Mankind has often chosen to settle in locations with a good geographical position and favourable environmental conditions, even though in some cases the land is not well suited to the construction of residential, industrial and commercial buildings. Slopes, mountainsides and inhospitable sites have been modified over time with continually developing technologies and methods. Hillside control works, the 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.
INTRODUCTION TO REINFORCED SLOPES

The term “geogrid reinforced slope” refers to a composite material which combines the strength of two different materials – fill soil and reinforcing geosynthetic – a combination which is synergistically improved. The geotechnical properties of the fill soil (compressive strength and shear strength) are improved by being combined with geosynthetics – polymer structures with a very high tensile strength – making it possible to construct and stabilise slopes and embankments with very steep inclines and small sections, thereby saving space and excavation material.

In the context of soil protection works with low, or zero environmental impact, the patented TENAX RIVEL System – an advanced reinforced slope technology – is used. The geosynthetic reinforcement element is an HDPE (high-density polyethylene) mono-oriented geogrid from the TENAX TT SAMP range. The system comprises of three elements: the reinforcing geogrid, the fill material and the facing elements.

A reinforced slope with a grassed face is a valid alternative to reinforced concrete, especially where the works are of a large scale and thus have a real environmental impact. On the TENAX industrial site, located in the heart of the green hills of Brianza (Italy), it has been necessary to increase the size of the storage facilities. Embankments were constructed using the TENAX RIVEL system, which has enabled the space right up to the edge of the site to be fully utilised by the erection of 10-metre high walls, with an inclination of 75°.

The face of the structure was completely grassed in a matter of weeks from the completion of construction and then planted with shrubs and tall trees. The two embankments follow the curvature and contours of the site and meet at the ramp forming the entrance; in the photograph below, the long “green wall” is broken up by a diagonal ramp and merges well with the surrounding countryside.
Geogrid reinforced slope technology is generally used for large-scale environmental engineering projects and in landscape planning as it is a valuable working tool for the consolidation of slopes. The flexibility of the TENAX RIVEL system and the simplicity of its installation means that it can also be employed in small-scale construction projects. For example, in the private sector, it can be used for the consolidation or profiling of inclines, steep slopes and banks, or to reduce the environmental impact of buildings and structures.

Photographs 2 and 3: retaining structures slope crest enlargement for a new residential development.

Photograph 4: railway embankment for a new railway track.

Photograph 5: architectural solutions to reduce the environmental impact of the construction of a new access to a private house.
Photograph 1 and figure 6: works to prevent landslip above the lay-by area of Grontone, along the Autocamionale della Cisa included major precision drainage works, the re-profiling of the slopes to a geometry which would guarantee their stability and their erosion control protection using matting made of natural material (straw and coconut bio-mats), reinforced with steel mesh. And at the foot of the slopes, the construction of completely grassed geogrid reinforced slopes.

Photograph 7: an example of environmental re-classification: the former Combi quarry in the province of Lecco (Italy). The geogrid reinforced slopes are now environmentally friendly hillsides following the planting of native tree species.

Photograph 8: geogrid reinforced sound deadening barrier, built along the Bologna-Casalecchio dual carriageway.

Photograph 9: supporting structure behind a residential area.

Photograph 10: A32, Savoulx-Bardonecchia stretch: non-routine maintenance works to improve safety conditions, including the construction of a fourth lane.

Photograph 11: retaining structure on landfill site with a mechanical plant access ramp.
The TENAX RIVEL system is easy to install and does not require the use of specialised labour. For best results, however, it is essential to follow the specific design instructions and installation procedures.

1. Preparation of the foundations:
   To avoid excessive settlement of the structure and possible deformation of the geometry, it is important that the foundations are suitably prepared to take the design load. It is also advisable to put in place a basic drainage layer. Mark out the line of the embankment (Photograph 1).

2. Installation of the system:
   2.1 Position and align the metal formwork components, attaching them to each other with wire;
   2.2 Unwind the rolls of geogrid and cut them to the lengths stated in the design (it is advisable to allocate an area for carrying out this operation). The length is determined by the anchoring depth, the return on the face (approx. 70 cm) and the length of the return at the top (150 cm minimum);
   2.3 Position the cut lengths of geogrid carefully on the foundation level inside the formwork, in layers perpendicular to the face; the geogrid must run along the internal face of the formwork and extend approx. 150 cm outside (to form the return) (Photograph 2);
   2.4 The ends of the cut lengths of geogrid are to be fixed to the ground with U-shaped steel pins to hold the geogrid taut and in position.
   2.5 If required install the erosion control matting ensuring adequate coverage (Photograph 3);
   2.6 Position the retaining bars that are used to brace the formwork at approx. 45 cm intervals (Photograph 4).

3. Spreading and compacting the fill material:
   3.1 Spread the fill material over the geogrid in layers approx. 30 cm thick; near the face, it is advisable to use a depth of 25-30 cm of topsoil to allow for the rapid establishment of grass growth (Photograph 5);
   3.2 Use a vibrating roller and compact to not less than 95% of the Proctor Standard up to 1 m from the face. For the area closest to the face, compact using a vibrating compactor or vibrating plates (Photograph 6 and 7);
   3.3 Once the filling operation is completed, turn back the section of geogrid, previously left outside the metal formwork, onto the compacted embankment, tension it slightly and secure 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, hydro-seed the face or plant ground-cover plants, shrubs, or cuttings.
THE SYSTEM COMPONENTS

The reinforcement component

TENAX TT SAMP geogrids are two-dimensional structures manufactured from HDPE by a process of extrusion and mono-directional drawing and are certified for the construction of steep reinforced slopes with inclines of up to 85° by the ITC-CNR (Institute for Construction Technology-National Research Council).

LONG-TERM DESIGN STRENGTH (LTDS)

TENAX TT SAMP geogrids have undergone tensile creep tests for over 10 years at various temperatures. From the results of these tests, extrapolated to 1,000,000 hours (120 years), a long-term strength greater than 40% of the peak strength is obtained.

The long-term strength of various geogrids on the market must be compared on the basis of the same test method, showing the performance of the geogrid and not of its components. For example, creep tests on the fibres of woven geogrids are misleading: the LTDS figure of 60% for tensile strength relates to the fibre of which the woven geogrid is made, whereas the effective figure is actually 40% of the peak.

Table A - TENSILE STRENGTH OF TT SAMP GEO (Certified ITC no. 580/02)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>U.M.</th>
<th>TT045 SAMP</th>
<th>TT06 SAMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>kN/m</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>Peak deformation</td>
<td>%</td>
<td>11.5</td>
<td>13</td>
</tr>
<tr>
<td>Strength of joins</td>
<td>kN/m</td>
<td>36</td>
<td>50</td>
</tr>
<tr>
<td>Long-term strength (LTDS) at 120 years</td>
<td>kN/m</td>
<td>21.2</td>
<td>28.3</td>
</tr>
<tr>
<td>Strength at 2% elongation</td>
<td>kN/m</td>
<td>11.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

Table B1 - SAFETY FACTOR FOR DAMAGE (I.T.C.)

<table>
<thead>
<tr>
<th>Type of ground</th>
<th>(D_{\text{max}}) of particles (mm)</th>
<th>Factor (f_{\text{m2}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate with stones</td>
<td>&lt; 125</td>
<td>1.07</td>
</tr>
<tr>
<td>Large-grade aggregate</td>
<td>&lt; 75</td>
<td>1.03</td>
</tr>
<tr>
<td>Medium-grade aggregate</td>
<td>&lt; 40</td>
<td>1.00</td>
</tr>
<tr>
<td>Sand, clay and silt</td>
<td>&lt; 6</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table B2 - SAFETY FACTOR FOR DAMAGE (FHWA)

<table>
<thead>
<tr>
<th>Reinforcement typology</th>
<th>Soil typology</th>
<th>(D_{\text{max}}) 100 mm</th>
<th>(D_{\text{max}}) 20 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC-covered PET woven</td>
<td></td>
<td>1.30 – 1.85</td>
<td>1.10 – 1.30</td>
</tr>
<tr>
<td>Woven geotextiles (PP and PET)</td>
<td></td>
<td>1.40 – 2.20</td>
<td>1.10 – 1.40</td>
</tr>
<tr>
<td>Nonwoven geotextiles (PP e PET)</td>
<td></td>
<td>1.40 – 2.50</td>
<td>1.10 – 1.40</td>
</tr>
<tr>
<td>Geotextiles strips (PP)</td>
<td></td>
<td>1.60 – 3.00</td>
<td>1.10 – 2.00</td>
</tr>
</tbody>
</table>

RESISTANCE TO CONSTRUCTION DAMAGE

When the fill material, especially if it is sharp gravel, is placed on the geogrid and compacted, the geogrid can be damaged by the puncturing and abrasion effect of the aggregate. Extensive test programmes, carried out to assess the residual tensile strength of various geosynthetics subjected to damage procedures in the laboratory and in situ, show that the performance of extruded geogrids and woven geogrids is completely different.

The production process for TENAX extruded geogrids means that a product is obtained with (longitudinal and transversal) elements guaranteeing the continuity of the molecular chains over the entire monolithic structure of the geogrid. This structure is less sensitive to cutting, abrasion, perforation and damage from compaction, even where the impact force is high when the aggregate is unloaded directly onto the geogrid. The Safety Factor for damage during construction can be assumed to be as stated in Table B1. In contrast, the individual fibres making up the longitudinal and transversal elements of woven geogrid are easily cut by pieces of aggregate and the thin covering of PVC or similar material is not sufficient to protect it.

Information about the parameters of reduction due to mechanical damage for some types of reinforcement geosynthetics on the market has been provided by the Federal Highway Administration of the USA (Elias, 1996), as illustrated in Table B2.
The strength of joints is a fundamental parameter for assessing the lateral confinement provided by the geogrid in the ground and the integrity of the transversal and longitudinal ribs of the geogrid itself. In addition, whenever a longitudinal connection has to be made between two pieces of geogrid using bodkin connections, the strength of the joints is structurally important, as it must allow the transmission of forces from adjacent lengths of geogrid. As geogrids are designed on the basis of their Long-Term Design Strength (LTDS), they are never subjected to greater tensile stresses than the LTDS. Therefore, a rational approach to a specification is that the strength of a geogrid must be equal to at least 1.50 x LTDS, as is the case with TENAX TT SAMP geogrids. If this ratio is met, then no further safety co-efficient 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.

### 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 carried out in the USA on TENAX TT SAMP geogrids in accordance with standard E.P.A. 9090, certify that there is no danger of chemical attack from substances naturally occurring in the soil, or even in particularly aggressive environments (for example controlled household refuse landfill). No safety co-efficient for chemical resistance needs to be applied for TENAX TT SAMP HDPE geogrids. However, after 20 months’ exposure to an environment with a pH of 9, PET can undergo a loss of strength of 9% (even in dirty water, over a similar period, hydrolysis causes a 3% loss of strength). For PET materials (geotextiles or woven geogrids) without suitable certificates guaranteeing resistance, the American FHWA suggests adopting very conservative partial safety factors (see Table C).
THE SYSTEM COMPONENTS

The face components

FILL MATERIAL

Geogrid Reinforced Slope technology allows the use of many types of fill. However, it is preferable to use a free-draining granular material with a high angle of internal friction, if possible without large stones as they would make compaction difficult.

If using on site material with poor mechanical properties, it is advisable to mix it with sand and aggregate. It is also possible to use poor soil using the lime stabilised technique. This approach is effective with extruded HDPE geogrids but cannot be used with PET reinforcement as it is subject to chemical degradation in alkaline environments.

Near the face, it is recommended filling with topsoil in order to create optimum conditions for plants to become established and to ensure the durability of the vegetation. The fill material should be placed and compacted in layers, with a recommended thickness of 0.30 - 0.35 m, to reach a compaction of not less than 95% of the Proctor Standard.

FIRE RESISTANCE

To verify the actual danger to the stability and integrity of a geogrid-reinforced slope structure using TENAX TT SAMP, the following situations need to be considered:

Fire after installation but before plant growth
In these conditions, the reinforcement element present on the face could be damaged by fire. However, the metal formwork used in the TENAX RIVEL system provides effective support to the face even where the reinforcement element is destroyed locally. The stability of the structure is not compromised in any way since the part of the reinforcement which provides stability is within the structure.

For a fire to spread, a combustible and combustion agent needs to be present. All plastics, including self-extinguishing ones, are combustible.

The combustion agent needed to allow the fire to spread is oxygen. Inside the soil forming the reinforced soil, there is no combustion agent; the flame, finding no oxygen, therefore cannot spread and damage the section important for structural stability.

Fire after installation and following grass growth
In this case, the real combustible is grass. The flames spread over the surface of the ground as the flames tend to spread upwards. Therefore, the area on fire is remote from the reinforcement element present in the face of the structure.

TENAX TT SAMP geogrids are stabilised using a black colour master batch containing carbon black which protects the polymer from degradation caused by UV rays.

Table C - REDUCTION FACTORS FOR CHEMICAL ATTACK FOR DIFFERENT DEGREES OF ACIDITY OF THE GROUND (FHWA)

<table>
<thead>
<tr>
<th></th>
<th>3 ≤ pH ≤ 5</th>
<th>5 ≤ pH ≤ 8</th>
<th>8 &lt; pH ≤ 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET geotextiles</td>
<td>2.00</td>
<td>1.60</td>
<td>2.00</td>
</tr>
<tr>
<td>Woven PET PVC-coated geogrids</td>
<td>1.30</td>
<td>1.15</td>
<td>1.30</td>
</tr>
</tbody>
</table>
THE ELECTRO-WELDED MESH FORMWORK

The TENAX RIVEL system uses, on the face of the structure, formwork made of electro-welded mesh (6-8 mm rebar with a 15 x 15 cm mesh size) acting as a guide support and which is left in place. It does not have a structural function but speeds up the installation process and allows accurate profiling of the structure. It is not unreasonable to expect a 30% increase in daily production when compared to traditional methods of construction. The formwork is supplied with stiffening rods (one every 0.45 m approx.) and U-shaped steel pins, 0.30 m long, for fixing the geogrid to the ground (approx. every metre).

THE EROSION CONTROL MAT

Planting plays an active role in the protection of the slope in all landscaping projects. Without it, the work would be incomplete and would be less effective. The grassing of the face by hydro-seeding disguises the artificial elements of the system and drastically reduces the environmental impact of the slope.

The choice of mix and quantity of seed per square metre can be calculated as appropriate for the particular project requirements and the pedological and climatic conditions.

The time for germination and greening of the structure can range from four to eight weeks, depending on the seasonal weather conditions. It is advisable to carry out hydro-seeding in the wetter months of the year.

In order to protect reinforced slopes from erosion and to provide a suitable surface for hydro-seeding a biomat made of biodegradable viscose containing seeds of various grass species and a fertiliser to aid rapid grass growth.

The pre-seeded biomat allows rapid and uniform growth of vegetation and guarantees total coverage of the face, reducing the loss of seeds and topsoil.

Germination is facilitated by the slow biodegradation of the woven textile which, being eco friendly, does not upset the equilibrium of the surrounding area. The choice of mix and quantity of seed per square metre can be calculated as appropriate for the particular project requirements and the pedological and climatic conditions.

The face of the slope can be planted with cuttings, shrubs, bulbs and other plants that are installed between one reinforcement layer and the other. In this way, a uniform cover effect is guaranteed.

To avoid carrying out hydro-seeding, a pre-seeded biomat can also be used. This material comprises of a fibre filling made of biodegradable viscose containing seeds of various grass species and a fertiliser to aid rapid grass growth.
Photograph 8: example of positioning of a parapet or guard rail.

Photograph 9: detail of the connecting angle between the reinforced ground and the existing reinforced concrete structure (wing wall, bridge seat).

Photograph 10: concealment of a reinforced concrete hangar to integrate it in the landscape.

Photograph 11: the geogrids are placed at the front or back depending on whether the section is convex or concave.

Photograph 12: parapet in accordance with site safety standards.

Photograph 13: before filling the last course of the embankment, it is possible to create recesses to take street lighting.

Recommended accessories for speed of installation:

- Trestles with beams for un-rolling the geogrid;
- Cutter or scissors to cut the geogrid;
- Cutting pliers for to cut parts of the formwork;
- Metal wire for connecting formwork.
A simple model helps explain the principle on which reinforced slope technology is based.

A ground element (Fig. 1a), part of an undefined mass, following application of a vertical stress $\sigma_v$, undergoes a horizontal deformation $\varepsilon_h$. The adjacent soil opposes this deformation with a horizontal confinement action $\sigma_h$.

Where a reinforcement element is inserted into the soil (Fig. 1b), the horizontal deformation $\varepsilon_h$, to which the soil is subject, causes a deformation of the reinforcement itself, to which the said reinforcement opposes a reaction $F$ translating to a subsequent compressive stress $\sigma_h^*$. A reinforcement element can therefore be inserted to increase the compressive resistance of the soil.

Considering the shear stresses (Fig. 2), in one element of loose soil we have:

$$\sigma_y \tan \phi_{\text{max}} = (T/A) \cdot \cos \theta + (T/A) \cdot \sin \theta$$

where:

- $\phi_{\text{max}}$ = maximum angle of shear strength of the soil;
- $(\tau_{xy})_{\text{max}}$ = maximum force of shear strength provided by the soil.

Where the element of soil is crossed by a reinforcement element with an angle of inclination $\theta$ in relation to the vertical (Fig. 3), the state of tension is modified because the stress $T$ generates a shear force produced by the tangential component $T \cdot \sin \theta$, whereas the normal component $T \cdot \cos \theta$ generates another $\tau_{xy}$ due to the friction angle $\phi_{\text{max}}$ of the soil.

$$\sigma_y \tan \phi_{\text{max}} = (T/A) \cdot \tan \phi_{\text{max}} \cdot \tan \phi_{\text{max}} + (T/A) \cdot \tan \phi_{\text{max}} \cdot \sin \theta$$

where:

- $A_s$ = area of the reinforcement element.
- $(\tau_{xy})_{\text{max}}$ = maximum shear resistance value of the reinforced slope.

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

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

whereas the maximum shear stress which the soil can bear is increased by:

$$\tau_{xy}^\wedge = (T/A) \cdot \cos \theta \cdot \tan \phi_{\text{max}} + (T/A) \cdot \sin \theta$$

The factors influencing the shear resistance of reinforced soil are:

- the strength and rigidity of the reinforcement relative to the surrounding soil;
- the position of the reinforcement;
- the shape of the reinforcement which must be able to develop a high apparent angle of friction at the interface with the soil;
- the creep characteristics (elongation under constant tensile load) of the reinforcement during the design life;
- durability of the reinforcement.

In particular, the geometric structure of the reinforcement must guarantee high friction, so as to avoid the reinforcement itself unwinding due to the tensile stress $T$ to which it is subjected. It should be noted that an excessively rigid reinforcement, for example a metallic element, can break when subjected to minor deformations without mobilising high strength values; excessively extensible materials (such as non-woven geotextiles) cannot provide sufficient reinforcement if large deformations have already occurred, which are usually incompatible with the lifetime of a structure.

Shear test carried out in the laboratory of TENAX SpA.
The design of a reinforced slope follows an extremely simple logical procedure. For any material, there is an incline limit \( \beta_{\text{lim}} \) within which a non-reinforced slope can be safely constructed. In the case of loose, dry material, the limit angle of inclination is the same as the angle of internal friction of the soil.

\[
\beta_{\text{lim}} = \phi
\]

A slope with an inclination greater than this limit is called a steep slope. To construct an embankment with a steep slope, additional forces are needed to maintain equilibrium. Reinforced slope technology consists of supplying additional forces by installing reinforcement layers.

The additional forces required for the equilibrium of a steep slope, with an adequate safety margin in relation to each potential failure mechanism, can be determined by a limit equilibrium analysis. This consists of considering the possible failure surfaces and matching the forces which could cause the movement of the soil for each factor (self weight, loadings, dynamic stresses due to earthquakes, impact or interstitial pressure) with resisting forces (friction, cohesion and obviously, the resistance of geogrids). It is possible to use surfaces of different shapes: circular, linear, bi-linear, logarithmic spiral, broken linear. Surfaces with complex shapes require analyses very close to reality but clearly higher calculation loads. For each surface, the Safety Factor is calculated as the ratio between the maximum resisting shear force and the acting force which develops along the surface concerned. The surface characterised by the lowest Safety Factor is the critical one. Various calculation programmes are available in the market based on different failure mechanisms, but using the same principle and enabling these checks to be carried out by analysing a considerable number of surfaces and selecting the critical one from them.

**TNXSLOPE** is the software developed by the TENAX Geosynthetics Division for designs using static conditions with homogenous soils and simple geometry of reinforced slopes using mono-oriented HDPE geogrids. The software performs an internal stability analysis which determines the type of reinforcement geogrid necessary for the project, the depth, the quantity and the spacing of the reinforcement layers. The programme is based on the calculation method proposed by Prof. Jewell and presented in the article entitled “Application of Revised Design Charts for Steep Reinforced Slopes” published in the Geotextiles and Geomembranes magazine in 1991.

Based on alignment charts presented in the publication by Prof. Jewell, **TNXSLOPE** determines the value of the pressure coefficient and the spacing between the geogrid layers, and the reinforcement length. The software also provides the result of analyses of the forces and estimates the quantities of geogrid needed for each square metre of the face or linear metre of the embankment. The entire process is displayed as a graphic outline.

The software considers the presence of a stable and well-consolidated foundation. For cases characterised by complex geometries, with seismic stresses, or with different soil properties, the use of more specific software and to carry out a global stability analysis is advisable.

In particular, if the structure is to be built in an earthquake zone, further stability checks are necessary which take account of the design seismic acceleration for the area in accordance with either national or international standards. If internal stability is assured, the creep stability at the base, the only significant external stability check, is also guaranteed. For reinforced soils, stability against overturning is always ensured as a result of the extreme flexibility of the structure which cannot pivot rigidly, the position of its centre of gravity and its geometry.

Finally, as regards the bearing capacity check, it is important to underline that a reinforced slope structure is less “lighter” than traditional reinforced concrete structure or gabions and is therefore possible to construct on soils with a poor bearing capacity by using “lighter” fill material.

If the structure is built on a slope and if the soil behind the structure is of a different type from that used for the fill, global stability checks are then necessary to investigate deep failure surfaces, and if necessary, to modify the reinforced slope structure to obtain an appropriate Safety Factor. The same check must be carried out for seismic conditions.
SPECIAL APPLICATIONS: ROCKFALL BARRIER SYSTEMS

To guarantee the protection of residential buildings or roads located close to hills and mountains where there is a risk of rockfall, technological solutions of an active type (able to prevent rocks breaking away), or of a passive type (able to intercept or divert moving rocks), can be used. These structures can be designed and planned to reduce the risk or vulnerability associated with rockfalls. In particular, passive defence works are normally located so as to intercept the trajectory of a falling mass. The definition of the motion of the block and the kinetic energy to be absorbed is a very important factor for a correct design.

The rockfall barrier embankments constructed using the TENAX RIVEL System are protective works of a passive type with high energy absorption which are more effective than metal barriers because:

- they provide effective protection even in the event of “showers” of rocks or repeated falls along the same line;
- they require much less maintenance even following intensive periods of rockfalls and are not subject to corrosion;
- they are durable and not subject to damage or disintegration;
- the environmental impact is negligible especially if the structure is concealed by suitable landscaping works;
- they can be made by re-using material from previous rock falls.

A TENAX RIVEL reinforced slope has many advantages over a traditional embankment:

- smaller footprint with a consequent reduction of the soil to be moved;
- fewer difficulties in identifying suitable areas from a topographical point of view;
- lower risk of rocks tipping over the structure because of the greater inclination of the face.

In reinforced slopes, the soil is “bound” by the geogrid. The tensile strength provided by the geogrid and its rigid structure prevents the rocks breaking through the embankment, notwithstanding the reduced area compared with a traditional embankment. If the width of the crest of the structure is less than 2.00 m (particularly narrow structures), to increase the binding effect, it is advisable to position a second reinforcement structure perpendicular to the main one (i.e. longitudinally to the embankment).

TENAX TT SAMP geogrids have an elastic-plastic-viscous type behaviour depending on the load factors and the conditions of application. The analysis of the stress situation induced by an impact, (which can be modelled as an instantaneous loading of a high intensity), has meant that it is possible to identify a stiffening of the geogrid-soil system or an increase in the modulus of elasticity. Following these stresses, the force-deformation curve has a greater incline and the geogrid reacts to the stresses by minor deformations.

Given the almost instantaneous duration of the phenomenon, viscous-type deformations (creep) have no way of manifesting themselves. The reinforcement is, therefore, able to mobilise a tensile strength close to the peak value and no longer the long-term strength to which reference is made by the application of static loads. The greater “binding” of the soil involves a dynamic load distribution on a cone with a larger base and, therefore, a greater mass of soil is involved in the resistance to the impact and in the dissipation of energy.

Numerous tests and consequent scientific publications illustrate the model of interaction, validated by various series of laboratory tests between TENAX TT SAMP geogrids and the soil in the event of the application of dynamic loads.

The rockfall barrier embankment built in Valle Aurina (Italy) is 165 m long. The height of the downhill side is 21 m with a 70° inclination (above: a cross section of the embankment with the kind permission of the Engineers Pfostl & Helfer).
Reinforced slope barriers using TENAX TT SAMP geogrids have undergone repeated trials in the test field of Vigo di Meano (TN), accredited by the Polytechnic of Turin. Following these tests, the TENAX system was certified by the Polytechnic of Turin, which had demonstrated the effectiveness of barriers 4.20 m high, with a minimum crest width of 0.90 m reinforced with TENAX TT 045 SAMP extruded geogrids. The certificates issued for reinforced barriers using TENAX TT 045 SAMP geogrids state that they can be created using earth with frictional-type behaviour (good quality material) or with plastic-type cohesive material. In both cases, the barriers have demonstrated that they can withstand repeated shocks by a mass with energy of approx. 4,500 kJ. The results can be extended to any structures with a minimum geometry guaranteeing compliance with the proportions of certified structures.

Comparison between TENAX RIVEL rockfall barriers and embankments using metal gabions filled with rubble

The impact of a mass on the face of an embankment constructed using metal gabions produces chips of stone which could travel beyond the embankment itself, without the knowledge of their trajectory in advance. In contrast, the TENAX RIVEL embankment is able to “take” the impacting mass without crumpling. Following the impact, the mesh of the gabions can be torn, causing the partial or total emptying of the gabion and compromising the stability of those above with the real risk of triggering an uncontrollable and thus dangerous domino effect.

The function of the metal mesh is only to contain the backfill material. In contrast, a geogrid and the ground interact permanently with a consequent improvement in the strength of the structure. Each gabion in a rockfall barrier system transmits almost elastically the impact to the adjacent gabion and from the last one to the ground which can be projected outwards.

With the TENAX RIVEL system, the ground is spread and compacted considerably reducing the deformability of the material, thereby guaranteeing the continuing integrity of the individual elements of which the structure is composed, even following a violent impact on its face. The better “binding” of the ground enables the load to be distributed over a larger volume; the area of influence, usually conical in shape, therefore, has a wider base and thus a larger mass of ground is involved in the resistance to shock and dissipation of energy.

Video recordings of tests at actual scale carried out on reinforced rockfall barriers using TENAX geogrids have revealed that the downhill face moves back again once the displacement peak has been reached. This effect is certainly due to the presence and the action of the geogrid. This rebound effect, together with observation of the formation of tension cracks on the crest of the embankment, allows us to conclude that in the absence of a connection between the uphill and downhill faces, a barrier can be broken through, or at least, the volume of ground isolated by tension cracks can collapse on the downhill side.
TENAX is an international group which manufactures and supplies a wide range of geosynthetics certified by the major international technical organisations and used in projects of all sizes and complexities throughout the world.

Here are a few examples of uses of geosynthetics:

- the stabilisation and consolidation of collapsing sub-bases and the improvement of their bearing capacity (TENAX LBO SAMP, GT, MS);
- horizontal and vertical drainage via the transport of fluids and gases (TENAX CE, GNT, TENDRAIN, TN, TNT, TDP, NDP);
- the reinforcement of embankments of earth with a grassed surface or a surface of pre-fabricated blocks (TENAX TT SAMP, RIVEL);
- erosion protection and the planting of slopes (TENAX TENWEB, MULTIMAT).

Specialised technicians provide prompt, individual assistance from design through to construction, working with you to choose the right solutions for civil engineering and environmental problems.

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