Mechanically Stabilized Earth with Discrete Concrete Facing Panels

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Mechanically stabilized earth (M.S.E.) has been used extensively in lieu of traditional cast-in-place reinforced concrete retaining walls since the inventor of Reinforced Earth,™ French architect/engineer, Mr. Henri Vidal, first published the results of his extensive studies in 1963. Based on Vidal's work, M.S.E. is a standard construction technology used in transportation, commercial, industrial and military applications.

United States highway projects in mountain and urban areas routinely utilize M.S.E. for bridge abutments and retaining walls. Also, designers of sea walls, dams, and bulk storage facilities utilize this technology based on the proven economics, dependability, and the ability to shorten the construction process.

Henri Vidal, awarded the prestigious American Society of Civil Engineers (A.S.C.E.) Martin S. Kapp foundation award in 1978 for his invention of the Reinforced Earth™ technology, saw competition and maintaining high engineering performance standards as equally vital to the extensive use of this technology. Vidal licensed five firms or organizations in the U.S. to market and produce discrete precast concrete panel M.S.E. systems using metallic earth reinforcement. The first and the largest licensee of Vidal is the Reinforced Earth Company, with service offices located in thirteen cities in the U.S.

Analogous to reinforced concrete, M.S.E. improves the engineering properties of select granular backfill. Specifically, the predictable and well understood shear and compressive strengths of granular, cohesionless soil are improved through the introduction of a strong tensile strength material: steel.

An M.S.E. structure is a single, coherent gravity mass engineered for site-specific geometry, loading, and construction staging requirements. Under the gravity load of the M.S.E. volume and all external loads, the stresses produced in the M.S.E. volume are transferred to the steel reinforcements by friction. The volume is then faced with discrete precast concrete elements for architectural appearance and to contain potential spillage of granular material between the levels of steel reinforcements.

More important than the technology and performance advantages, the primary reason for the acceptance of M.S.E. is the inherent economy. The reliability, low material costs, and rapid, predictable construction pace are the basis for the current extensive usage. Savings over conventional cast-in-place retaining walls are suggested to be 20 percent to 50 percent.

As M.S.E. technologies generally are proprietary in nature, different in engineering concepts, different in behavior, and are not universally adaptable to all applications, nor necessarily interchangeable with one another, the specific details presented in the balance of this paper shall deal mainly with one M.S.E. system, Reinforced Earth™ (R.E.).

Bid plans for R.E. take the form of one of two presentation formats: complete plans and technical specification, or a three-line drawing and performance specification.

The complete plan format is, as the name implies, a complete set of detailed and biddable drawings issued by the design professional. The plans contain all details, dimensions, panel sizes, locations, line and grade, and other information required by the contractor to bid and build the noted structures. The complete design is prepared and detailed by the selected M.S.E. supplier or suppliers who are pre-approved to bid the project in conformance with stringent performance specifications.

For the complete plan format, the design is based on site-specific information such as geometry, line and grade, and much general information must be finalized or must be updated before the M.S.E. system is designed or bidding changes are made by the design professional. The compatibility of the M.S.E. structure with other structures, specific finish details, and site grading and drainings must be verified before bid documents are issued.

Due to the proprietary nature of M.S.E. technologies, the design in either format is generally prepared by the selected M.S.E. supplier or manufacturer. The firm professionally seals the plans where required and takes the complete design responsibility for the internal stability of the structure.

For the three-line drawing format, the design professional prepares only a schematic design which notes the top of the wall elevation, the bottom of the wall elevation, finished grade elevation, horizontal geometry, and starting and ending stations of the wall.

The M.S.E. supplier must prepare the design in accordance with a very detailed performance specification which includes design procedures, factors of safety, and other performance criteria. The M.S.E. supplier must prepare the design and detailed bid quantity drawings and distribute these drawings, with a priced proposal, to interested contractors between the advertisement date and the bid date for evaluation and bidding in accordance with document instructions.

With either plan format, the design professional may prepare bid documents whereby both the M.S.E. design and the more traditional, cast-in-place reinforced concrete retaining wall design appear on the bid plans. With both options on the bid plans, they are easily evaluated within the competitive bid process by the contractor or contractors involved.

Where two or more alternatives are detailed in the bid documents, each alternative is set up as an all inclusive collection of bid items to be evaluated by each contractor. Using comparable solutions detailed by line item with estimated quantities, each contractor can select the alternate to be used: a specific M.S.E. system or a cast-in-place solution. This process occurs within the competitive bid process used to select the successful contractor.

The R.E. discrete panel system alternative generously includes bid tabulation of these items:

excavation or site preparation,
furnishing and placing the unreinforced concrete leveling pan,

furnishing and placing select granular backfill,
furnishing and placing random backfill,
furnishing wall facing panels and volume reinforcement,
placing wall facing panels and volume,
furnishing and placing cast-in-place concrete, and
furnishing and placing reinforcing steel.

For the complete plan format, the tabulation of quantities for each alternate allows for the differences in select granular fill, random backfill, wall area, and excavation quantities, which are associated with each alternate. The contractor bids only one of the detailed alternates.

Where the three-line drawing format is used, the design professional may prepare the documents to allow only a lump sum pricing by the contractor for the M.S.E. scheme selected. Obviously, the more detailed the design drawing presented in the bid documents, the more accurate the estimate can be. Quality drawings minimize the chance of a missed item, missed detail, or an expensive conflict that will be found later or perhaps in the field. Less risk is associated with complete plan bids than with the three-line format bid.

It is not necessarily true that more select granular backfill is required for an M.S.E. type wall system than is required for a cast-in-place reinforced concrete scheme. The quantity depends on the standard detail being used for the cast-in-place scheme. Also, the granular backfill quantity, like the wall area itself, may differ from one M.S.E. system to another due to panel size and foundation elevation differences. For complete plan projects, the difference in granular backfill wall quantities and the like must be evaluated in the extension of the plan quantities.

A design professional can estimate fairly accurately the in-place cost of a typical reinforced concrete structure and of an R.E. structure, using historic bid tabulation. However, until the importance of the speed of construction is evaluated in the specific time frame and with the specifications of a particular project, the savings offered using the discrete panel precast system are generally understated by the design professional.

On large projects, R.E. can shorten construction time a full construction season or more. When cost incentives are available to the contractor, any scheme to shorten the construction process or to work through marginal weather periods must be given an extensive and in-depth cost evaluation under the specific bid circumstances.

Erection of prefabricated and stored materials allows wall construction in weather where cast-in-place concrete construction is halted. Because R.E. facing panels can be placed and aligned as fast as the backfill is placed, construction of a discrete panel system is generally much faster than reinforced concrete structures.

R.E. lends itself to staged construction. Structures are stable at any elevation short of the finished structure elevation; hence, placing of the precast facing panels and the select granular fill can start and stop vertically or horizontally as needed when coordinating with other structures or as dictated by the construction schedule.

Casting panels at an off-site precast yard provides quality control and labor cost advantages. Production can take place during periods when the job is shut down or well in advance of the need for the panels at the site. Clauses regarding payment for stored materials generally include facing panels for state and federally funded projects.

As various M.S.E. systems function differently and are designed differently, bid prices for one M.S.E. solution where plans are supplied are not valid for alternate systems. Panel dimensions for various discrete panel systems are not identical, and details will vary. M.S.E. components cannot, like rebar, be secured from local sources. The design procedures and performance parameters must be consistent with the components selected.

In the evaluation of a specific M.S.E. technology by a contractor, the specifics of the M.S.E. system details come into play. For example, R.E. discrete panels are typically 20 percent larger than another discrete system. Hence, to erect the same square footage of wall for a specific structure, fewer R.E. panels need to be handled.

The number of panels and the types of connections from the steel reinforcements to the panel need to be evaluated, also. It is possible that the system with the highest delivered material cost has a substantial amount of built-in labor, but when all factors are evaluated the higher material cost system has the lowest cost overall.

Foundation considerations and judgements have a great deal to do with the overall comparison of M.S.E. and cast-in-place systems. For instance, R.E. is constructed with a free draining select granular backfill and flexible facing panels. Hence, the freeze and thaw action of the subsurface under and adjacent to the wall is a lesser concern with R.E. walls than with cast-in-place concrete retaining walls.

Cast-in-place construction requires foundation embedments below the frost line in northern climates. R.E. specifications, where not overridden by a specific bid specification, require only a one-foot minimum embedment or 5 percent of the height of the structure rather than the three to three-and-one-half feet often used in northern climates for conventional cast-in-place structures.

A three- to three-and-one-half-foot embedment for a twelve foot conventional wall would require that 20 percent more square feet of wall be constructed than the same wall designed per the R.E. standard. Hence, it is of paramount importance to establish the specific criteria and to look for the differences in the specific, competing systems.

The design professional, in performing his role as the representative to the owner, conducts a site subsurface investigation. The subsurface investigation report findings are used to guide the design professional in designing both the M.S.E. structures and traditional cast-in-place structures. As a result of the subsurface investigation, a reinforced concrete retaining wall to be located on soft materials may require pile support or may be ruled technically unfeasible based on bearing capacity, settlement, or general stability concerns.

R.E. requires neither more nor less detailed foundation investigation or report information than is required for traditional structures. However, where the design professional would be reluctant to use the traditional reinforced concrete unless pile support were provided, R.E. may be utilized on more marginal materials without piles. This is due to the inherent flexibility of the discrete concrete facing system which can tolerate significant total settlements and differential settlements associated with construction on soft subsurface materials.

Traditional retaining walls are investigated for bearing capacity, overturning, sliding, settlement, and for rotational or slip failures in the subsurface. Due to the flexibility of an R.E. volume, the inherent ability to handle anticipated settlements and associated differential settlements, the design professional evaluates the R.E. wall differently than a conventional reinforced concrete wall.

R.E. structures may be designed to undergo major settlements and perform satisfactorily. However, slip joints may be required, phased construction planned for, and the initial elevation of the top of the wall may be adjusted to allow for settlement.

The entire R.E. volume (0.7 H or 0.5 H) rests on the subgrade, and the maximum pressure is less than the maximum toe pressure of a conventional wall. The maximum toe pressure is calculated using R.E. procedures. Designers who are unfamiliar with the R.E. technology and the design parameter may attempt to evaluate the bearing capacity like the bearing pressure under the footing of a cast-in-place wall which is designed with a high factor safety (F.S.=3.0).

This can often lead to the wrong conclusion as to the suitability of R.E. type structures on marginal materials when the type of structure to be utilized is selected.

The internal stability of the R.E. designs is the responsibility of the R.E. supplier. External stability remains the responsibility of the design professional who conducts the subsurface investigation or interprets the same and determines the suitability of the soil support for any type of structure.

As part of certifying the internal stability, the R.E. company does check and design for the proper factors of safety of the volume against overturning (F.S.=2.0) and sliding (F.S.=1.5) at the contact surface between the R.E. volume and the subsurface.

The design professional must check total settlement, differential settlement, and calculate factors of safety against a rotation or slip failure in the subsurface well below the contact surface between R.E. and the surface material.

Although the R.E. discrete panel concept is flexible and the panels can distort without causing failures and without cracking, it cannot be assured that any R.E. system can be used until routine stability is checked. The check must be made using the recommendations found in the subsurface investigation program. The subsurface report must provide time rate of settlement and total settlement information.

On occasion, design plans are used for bidding on R.E. structures with incomplete or non-existent subsurface investigation information and/or without any external stability checks of any kind being made. On some occasions, the field conditions are found to be different than the design professional had anticipated.

Field adjustments to accommodate the above faults are often made while using the panels or steel reinforcement materials on hand; however, verification that the assumed foundation conditions are present remains the responsibility of the design professional on all retaining wall projects, whether R.E. is used or not.

R.E. has been built and has performed successfully after understanding an anticipated twenty-four inch settlement. The term "settlement" represents the compression of the subsurface material, not the movement within the R.E. volume. The volume, constructed of a highly compacted, free-draining granular material, does not change significantly its dimension vertically in time. The amount of settlement may cause a delay in the casting of the top row of panels and/or an adjustment in the top of wall elevation.

Both the total settlement and the differential settlement must be dealt with. Differential settlement caused by a portion of an R.E. wall passing, for example, first over a soft material, such as clay, and then over a rigid item, such as a culvert or a buried and abandoned concrete structure, may pose the most challenge.

To handle anticipated total settlement and differential settlement problems, R.E. utilizes full height corner slip joints and midwall slip joints. These special concrete joining panels are secured to the volume using the same steel reinforcing strips that are used to secure the discrete panels. These joints must be designed into the system, not added in the field.

Through the design of the slip-lap panel edge, R.E. facing panels are not in contact with each other. They are separated by neoprene-like "bearing blok" that prevents concrete to concrete contact even when the panels undergo slight rotation or movement due to the settlement of subsurface materials. Filter fabric spans all horizontal and vertical panel joints to contain the fill.

R.E. strips, normally galvanized, are designed on a sacrificing metal theory. The standard ribbed R.E. strip is an A-572 grade 65 (high strength, low alloy Culombium-Vanadium steel of structural quality) galvanized according to ASTM A-123 with two ounces of zinc per square foot of material surface. The behavior of the reinforcing strip is based on 45 years of extensive research conducted by the U.S. National Bureau of Standards between 1910 and 1955 on black and galvanized steel specification. Based on this research and the ongoing R.E. corporate research, the overall predicted service life is approximately 195 to 210 years.

The corrosion potential for galvanized strips is directly related to the chemical make-up of the select granular backfill. Select granular backfill material meeting the Federal Highway Administration (FHWA) gradation requirements provides an electrical resistivity well within limits to support the service life noted. However, for very severe corrosion environments, the same strip coated with 18 mils of epoxy theoretically has an unlimited life as the epoxy is an inert material and not subject to corrosion. The decision to use epoxy-coated strips in lieu of standard, galvanized strips adds to the cost of the R.E. structure.

For example, epoxy strips are necessary to assure the design life where blast furnace slag or aggregate manufactured for recycled concrete is used.

After interpreting the results of the subsurface investigation, the design professional may wish to improve the subsurface conditions to minimize settlement or to solve a potential sliding, overturning, or slip circle problem. Subsurface site conditions may be improved by one of the following methods:

removal and replacement of bearing material,
addition of stone columns for support, or
modifications of bearing material by preloading.

When removal of an unsuitable foundation material and replacement with a superior material is required, the design professional makes the final decision on the removal and replacement limits after a field inspection. Unit price bidding is utilized for these items. In addition, removal and replacement of the soft material minimizes settlement and improves the overall stability as the dead load of the volume is transferred through a material with improved properties and is distributed over a larger bearing area.

Where the removal and replacement of material would cause stability problems for surrounding structures, RE structures may be supported on specially designed stone columns. The columns are drilled shafts that are engineered in diameter, length, and placing, and are placed to allow load transfer of the dead load of the volume through the unsatisfactory material to a more satisfactory material. With stone columns, the design load is transferred through the columns to a suitable material.

The cost of R.E. is best determined in a specific bid environment. However, bid tabulations for past or current public work represents an excellent source of information for the design professional to employ in estimating a proposed structure.

For any given site-specific structure, the R.E. package contains the design, precast facing panels, and steel reinforcement and jointing materials. The bid package price varies, depending on the location of the site with reference to the precast concrete production facility, the choice of galvanized or epoxy steel, the architectural treatment, the square footage of wall, and special details.

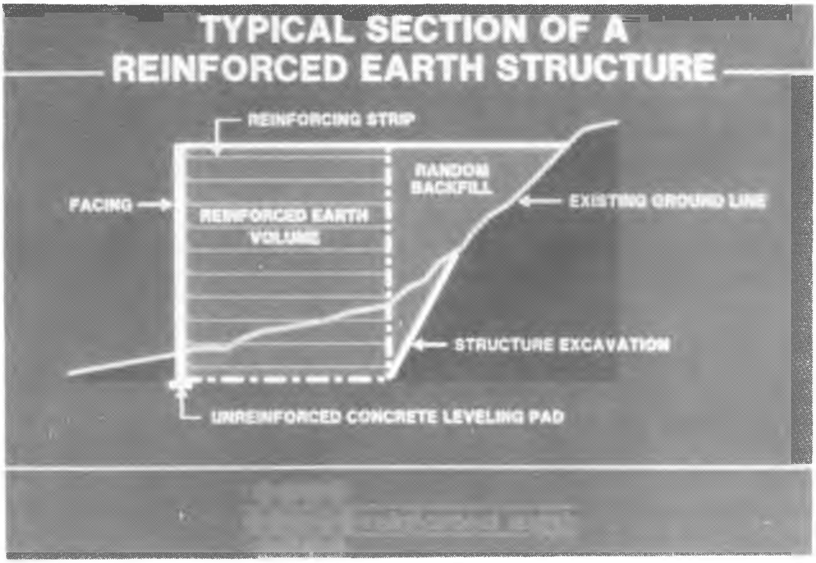
Bid tabulations for projects bid competitively in Indiana and Illinois during 1987 are attached herein for reference as Exhibit A. The cost of the R.E. system is calculated per square foot of wall without backfill and again with the cost of backfill added. Both projects were bid following the complete plan format and now are under construction using plain surface concrete panels.

Various architectural treatments can be applied to the RE discrete panel of form liners, yet the traditional cruciform panel shape remains constant. The addition of an architectural treatment may add from $0.50 to $2.00 per square foot to the panel package price, depending on the size of the project, the length of the casting period specified, and the specific surface specified.

The relative cost advantage for an R.E. system over a conventional cast-in-place retaining wall may vary depending on site-specific information. For the Indiana project noted in Exhibit A, the general contractor identified a savings of $800,000 to the Indiana Department of Highways in a project of 53,200 square feet with a maximum height of 26.87 feet. This amounts to $15.30 per square foot or 36 percent. A letter from the contractor making the cost comparison is attached as Exhibit B.

The wall embedment criteria is particularly important on low walls. On a smaller R.E. project in Indiana, a 27 percent savings was identified cn a Marriott Hotel project for a private owner where the wall height maximum was only twelve feet. A letter from the contractor making the cost comparison is attached as Exhibit C.

Retaining walls are generally utilized where normal ground slopes cannot be constructed due to property line restraints, land values, existing structures, or planning for future structures. RE represents a cost-effective, rapid construction technology to be utilized by the owner, design professional, or contractor as an alternative to cast-in-place cantilever or counterfort retaining walls.


TYPICAL SECTION OF A
REINFORCED EARTH STRUCTURE
REINFORCING STRIP
RANDOM
BACKFILL
FACING
REINFORCED EARTH
VOLUME
EXISTING GROUND LINE
STRUCTURE EXCAVATION
UNREINFORCED CONCRETE LEVELING PAD


REINFORCED EARTH® WALL
VS. CANTILEVER WALL
EXISTING
GROUND

Typical Reinforced Earth™ structure.
SR 66 Vanderburgh County
(constructed by Traylor Brothers, Inc. and Industrial Contractors, Inc.)