outward-batter the walls to preserve clearance behind the facings for the concrete bridge seats.

Clearance between the front of the bridge seat and the back of the wire facing (Figure 4) was so important it was also decided to modify the bridge seat design slightly. The centerline of bearing was fixed due to girder fabrication, so the footing was both widened (extending it farther back from the wall face) and thickened. This change ensured contact pressure remained below 191.5 kPa, that stresses were distributed into the reinforced soil at a safe distance behind the wall, and that local overstress of the facing was avoided.

5 CONCLUSION

Ultra-high hybrid Reinforced Earth abutments (Figure 5) were the clear economic choice for relocating a highway across a mine haul road in a deep ravine. Adverse foundation conditions were overcome by removal of certain subsurface material and replacement with an MSE mat. Structure cost was reduced by using Reinforced Earth precast concrete facing for the lower 9 m and Terratrel wire facing for the upper 15 m of these 24 m high structures. The change in facing type resulted in lessons learned regarding offset distances and plumbness with regard to the eventual setting of bridge girders. Post-construction performance, including settlement, has been as expected. After mine economic life ends, demolition will be simplified by the modular nature of these unique Reinforced Earth abutments.

6 ACKNOWLEDGEMENT

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