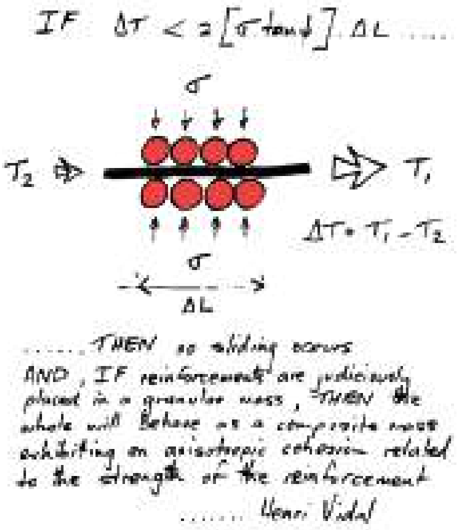
Reinforced Earth®

The original

REINFORCED EARTH
SUSTAINABLE TECHNOLOGY

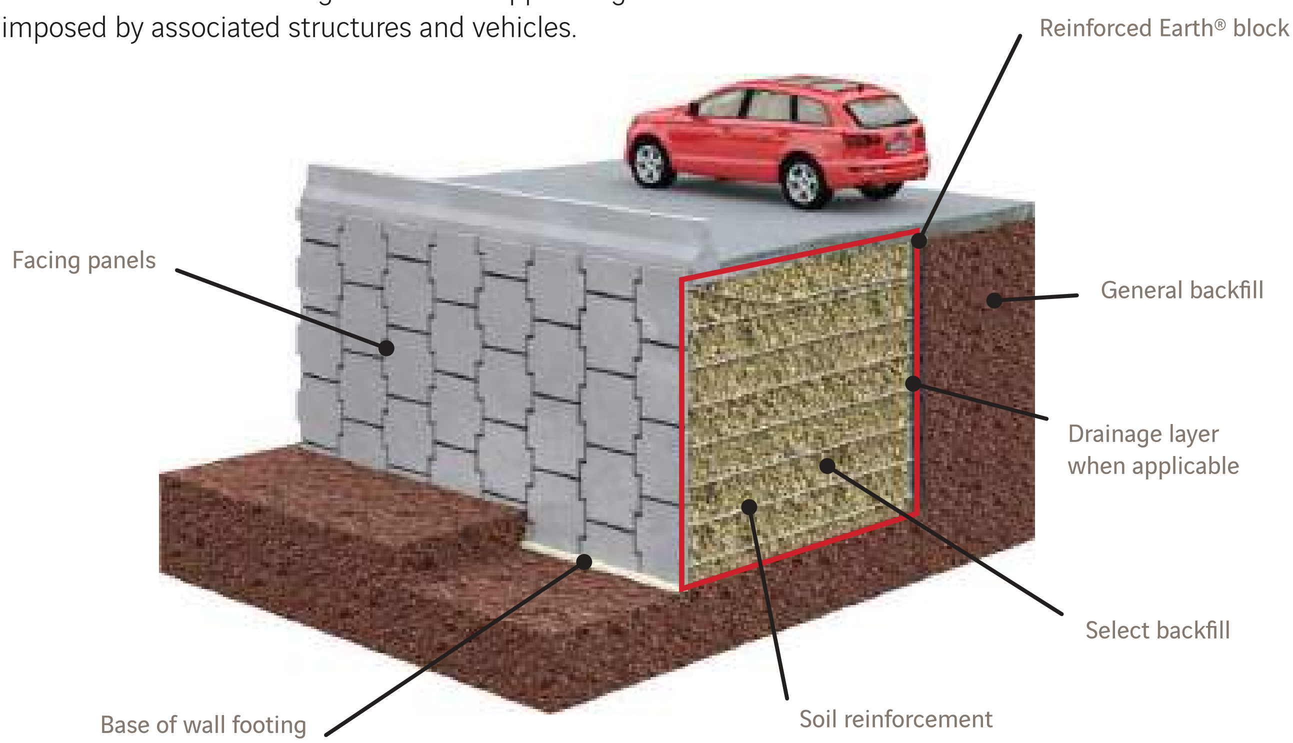


Principle

Reinforced Earth® is based on a simple concept. As originally conceived by its inventor, French architect and engineer Henri Vidal, the interplacing of soil and reinforcements develops friction at the points of contact between the two, resulting in a permanent and predictable bond and creating a unique composite construction material.

Reinforced Earth® structures combine select granular, engineered backfill with steel or geosynthetic tensile reinforcements and a modular facing system, generally made of precast concrete panels, welded wire mesh or semi-elliptical steel panels.

This unrivalled combination creates a durable, mass gravity retaining structure which in addition to its own weight is able to support large dead and live loads imposed by associated structures and vehicles.



Content

Cover page:
La Ravoire - A41 motorway - France

Benefits

The worldwide acceptance and utilization of the Reinforced Earth® technique makes it **one of the most significant civil engineering developments of the past 50 years**, perfectly served by the establishment of the Reinforced Earth® entities on the five continents which constitute Terre Armée Internationale. This success comes from the **unique benefits offered by the technique through its intrinsic characteristics**.

Strength

The resistance and stability of the composite structure provides significant load bearing capacity.

45 meter high tiered wall - SeaTac airport - USA

Resilience

The interaction between the engineered backfill and the soil reinforcements allows an effective absorption of vibrations such as those from heavy and high speed trains, industrial equipment or explosions as well as an exceptional response to earthquakes.

After the Izmit earthquake in 1999 - Turkey

Aesthetics

The variety of facings can meet all architectural requirements.

Tampa - Florida - USA

Reliability

The durability of the materials used is well documented and the safety of the structures unrivalled.

Durability samples

Flexibility

The modularity of the facing and the specific construction devices allow the structures to accept substantial total and differential settlement on poor foundations.

Rouen 6th crossing bridge - France

Limited environmental footprint

Using less materials, requiring limited right of way and generating less CO_2 than conventional solutions, the Reinforced Earth® technique reduces the impact of construction on the environment.

Vegetalized TerraTrel® bording a river

Cost effectiveness

The ease and speed of construction as well as the economy of materials and a limited maintenance are significant advantages in reducing overall cost.

Adaptability

is the key word describing Reinforced Earth® as a composite material and construction technique which provides solutions to complex cases and often proves to be the best answer to circumstances such as restricted right-of-way, unstable natural slopes, marginal foundation conditions and large settlements.

Soil reinforcements

The choice and density of the soil reinforcement in a Reinforced Earth® structure is directed by the features of the project:

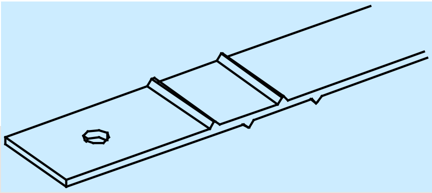
- The static and dynamic **design loads;**
- The select **backfill**, which can have demanding mechanical and chemical properties;
- The site **environmental** conditions;
- Specific and potentially aggressive **man made sollicitations**: vibrations, pollution, ...

Since the invention of the Reinforced Earth® technique at the beginning of the 60's, several soil reinforcement options have been developed in close collaboration with research laboratories and universities all over the world to provide clients with safer, more durable, environmentally conscious solutions and to give the right answer to fit to the characteristics of each project.

By offering a range of discrete reinforcement types, either metallic or geosynthetic, Reinforced Earth companies can customize each client's project for maximum structural, environmental and cost efficiencies.

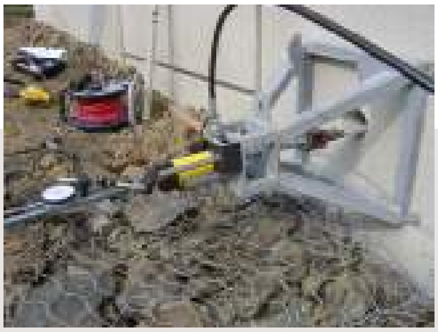
Galvanized steel reinforcements

High adherence steel strips and ladders are non extensible and unmatched for structural reliability and performance. Hot-dip galvanized steel soil reinforcement, when coupled with the complying select fill, can be designed for 100 years design service lives or more if required.



High adherence reinforcing strips (or **HA steel strips**) exhibit ribs perpendicular to their axis on both faces and a single bolt hole at one end for the connection to the facing. This is by far the most widely used Reinforced Earth® soil reinforcement with more than 40 millions square meters of structures built worldwide.

HA steel strips are the perfect solution for high static and dynamic design loads and the only sensible choice for high-end structures such as very high walls, bridge abutments, heavy duty mining and industrial retaining walls or railway supporting works.



The durability of galvanized HA steel strips in controlled environments is well documented and the adequacy between theory and practice has been proven for four decades. Durability samples can be placed in the Reinforced Earth® structures to validate the condition of the strips during the whole service life of the structures.

High adherence reinforcing steel ladders (or **HA ladders**) consist in two parallel round bars welded to a series of cross bars. One end of the ladder has a flat plate welded between the longitudinal bars with a bolt hole for the connection to the facing. HA ladders have an extremely high pullout capacity and are most avantageous in structures up to 6 meters high.

Geosynthetic reinforcements

Polymeric soil reinforcements have become an efficient solution when the chemical characteristics of the select backfill or the environmental conditions are not suitable to the utilization of galvanized steel. To fit to such conditions, Terre Armée Internationale has developed a comprehensive range of polymeric reinforcing strips.

GeoStrap® reinforcements are made of high tenacity polyester tendons contained in a polyethylene sheath. This soil reinforcement is particularly well adapted when the Reinforced Earth® structures are affected by the presence of chloride or sulphates, or in the case of a low pH level (acidic environment). High tenacity polyester yarns for soil reinforcement have been widely and successfully used all over the world for the past 20 years. The soil/strip adhesion capacity has been enhanced with the development of the **HA GeoStrap®** (patent pending) reinforcements which provide a strong advantage when friction is a governing design factor.

EcoStrap™ reinforcements, made of polyvinyl alcohol (PVA) tendons contained in a polyethylene sheath, are perfectly suited to high pH (basic environment) as it is the case when recycled concrete or lime (or cement) stabilized soils are used as the select backfill. EcoStrap™ polymeric strips also provide additional benefits in terms of stiffness and capacity to sustain higher temperatures.

The **HA EcoStrap™** strips (patent pending) are the ultimate geosynthetic soil reinforcement with enhanced frictional properties in addition to their chemical and mechanical benefits. They are particularly suitable for finer-grained backfill materials.

Facing options

The primary function of Reinforced Earth® facings is to provide local stability and erosion protection to the reinforced backfill. They also constitute the visible part of the structures and thus the **signature of the projects**.

A75 Motorway - France

Precast concrete panels for extended durability

Cruciform shape panel: TerraClass®

Standard precast concrete panels come in a **variety of shapes** (cruciform, square, rectangular and tee) **and dimensions** (from 2.25 m² to 4.5 m²) to fit to the technical and architectural requirements of the projects.

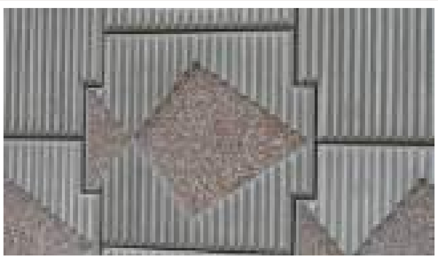
Rectangular shape panel: TerraPlus®

Square shape panel: TerraSquare®

Tee shape panel: TerraTee®

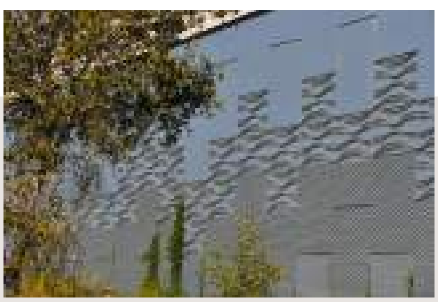
Rectangular shape panel: TerraSet®

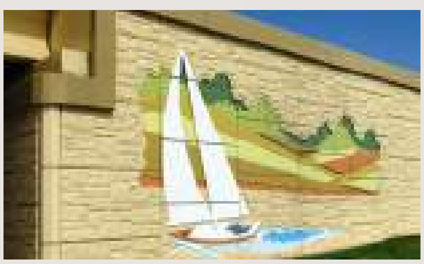
Architectural finishes for blending the structures into the environment



The most successful civil engineering projects are those which combine excellent performance with attractive appearance. Even on smaller scale projects, owners, architects and engineers are interested in demonstrating their professional capabilities by designing structures which æsthetical integrate into their environment and enhance their surroundings. Due to the diversity the facings proposed, the Reinforced Earth® technique offers extended æsthetical possibilities in addition to its well established high level engineering, fully in line with the sustainable development challenges.

The appearance of precast concrete panels can be enhanced by using either standard or customized architectural form liners. Additional æsthetical features can be obtained by specific treatments of concrete such as coloring or exposed aggregates.





Connections for all technical and environmental requirements


GeoMega® connection

The connection between soil reinforcements and precast concrete panels is a key characteristics of the Reinforced Earth® systems.

The well proven "**TA Classic**" connection is used with steel strips and HA ladders which are connected to galvanized tie strips embedded in the facing panels, using a high strength nut-bolt-washer assembly.

The **GeoMega®** solution is a fully synthetic connection embedded in the concrete facing panel during precasting. Combined with GeoStrap® or EcoStrap^{TM} soil reinforcements, it allows Reinforced Earth® structures to be constructed in chemically aggressive environments.


TA Classic connection

Steel for lightweight and versatility


Vertical wire mesh facing

Steel mesh facings associated with steel reinforcements (**TerraTrel®** system) or geosynthetic strip reinforcements (**GeoTrel®** system) are used for a variety of permanent or temporary applications. They are perfect solutions for cost-effective delivery to remote locations.


Inclined wire mesh facing


Mineral TerraTrel®

Combined with stones, TerraTrel® and GeoTrel® systems provide extended æsthetical possibilities to integrate the structures into their environment. They can also be used for vegetalized steepened slopes.


Vegetalized TerraTrel®


TerraMet® facing

The **TerraMet®** facing, consisting in galvanized semi-elliptical steel panels and associated to steel strips, combines unique characteristics such as lightweight, structural properties and continuity which makes it particularly suitable for industrial and mining applications.

Straightforward construction

The construction of Reinforced Earth® structures requires neither scaffolding nor heavy weight machine. In addition to the traditional earth-moving equipment used to place and compact the backfill, a light crane is necessary to move concrete facing panels. Handling of steel facings can be done manually.

Installation of facing panels

After the placing of the first row of panels on a smooth finish concrete pad which is well-levelled to ensure a correct initial positioning, the upper rows of panels are installed as the backfilling operations process. In the case of concrete facing panels, elastomeric bearing pads are installed inside the horizontal joints between panels to provide enhanced flexibility and compressibility to the facing.

Placing of soil reinforcements

The reinforcement layers are spaced 70 to 80 cm apart, which generally correspond to twice the thickness of the backfilling layers. They are installed on the compacted backfill layer and connected to the facing panels, either bolted in the case of steel reinforcements, or threaded through specific connections in the case of geosynthetic reinforcements.

Backfilling and compacting

The backfill is placed in layers 30 to 40 cm thick and compacted with the adequate equipment. The compacting rate at any point of the Reinforced Earth® structure should be 95% of the Normal Proctor optimum as it is the case for road backfills.

Roads & motorways


Badarpur - New Delhi - India


Culiacancito - Mexico


A40 motorway - France

The Reinforced Earth® technique has been widely used in the past 50 years for the construction of roads and motorways, in urban, suburban, country and mountainous environments.

Most applications are for the construction of retaining walls, either single or tiered, supporting roadways:

- access ramps to viaducts
- complex grade separations at interchanges
- structures on slopes
- road widening

Reinforced Earth® benefits are obvious in case of foundation soils with low bearing capacities and limited right of way such as in urban areas.

The short construction time, the minimum disruption of traffic and the geometrical flexibility make Reinforced Earth® a sensible choice for the owners and engineering consultants.

Reinforced Earth® walls along highways and local roads frequently include standard or customized architectural finishes, adding beauty to functionality.


A73 Blerick - The Netherlands


Al Nahda interchange - Sharjah - UAE

Altunizade intersection - Istanbul - Turkey


State Route 431 - Carmel - Indiana - USA


Spaak interchange - Montpellier - France



Haan-Gruiten noise absorbing wall - Germany


Snider Diamond Toronto - Ontario - Canada

The Reinforced Earth® structures associated to railways are of one of two distinctive types, those which stand adjacent to the tracks and those which support the tracks.

Structures adjacent to the tracks require no specific foundation, take up very little space for construction and are adaptable for bends and curves. They can be built with a minimal impact on the rail traffic.

Hundreds of Reinforced Earth® structures support railways and light rail systems in many countries. The applications use the same technology as that used for roads. However design is adapted to comply with the stringent requirements related to heavy load and safety, especially for high-speed and heavy freight railways. Reinforced Earth® structures absorb the vibrations induced by passing trains, inherently well and are designed to accommodate sudden heavy loads and associated braking decelerations in addition to vibrations.

Widening of railway embankments can be performed with Reinforced Earth® structures built either adjacent to or on top of the existing embankment.


FT Worth Intermodal - USA


Bordeaux Tramway - France


Shinkansen - Shin-Onomichi - Japan


Charlotte Light Rail Transit - NC - USA


Kyung-Bu high speed rail - South Korea


Gautrain - Johannesburg - South Africa

APPLICATIONS
Bridges

A87-A71 - Vierzon - France

Bridge abutments are considered as critical structures and the unique strength and load distribution capabilities of Reinforced Earth® address that criticality in an economical and structurally efficient way.

For many road or railway bridges, a beam seat can be supported directly on the reinforced soil mass, thus eliminating the use of piers and piles. Such pure abutments are perfect solutions in case of compressible foundation soils. If the foundation soil is very compressible the combination of soil improvement and Reinforced Earth® techniques is a very cost effective solution compared to piled and cast-in-place concrete abutments.

Going one step further in terms of engineering, Reinforced Earth® integral abutments eliminate the need for structural bridge bearings and expansion joints, thus considerably reducing the operational and maintenance costs of the structures.

When piles are necessary, reinforcing strips can be placed between them as they are easily diverted. In both configurations, the shallow foundation depth, typical of Reinforced Earth® structures and, the limited use of cast-in-place concrete, lead to significant time and cost savings.

Combined with TechSpan® concrete arches, another technique developed and implemented by Reinforced Earth® companies, Reinforced Earth® bridges can be constructed, providing highly technical characteristics associated to æsthetically pleasing features.

Putty road - NSW - Australia

Gerede-Gumusova motorway - Turkey

George Street Bridge - New Jersey - USA

A432 - France

Hydraulic works


Majaz canal Sharjah - UAE


Langkawi seawall - Malaysia


Taylor Draw dam - Colorado - USA

A variety of hydraulic Reinforced Earth® structures have been built worldwide, including retaining walls supporting river or coastal roads, quay walls, sea walls, dykes, dams, weirs and reservoirs.

The Reinforced Earth® technique offers specific advantages for hydraulic works:

- Resistance to very severe pressure of water through waves, tidal actions, storms, ice, flooding and rapid drawdowns
- Resistance to shocks and collisions
- Comprehensive range of soil reinforcement to fit to aggressive environments (sea or brackish water, chemicals...)
- Speed of erection of the structures in dry and tidal conditions

The adaptability of the Reinforced Earth® technique is evidenced in hydraulic works since depending on the nature of the structure to be built, solutions can be proposed to suit very diverse requirements in terms of water tightness. While Reinforced Earth® structures with a very good drainage capacity can be built to cope with tides or rapid drawdowns, the application of waterproofing membranes, either on the front face or on the back face of the panels, allows to obtain water tight Reinforced Earth® structures, a key benefit for reservoirs or dams.

Whilst the Reinforced Earth® technique is being used to construct new structures, it has also proved to be an efficient solution to raise the crest of existing dams or dykes and to rehabilitate dams which were in a poor condition, thus contributing to the upgrading of valuable assets and to the protection of lives and properties.


RN202 bis - Baus-Roux Saint Isidore - France


OCCA marina - Omaha - Nebraska - USA


Prado dam - Corona - California - USA


Trekkopje reservoir - Namibia


Lake Lenexa dam - Kansas - USA


Kromellenboog dam - South Africa

New Acland coal mine - Queensland - Australia

Reinforced Earth® structures are resistant to vibrations and can support the extreme live loads associated with fully loaded mine vehicles.

The versatility of the facing technology means that concrete panels, semi-elliptical steel panels or welded wire mesh can be used to conform to the required geometry (face inclination, straight or curved alignment). The choice of facing also depends on the required design life of the structure and factors such as site location.

In addition to retaining walls and bridge abutments, the Reinforced Earth® technique allows to build a variety of specific mining structures:

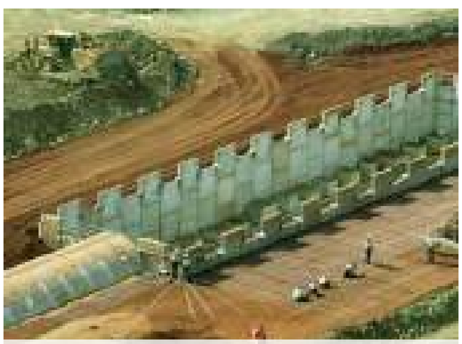
- Dump walls
- Storage silos and reclaim bunkers for coal, iron ore...
- Feed chamber units
- Containment dykes
- Haul road overpasses
- Reservoirs for mining wastes

Today several hundreds Reinforced Earth® dump-walls are in service in mines on all continents, and many of them rank among the highest Reinforced Earth® structures.

Ukhaakhudag (UHG) coal mine - Mongolia

Veladero mine - Argentina

Freeport mine - Indonesia



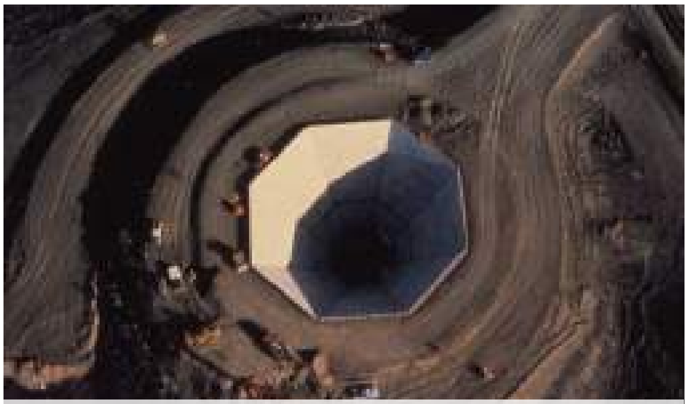
Iron ore mine - Western Australia

Dorstfontein coal slot storage - South Africa

Syncrude - Alberta - Canada

APPLICATIONS
Industry & Energy

Calide power station - Australia



«Glory hole» coal handling facility - Canada

From the early days, Reinforced Earth® companies were asked to assist in solving construction problems on industrial and energy sites. Since then efficient solutions for handling, storage and protection applications have been developed and implemented.

Industrial and energy Reinforced Earth® structures have unique features such as:

- Load bearing capacity (heavy equipment and machinery)
- Resistance to vibrations (crushing and screening)
- Outstanding resistance to thermal variations (accidental fires)
- Shock absorbing capacity (explosions, impacts)

The **working safety** is an essential parameter on industrial and energy sites and it is ensured when building Reinforced Earth® structures which can resist to accidental fires lasting several days in storage silos or to extreme temperatures differences, from -160°C for liquefied natural gas up to a flame temperature of about 1100°C. After such events, minimal repair works are required.

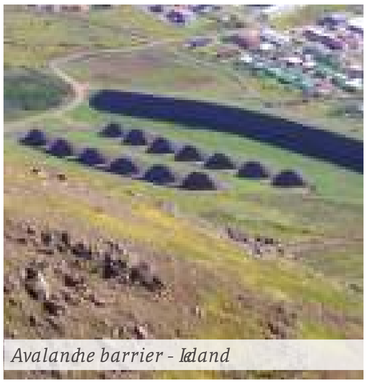
Blast barrier - Townsville - Australia

Oil sands separator tanks - Muskeg - Canada

Containment dykes of ammonia tanks - Montoir - France

Valdez pipeline terminal - USA

Quality of life



Avalanche barrier - Iceland

Kyushu - Japan

Gaspé seawall - Québec - Canada

With its technical and architectural benefits, the Reinforced Earth® technique provides solutions for bettering the quality of life in a broad meaning.

Risk mitigation

Reinforced Earth® structures have been built to protect lives and properties against natural disasters as well as industrial hazards. Strength and ductility are two essential features of the technique when the structures are submitted to earthquakes, avalanches, tsunami waves or explosions.

The analysis of structures which have been actually affected by earthquakes has demonstrated that Reinforced Earth® performed extremely well as a construction material in such events and, confirmed that the safety level and the design were particularly well adapted.

Land development and architectural applications

The architectural flexibility of the Reinforced Earth® technique clearly appears when, working closely with architects, city planners or landscapers, it is used for land development or housing. Concrete facing can have many types of patterns and finishes and steel mesh facings provide durable solutions to the construction of steep sided embankments easily fitting into the environment, either by covering with vegetation or by decorative rocks.

Reinforced Earth® is a unique and versatile construction material, adequate not only for infrastructures but also for buildings such as stadiums.

Den Bosch - The Netherlands

Medical Center Atlanta, Georgia - USA

Noise absorbing panels - Germany

Crailo ecoduct - The Netherlands

Pueblo Bonito - Mexico

"Our experience,
Your success"

REINFORCED EARTH

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