Contracting for Mechanically Stabilized Backfill Walls

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The key differences in the mechanically stabilized backfill (MSB) walls available in the U.S. market are discussed, particularly with respect to their impact on the walls' stability and long-term performance. These differences are mainly in the soil-reinforcement interaction, the strength and stiffness of the reinforcement, the bond between soil and reinforcement, and the durability of the system. Other factors that make a difference include the strain compatibility between soil and reinforcement, the deformation characteristics of the backfill, and the aesthetic and environmental impacts of the facing. Contracting procedures for MSB wall projects are discussed, and lessons learned from case applications are highlighted with particular reference to contracting methods and economical benefits. A preferred method that would ensure low cost, speedy process, and minimum confrontation between the design engineer and the vendor is recommended.

Mechanically stabilized backfill (MSB) walls and embankments have many advantages over conventional systems. Low cost, simple and rapid construction, no required formwork, construction at low temperatures, aesthetically pleasing facings, flexibility, and tolerance to vertical and horizontal movements make the use of these systems attractive. In recent years, construction of MSB walls and embankments has resulted in substantial savings in cost and right-of-way and marked reductions in environmental impacts, such as when used for embankments adjacent to or crossing wetlands.

The MSB walls come in a wide variety of looks, shapes, sizes, and materials, each promoted by a specialty contractor, a product manufacturer, or a combination of both. Although their basic principle is the same, distinct differences in these systems are serious enough to affect their performance if they are not attended to. These differences also make contracting for such systems a difficult, sometimes frustrating task facing the wall owners and their engineering representatives.

The purpose of this paper is to discuss contracting for MSB walls in the United States. Different procurement procedures will be discussed and lessons learned from several case applications will be presented. The differences in the available wall systems that fall under the MSB category will be discussed and guidelines will be established for use by the design engineer in approving or rejecting a particular wall system proposed by the contractor.

MSB WALLS—AN OVERVIEW

MSB walls are mechanically stabilized earth walls that involve the use of backfill. They are formed basically by the inclusion of reinforcing elements within a compacted backfill behind a vertical or near-vertical wall face. The backfill soil and the reinforcing elements act in unity to form a composite structure that resists the applied loads.

The development of these walls began when Henry Vidal introduced and patented the system of terre armee (reinforced earth) in 1966. The first application of the system was a highway project in Nice, France. Its first U.S. application was a 55-ft-high wall in the San Gabriel Mountains of Southern California. Since then, numerous types of walls have been developed and successfully applied in construction of highways, bridges, railroads, dams, seawalls, and other structures. Table 1 lists most of the MSB walls used in the United States.

An MSB wall has three main components: reinforcing inclusions, backfill, and facing. Different materials (metals, polymers, geotextiles) and shapes (strips, grids, sheets, rods, fibers) have been used for reinforcement. The backfill material usually consists of cohesionless free-draining soil, but other soils have been used with some systems. At the edge of the reinforced backfill, a facing is provided to retain the soil at the face and protect the exposed reinforcing elements from weathering effects. The facings currently used include precast concrete elements, metal sheets and plates, welded wire mesh, concrete blocks, timber, rubber tires, shotcrete, and others.

Construction of MSB walls involves placement of alternating layers of compacted backfill and reinforcement, with each reinforcing element connected to a facing unit or wrapped around the backfill layer at the face. Drains are installed, if needed, and the exposed reinforcement is protected from weathering effects. Before placement of the first backfill layer, the site is prepared and unsuitable soils are removed. Although the general construction approach is the same, certain construction details may differ from one system to another as a result of differences in the reinforcing elements, the wall facings, the labor and equipment requirements, and the experiences of the specialty contractors.

The design of an MSB wall involves determining external and internal stability. For external stability, the backfill and reinforcing elements are considered a coherent body subjected to loads from the in situ soil behind it and any surface loads from traffic, adjacent structures, and so forth. The reinforced-soil block is then analyzed against sliding, overturning, bearing capacity failure, and deep-seated shear failure. The internal stability of the system involves analyzing the tension in the reinforcement, the pullout resistance in the soil-reinforcement interface, and the durability of the reinforcing elements against long-term weathering effects. In seismically active areas, the seismic capacity of the reinforced-soil system is analyzed. The design of MSB walls has been documented in a number of comprehensive references (*1–3*). Recommended safety factors against internal and external stability considerations are summarized elsewhere (*4*).

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TABLE 1 MSB Walls Used in the United States

Wall System	Reinforcement	Facing
Reinforced Earth	Steel Strips	Concrete Panels
VSL Retained Earth	Steel Grid	Concrete Panels
Websol Reinforced Soil System	Plastic Strips	T-Shaped Concrete Panels
Welded Wire Wall	Welded Wire Mesh	Wrapped Around Wire Mesh
Reinforced Soil Embankment	Welded Wire Grid	Conrcete Panels
Eureka Reinforced Soil	Welded Wire Mesh	Cast-in-Place Concrete
Hilfiker Stabilized Embankment	Welded Wire Mesh	Large Smooth Concrete Panels
Tensar Geogrid System	Geosnythetic Grid	Wrapped Grid, Shotcrete, Blocks
Matrix Geogrid Wall	Geogrid Mats	Wire Mesh and Geotextile
USFS Geotextile Wall	Geotextile Sheet	Wrapped Sheets, Shotcrete
CTI Wall	Geosynthetic Grid	Timber
Modular Block Geotextile Wall	Geotextile Sheets	Stacked Concrete Blocks
Mechanically Stabilized Embankment	Steel Bar Mats	Precast Concrete Units
Georgia Stabilized Embankment	Steel Bar Mats	Concrete Panels
Miragrid System	Geosynthetic Grid	Precast Concrete Units
Geocell Wall	Geosynthetic Grid	Cellular Confinement System
Pyramid Modular Block System	Steel Strips, Geostraps	Concrete Blocks
Maccaferri Terramesh System	Steel Wire Mesh Sheets	Rock Filled Wire Baskets
Anchored Earth Wall	Steel Rods	Concrete Panels
Tire-Faced Wall	Geotextile Sheets	Stacked Tires

KEY DIFFERENCES IN MSB WALLS

Although all MSB walls follow the same basic principle and design philosophy, there are distinct differences among the available systems, because of the use of different types and configurations of reinforcing elements, types and geometries of wall facings, and composition and grading of backfill materials. These differences should be carefully evaluated when attempting to substitute one wall system for another.

The key differences in the MSB walls are in the soil-reinforcement interaction and the fundamental aspects of the design, namely the strength and stiffness of the reinforcement, the bond between soil and reinforcement, and the durability and long-term performance of the system. In addition to its impact on the design, changing the wall system may affect other aspects of the project, such as rate of construction, aesthetics, and environmental impact. Following is a brief discussion of the key differences in MSB walls on the market. The differences are mainly the result of changes in the three major components of the reinforced-soil system: the reinforcement, the backfill, and the facing.

Soil-Reinforcement Interaction

The stress transfer between the soil and the reinforcement takes place through one or both of the following interactions: (a) friction along the soil-reinforcement interface and (b) passive soil resistance along the transverse members of the reinforcement.

The relative contribution of each factor depends on the size and configuration of the reinforcement, the soil properties, and the stress-strain characteristics of the system. For strip or sheet reinforcement (reinforced earth, Websol, USFS, CTI, etc.), the interaction between the soil and the reinforcing elements is mainly through friction along the soil-reinforcement interface. In grid-reinforcing systems (Tensar, Welded Wire, VSL, RSE, MSE, GASE, etc.), the pullout resistance is provided by friction and passive soil resistance.

The reinforcing elements are either extensible or inextensible. In inextensible systems (metal or polymer), the strains required to mobilize the full strength of the reinforcing elements are smaller than those needed to mobilize the full strength of the backfill. For extensible materials (geotextile), the required strains are much larger. Therefore, relatively large internal deformations usually occur in these walls. In these cases, the soil's strength properties should be measured at large strains (residual strength). Based on the results of pullout tests, displacements as small as 1.3 mm (0.5 in.) for mobilization of the friction along the reinforcing elements and as large as 100 mm (4 in.) for complete mobilization of the passive soil resistance along the transverse members of the reinforcement are reported (*5*). Strain compatibility between the soil and the reinforcement is an important factor to be evaluated when comparing two wall systems.

Strength and Stiffness of Reinforcing Elements

The tensile strength of the reinforcement is influenced by its size, shape, arrangement, material characteristics, and a number of external factors, such as temperature, durability, and construction damage. These factors often differ from one system to another.

Where steel is used, the allowable tensile stress is equal to 0.55 F_y (yield stress of steel) for strip reinforcement and 0.48 F_y for grid reinforcement with longitudinal and transverse grid members being of the same size.

In geosynthetic reinforcement, the tensile strength depends on the tensile properties of the load-carrying elements (fibers) and the geometrical arrangement of these elements within the geosynthetic matrix. The tensile characteristics of various load-carrying elements used in geosynthetic materials are illustrated in a work by Lawson (*6*). With the exception of polyaramid fibers, which exhibit characteristics similar to steel, the stress-strain behaviors of the geosynthetic materials are characterized by lower maximum strengths and higher maximum extensions than those exhibited by steel.

The allowable tension capacity of the geosynthetic reinforcement is influenced by three major factors representing creep, durability, and construction damage. Creep is the increase in extension of a material under a constant applied load that occurs when the material's behavior has reached the plastic state. Because the ambient temperatures of most polymeric-based materials coincide with or are close to their viscoelastic phase, creep becomes a significant factor in assessing their long-term load-carrying capacity. Creep, on the other hand, is not a significant factor when steel reinforcement is used.

Creep reduction factors (defined as the creep limit strength, obtained from creep test results, divided by the ultimate tensile strength) of 0.2 to 0.4 for different types of geotextile are reported (*3*). At high temperatures, significant creep is experienced by reinforcements made of polyethylene or polypropylene. On the other hand, little change occurs in the load-carrying characteristics of polyestic reinforcement due to temperature.

Placement and compaction of the backfill material against the geosynthetic may reduce its tensile strength. Variations in the installation damage factor of different geosynthetic reinforcements are illustrated elsewhere (*6*). These variations should be taken into account when an MSB wall with one type of geosynthetic reinforcement is substituted for another.

Bond Between Soil and Reinforcement

Tensile stresses in the reinforcing elements are transferred to the surrounding soil by forming a bond between the soil and the reinforcement. This bond is formed through friction, passive soil resistance, or a combination of both.

The frictional bond is developed along both sides of the section of the reinforcing element in the resisting zone behind the failure plane. To maintain equilibrium, the frictional bond must resist the maximum tensile load carried by the reinforcing element (pullout resistance).

The apparent coefficient of friction between the soil and the reinforcement is a function of the composition and gradation of the backfill material and the shape and material properties of the reinforcing elements. For instance, the apparent coefficient of friction of ribbed steel strips is twice that of flat tape geotextiles.

Durability and Long-Term Performance

The service life of an MSB wall depends to a great extent on the durability of the reinforcements and to a lesser extent on that of the facing elements. The durability of metallic reinforcements is usually measured by their resistance to corrosion. That of geosynthetics is assessed by the resistance to (a) ultraviolet light exposure, (b) hydrolysis in polyester, and (c) oxidation in polyethylene and polypropylene. These durability factors should be carefully evaluated when comparing two types of MSB walls.

The use of an MSB wall with metallic reinforcements in place of one reinforced with geosynthetics should be carefully evaluated in the presence of highly corrosive environments, such as stray DC currents adjacent to railroad tracks or deicing salts in areas with frequent snowfalls.

The durability of geosynthetic reinforcements is more complicated than that of metallic ones. Geosynthetics are generally made of synthetic polymers manufactured by different processes. Four synthetic polymers are usually used in production: polyamide, polyester, polyethylene, and polypropylene. Although all are subject to degradation by exposure to ultraviolet light, their reactions to other durability effects differ from one to another. For instance, although polyester is susceptible to hydrolysis and loss of strength when in contact with water, the other three materials are not affected. On the other hand, thermal oxidation in the presence of heat and oxygen, which tends to cause a breakdown and cross linking of the molecular chain, is mostly felt by polyethylene and polypropylene.

Other Factors That Make a Difference

The performance of an MSB wall is also influenced by certain factors that may be characteristic of a particular system; thus, the wall may be negatively influenced if another system is used. For instance, although most walls use granular backfill, some promote the use of on site materials. Because the granular soils are well drained, the effective normal stress transfer between the reinforcement and the backfill soil would be immediate as each lift of backfill is placed. For the design loads normally associated with MSB walls, the granular soils behave as elastic materials; thus, no post-construction movements are anticipated. If fine-grained soils are used, their poor drainage characteristics may produce high pore water pressures, which delay the transfer of stresses from the soil to the reinforcing elements, thus producing greater loads against the facing and more deformations during construction. This may require a slower construction schedule or result in a lower safety factor during construction.

The reduced dilatancy and internal drainage of the fine-grained soil also affect the long-term stability and deformations of the system. Outward movements of the wall may be experienced from consolidation of the backfill. Long-term seepage forces and freeze-thaw softening effects may also be experienced if a poorly drained, fine-grained soil is used for backfill.

The facings used have different impacts on the performance of the MSB walls. When discrete elements such as concrete panels are used, they provide flexibility to tolerate differential movements without structural distress. Walls with metal facing elements (metal plates or grids), on the other hand, have the disadvantage of a shorter life because of the potential for corrosion of the metal. When metal wires are used (welded wire or gabions), they also have the disadvantages of an uneven surface, exposed backfill, and susceptibility to vandalism. However, they provide good drainage, flexibility, and ability to vegetate the facing.

Aesthetics and environmental impacts are important factors to consider when substituting wall types. Certain facings (metal plates or grids), for instance, may be more economical but not as attractive as the ones originally selected. To reduce traffic noise in environmentally sensitive areas, walls with open and vegetated facings (gabions, welded wire, etc.) are acoustically superior to those using concrete facings. The open nature of the wall face and the foliage covering in some are effective in absorbing the noise hitting them, compared with other walls where the traffic noise is reflected on hard or smooth continuous surfaces.

CONTRACTING FOR MSB WALLS

The earth-retaining structure is usually a part of a large civil engineering project. In most countries around the world, the contracts for MSB walls are awarded on a design-build basis. The terms of reference specify the requirements of the final product using performance-type specifications; it is left to the contractor to select a wall system, design it, detail it, and, ultimately, build it. In the United States, however, the present contracting policies and procedures for civil engineering projects require the engineer to select and design the structure and to prepare detailed plans and specifications to be followed closely by the contractor in the field. The construction manager and the field inspectors make sure this is done. Technical, practical, economical, and political factors affect the wall selection. These factors are discussed elsewhere and a selection process is recommended (*7*).

Because of the many systems available on the market and in the interest of economy, alternative designs are usually performed for each project. These designs have been made in one of three ways:

- As a design task performed by the design engineer,
- As the result of a value engineering study performed during design or construction, or
- As an alternative design proposed by the contractor.

Because of the specialized nature of the MSB walls, the vendors are often asked to perform the internal design of the system and the design engineer addresses external stability. The design engineer then prepares a set of construction plans and specifications for bidding purposes. Because procurement of proprietary items is usually not allowed on public-sector projects, the bidding documents usually specify a particular system or "proven equal." The general contractor then shops around for the cheapest MSB wall on the market and proposes it as the "equal." As shown in this paper, however, key differences exist among the many systems that can be categorized as MSB walls. These differences would affect the wall's performance and may even result in failure if they were not attended to. The task of the design engineer then would be to ensure that a proposed alternative is a true equal and to recommend the modifications that should be made to make it so. The recommended changes can be in either the design procedures and parameters or the materials used and construction details.

Another method of procurement that has proven beneficial is one in which the engineer designs more than one system and prepares plans and specifications for alternative designs. The contractor is then asked to bid on one or more of the designed alternatives. In this way, the alternative designs will not be questionable and the procurement process will allow fair and equitable competition among qualified specially contractors.

CASE STUDIES

Following are brief case studies documenting contracting procedures used in procurement of MSB wall projects.

Case 1—North Halawa Valley Access Road, Hawaii

To construct the H-3 Highway tunnel through the Koolau Mountain Ridge of the island of Oahu, access roads with extensive retaining walls were needed on both sides of the mountain. Because the retaining walls were to be constructed in mountainous terrain with difficult accessibility, alternatives requiring heavy machinery were ruled out, and the wall selection concentrated on the three most promising alternatives—a reinforced earth wall, a gabion wall, and a geotextile wall. To minimize construction cost, all three alternatives were designed and the prospective bidders were asked but not required to bid on all three. All walls were required to have a service life of 10 years and to be resistant to the moderately to highly acidic in situ soils.

Figure 1 illustrates typical cross sections of the alternatives. Design of the walls has been discussed elsewhere (*8*). The average bidding price for the geotextile wall was approximately 32 percent less than that for the reinforced earth wall and 42 percent less than that for the gabion wall. The contract was awarded in 1987 for construction of geotextile walls at a bid price of $175/m^2 ($16.10/ft^2). Because all alternatives were designed ahead of time and detailed in the bidding documents, there were no controversial issues and construction proceeded smoothly and expeditiously.

Case 2—Baltimore Central Light Rail Line, Maryland

The Baltimore Central Light Rail Line is a 43-km-long (27-mi) transit facility linking Baltimore County, Baltimore City, and Ann Arundel County in Maryland. At least nine different retaining wall types have been constructed on this project. The bid documents for each segment included alternative retaining wall types to obtain the lowest cost. In addition, two wall types, a tensar wall and a techwall, were proposed and designed by the contractors as cost-cutting alternatives.

The wall alternatives designed and detailed in the bidding documents included MSB walls, gravity-type walls, cast-in-place concrete walls, and others. The MSB walls included reinforced earth and VSL retained earth. For each MSB wall shown, a conventional alternative was included. In each case, however, the MSB alternative received the lowest bid. Reinforced earth walls were selected in three contracts for low bids of $675 to $795/m^2 ($62 to $73/ft^2). VSL retained earth walls received the low bids of $468 to $479/m^2 ($43 to $44/ft^2) in a fourth contract. The bid price for the tensar wall is not available because it was included in the lump-sum bid of a total construction package.

The internal stability calculations of the MSB systems were performed by the vendors and submitted as shop drawings; review and approval of these submittals went smoothly because they were performed according to criteria established in the contract documents. The tensar wall, however, was proposed by the contractor. Because there were no design criteria in the contract documents for this type of wall, a lengthy review process occurred and several discussions took place between the designer and the vendor regarding design issues, factors of safety, and construction details. The proposed design was finally approved after all the designer's requirements were met. Figure 2 shows construction of a tensar wall with a full-height panel facing.

Case 3—Bronx Parking Facility, New York

High retaining walls were needed to construct a car parking lot adjacent to a school in the Bronx, New York. Several alternatives were analyzed in the design stage and a reinforced earth wall was selected and included in the bidding documents. Because proprietary items were not permitted on that project, the contract specifications allowed substitution of the designed MSB wall with a proven equal. The general contractor proposed a wall alternative using geosynthetics for reinforcement and modular blocks for facing. The con-

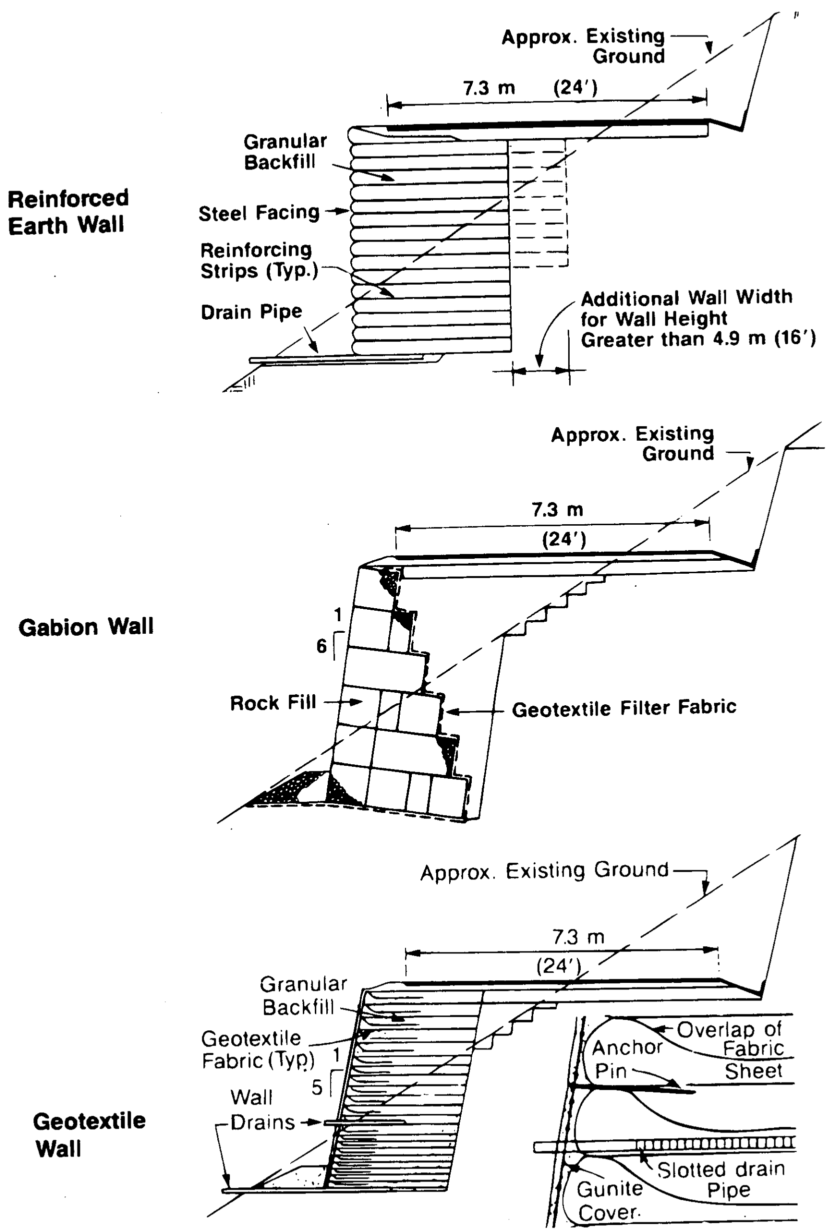

FIGURE 1 Cross sections of wall alternatives.

tractor also proposed on site material for backfill in place of the granular backfill originally specified for the project.

A lengthy review process, including material testing, took place and a number of modifications for the contractor's scheme had to be done before the proposed alternative was accepted (Figure 3). The facts learned from the analyses performed during this evaluation are (a) the backfill should be granular and free draining, (b) uniform compaction is a must, (c) the foundation of the wall facing should be below the frost line and flexible enough to accommodate initial movements, (d) the facing units should have adequate compressive strength and the wall facing should be flexible enough to tolerate vertical and horizontal movements, (e) free drainage immediately behind the wall facing is a must, and (f) the methods of analysis and the safety factors used by the vendors in their designs should be carefully evaluated.

Case 4—Amman–Naur–Dead Sea Highway, Jordan

To cross a landslide area along the Amman–Naur–Dead Sea Highway in Jordan, split-level carriageways were constructed behind retaining walls. Two retaining wall alternatives were considered: a cast-in-place concrete wall and an MSB wall. Because no MSB walls had been built in Jordan before that time and after evaluating previous experiences of the various systems considered, the reinforced earth (RECO) wall was selected by the Jordanian Ministry of Public Works for inclusion in the bidding documents, with no mention of any equal.

After winning the project, however, the general contractor shopped around and proposed an alternative scheme developed by the Hilfiker Corporation, as a modification of their reinforced soil embankment system, to resemble the reinforced earth features

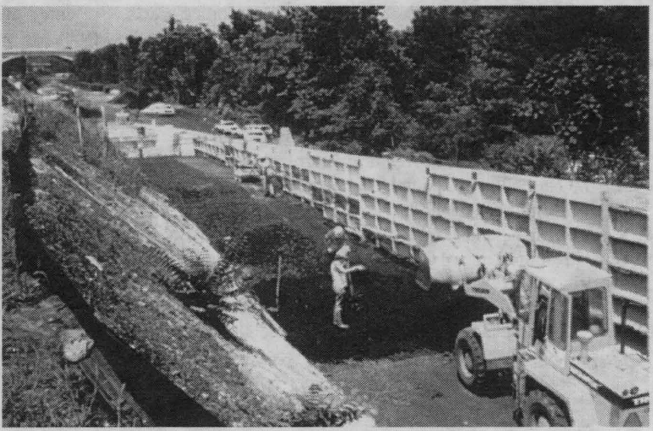

FIGURE 2 Construction of a full-height-panel tensar wall.

FIGURE 3 Geogrid reinforced wall with modular block facing.

included in the bidding documents. No reduction in the bidding price was offered for the proposed alternative.

The internal stability calculations submitted by the contractor showed adequate safety factors. The Ministry, however, refused to substitute wire mesh for the steel strips of the original RECO design. The contractor then proposed to use steel strips with wire ribs welded to the strip surface to resemble the conventional ribbed strips used in the reinforced earth system. Extensive pullout tests were performed at Utah State University on both conventional RECO ribbed strips and the new proposed strips. Both strips were embedded in a silty coarse sand backfill material and tested under overburden pressures corresponding to approximately 6 m (20 ft), 12 m (40 ft), and 18 m (60 ft) of fill. The soil was compacted to 95 percent of maximum density as per AASHTO T-99 Method C and allowed to reach equilibrium under the vertical load for at least 30 min before testing. The pullout resistance of the welded strips was approximately 15 percent higher than that of the conventional RECO strips; the welded ribs were not damaged or sheared off during testing.

Based on the testing results supplied, substitution was allowed, and the alternative scheme was constructed (Figure 4).

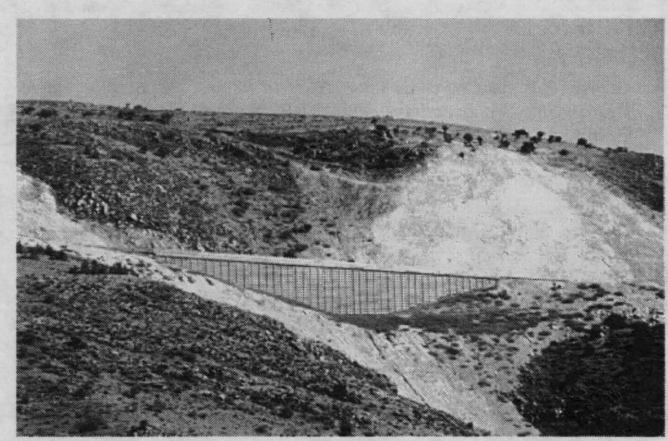

FIGURE 4 MSB wall along the Amman–Naur–Dead Sea highway.

CONCLUSION AND RECOMMENDATIONS

Although the basic principle of the MSB walls is the same, there are key differences among the various systems that affect their stability and long-term performance. These differences are mainly in the soil-reinforcement interaction, the strength and stiffness of the reinforcement, the bond between soil and reinforcement, and the durability of the system. Other factors that make a difference include the strain compatibility between soil and reinforcement, the deformation characteristics of the backfill material, and the aesthetic and environmental impacts of the wall facing. These differences should be carefully evaluated when comparing two MSB systems.

Because of the influx of the MSB systems into the U.S. market and the serious differences among the many systems, the wall design should not be left freely in the hands of the contractor. Selecting the best system or proving an equal is, therefore, a difficult task facing the design engineer who must be familiar with the differences among the various systems and their impacts on the wall's performance. A preferred method that would ensure low cost, speedy process, and minimum confrontation would be to design a number of alternatives and include them in the bidding documents. The contractor is then asked to bid on one or more of the already-designed alternatives. In this way, the alternative designs will not be questionable and the procurement process will allow fair and equitable competition.

In all the case studies presented, regardless of the contracting procedures used, the MSB walls finally constructed were more economical than the other retaining walls included in the bidding documents.

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