REINFORCED EARTH® RETAINING WALLS

Groupe TAI
Since the invention of Reinforced Earth® a little over 20 years ago, and its subsequent development for use in transportation and civil engineering applications, more than 7,000 retaining walls have been constructed throughout the world.

On first examination, the design and performance of these structures may appear simple, as in the case of large gravity walls. However, the internal mechanism of Reinforced Earth is unique and complex. Following the conception and initial studies by Henri Vidal, the Reinforced Earth Group continued research in order to extend the knowledge of the behavior of Reinforced Earth in retaining wall applications. That research continues today. It has involved varied but complementary methods, ranging from laboratory studies on reduced-scale models and instrumentation of actual projects and full-scale experimental walls, to computerized mathematical studies including finite element method analysis.

The synthesis of this considerable mass of data has made it possible to develop practical, accurate design procedures for current projects. It has also enabled designers to optimize the geometry of Reinforced Earth structures to their intended use and environmental setting.

In addition to the experience acquired on difficult sites, research results have contributed to the careful design of retaining structures for large, sloped embankments (or terraced structures), for walls built on poor or compressible ground, and for projects built in mountainous areas, on both rocky flanks and unstable talus slopes.

The following pages chronicle some of the research conducted on the performance of Reinforced Earth retaining structures, and describe how the results of this research have been applied to the internal and geometric designs of the projects.

List of Symbols

- \( T \) – tensile force in reinforcing strip
- \( \sigma_v \) – vertical stress
- \( \sigma_h \) – horizontal stress
- \( K \) – ratio between \( \sigma_v \) and \( \sigma_h \)
- \( K_a \) – coefficient of active earth pressure
- \( K_s \) – coefficient of earth pressure at a rest
- \( \gamma \) – unit weight of soil
- \( L \) – reinforcing strip length
- \( H \) – wall height
- \( \phi \) – angle of internal friction
- \( N \) – number of strips per unit of wall facing surface
- \( \Gamma \) – coefficient of apparent friction
- \( \beta \) – inclination angle of resultant earth pressure behind fill
- \( q \) – surcharge load
- \( Z \) – depth of fill above reinforcing strip

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Gravity Structure

Massive gravity-type retaining walls were the first, and remain the most widespread application of Reinforced Earth (Fig. 1). The term "massive" clearly implies that the material, although composite and flexible, forms a continuous, homogeneous block. It is this block, as heavy and stable as a large masonry wall, that retains the fill or soil. In addition to its own weight, the block transfers the effects of surcharges and earth pressures to the foundation, and distributes them evenly over the entire width of its base. Due to the flexibility of the wall, this wide foundation prevents concentrations of loads, making it possible to build a Reinforced Earth retaining wall directly on the ground, even on very poor foundation soils.

Research and Development of Overall Structure Dimensions

Therefore, designers of Reinforced Earth structures initially preferred the stable shape of a wide rectangular form, one which imposed a minimum and uniform stress on the ground (Fig. 2).

While early research was performed on structures of this type, nearly triangular wall shapes were also conceptualized for use where appropriate (Fig. 3). Whereas the shape of the structure was adapted to the profile of the ground, a somewhat intuitive effort was also made to make the design encompass all potential internal failure planes.

Thus, in addition to theoretical and laboratory studies on the fundamental behavior of Reinforced Earth (including, among others, triaxial tests), a considerable amount of applied research on Reinforced Earth retaining walls was conducted. There were three primary objectives of this research:

- To study the behavior of the structure; to analyze how such external factors as the structure's own weight, surcharge loading, and earth pressures behind the Reinforced Earth mass affect the development and transmission of internal stresses within the backfill, the reinforcing strips, and the facing.
- To analyze the influence of a structure's overall geometry, shape, and width-to-height ratio on its behavior — and the resulting foundation loading; and to study the effects of variations in the modulus of elasticity of the reinforcements on overall structural performance.
- To develop new designs for Reinforced Earth retaining walls. For example, the development of a narrow profile wall for projects where it is more important to reduce the overall width of a structure built in a cut than to limit the pressures exerted by the retaining wall on the foundation (Fig. 4). This has been a topic of recent research. Results of the most important research activities are discussed in following sections.
Since the introduction of Reinforced Earth technology, laboratory-scale models have proven useful in gaining an understanding of the behavior of full-scale structures. Henri Vidal, the inventor of Reinforced Earth, constructed and studied sand and paper models in the early 1960s. From 1969 to 1982, with the cooperation and financial support of the Reinforced Earth Group, independent laboratories around the world conducted more than a dozen scale-model research projects.

**Bidimensional Models**

At the Laboratoire Central des Ponts et Chaussées (LCPC) in Paris, two-dimensional models of steel rods and sheets of aluminum made it possible to distinguish between failures due to slippage or to breakage in the reinforcing strips (Fig. 5).

**Tridimensional Models**

Subsequently, with the use of three-dimensional sand models built by LCPC and the Institut National des Sciences Appliquées (INSA) in Lyon, it was possible to observe the shape of failure surfaces. Computational methods were deduced from these model studies.

**Centrifuge Testing**

Unfortunately, stresses and other forces in small-scale models are themselves small, and therefore difficult to measure directly.

LCPC obtained consistent results for the variations in tensile force levels along reinforcing strips as a function of depth, and for the foundation pressures transmitted to the ground. Analogous methods were used at the École Nationale des Ponts et Chaussées (ENPC) in France to study sloped and heavily surcharged structures. However, scale models do not faithfully reproduce the true flexibility of the wall facing, the effects of compaction or dilatancy of the fill. Tests on full-size structures were indispensable during initial development, and remain so today.
The best method for obtaining reliable data on the behavior of walls or embankments is the instrumentation of structures built under normal field conditions. This has been done at a number of sites around the world, beginning with several of the early Reinforced Earth projects. Many of these experiments were financed in whole or in part by companies of the Group. Today, results from measurements taken on 20 actual structures and nine experimental structures are available for analysis. The findings of this instrumentation program are presented below.

**Instrumentation**

Instrumentation for studying Reinforced Earth structures typically includes:

- Strain gauges set at predetermined intervals along a majority of the reinforcing strips in a single vertical cross-section. Each point requires a gauge on both the upper and lower surfaces to eliminate the effects of local bending. To minimize localized irregularities due to the normal construction process, several reinforcing strips in the same layer are usually instrumented.

- Total pressure cells for measuring stress levels in the fill, particularly behind the wall facing and at the base of the structure. Here, too, measurements may sometimes vary due to local irregularities.

- Surveys, inclinometers, and settlement indicators to record movements of the structure.

Of course, it has not been possible to instrument all monitored Reinforced Earth walls in such a complete way. However, cross-checks using a sufficient number of experimental and instrumented structures, as shown in Figure 8, have enabled researchers to draw solid, convincing conclusions regarding the behavior and mechanisms of Reinforced Earth.

![Instrumentation of the Fremsendorf wall, Germany.](image-url)
Tensile Forces in the Reinforcing Strips

Strain gauge measurements show the variations in tensile forces along reinforcing strips, or (at a minimum) the averages of these variations (Fig. 9).

From these curves, it is possible to locate the point of maximum strip. By connecting these points, one can derive the line of maximum tensile force in the structure.

Figure 9: Silvermine wall, South Africa, 1978.

Variation of the Tension with Depth

A graph showing variations in maximum tensile force as a function of depth can also be derived from these measurements (Fig. 10). In all projects, it has been observed that stress is not entirely proportional to depth. Stresses are higher at the top of the wall and lower at the base.

This was confirmed with measurements taken on a wall built at Granton, Great Britain, where it was shown that higher stresses at the top of the structure are caused by forces developed during compaction (Fig. 11). In contrast, stresses are often reduced at the base of the wall because the foundation soil—due to its cohesion—"relieves" the lower levels of reinforcing strips.

Stresses at the Wall Facing

When gauges are placed close enough to the facing of a Reinforced Earth retaining wall, it is possible to estimate forces at the connection between facing and the reinforcing strips. Otherwise, these forces are derived from the horizontal stresses measured behind the facing where total pressure cells have been installed. These measurements have shown that stress levels at the face are lower than the maximum levels (Fig. 12). However, test results are far from uniform, thus demonstrating the necessity and value of numerous measurements.
Pressure at the base. Earth pressure due to the retained fill.

When an adequate number of pressure cells are installed under the base of a structure, it is possible to determine the variation and magnitude of the foundation loading exerted by the wall on the underlying soil (Fig. 13). The Fremersdorf wall (Fig. 8) provided such an opportunity. Tests on that structure demonstrated that loading is greater toward the front of the structure due to earth pressure imposed by the retained fill behind the wall. In addition, the total load was slightly greater than the total weight of the wall, indicating that the thrust behind the structure was inclined.

The difference between total loading and weight, and the location of the resultant, makes it possible to compute the thrust angle $\theta$.

Figure 13: Fremersdorf wall, bearing pressure.

Trapezoidal Walls

Among the structures in service that have been instrumented, several were built with reinforcing strips shorter at the base than at the top. The Asahigaoka wall in Japan is a case in point. The results of field measurements on this structure are in very close agreement with those obtained on walls with a rectangular cross-section of the same general dimensions (Fig. 14).

As observed in a structure in Lille, France, excessively extended lengths of reinforcing strips used for abutment loading can result in the secondary maximum of tensile stress due to the cantilever of the extended Reinforced Earth fill over the more compressible random backfill (Fig. 15).

Figure 14: Asahigaoka wall, Japan.

Figure 15: Lille wall, France, 1972 (before construction of abutment superstructures).
Actual projects that have been instrumented were, of course, designed according to the current state-of-the-art standards. These walls have been subjected to no more than design loadings.

Experimental walls, on the other hand, are generally intended for testing new designs or technologies. They are often loaded to failure.

The Tinel wall, for example, built in 1975 by La Terre Armée S.A., France, was constructed to verify the behavior of high-adherence reinforcing strips, and to check the effects of vibrations.

Another experimental wall, erected in 1976 by the U.S. Army Corps of Engineers in Vicksburg, Mississippi, was built using non-standard metal facing panels of the military's design. It was then loaded to failure.

As part of the research into the durability of buried steel, Tierra Armada S.A., Spain, built a six-meter-high wall in Madrid in 1977 using thin reinforcing strips (0.6 mm). The structure was then inundated with brine to accelerate corrosion. Failure developed along a surface very similar to the line of maximum tensile force established by previous research. In addition, at the moment of failure the overall residual resistance of the reinforcements was very close to the sum of the theoretically predicted maximum tensile forces.

In 1978, the Public Works Research Institute (PWRI) of Japan built a six-meter-high experimental wall (Fig. 16) to study the effects of a sloping surcharge and the consequent role of the wall facing. When the reinforcing strips were unbolted from the outside, the face at first remained stable, confirming the hypothesis that it plays only a minor structural role. When the structure was loaded to failure, the break in the fill closely followed the theoretical line of maximum tensile stress, as shown in Figure 17.
Narrow Profile Walls

In 1983, The Reinforced Earth Company, United States, built and instrumented a six-meter-high wall with short reinforcing strips at Millville, West Virginia. The structure has two cross-sections: one is rectangular, with reinforcing strips of 2.7 meters, \(L/H = 0.45\); the other is trapezoidal, with reinforcing strips of 1.8 to 3.0 meters, \(L/H = 0.30\) to 0.50.

An experimental wall of the same type, but with a height of 10.5 meters, was constructed in France near Fontainebleau by La Terre Armée S.A. and LCPC (1986/7). Building the wall, equipping it with complete instrumentation, and taking measurements cost about $360,000, of which 90 percent was provided by the Reinforced Earth Group.

As in Millville, the project included two separate sets of measurements. (Fig. 18). One set involves a rectangular cross-section and reinforcing strips of five meters, \(L/H = 0.5\); the cross-section of the other set is trapezoidal, with reinforcements four to six meters in length, \(L/H = 0.4\) to 0.6.

Deliberately built on relatively poor foundation soils and with fill of average quality, this experimental wall was designed to test practical construction conditions as well as the overall stability and design principles associated with a narrow profile structure.

Instrumentation of Fontainebleau

In total, the instrumentation shown in Figure 18 included:

- 355 locations for determining the tensile stresses in reinforcing strips (two strain gauges per location).
- 52 locations for measuring the vertical stresses in the soil (Glotz cells).
- 24 load cells, specially developed for this purpose and designed to measure the force transmitted from one panel to another within the wall face.
- 28 settlement meters, six inclinometers, plumb lines, and topographical benchmarks for assessing movements.

![Diagram of instrumentation](Figure 18: Instrumentation.)
Scale models can only provide limited results. Full-scale experiments, on the other hand, are very expensive and require a great deal of time. Thus, only a limited number of structures and loading conditions can be studied. However, computer analyses using the finite element method make it possible to vary many parameters, and to examine stress and deformation created by a wide number of loading conditions at any point in the model.

The Model

From 1982 to 1984 Terre Armée Internationale employed the Rosalie program to conduct Finite Element Method (FEM) studies on elastoplastic models that included friction-separation elements. This method allows a bar element to slide when the force it is transmitting becomes greater than the limiting friction. The system is thus computed by successive iterations until stabilization or failure. Moreover, the model in Figure 19 is practically three-dimensional. In fact, the soil is in contact with the reinforcing strips through the friction-separation elements; at the same time the soil is continuous between the reinforcements and through non-sliding soil-soil friction elements.

Variation of Design Parameters

The reliability of this model was initially tested by verifying that it produced results that were very close to those previously obtained by instrumentation of actual structures. This was followed by a study of 50 different walls, not including works subjected to concentrated loads. The following parameters were varied simultaneously:

- height H (10.5 or 6m);
- section through wall rectangular 0.7 < L/H < 0.4 or trapezoidal;
- uniform surcharge;
- distribution of metallic reinforcing strips;
- type of wall facing, and
- modulus of the foundation soil.
Results

For each of the models considered, results of the computations were expressed graphically by computer (Fig. 20). Superimposing the curves made it possible to analyze the influence of the length of reinforcing strips on: variations in tensile stress along the strips; increases in maximum tensile stress with depth; and the shape of the active zone. These comparisons confirmed that a Reinforced Earth structure with metallic reinforcing strips as short as 0.4H always behaves in the same way, even when the structure has a trapezoidal cross-section.

These test results also made it possible to evaluate the effect of the type of facing on the tensile stresses at the connections. One can also produce an amplified representation (Fig. 21) of the natural deformations of the structure, which are always small with steel reinforcing strips.

Detailed analyses of the stresses on the boundaries of the structure also make it possible to determine variations in the earth pressure beyond that boundary, and its inclination (which is relatively sensitive to the width of the structure – see Fig. 22), as well as the pressure transmitted to the foundation (Fig. 23).

Figure 20: Variations of tensile stress forces.

Figure 21: Amplified deformations.

Figure 22: Variation and inclination of earth pressure behind Reinforced Earth.

Figure 23: Bearing pressure.
Overall Behavior

The available composite data confirms that a Reinforced Earth structure behaves like a gravity wall. To the weight of the wall and the superimposed loads are added the effects of earth pressure from the retained fill (Fig. 24). Because of the wall’s flexibility, this earth pressure corresponds to the active state; as a general rule, the slope of its resultant becomes steeper as the embankment becomes narrower (Fig. 25).

Instrumentation of actual structures and finite element analyses demonstrate that at the base of the structures and at intermediate levels, vertical stress in the embankment is higher closer to the facing and is on average greater than \( \gamma Z \). Use of the Meyerhof formula provides a good estimate of maximum stress in the structure (Fig. 26).

Internal Stress Distribution

Tensile stresses within the reinforcing strips are at a maximum at a certain distance behind the facing. The line joining the points of maximum tensile force separates the active zone, in which the reinforcing strips retain the fill, from the passive zone, in which the friction of the fill retains the reinforcing strips.

All data confirms that when metallic reinforcing strips are used, the line separating the two zones begins at the toe of the structure and follows a nearly vertical path to a point less than 0.3H from the facing at the top of the structure. This is true regardless of the structure’s dimensions (up to L/H = 0.4), even for structures with a trapezoidal cross section (Fig. 27).

The shape of the active zone has also been established by kinematic analysis of the mechanism of rupture along a logarithmic spiral.

Figure 24: External loads and global equilibrium.

Figure 25: Thrust gradient.

Figure 26: Meyerhof formula.

Figure 27: Active zone, measurements taken on actual projects, line obtained using scale model; results of finite element analysis.
Maximum Stress Levels in the Reinforcing Strips

Adopting the hypothesis that the shear force is zero in planes lying midway between reinforcing strips (Fig. 28), the equilibrium of the zone thus established within the active zone implies that $N \cdot T_{\text{max}} = \sigma_n$ (with $N$ the number of reinforcing strips per unit of surface of the wall facing). Horizontal stress within the structure at the point of maximum tensile stress is a function of the vertical stress at this maximum point, expressed by the equation: $\sigma_n = K\sigma$, with $\sigma_n$ the value calculated by the Meyerhof formula. The experimental results and finite elements study (Fig. 29) show that $K$ is practically equal to the active earth pressure coefficient, $K_a$.

At the top of walls and to a depth of approximately six meters (Fig. 30), the values of $K$ calculated from measurements of actual structures are significantly higher, largely due to the stresses induced by compaction. They approach a value in the region of $K_a$, the coefficient of earth pressure at rest.

**Figure 28:** Local equilibrium.

**Figure 29:** Analysis of $T_{\text{max}} = K\sigma_n / N$.

**Figure 30:** Measured values of coefficient $K$.

**Figure 31:** Ratio between tensile loads at connection and maximum tensile forces.

Tensile Stress Levels at Connection

Based on a conservative evaluation of actual measurements and finite element computations, tensile stress levels at the connections to the concrete facing panels may reach 85 percent of maximum tensile stress, and up to 100 percent at the base of the wall (Fig. 31).

With metal facing elements, this stress level never exceeds 75 percent of the maximum tensile force in the strip.
Geometry of Structures

A synthesis of the results previously summarized makes it possible to define practical design methods for Reinforced Earth retaining walls.

These methods are applicable to structures of rectangular cross-section with a maximum height-to-width ratio of $2(L/H \geq 0.5)$. They can be adapted to "trapezoidal" structures, narrower at the base ($H/3$ and $2H/3$ wide at the base and the top, respectively) provided the dimensions do not affect the overall stability of the structure (Fig. 32). In these formulae, height $H$ is understood to extend to the top of low embankments supported by the structure. Reinforced Earth structures that support long slopes or heavy surcharges are subject to special design procedures.

Earth Pressure Behind the Structure

Generally, the resultant of earth pressure due to the fill behind the structure is assumed to be inclined at the angle: $\beta = (1.2 \cdot L/H)\varphi_f$, with $\varphi_f$ the angle of internal friction of the fill. Earth pressure is computed using the Coulomb coefficient, which has as its horizontal component:

$$ K_h = \frac{\cos^2 \varphi_f}{[1 + \frac{\sqrt{3}}{2} \sin (\varphi_f + \beta) \sin \varphi_f / \cos \beta]^2} $$

Figure 32: Geometry of typical Reinforced Earth retaining walls; overall equilibrium.

Stresses Within the Structure

At the foundation level and at any intermediate reinforcement level, vertical stress $\sigma_v$ is computed from the vertical resultant $\Sigma V$ of the loads applied to the structure using the Meyerhof formula. With $M$ the moment of those loads with respect to the midpoint of the base,

$$ \sigma_v = \frac{\Sigma V}{L - 2M/2V} $$

The maximum horizontal stress, $\sigma_h$, is computed using the relation $\sigma_h = K_h \sigma_v$, where $K_h$ varies from $K_h = 1 + \sin \varphi_f$ at the surface to $K_h = \tan^2(\varphi_f/4)$ below depths of six meters, with $\varphi_f$ the angle of internal friction of the Reinforced Earth fill (usually $\geq 36^\circ$). See Figure 33 for resultant loads of stresses.

Figure 33: Calculation of $\sigma_v$ and $\sigma_h = K_h \sigma_v$. 
Tensile Stresses in the Reinforcing Strips

The maximum tensile stress in the reinforcing strips is distributed at the given reinforcement level into the number of reinforcement per unit of facing surface. This is equal to $T_{\text{max}} = \sigma_r / N$. The line joining the points of maximum tensile force starts at the toe of the structure, as shown in Figure 34.

At the connection point between the reinforcing strip and the facing, tensile force, $T_r$, varies (depending on the level in the structure) between 65 to 100 percent of $T_{\text{max}}$ with concrete facing, and equals 75 percent of $T_{\text{max}}$ when metallic facing is used.

The adequacy of the cross-section of reinforcing strips shown in Figure 35 is checked at the point of maximum tensile force and at the connection (net section) as a function of the permissible stress, applicable codes, and any sacrificial thickness applied for service life design.

Adherence
(Soil-Strip Interaction)

The assumed length $L$, the width $b$ and the number $N$ of reinforcing strips are then checked with respect to the minimum available frictional capacity in the passive zone. Research on friction shows (Fig. 36) that in backfills normally used in Reinforced Earth construction – correctly compacted and unsaturated – the coefficient of apparent friction ($f^*$) between earth and high-adherence reinforcements, decreases as a result of dilatancy from a maximum value of $f_*^* = 1.5$ at the surface, to $\tan \phi_1$ at a depth of six meters and beyond. For smooth reinforcing strips, $f^* = 0.4$ is used throughout.

The design consists of satisfying the following equation:

$$T_r \leq T_{\text{max}} = 2b f^* (L-D) \gamma Z / \gamma,$$

where $\gamma$ is a safety factor, $L-D$ the length of the reinforcing strip in the stable zone, and $\gamma Z$ the weight of the fill above the reinforcing strip; that is, a value slightly but conservatively smaller than the actual vertical stress, $\sigma_v$.

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Figure 34: Line of maximum tensile forces; tensile Loads at connection.

Figure 35: Strip cross-sections.

Figure 36: Adherence capacity.
Sliding Beneath The Base

The internal design of a Reinforced Earth mass does not predetermine the general stability of the structure, the soil it supports, or the soil on which it is founded.

As in the engineering of any soil-supported retaining wall, with Reinforced Earth one must first determine that there is no risk of horizontal sliding under the base of the structure (Fig. 37). In the typical case of a structure supporting a horizontal backfill, this criterion rarely governs. When it does, because of the characteristics of the foundation soil or the backfill, it may require a widening of the structure, that is, a lengthening of the reinforcing strips.

Slope Loads

The criterion for horizontal sliding is often more critical when there is a heavy surcharge behind the structure; for example, when supporting a high, sloping embankment (Fig. 38a). The minimum proportions of the structure depend primarily on the magnitude and inclination of earth pressure behind the wall.

Superimposed Structures

A special case of this problem is encountered when one Reinforced Earth structure is built on top of another Reinforced Earth-supported embankment (Fig. 38b). Such cases are not rare. They are possible because Reinforced Earth structures can be built on both embankments and soft natural ground.

In these cases, the two Reinforced Earth embankments are two independent structures, each requiring its own internal design.

Terraced Structures

This is no longer true when the Reinforced Earth structures are directly superimposed, one on another, which is done when a very high wall is divided into a number of terraces (Fig. 39).

These offset structures are obviously similar to a single embankment with a sloping face. In fact, they exhibit essentially the same overall behavior, and are designed as sloping faced Reinforced Earth walls. Inclined retaining walls have been used extensively in the mining industry for construction of large ore storage structures and have been the subject of considerable, specific research.
External stability design also requires a determination that the bearing capacity of the foundation is capable of supporting the load superimposed by the structure, and requires a calculation of the total anticipated differential settlement.

Settlements

Depending on the amount of settlement and the time required for it to occur, there are several methods of adapting a Reinforced Earth retaining wall to the site conditions or of accelerating the consolidation of the site, should that be required.

Rapid settlements can generally be accommodated during the construction process by final adjustments to the dimensions of the top course of facing panels, as in Figure 40a.

Slower settlements, if large in magnitude, must often be accelerated to allow for corrective measures during construction. Methods for accomplishing this include temporary surcharging of the structure foundation, installing vertical drains, and other traditional methods (Fig. 40b).

When differential settlement along the facing is expected to exceed the one-to-two percent which can be accepted by the facing system without risk of damage, the wall face can be given additional "degrees of freedom" by installing vertical slip joints (Fig. 40c).

Soil Improvement

On soils of poor quality, both settlement and bearing capacity problems may be solved by improving the foundation, by partial replacement, preloading, or even use of stone columns or a lightweight backfill (Fig. 41a and b).

Adaptation of the Reinforced Earth Structure

On a marginal foundation soil, it is possible to use the flexibility of Reinforced Earth to build retaining walls without resorting to special procedures.

This may be done:

1) By building the project at a rate which will allow the soil to consolidate, including building the project in stages if necessary;

2) or, in some cases, by lengthening the lower levels of reinforcing strips to widen the foundation of the structure, thus reducing the foundation pressure and providing assurance against a deep bearing capacity failure (Fig. 41c).

For all Reinforced Earth retaining walls built on problem soils, the best approach is often a combination of these solutions. However, by attempting first to take advantage of the ability of Reinforced Earth structures to accept deformation, it may be possible to reduce the requirements for some of the more expensive soil-improvement techniques.
Research is being conducted on Reinforced Earth walls of narrow or trapezoidal cross-section with the aim of developing reliable design procedures for structures suitable to sites where excavation must be limited.

Excavation
One such case (Fig. 42) is a project constructed in a cut and on a very stable or rocky natural ground, where it would be paradoxical to replace too much of the existing terrain with fill, even if it was reinforced.

Walls On Rock Slopes
For embankment projects built on rocky slopes, the length of reinforcements at the base of the wall is reduced (Fig. 43).

When a slope is very steep, it may be economically and technically advantageous to support the base of the Reinforced Earth structure with a concrete substructure tied into the rock, as in Figure 44.

Unstable Slopes
The most difficult cases are those where the slope consists of relatively unstable, or marginally stable materials, such as thick debris or talus.

Dimensions of the Reinforced Earth embankment must then provide a compromise between the stability of the slope above the excavation during construction and the stability of the ground below, once the latter is supporting the load of the structure (Fig. 45).

The first condition requires that the reinforcing strips be shortened, whereas the second calls for lengthening them to tie the overload to the existing ground more securely and to deepen any potential rupture lines. (The solution may also call for a temporary shoring of the excavation, and construction proceeding in small and progressive sections). Such an optimization process requires careful geotechnical studies as well as stability calculations that take into consideration the resistance of any reinforcing strips intersected by the lines of possible major faults or slides.
Autoroute 40

A still more difficult case was presented near Nantua, France, on a section of the highway linking Lyon, France with Geneva, Switzerland. The talus slope there was in such precarious balance that it was practically impossible to excavate it, even to modest depths. For the same reason, the slope could not support heavy fill surcharges. Therefore, the highway was designed with two vertically offset roadways to follow as closely as possible the natural contours of the terrain. The wall now separating the two grades of the roadways was built approximately half cut and half fill.

The lower section is in the form of a tieback-anchored wall built downward from the surface. The upper part is a Reinforced Earth structure, constructed almost without excavating into the existing terrain. The anchors provided stability first for the excavated talus slope, and then for the slope supporting the fill surcharge and the Reinforced Earth embankment.

The downhill roadbed is itself supported by a Reinforced Earth structure that was also set close to the slope line when necessary, after the slope had been stabilized by one or two levels of tiebacks. In other sections, where stability was not as critical, the lower wall of Reinforced Earth was terraced to blend with the site.

Conclusion

Because of its technical superiority and economic advantages, Reinforced Earth has become widely used in the construction of earth-retaining structures.

Presently, more than 7,000 retaining structures are in place throughout the world. The International Reinforced Earth Group of companies continues to expand the state-of-the-art and to adapt this technology to an increasing range of problems, sites, and requirements.
Licensed under the patents issued to Henri Vidal throughout the world, the Reinforced Earth Group of companies operates in 34 countries on six continents. Although part of the same group, each company is independently managed by nationals of that country who are professional engineers that understand local conditions, codes of practice, and construction capabilities and techniques.

All Reinforced Earth companies are fully staffed with experienced engineers and project managers and provide a complete range of services:

- Engineering, from conceptual designs to finished construction plans and shop drawings.
- Materials specification, production and delivery.
- Specification and production of customized components, such as traffic safety barriers, seawall wave deflectors, and architectural finishes.
- Detailed cost estimates.
- On-site construction assistance and advice.
- Fixed-price contracts covering both services and materials.

Research and other technological activities among the different companies are coordinated from Paris, by Terre Armée Internationale. For new applications and special or unusual projects, Terre Armée Internationale can pool the resources of several companies to create optimum project designs and material specifications. It also acts as the central technical service organization, and maintains the primary information database collected from new applications, special projects and research.

Terre Armée Internationale takes the lead in organizing and developing research projects, both under its own direction and through coordination among the other companies. Analysis and synthesis of research and technical data by Terre Armée Internationale result in technical recommendations and design improvements published in routine reports disseminated to all the Reinforced Earth companies.

The dynamics of this organization allow each Reinforced Earth company to offer government agencies, owners, consultants and contractors the understanding and flexibility of a local business, combined with the vast resources and technological advantages of a global concern.

Worldwide, the Reinforced Earth Group has a staff of some 500 professional and administrative employees. More than 10,000 Reinforced Earth structures have been completed in 56 countries.