



GEOGRIDS REINFORCED SLOPES

TENAX

Man. Technology. Environment.

GEOGRIDS REINFORCED SLOPES



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On the cover.
*Construction of a reinforced embankment
for the creation of a cell at the Ischia Podetti
Landfill in collaboration with Bautechnik and
Ter System Srl.*

In the following pages.
*25.000 sqm reinforced slope facade as part
of the hydraulic remediation project in the
area of the Val Pola landslide (Italy).*



Mankind has often chosen to settle in locations with a good geographical position and favorable environmental conditions, even though in some cases the land is not well suited to the construction of residential, productive, and commercial buildings.

Slopes, mountainsides, and harsh sites- over time have been modified with continually developing technologies and methods. Hillside control works, consolidation of road embankments, slopes subject to landslides, rockfall barriers, canals, dams, and landfill sites are just a few of the many applications for geogrid reinforced slopes using geosynthetic elements – a structural technique used throughout the world in advanced civil engineering, environmental, and geotechnical projects which fully respect the environment.

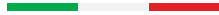
OUR HISTORY

TENAX was established in Viganò Brianza (Lecco) in 1960, following the advent of polypropylene and thanks to its technological ability to transform this new polymer into grid-like structures.

Technical skills and internationalization have allowed us a strong development, enabling us to create products and solutions in different sectors such as gardening, agriculture, industry, construction, and geotechnics.

Within the latter category, since the 80s, we've developed a diversified range of geosynthetic products: high-tech plastics materials, which represent an economical solution with less impact on the environment than works carried out in civil engineering and environmental projects with traditional solutions.

MADE IN ITALY



All TENAX products are developed in research and development laboratories before being entirely manufactured in our own plants, which are also designed and created independently.

A sophisticated monitoring system applied to all automated production plants, constantly collects data on each batch under production.

The so obtained data allows the entire process to be constantly monitored with a dual advantage both in terms of production planning and quality control.

TECHNICAL-SCIENTIFIC SUPPORT

“Technical Competence Centre” is a TENAX in-house structure made up of a team of technicians, problem-solving oriented, always close to the customer, which offers a wide range of specialized services such as:

- On site inspection;
- Feasibility studies and executive projects;
- Technical data and costs analysis for tender specification;
- Installation guideline and instructions;
- On site staff training;
- Independent laboratory tests following the European and international standards;
- Organization of seminars, scientific workshops, and corporate training.

“AD HOC” SOLUTIONS AND PRODUCTS

The wide range and ready availability of geosynthetics products allow TENAX to promptly satisfy most of the project requirements.

We have always been supporting our clients by offering technical expertise with “tailor made” solutions from the design phase up to the on-site implementation.

New products with on-request, specific characteristics, are manufactured in synergy with the internal TENAX laboratory where mechanical, hydraulic and durability tests necessary for the their development, are carried out.

OUR ECO-FRIENDLY COMMITMENT

Protecting who has always welcomed us is our goal. TENAX's commitment to protect the environment is realized thanks to the use of eco-friendly production technologies, performance optimization and energy saving, waste reduction and the use of 100% recyclable polymers. With a crucial purpose: economic, social, and environmental sustainability.



TENAX has started a process for defining the sustainable strategy in collaboration with LifeGate. (www.lifegate.it - Milano FM 105.1).

TENAX products and systems are certified by the most accredited international bodies. In order to develop, test and promote Geosynthetics we cooperate with qualified University and Research Institutes.

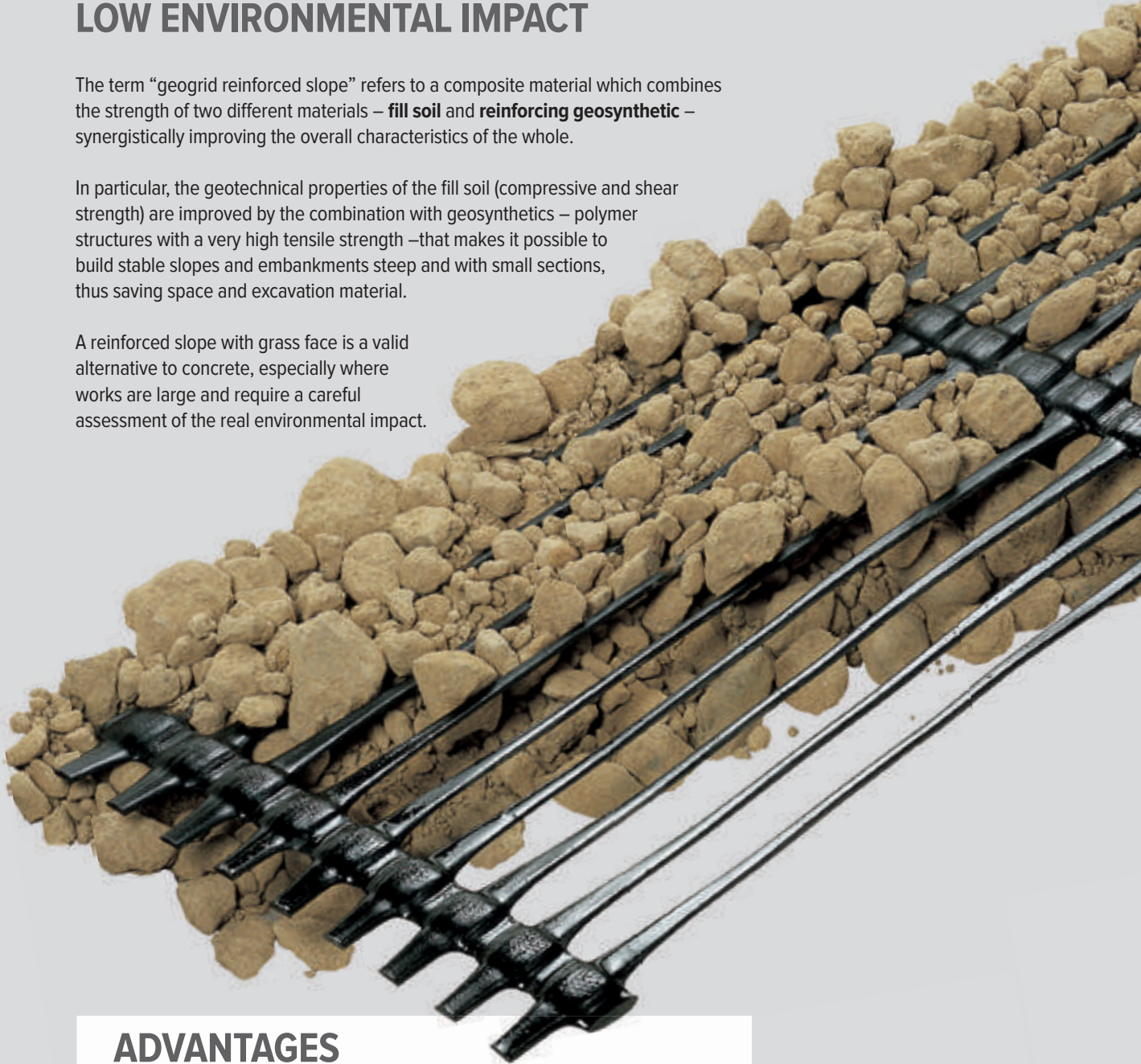
<p>Certifications</p> <p>ISO 9001 ISO 14001</p> <p>0799-CPR-25</p> <p>Environmental Product Declaration</p> <p>UK CA</p>	<p>Memberships</p> <p>AGI</p> <p>igs</p> <p>uni</p> <p>AssINGeo</p>	<p>Active participation in Geosynthetics technical committees: UNI, CEN, ISO.</p>
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TENAX GEOSYNTHETICS: INNOVATIVE, HIGH PERFORMANCE SOLUTION, LOW ENVIRONMENTAL IMPACT

The term “geogrid reinforced slope” refers to a composite material which combines the strength of two different materials – **fill soil** and **reinforcing geosynthetic** – synergistically improving the overall characteristics of the whole.

In particular, the geotechnical properties of the fill soil (compressive and shear strength) are improved by the combination with geosynthetics – polymer structures with a very high tensile strength –that makes it possible to build stable slopes and embankments steep and with small sections, thus saving space and excavation material.

A reinforced slope with grass face is a valid alternative to concrete, especially where works are large and require a careful assessment of the real environmental impact.



ADVANTAGES

Construction of geogrids reinforced slopes is easy, fast and it does not require skilled labor or special machinery. The components can be manually moved and, most often, on site material can be used as fill soil, thus saving space and excavation material.

- **SPEED OF EXECUTION**
- **EASY TO INSTALL**
- **COSTS SAVING**
- **REALIABILITY**

TENAX RIVEL System



The patented **TENAX RIVEL** System is used in soil protection works, characterized by low or zero environmental impact. It represents an advanced reinforced slope technology, in which the synthetic reinforcement element is a 100% HDPE (High Density Polyethylene), integral junction, **TENAX TT** mono-oriented geogrid.

*On **TENAX** industrial site, located in the heart of the green Brianza hills, it has been necessary to expand the products storage yard. Embankments were built by using **TENAX RIVEL** System, which enabled to increase the space up to the property edges, thanks to the construction of 10 m high walls, with 75° slopes, completely grassed and planted with shrubs and tall trees.*



THE SYSTEM VERSATILITY

Geogrid reinforced slope technique is usually used in large environmental and landscape engineering projects, being a valuable tool for slope consolidation and prevention of hydrogeological instability phenomena.

Thanks to its flexibility and installation easyness, **TENAX RIVEL** can be used either in small works and for stabilization and alignment of slopes, embankment, banks, or to reduce the environmental impact in construction works.



Ecopark Durazzo: 21 m high reinforced embankment to reduce thrust on a 28 m high concrete climbing wall.



Bridge abutments, Peljesac Bridge, Croazia.



Terraced gardens using TENAX reinforced slopes at Merano Botanical Garden, Italy.



Special maintenance and stabilization of the cliff under the historical site in Genzano di Lucania (PZ).



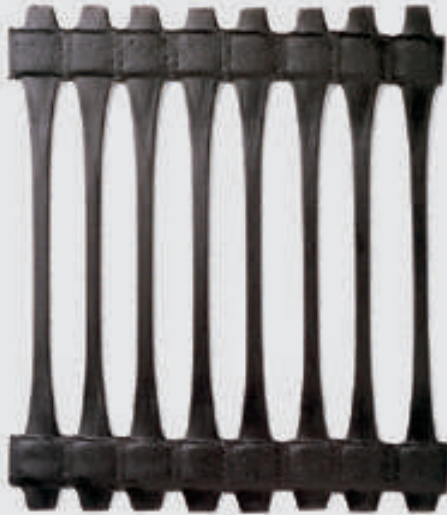
Repair of a collapsed slope in Serravalle Pistoiese on the Firenze-Lucca railway line.

COMPONENTS OF THE SYSTEM

TENAX TT geogrids

The reinforcement

TENAX TT geogrids are bidimensional structures manufactured by extruding and uniaxial stretching of HDPE, certified from ITC-CNT (Istituto per le Tecnologie della Costruzione- Consiglio Nazionale delle Ricerche) for the construction of reinforced steep slopes up to 85°.



Junction Strength

Junction strength is a fundamental parameter to evaluate the lateral confinement provided by the geogrid to the soil and therefore the pullout behavior of the geogrids itself. In addition, whenever a longitudinal junction (edge to edge), between two portions of geogrids is required it can only be done by means of bodkin connectors. For the bodkin Junction Strength is structurally fundamental as it allows the transmission of forces from one portion of geogrid to another.

Geogrids are designed based on their Long-Term Design Strength (LTDS). Therefore, they can never be subjected to tensile stresses greater than the LTDS. A rational approach to a specification is that the junction strength of a geogrid must be equal to at least 1.50 x LTDS, as for TENAX TT geogrids. If this ratio is met, then no further safety coefficient needs to be applied for the connection strength.

There is a clear difference between the junction strength of extruded geogrids and those of woven and welded geogrids, for which the junction strength is equal to a maximum of 20% of the peak value.



Bodkin:
longitudinal connection of two pieces of TENAX TT geogrid.

Available in 500/1000 m Jumbo rolls.

Long-Term Design Strength (LTDS)

TENAX TT geogrids have been continuously subjected to tensile creep tests up to 30 years, at various temperatures; extrapolation to 1,000,000 hours (120 years), of the results of these tests provides a long-term resistance greater than 40% of the peak.

Long-term design strength of different geogrids on the market must be compared basing on a common test method, showing the behavior of the geogrids and not of their components; for example, creep tests on woven geogrid fibers can be misleading: the LTDS value equal to 60% of the tensile strength refers to the fiber constituting the woven geogrid while the actual value could correspond only to 40% of the peak.

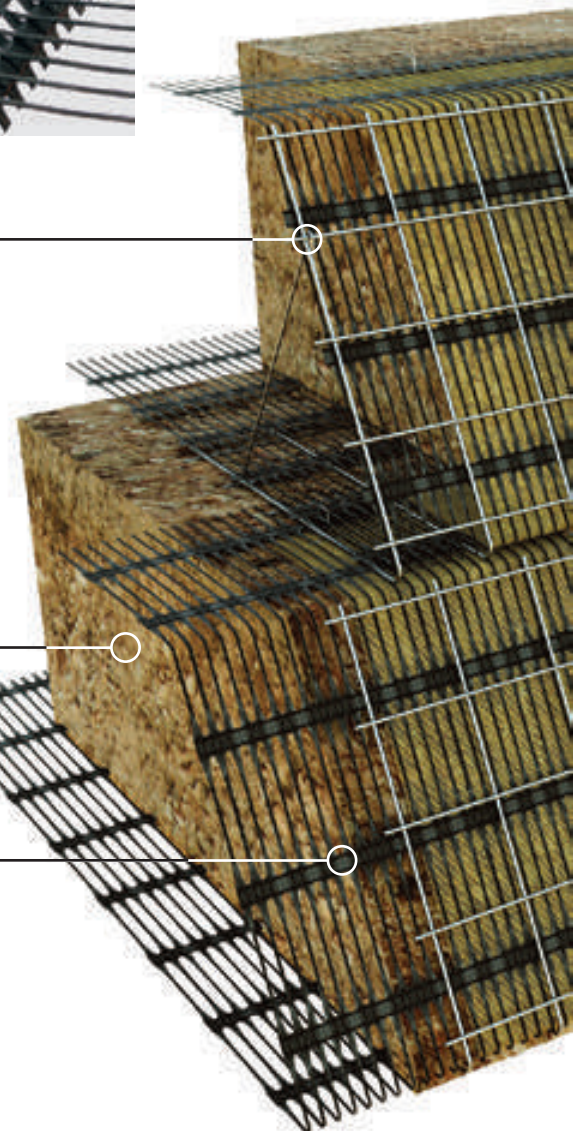
TENSILE STRENGTH OF TENAX TT GEOGRIDS (ITC 580/02 Certificate)

		TT045	TT060	TT090	TT120	TT160
Peak tensile strength	kN/m	45	60	90	120	160
Yield point elongation	%	11.5	13	13	13	13
Junction strength	kN/m	36	50	80	110	130
Long-term design strength (LTDS 120 years)	kN/m	18.5	24.6	36.9	49.2	65.6
Strength at 2% strain	kN/m	11.0	17.0	26.0	36.0	45.0

Steel formwork

Fill material

TENAX TT Geogrids



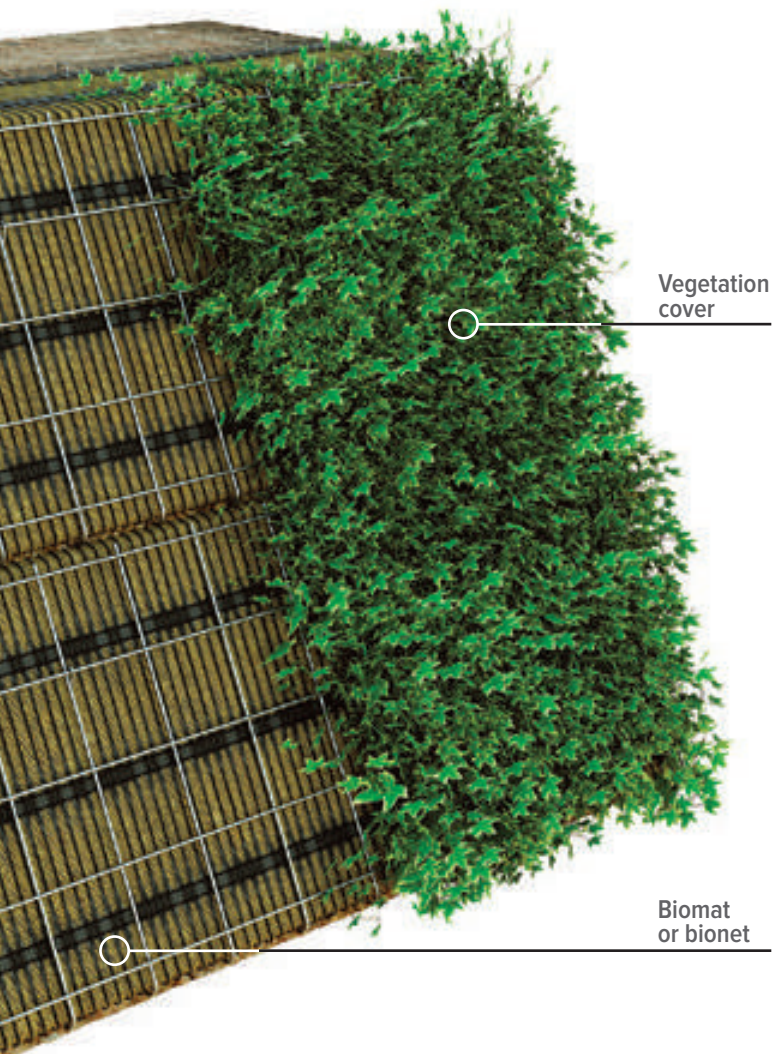
Construction Damage Resistance

When fill material, especially sharp gravel, is spread and compacted over the geogrids, they can be damaged by the puncturing and abrasion effects of the aggregate. Extensive test programs carried out to evaluate the residual tensile strength of various geosynthetics subjected to laboratory and full scale damage procedures, show the complete difference performance of extruded geogrids and woven geogrids.

The production process of TENAX extruded geogrids allows to obtain a product with elements (longitudinal and transversal) able to guarantee the continuity of the molecular chains over the entire monolithic structure of the geogrid.

Such structure is less affected to shear, abrasion, perforation, and compaction damage, even under high impact energies such as direct unloading of the aggregate onto geogrids. The Safety Factor to damage during construction is shown in Table B1.

Unlike, the individual fibers constituting the longitudinal and transversal elements of woven geogrids are easily cut by the aggregate particles and the thin coating in PVC or similar materials, is not enough to protect them.



Indication on the reduction parameters due to mechanical damage for different geosynthetics reinforcements available on the market has been provided by the Federal Highway Administration of the USA (Elias, 1996), as illustrated in Table B2.

Table B1

SAFETY FACTOR FOR DAMAGE (I.T.C.)		
Soil	D_{max} particles (mm)	Factor f_{m21}
Aggregate with stones	< 125	1.07
Large grade aggregate	< 75	1.03
Medium grade aggregate	< 40	1.00
Sand, clay and silt	< 6	1.00

Table B2

Reinforcement type	Soil type	
	D_{max} 100 mm	D_{max} 20 mm
	D_{50} 30 mm	D_{50} 0.7mm
PVC-coated PET woven	1.30 - 1.85	1.10 - 1.30
Woven geotextile (PP and PET)	1.40 - 2.20	1.10 - 1.40
Nonwoven geotextile (PP and PET)	1.40 - 2.50	1.10 - 1.40
Slit film Geotextile (PP)	1.60 - 3.00	1.10 - 2.00

Chemical Resistance

Chemically aggressive environments can affect the long-term performance of geogrids depending on their polymer composition. HDPE is universally considered the most inert polymer and therefore, the most resistant to chemical attack.

Tests performed in the USA on TENAX TT geogrids in accordance with standard E.P.A. 9090, certify that they are not affected by chemical attack resulting from substances naturally occurring in the soil, or even in particularly aggressive environments (i.e. Municipal Solid Waste Landfill).

No safety coefficient for chemical resistance needs to be applied for TENAX TT HDPE geogrids.

On the other hand, after 20 months' exposure to an environment with a pH of 9, PET might suffer a loss of strength of 9% (even in clean water, over a similar period, hydrolysis causes a 3% loss of strength).

For PET materials (geotextiles or woven geogrids) without suitable resistance certificates, the American FHWA suggests adopting very conservative partial safety factors.

	REDUCTION FACTORS FOR CHEMICAL ATTACK FOR DIFFERENT DEGREES OF ACIDITY OF THE GROUND (FHWA)		
	$3 \leq pH < 5$	$5 \leq pH < 8$	$8 \leq pH < 9$
PET geotextiles	2.00	1.60	2.00
PVC-coated Woven PET geogrids	1.30	1.15	1.30

TENAX TT geogrids are stabilized by mean of a carbon black which protects the polymer from degradation caused by UV rays.

COMPONENTS OF THE SYSTEM

Fill Material

Geogrids reinforced slopes technique allows the use almost any kind of fill soil; however, the use drainage of granular material with a high internal friction angle, possibly without large size pebbles which would make compaction difficult is preferable.



When using on site material with poor geomechanical properties, mixing with sand and aggregate is recommended. Likewise, poor soil can be lime treated.

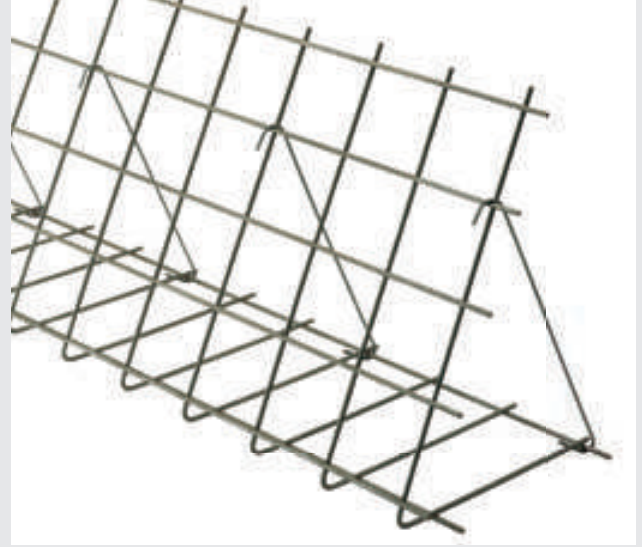
The use of this technique is effective with extruded HDPE geogrids, but it cannot apply to PET reinforcement as it is subject to chemical degradation in alkaline environment.

To create the optimal condition to favor the growth and durability of vegetation, the use of topsoil at the face is strongly suggested.

The fill material should be placed and compacted in layers, with a recommended thickness of 0.30-0.35 m, so to reach a compaction not less than 95% of the Standard Proctor.

Welded Steel Mesh Formworks

On the face of the structure TENAX RIVEL System uses a welded "sacrificial" formwork (ø 6-8 mm / mesh 15x15 cm). It has no structural function but provides a guide for a quick installation and an accurate alignment of the structure.



Formworks are supplied with stiffening rods (1 every 0,45 m approx).

Fire Resistance

To evaluate the effects on the stability and integrity of a reinforced structure with TENAX TT geogrids, the following situations must be considered:

- Fire after installation, before vegetation growth. In these conditions, the reinforcing element on the facade could be damaged by the fire; however, the steel mesh formworks used in the RIVEL System provides effective support to the facade soil even in the event of localized damage of the reinforcing element. The stability of the structure, on the other hand, is not compromised at all, since the reinforcement part that gives stability is the one inside the ground. For a fire to spread, the presence of a fuel and an oxidizer is necessary. All plastic materials, even if self-extinguishing are combustible, while the comburant necessary for the flame propagation is oxygen.
- Inside the ground of the reinforced slope the comburant is missing; the flame, without oxygen, has no way to spread and then damaging the portion that is important for the stability of the structure.
- Fire after installation with grassed slope. In this case the real fuel is grass; the flames spread above the surface of the ground, as flames typically spread upwards; therefore, the burning surface is distant from the reinforcing element present on the facade.

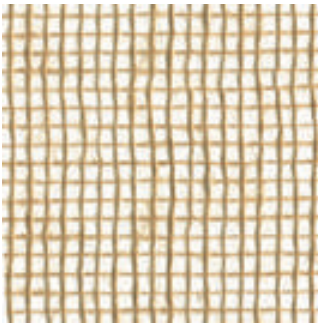
Erosion Control Mat

In every naturalistic engineering work, vegetation plays an active role in the slope protection. A finish work without a proper vegetative cover will look uncompleted and less effective.

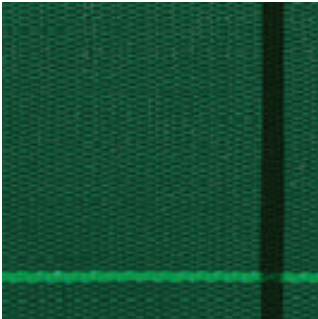
The grassing of the face by hydroseeding hides the artificial elements of the system and drastically reduces the environmental impact of the slope.

Biomat

Usually, perennial herbaceous species belonging to the legume and gramineae family are used for the grassing with hydroseeding of the geogrid reinforced slopes. The time for germination and greening of the structure can range from four to eight weeks, depending on the seasonal weather conditions. Carrying out hydroseeding in the wetter months of the year is advisable. To protect reinforced slopes from erosion and provide a suitable surface for hydroseeding, a jute, straw, or coconut fiber biomat can be used on the face of TENAX RIVEL System.

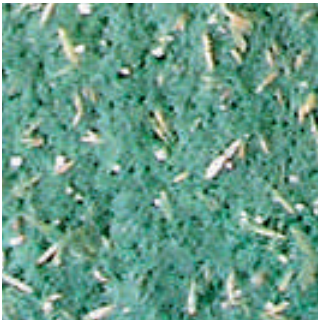


Mulching



The green covering of the face can also be done with ivy or climbing plants. In this case the use of a mulching sheet is suggested as it prevents the spontaneous growth of any herbaceous or shrubby essence present in the soil, thus allowing better maintenance of the greenery.

Pre-seeded Vegetative Felt

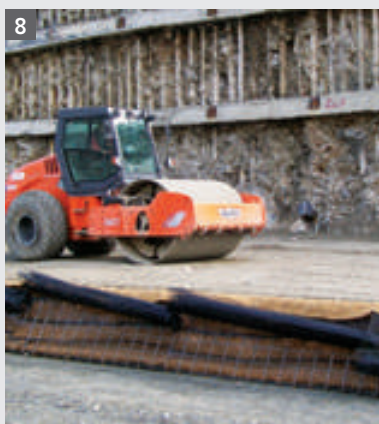
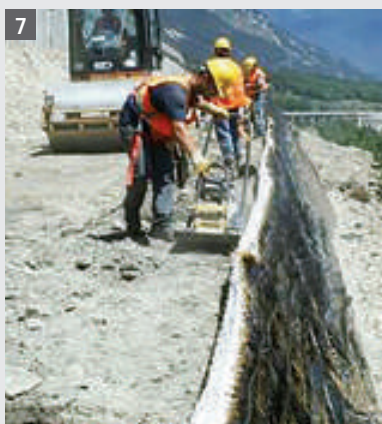
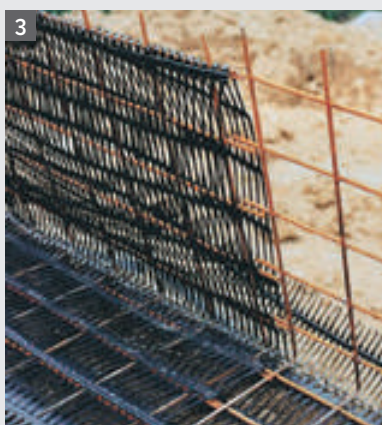


To avoid hydroseeding costs and extra work, TENAX FVP Pre-seeded Vegetative Felt can be used. It consists of a biodegradable cellulose fibers geotextile containing seeds of various herbaceous species and fertilizers: The Pre-seeded Vegetative Felt allows rapid, widespread, and uniform growth of the vegetation and guarantees total coverage of the face, minimizing the removal of seeds and topsoil by atmospheric agents.

The slow biodegradation of the textile supports its germination which, being ecofriendly, does not alter the balance of the surrounding ecosystem. The choice of mix and quantity of seeds per square meter can be specifically conceived for specific design, soil and climatic conditions requirements. The face of the slope can be greened by planting cuttings, shrubs, bulbs and other plants, placed between one reinforcement layer and the other. In this way a uniform cover effect is guaranteed.



INSTALLATION PROCEDURES



TENAX RIVEL system is easy to install and does not require skilled labor. For best results, however, it is essential to follow the specific design instructions and installation procedures.

1. Preparation of the foundation surface: To avoid excessive settlement of the structure and possible deformations of its geometry, foundation must be adequately prepared. Including a drainage layer at the base is advisable. Alignment mark of first row of the embankment (photo 1).

2. Assembly of the system:

2.1 Place and align the steel formworks by connecting them together with steel wire;

2.2 Unroll the geogrids and cut them according to the design requirement lengths (better to set up a specific area to perform this operation). The length is determined by the anchoring depth, the face overlap (approx. 70 cm) and the upper overlap (150 cm typically) (photo 2);

2.3 Place the cut geogrids on the foundation inside the formwork perpendicularly to the face; the geogrid must run along the inner face of the formwork and extend outwards by the overlap portion (approx. 150 cm) (photo 3);

2.4 The rear ends of the geogrids must be fixed to the ground with U-shaped steel pins to keep the geogrids tight and in position;

2.5 Proceed with the erosion control mat: internally line the front by unrolling the mat provided in rolls of appropriate height (approx 100 cm) (photo 4);

2.6 Place the retaining rods to stiffen the formwork at 45 cm spacing approximately (photo 5).

3. Spreading and compacting the fill material:

3.1 Spread the fill material provided on site over the geogrid in approx. 30 cm thick layers; in proximity of the face, using **topsoil (approximately 25-30 cm)** it is advisable (photo 6).

3.2 Use a light vibrating roller and compact until achieving a compaction not less than 95% of the Standard Proctor. For the area closest to the face, for a width of approximately 1 m, compact using a hand vibrating compactor or vibrating plates. In the rear area suitable capacity compactor roller are used (photo 7 and 8);

3.3 Once the filling operation is completed, fold back the portion of geogrid, previously left outside the metal formwork onto the compacted embankment, stretch it slightly and secure it with U-shaped steel pins.

4. Repeat the installation operations from step 2.1 to step 3.3 until the design level has been reached.

5. Where a pre-seeded erosion control mat is not being used, proceed with hydroseeding the facade or with planting ground-covering plants, shrubs, or cuttings.

CONSTRUCTION DETAILS



Geogrids are overlapped at the front or back depending whether the section is concave or convex.



Safety-rules compliant railing on construction site.



Placement of drainage pipes.



Placement of steel drainage tiles.

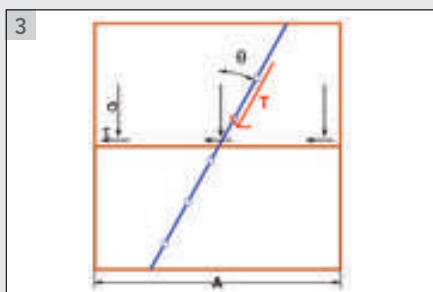
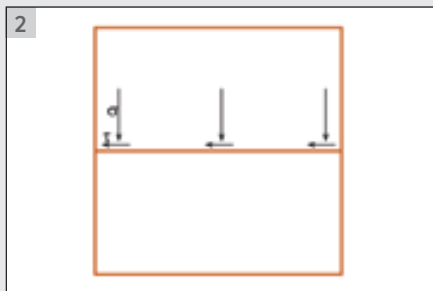
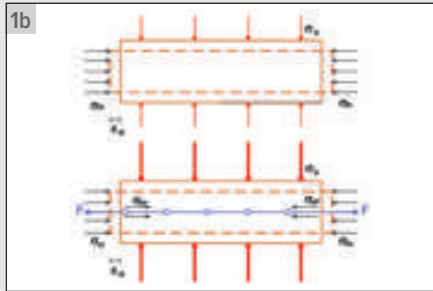
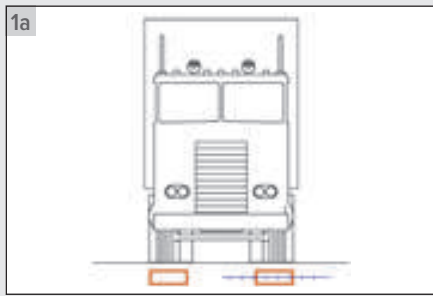


Creation of bends and corners. Positioning of metal roof tiles for the outflow of surface water.



Detail of the connection between reinforced slope and existing concrete structure.

BRIEF THEORY



A simple model helps explaining the principle behind geogrid reinforced slopes technique. A soil element (Fig. 1a), part of an indefinite mass, when subjected to a vertical stress σ_v undergoes horizontal deformation ϵ_h . The adjacent soil counteracts this deformation with a horizontal confinement action σ_h . When a reinforcement element is inserted into the soil (Fig. 1b), the horizontal deformation ϵ_h experienced by the soil causes deformation of the reinforcement itself, to which the reinforcement reacts with a force F, resulting in additional compressive stress σ_h^* . The inclusion of a reinforcement element therefore increases the soil's compression resistance. Considering the shear stresses (Fig. 2) in an incoherent soil element, we have:

$$(\tau_{xy})_{\max} = \sigma_y \cdot \tan \varphi_{\max}$$

where:

φ_{\max} = maximum soil shear resistance angle;

$(\tau_{xy})_{\max}$ = maximum soil shear stress.

When the soil element is crossed by a reinforcement element inclined at an angle θ respect to the vertical (Fig. 3), the state of stress is modified; the tension force T generates a shear stress produced by the tangential component $T \cdot \sin\theta$, the normal component $T \cdot \cos\theta$ generates another τ_{xy} due to the soil's friction angle φ_{\max} .

$$\begin{aligned} (\tau_{xyr})_{\max} &= \underbrace{\sigma_{yr} \cdot \tan \varphi_{\max}}_{\substack{\text{Total} \\ \text{shear} \\ \text{resistance}}} + \underbrace{(T/A_s) \cdot \cos \theta \cdot \tan \varphi_{\max}}_{\substack{\text{Shear stress} \\ \text{generated} \\ \text{by the normal} \\ \text{component of T}}} + \underbrace{(T/A_s) \cdot \sin \theta}_{\substack{\text{Shear stress} \\ \text{generated} \\ \text{by the tangential} \\ \text{component of T}}} \end{aligned}$$

where:

A_s = area of the reinforcement element.

$(\tau_{xyr})_{\max}$ = maximum shear resistance value of the reinforced soil.

In this way, the normal stress on the soil element is increased by:

$$\sigma_y^{\wedge} = (T/A) \cdot \cos \theta$$

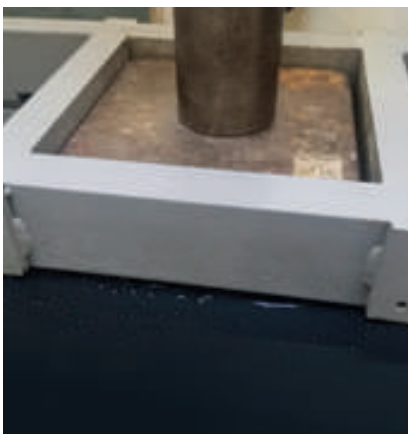
while the maximum shear stress that the soil can withstand is increased by:

$$\tau_{xyr}^{\wedge} = (T/A_s) \cdot \cos \theta \cdot \tan \varphi_{\max} + (T/A_s) \cdot \sin \theta$$

The factors influencing the shear resistance of reinforced soil are:

- Strength and stiffness of the reinforcement related to the surrounding soil;
- Position of the reinforcement;
- Shape of the reinforcement, which should be able to develop a high apparent friction angle at the interface with the soil;
- Creep characteristics (elongation under constant tensile load) of the reinforcement during the project lifespan;
- Durability of the reinforcement.

In particular, the geometric structure of the reinforcement must ensure high friction to prevent potential slipping of the reinforcement due to the tensile force T it is subjected to. It should be noted that overly rigid reinforcement, such as a metallic element, may break at small deformations without mobilizing high strength values. On the other hand, excessively extensible materials (such as nonwoven geotextiles) would not be able to provide sufficient reinforcement unless significant deformations occur, typically incompatible with the lifespan of a structure.



Shear Test conducted at Tenax S.p.A. Laboratory.

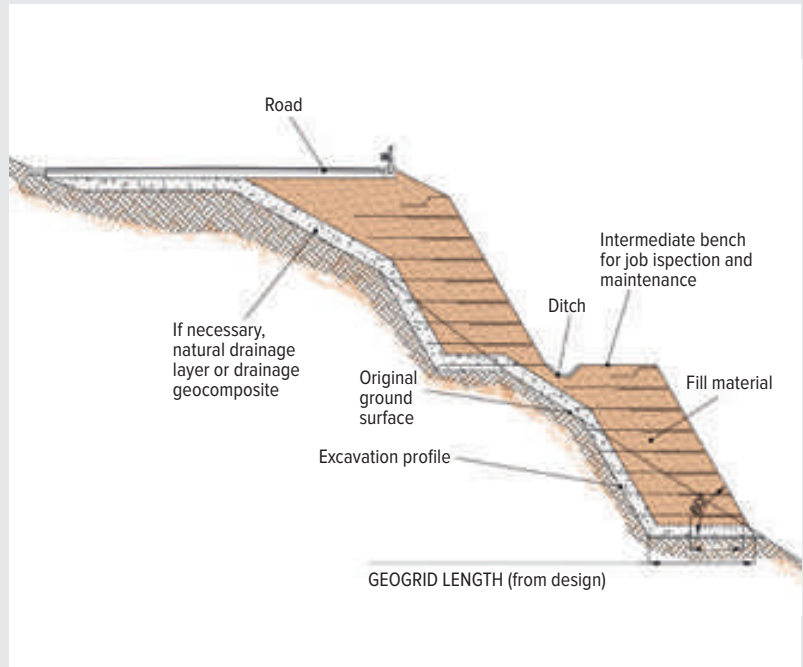
DESIGN OF REINFORCED SOIL STRUCTURE

Supporting element for design in the light of current regulations

The stability analysis of a reinforced soil structure is generally a fairly simple operation, but anyway necessary. Underestimating the importance of such analyses, as well as neglecting the necessary preliminary investigations outlined below, can lead to design or construction mistakes which could result in medium term stability issues.

Before designing, it is advisable to proceed as follows:

- Perform a topographic survey of the project area to obtain detailed plan and cross-sections;
- Gather geotechnical and hydrogeological data of the site, including soil composition, layering, water presence, seismic activity, geomechanical properties (effective friction angle Φ , cohesion c' , and soil unit weight γ). Conduct particle size analysis to ensure proper design and implementation of an effective water collection and drainage system.
- Gather relevant “historical” information regarding past events such as landslides and active or potential sliding surfaces that have affected the area.
- Define the structural geometry and determine surcharges to be considered in the design process.



The design of a reinforced soil structure follows a logical and systematic approach.

There is a specific limiting slope angle β_{lim} , within which an unreinforced slope can be constructed safely.

In the event of incoherent and dry material, the limiting slope angle is equal to the internal friction angle of the soil: $\beta_{lim} = \Phi$.

A slope with an inclination greater than the limiting angle is defined as a steep slope. Additional forces must be provided to guarantee the equilibrium of a steep slope.

Reinforced Slopes technology consists of providing these additional forces by inserting reinforcement layers.

A limit equilibrium analysis allows to determine these additional forces, with an adequate safety margin and against any potential failure mechanism. Every possible failure surface has to be evaluated; for each of them, forces inducing soil movement (self-weight, additional loads, dynamic loads due to earthquakes or impacts, interstitial pressures) vs resisting forces (friction, cohesion, and, of course, the strength of the geogrids) should be considered. Different failure surfaces can be used: circular, linear, bilinear, logarithmic spiral, polyline; advanced and complex surfaces could be more accurate but certainly require higher but not strictly requested computational efforts.

Safety Factor is calculated as the ratio between the maximum resisting shear force and the acting force developed along each surface. The surface having the lowest Safety Factor is considered as the critical one.

There are various software on the market based on different failure mechanisms, but they essentially exploit the same principle and allow these verifications by analyzing a significant number of surfaces and choosing the critical one among them.

Stability verifications of a reinforced soil structure are carried out in accordance with the provisions of the locally available Technical Standards for Construction.

Usually, the stability analysis of the structure is carried out at the ultimate limit states (ULS).

Considering the nature of the structure, its flexibility, and deformability, serviceability limit states does not appear to be critical, as the structure can withstand deformations that do not compromise its functionality and use.

Displacements and deformations that could limit the use of the construction, its efficiency and layout, may only occur in the event of structural collapse, and therefore, as a consequence of load and stress conditions covered by the verifications at the more stringent ultimate limit states (ULS).

For seismic checks, the designed works must comply with the Ultimate Limit States verified in the seismic field, setting the partial coefficients on the actions and geotechnical parameters equal to unity and using the design resistances with the appropriate partial coefficients γ_R . The seismic action must be combined with the other design actions.

The safety analysis of retaining walls under seismic conditions can be performed using pseudo-static methods. Calculation model must include the retaining structure, the volume of soil behind the structure, and any additional loads acting on that volume.

In the pseudo-static analysis, the seismic action is represented by an equivalent static force equal to gravitational forces multiplied by an appropriate seismic coefficient.

TENAX RIVEL System | Rockfall barrier



To ensure the protection from the risk of rockfall of residential buildings or transit routes located behind mountain areas, the use of active technological solutions (aimed at preventing detachment) or passive solutions (aimed at intercepting or diverting moving blocks) is possible. Such structures can be designed and dimensioned to reduce the risk or vulnerability associated with rockfall and collapse. In particular, passive defense structures are typically positioned to intercept the trajectory of falling rocks.

The definition of the block's motion and the kinetic energy to be absorbed are crucial factors for proper design.

Rockfall embankments made up with the TENAX RIVEL System are passive protection structures more efficient compared to high energy absorption metal barriers because:

- They provide **effective protection** even in the case of repeated collapses along the same direction;
- They require **minimal maintenance**, even after extensive collapse events, and they are not subject to corrosion;
- They are **durable** and resistant to deterioration;
- They have a **negligible environmental impact**, particularly after the structure is properly vegetated;
- The **collapsed material available on site can be reused**.

The TENAX RIVEL reinforced slope System offer several advantages compared to traditional embankments:

- **Smaller base footprint**, resulting in a reduction of the amount of soil to be moved;
- **Fewer difficulties in identifying suitable areas** from a planimetric and altimetric perspective;
- **Lower risk of the structure being overpassed** by rolling rocks thanks to the steeper face inclination.

Comparison between TENAX RIVEL rockfall barrier and metal gabion embankments filled with stones

The impact of a boulder on the face of a metal gabion embankment produces splinters which could overpass the embankment itself, as their trajectory cannot be predicted in advance. On the contrary, TENAX RIVEL embankment can “absorb” the impacting rock without shattering it. Following the impact, the metal mesh of the gabions could tear, causing partial or total emptying of the gabion and compromising the stability of those above, with the real risk of triggering a dangerous and uncontrollable domino effect.

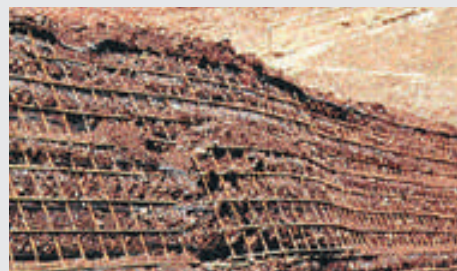
The function of the metal mesh of the gabions is solely to contain the filling material, whereas in TENAX RIVEL System, geogrid and soil interact permanently, resulting in an improvement in the strength of the structure. Each gabion in a rockfall barrier system transmits the impact almost elastically to the adjacent gabion, and from the last gabion to the soil, which can be thrown outward. TENAX RIVEL System requires to spread and compact the soil, significantly reducing its deformability, thereby guaranteeing the integrity of the elements composing the structure, even after a violent impact on its face.

The greater “binding” of the soil allows a distribution of the load over a greater volume; the area of influence, approximately conical, therefore has a wider opening involving a greater mass of soil involved in impact resistance and energy dissipation.

Video recording from real-scale tests carried out on rockfall embankments reinforced with TENAX geogrids, revealed a movement of the downhill face after reaching the peak displacement. This effect is certainly due to the presence and action of the geogrids. The observed formation of tension cracks at the top of the embankment, combined with this rebound effect, suggests that in the absence of a connection between the uphill and downhill faces, the barrier can be breached, or at the very least, the volume of soil isolated by the tension cracks may collapse on the downhill side.



The reinforced rockfall barrier after the impact shows minimal damage.



Negligible displacement of the embankment's lower face.



A rocky boulder stopped by TENAX reinforced rockfall barrier in the Créton area of Rhêmes Saint-Georges municipality (Italy).

In reinforced slope, the soil is “bound” by geogrids. Despite the significantly reduced geometry compared to a traditional embankment, the tensile strength provided by the geogrids and their high resistance to sliding prevent the breakthrough of the embankment by rocks.

When the embankment's crest width is less than 2.00 m (particularly narrow structures), to enhance the binding effect, placing a second reinforcement structure perpendicular to the main one (i.e., longitudinally to the embankment) is possible.

TENAX TT geogrids exhibit an elastoplastic-viscous behavior in relation to the magnitude and duration of loads. Analysis of the stress induced by impact, which can be represented as a sudden and intense load, has demonstrated a stiffening effect on the geogrid-soil system. An increase in the elastic modulus, resulting in a steeper force-deformation curve and lower strains of the geogrid are observed. The short duration of the impact event prevents viscous deformations (creep) developments; consequently, the geogrid reinforcement can mobilize a tensile strength close to its peak value, rather than relying on the long-term strength typically considered for static loads.

Numerous full scale tests and subsequent scientific publications illustrate

the interaction model between TENAX TT geogrids and the soil in the event of dynamic load application.

Certification of TENAX Rockfall Barriers

The reinforced slope barriers using TENAX TT geogrids have undergone repeated trials at the Vigo di Meano (Italy) test field, accredited by the Polytechnic University of Turin and at Erzberg (Austria) accredited by the University of Trento. Following these tests, TENAX system has been certified by both Universities, which have confirmed the effectiveness of barriers reinforced with TENAX TT/GS extruded geogrids.

The certificates issued for reinforced barriers using TENAX TT 045 geogrids indicate that they can be constructed with both frictional behavior soils (good-quality material) and cohesive plastic materials. With frictional fill, the barriers have demonstrated their ability to withstand repeated impacts from rocks with an energy level of approximately 7000 kJ.

The results can be extended to any structures whose minimum geometry ensures compliance with the proportions of the certified structures.

TENAX RIVEL System | Noise protection barriers



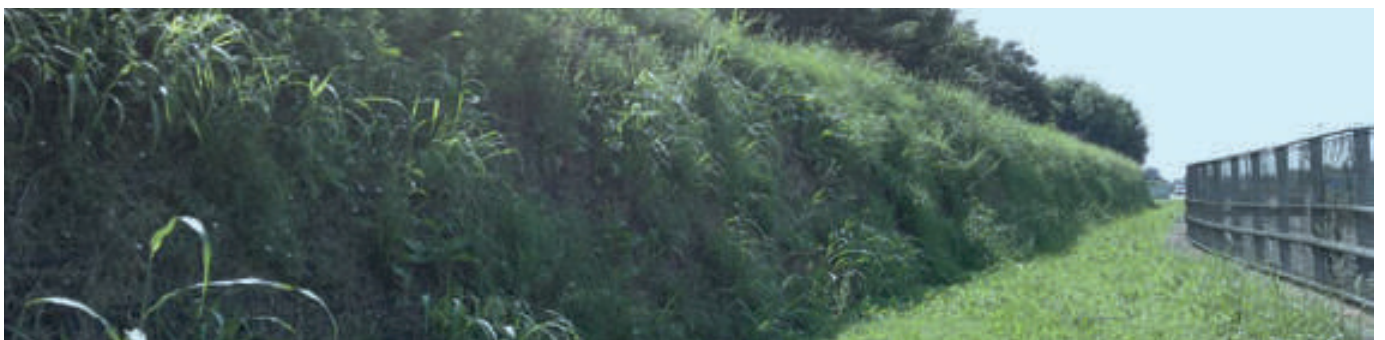
In recent years, increasing attention has been given to environmental issues, specifically to the problem of noise pollution which leads to the necessity to build noise barriers near residential areas and urban centers, especially along busy roads, highways, and railways.

Traditional solutions typically involve the use of prefabricated panels of various types and finishes, which effectively reduce noise levels. However, these conventional solutions often show significant visual drawbacks as they do not harmonize with the surrounding environment and can cause disruptions, particularly due to their considerable length that is often required.

TENAX RIVEL System: the green solution

The highly effective alternative solution, increasingly adopted in recent years, is the construction of **reinforced slopes noise barriers**. Several projects have been implemented throughout Italy.

The success of this approach lies in its **better integration with the natural landscape** and the **simplicity of the construction system**. The embankment face can be covered with local vegetation, ensuring perfect integration with the surrounding environment. **The construction process is fast** and does not require skilled labor or large machinery.





Works on the A51 ring road in Milan for the construction of a noise barrier using vegetated reinforced slopes, to protect adjacent residential areas. The structure is approximately 300 meters long and 3 meters high.



Northern Ring Road of Pavia. Construction of a 400-meters-long noise barrier and wing walls using vegetated reinforced slopes, covering a total face area of 2500 square meters.

Integration between functionality and aesthetics

TENAX offers an integrated solution, the RIVEL System, that allows the construction of noise barriers using grassed reinforced slopes as an excellent alternative to traditional prefabricated panels.

Functionality is ensured by the soil mass held within the geogrids, which acts as a protective element against noise sources.

Aesthetics are guaranteed by the presence of vegetation on the face. The inclusion of greenery significantly reduces the visual impact of the structure, even for high barriers, while maintaining a natural appearance.

The TENAX RIVEL system allows the building of reinforced slopes with limited support surfaces, making them particularly suitable for areas with limited space availability.

Certified effectiveness

Thanks to a **research collaboration between TENAX and CIRI Edilizia e Costruzioni - Alma Mater Studiorum University of Bologna**, a field verification was conducted on the intrinsic acoustic characteristics of a noise barrier built with the TENAX RIVEL system.

The measurements were carried out at the construction site of Assago Green Village in Assago (Italy), adjacent to the Eastern ring road of Milan, an area known for high traffic flow and significant noise pollution.

The studied reinforced slope is a 6 m high, 300 m long green wall, which is also a base for a cycle path on top.

The results confirmed the effectiveness of the adopted solution: **TENAX RIVEL system was certified as a highly effective noise barrier**, with good *reflection index* and *sound insulation indexes*.

The construction of noise barriers using the TENAX RIVEL system provides an alternative solution to traditional technologies, ensuring better integration with the landscape while maintaining excellent performance in noise containment and reduction.

TENAX T-BLOCK System



The systems used for the construction of retaining walls with geogrids and modular concrete facing have long been a solution known for their technical, aesthetic, and economic versatility.

TENAX T-BLOCK provides a valid alternative in terms of technical and structural aspects

compared to traditional reinforced concrete structures, especially when stone revetment is requested, as well as to precast reinforced or cellular concrete walls.

Its greater economic competitiveness is achieved by removing carpentry, concrete casting and pouring operations, with a reduction in overall cost of up to 25%.

*Above.
Pontoglio (Italy) - Improvement
of access ramp to a residential
complex.*

*On the right.
South Korea, Chunsugyo/Saebeari
- Highway embankment built with
a hybrid solution of retaining wall
System TENAX T-BLOCK.*

SYSTEM VERSATILITY

The great versatility of the TENAX T-BLOCK system is due to its extreme simplicity. Its technical and structural effectiveness is based on just three components.

Modular facing elements in reinforced concrete blocks

The geometry of the TENAX T-BLOCK modular concrete element has been successfully used for over 30 years in the construction of retaining walls, wing walls, bridge abutments, road access ramps, and many other structures, demonstrating its versatility even in private construction projects. **The geometry of the T-BLOCK modular element ensures high resistance to static and dynamic loads transmitted by the soil, while guaranteeing maximum easiness and speed of installation.**

TENAX TT geogrids for soil reinforcement behind the facing wall

The TENAX TT mono-oriented geogrids with integral junctions are reinforcement elements with a high elastic modulus and junction strength $\geq 80\%$ of the maximum tensile strength value. The continuous planar distribution of reinforcing geogrids allows both anchoring the facing wall and internally reinforcing the soil in a uniform manner, with a more effective action than anchoring systems made up of isolated and discrete strips or bars.

The high “elastic modulus” reinforcement geogrids TENAX TT, are manufactured in 100% HDPE to ensure complete chemical inertness and resistance to the phenomena of stray currents.

T-CLIP element for block/geogrid mechanical connection

The patented T-CLIP connection element allows an effective mechanical connection of the TENAX TT reinforcement geogrid to the T-BLOCK facing elements.

The T-CLIP connector, made of 100% HDPE, is a patented component designed to develop a strength comparable with the design reinforcement tension when used together with the TENAX TT geogrid.

ADVANTAGES

TENAX T-BLOCK system offers many advantages compared to traditional methods while maintaining the same design standards.

- No height limitations;
- Limited footprint of the area facing the structure;
- Cost savings compared to reinforced concrete solutions and stone-clad walls;
- Fast construction times, even in tight spaces, thanks to easy installation by unskilled personnel;
- Lightweight and compact blocks that can be easily manually installed without mechanical equipment;
- Extremely durable system with a water-repellent and “freeze-thaw resistant” architectural facing, fire-resistant.
- Designed to withstand static and dynamic loads;
- Good ability to absorb dynamic effects resulting from seismic actions;
- Design lifetime up to 120 years;
- High standard finishes and possible customized aesthetic solutions;
- Numerous successful projects worldwide;
- No maintenance required.



COMPONENTS OF THE SYSTEM

TENAX TT Geogrids

The reinforcing element

TENAX TT geogrids are bidimensional structures manufactured by extruding and uniaxial stretching HDPE. This technology allows to manufacture products with remarkable technical qualities, enabling their use in innovative solutions.



TENAX TT geogrids, chemically inert and with high tensile strength, are specifically designed for soil reinforcement. Soil or aggregate particles interlock within the geogrid openings, providing an effective confinement action that limits relative movement and improves shear resistance.

Under normal loading, the particles create an interlock between the two faces of the geogrid; so that it's necessary to reach a minimal tensile value to cause movement.

The soil-geogrid composite structure behaves as if it has an intrinsic tensile strength. The introduction of the geogrid generates a sort of cohesion in otherwise non-cohesive materials.

The soil-geogrid structure combines the high compressive strength of the particles with the tensile strength of the geogrid, creating a material that has greater stiffness and stability than aggregate alone.

The ability of the geogrid to receive and redistribute forces further enhances the characteristics of resistance to static and dynamic loads.

TENAX TT geogrids represent an innovative solution from both a technical and economic point of view in all applications that require improvement in the characteristics of granular, cohesive, loose, or bounded materials.

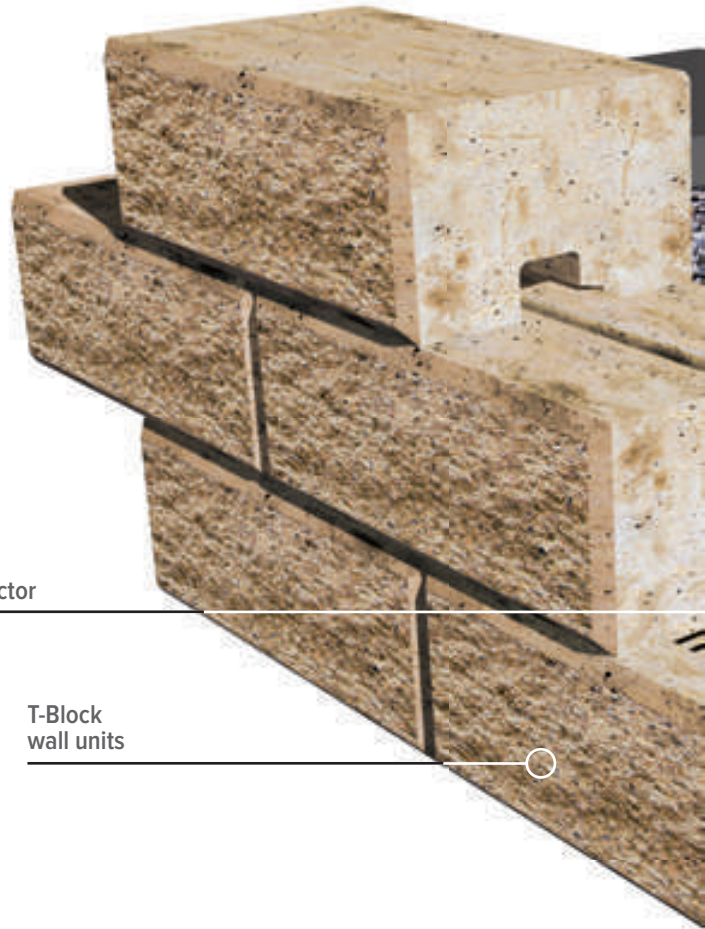
TENAX TT geogrids are manufactured and controlled according to the procedures established by the TENAX Quality System implemented and certified according to ISO 9001:2000 and ISO 14001:2015 standards.

This endures the achievement and constant maintenance of the expected standards through an accurate control of all phases of the production, storage, delivery, and assistance process.

CONNECTION STRENGTH TENAX TT GEOGRIDS-BLOCK

		TT045	TT060	TT090	TT120
Connection Efficiency (*)	%	195	155	125	120
Long Term Design Strength	kN/m	21.2	28.3	42.4	56.5
Peak Tensile Strength at 2% deformation	kN/m	11.0	17.0	26.0	36.0

(*) Confining pressure 100 kPa, compared to Long Term Design Strength.



T-CLIP connector

T-Block wall units

T-Block wall units

Facing element

The T-BLOCK units are high strength precast concrete modular facing units with an average compressive strength of 20 MPa and a moisture absorption limit lower than 5%.



The face area of each individual block is 600 cm² (150 x 400 mm x 240 mm in depth). The block features a groove at the base and a rib at the top (male) for interlocking between blocks and a groove on both base and top (female) for interlocking at geogrids elevation, ensuring a securely connected face. To meet architectural/aesthetic requirements, the blocks can be customized in color to meet design specifications.

T-CLIP connector

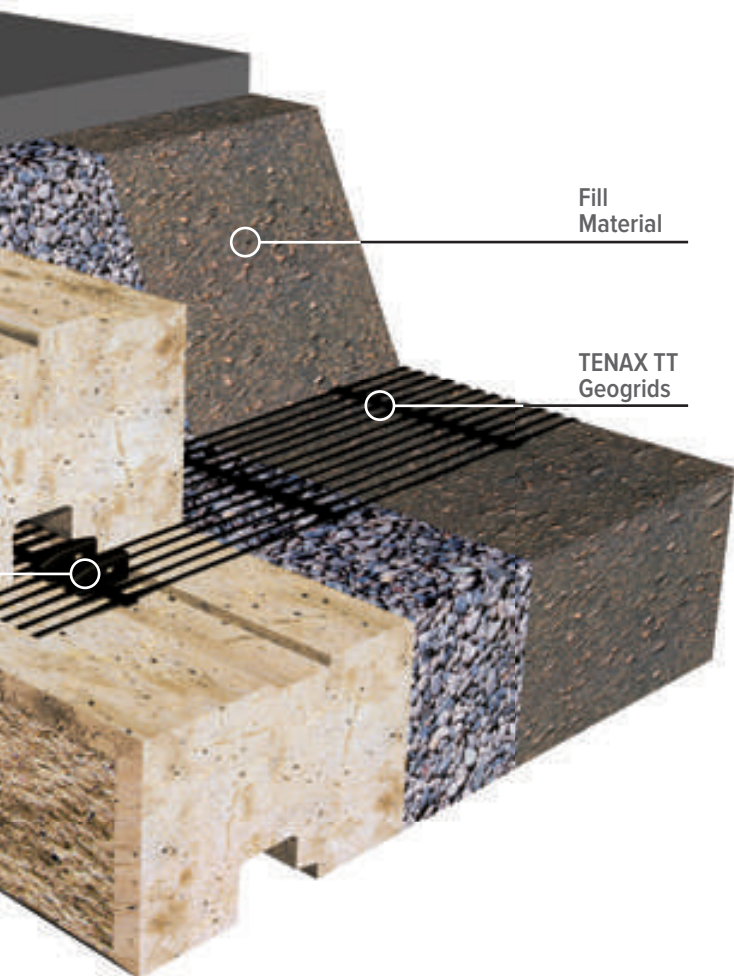
Connection element

The connection element T-CLIP is the result of 20 years of research and international experience in mechanical connection systems for geogrids and modular concrete blocks.



Among all the mechanical connection systems available on the market, T-CLIP ensures the achievement of the highest values of connection strength between the reinforcement element (integral HDPE geogrids) and the modular concrete blocks.

The previous experience in “Integrated Systems” was based on the “frictional connection” of block/geogrid components, with all the technical and practical limitations of this technology. This led TENAX to improve the system by simplifying and speeding up the installation process, searching for a small-sized connection element that easily attaches to the geogrids and fits into the top grooves of the female blocks, creating a fully integrated structure. This system allows for securely anchoring the reinforcement geogrids to the blocks and, at the same time, keeping them in the correct position relative to the subsequent layer, ensuring an extremely strong mechanical connection capable of developing tensions \geq the design tensions.



Fill Material

Typically, it consists of compacted granular material, which can be either locally selected or imported.

Carefully recycled, selected, or stabilized fill materials may be used, as long as they meet the minimum requirements specified in the design phase.



ARCHITECTURAL DETAILS



Construction of curved sections.



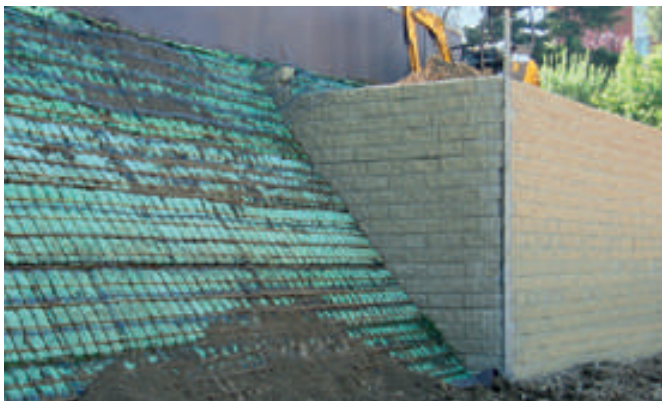
Connection with ramp.



Connection with fence.



Connection with ladder.



Connection with reinforced slopes.



Connection with green embankment.



Connection with reinforced concrete structures.



Creation of graphic elements, including different colors.

INSTALLATION PRECEDURES

Below is a summary of the main installation steps for the TENAX T-BLOCK system, details available on request.

Foundation Plan

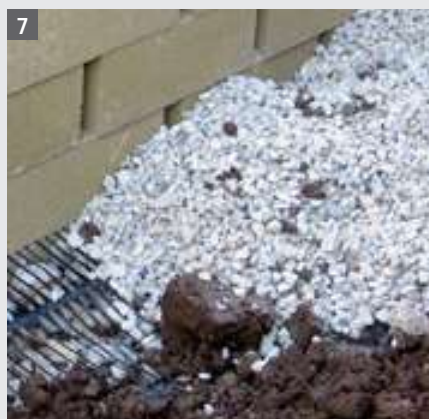
- A suitable foundation plan must be properly leveled and compacted (95% of the Proctor Standard is recommended) in order to lay the geogrids horizontally along the entire length of the project.
- The excavated material, if used for backfilling, should be protected from weather events.

Foundation Kerb

- The structure must rest on a properly sized concrete foundation curb (photo 1) to withstand the acting forces and ensure its bearing capacity.
- The kerb surface must be perfectly smooth and flat; embedment of a metal “profile” into the kerb to align the first row of blocks is possible.

Wall construction

- Lay the first row of blocks, paying particular attention to their longitudinal alignment and ensuring the top surface is perfectly leveled.
- Place a perforated drainage pipe behind the first row of blocks and spread a thin layer of gravel around it.
- Spread and compact the first layer of backfill material up to the high of the first selected geogrid level as per the design specifications.
- Compact the backfill material near the face using a small compactor roller or a vibrating plate, while using a heavier compactor roller as you move away from the front.
- Cut the pre-established lengths of the reinforcing geogrid portions (photo 2) and insert the T-CLIP connectors near the cross bar intended for interlocking (photo 3).
- Position the reinforcement geogrid portions at the designated heights, inserting them into the appropriate groove of the blocks.
- Continue with the next courses by placing the blocks and sliding them into the correct position (photo 4, 5, and 6).
- Complete the construction of the wall by placing and compacting the backfill material (photo 7), adding additional layers of geogrid and face blocks until the desired height is reached.



1. Foundation kerb.
2. Cutting of the geogrid.
3. Placement of the connectors.
4. Blocks placement on geogrids.
5. Blocks laying.
6. Blocks alignment check.
7. Drainage material behind the blocks

APPLICATION EXAMPLES



*St. Petersburg ring road, Russia.
Geogrid reinforced wing wall.*



*Seoul, South Korea.
Integrated solution with the urban context
of the surrounding area.*



*Sochi, Russia.
Work carried out for the Olympics.*

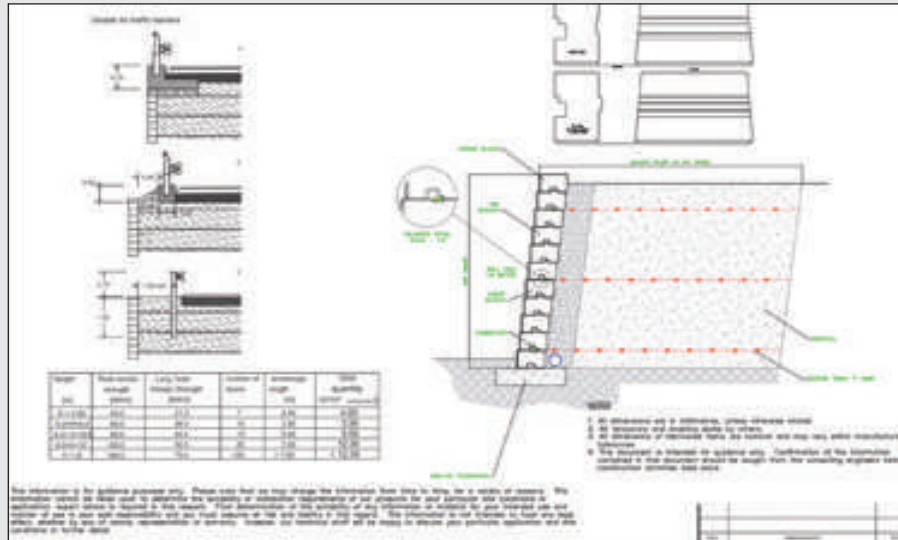
DESIGN ASSISTANCE

Experience gained in the Geosynthetics design allows TENAX's qualified team of engineers of the **Technical Competence Center (TTC)** to support customers (both public and private), designers and contractors with feasibility studies and detailed designed projects.

TENAX team also provides local assistance in:

- Installation support;
- Seminars, design workshops, and customized training;
- Use of specific software for geosynthetic design, offering a greater flexibility in managing design criteria to meet specific needs.

This flexibility allows TENAX engineers to perform the most suitable design for secure and cost-effective structures.



Detailed drawing by TENAX engineers for specific design requirements.



Educational seminar.



Installation support.



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Further information on geosynthetics and TENAX solutions is available upon request and on our website:

- Brochures;
- Technical Data Sheets;
- Installation Guidelines;
- Tender Specifications.



Geosynthetics for civil and environmental engineering



Landfills and contaminated sites



Geogrids reinforced slopes



Roads, railways, large areas



Landscaping and green areas