# THE USE OF GEOGRIDS IN ROAD AND RAILWAY APPLICATIONS

ALPEADRIA
TEXTIL

# THE USE OF GEOGRIDS IN ROAD AND RAILWAY APPLICATION

**Abstract:** The use of geogrids in road and railway projects is becoming an important practice all around the world for solving many design and construction problems.

Applications include: reinforced soil walls and steep slopes, asphalt reinforcement, stabilisation of road and railway bases on soft ground, basal reinforcement of embankments on soft soil, spreading of load over piles. The paper presents the various applications, focusing on the technical details and providing sketches about the available design methods. Then the characteristics required for the geogrids are introduced, together with the related testing methods. Specific geogrids presently available on the international market are introduced and practical recommendations are provided.

## 1 INTRODUCTION

The concept of soil reinforcement is not a new one. The Ziggurat of Agar-Quf, 5km north of Baghdad is believed to be some 3000 years old and is constructed of clay bricks reinforced with woven mats of reeds. The Great Wall of China is also constructed of a mixture of clay and gravel reinforced with tamarisk branches.

The modern concept of earth reinforcement and soil structures was postulated by Casagrande, who idealised the problem in the form of a weak soil reinforced by high strength membranes laid horizontally in layers.

The rapid development in polymer technology has produced a wide variety of geosynthetic materials resulting in the growth of many different reinforcing systems. The advent of geogrid polymer reinforcements, which have high pull out resistance, has enabled the use of cheaper low quality cohesive frictional soil as fill.

Reinforced soil is a composite material which combines the typical resistance of two different materials in such a way to minimize the weakness of each one. Particularly, a relative large quantity of the cheapest and compression resistant material, the soil, is improved in its engineering characteristics by the combination with a relatively small quantity of a more expensive and highly tensile resistant material, the geogrids. Thus a sinergy is developed between the tensile and compressive resistance of the two materials: this fact improves the global characteristics of the composite material, like with concrete and steel.

A relevant number of projects has already been realized worldwide, allowing the development of the techniques of design and construction of reinforced soil.

The peculiar characteristics of geosynthetic reinforced soil enabled the use of such systems both for slopes and walls applications, and for base reinforcement apllications.

Roads and railways are the sectors that most profited of the possibilities offered by geosynthetic reinforced soil structures.

# 2 BASIC PRINCIPLES OF REINFORCED SOIL

A simple model helps to explain the principle on which the reinforced soil techniques are based. Let us consider the soil element in *Fig. 1a*, which is part of an infinite mass of soil: the application of a vertical stress $\sigma_v$ causes a deformation in the element and the consequent horizontal stress $\sigma_h$ caused by the lateral compression suffered by the adjacent soil. Horizontally the soil element undergoes a "tensile deformation" $\varepsilon_h$, which is one of the principal causes of local failure.

When, as in *Fig. 1b*, a reinforcing element is put in the soil, the application of a vertical stress is followed by the deformation of the soil element and the extension of the reinforcement. This extension then generates a tensile strength T in the reinforcement, which in turn produce a horizontal stress $\sigma_h^*$. This stress, which also provides a confinement action on the soil granules, greatly contributes to resist the horizontal forces and to reduce the horizontal deformations.
Therefore the inclusion of a geogrid into the soil mass reduces the stresses and strains applied to the soil; on the other hand the vertical stress $\sigma_v$ applied to the soil mass can be increased, compared to the unreinforced soil, at equal deformations.
With regards to the resistance to the shear stresses, according to *Fig. 2* in a non-cohesive soil element we have:

$$\left(\tau_{yx}\right)_{\max} = \sigma_y \cdot \tan\phi_{\max}$$

where:

- $\phi_{\max}$ = maximum angle of shear resistance of soil;
- $(\tau_{yx})_{\max}$ = maximum overall shear stress provided by the soil

When the soil element is crossed by a reinforcing element which makes a θ angle with the shearing direction (*Fig. 3*), the state of stress is modified because the tension T generates a shear stress produced by the tangential component $T\cdot\text{sen}\theta$, meanwhile the normal component $T\cdot\cos\theta$ generates another $\tau_{yx}{}^{\wedge}$ caused by the friction angle $\phi_{\max}$ in the soil.

Therefore:

$$\left(\tau_{yxr}\right)_{\max} = \sigma_{yr} \cdot \tan\phi_{\max} + \left(T / A_S\right) \cdot \cos\theta \cdot \tan\phi_{\max} + \left(T / A_S\right) \cdot \sin\theta$$

where:

- $A_s$ = area of the soil element;
- $(\tau_{yxr})_{\max}$ = maximum overall shear stress of the reinforced soil

So the normal stress on the soil element is increased by:

$$\hat{\sigma}_y = (T / A_s) \cdot \cos\theta$$

while the maximum shear stress which the soil can carry is increased.
The main advantages of a reinforced soil structure are the following:

- lower global cost: the possibility to build with steeper slopes reduces the quantity of the material needed for an embankment;
- moreover, it is possible to use less valuable and then cheaper materials;
- improved stability: the reinforcement guarantees an improvement in the Factors of Safety;
- it is possible to build directly on low bearing capacity soils;
- a reinforcement on the base allows to build on soft soils, that would normally request a preliminary consolidation and great caution during construction.

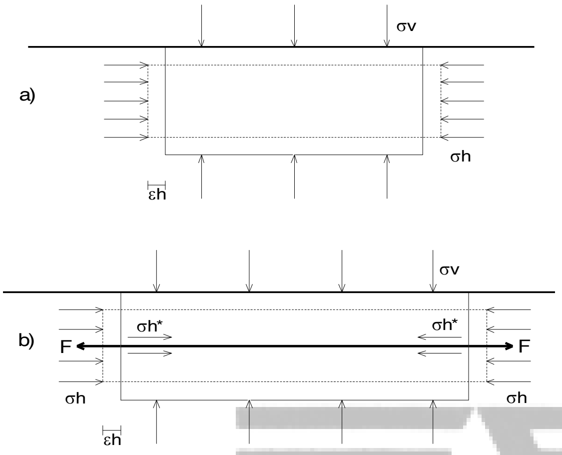


Fig. 1: Stresses and strains due to a vertical load in an unreinforced (a) and a reinforced (b) soil element.

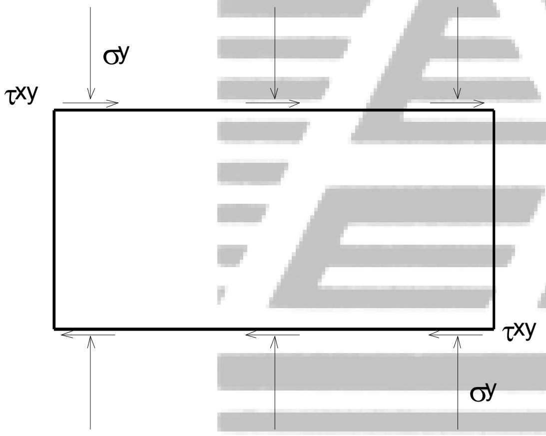


Fig. 2: Shear stresses in an unreiforced soil element

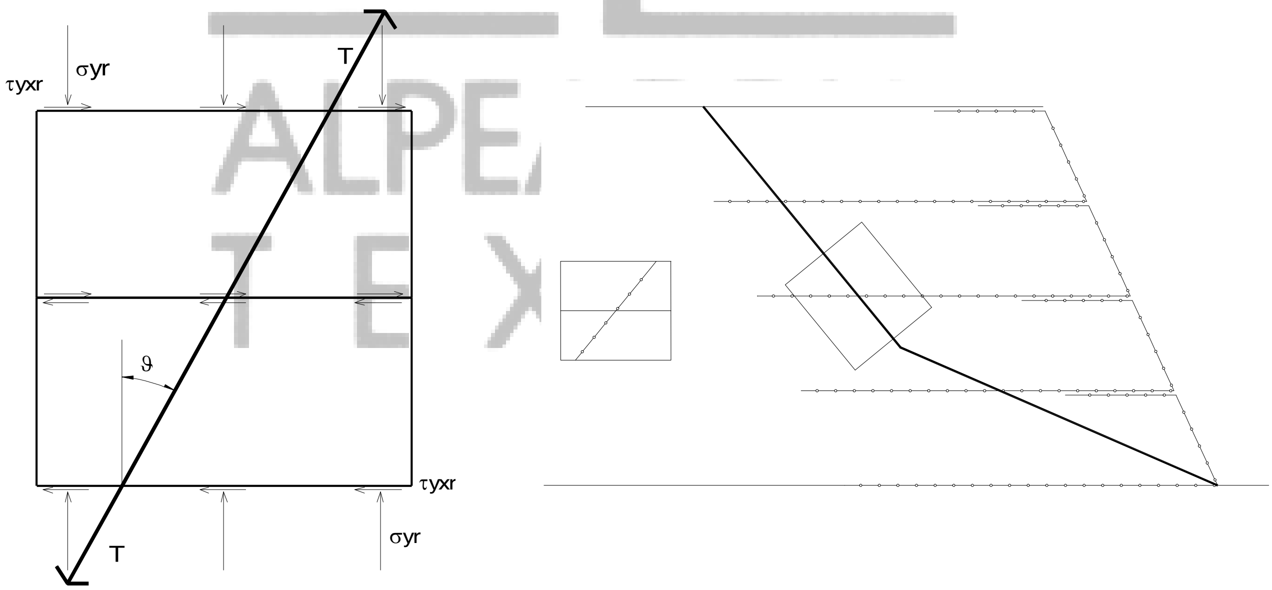


Fig. 3: Shear stresses in a reinforced soil element

# 3 POLYMERIC REINFORCEMENT

Polymeric reinforcement takes many forms, such as strips, grids or sheets which may or may not be connected to a facing. Like steel strips, polymeric strips are installed at predetermined vertical and horizontal spacings. In contrast, grids or sheets are usually installed as full width reinforcement in which case only a vertical spacing is specified. The most commonly used polymers are polyester and polyolefins although aramid and carbon fibre reinforcements are available. All polymeric materials used in the manufacture of fill reinforcement are subject to molecular orientation during production to minimise the effects of creep.

## 3.1 POLYESTER (PET)

Polyesther is a polymer commonly utilized in the form of fibres.
The most common form (*Fig. 5*) of Polyester is Polyethylene Terephtalate (PET), which is obtained by condensation of a dibasic acid and a dialcohol. It is composed of groups of ethylene and groups of terephtalate. The plain aromatic group stiffen the structure of the mulecular chain.
**The esteric groups of Polyester are either positive or negative, therefore they attract each other, allowing the adjacent polymer chains to line up in christalline form. This allow the production of thin fibers of high tenacity.**

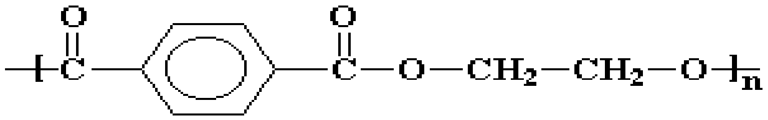


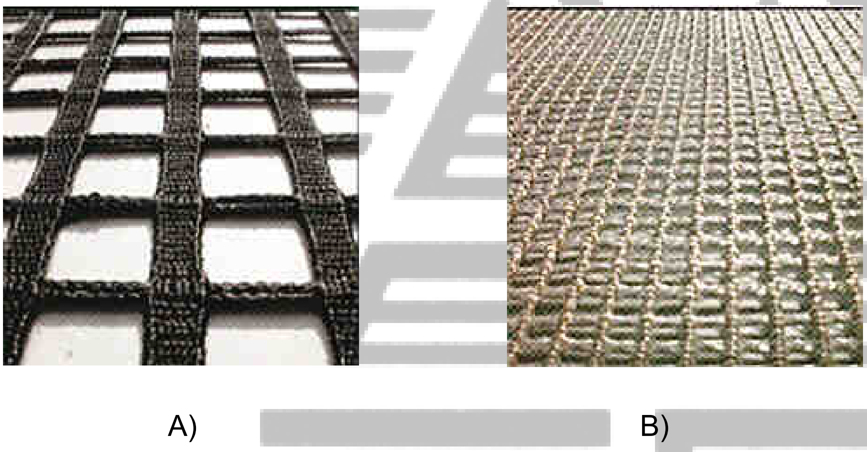
Fig. 4: The molecular structure of Polyethylene Terephtalate (PET)

The PET fibers can be composed into high strength yarns, which can be woven or knitted to produce high strength geotextiles and geogrids.
Geotextiles and geogrids produced with high tensile modulus Polyester yarns present high tensile strength with excellent low creep properties.
PET is generally sensitive to chemical degradation due to hydrolosis in very acid (pH < 2) or very alcaline (pH > 12) environvent. The resistance against chemical degradation is influenced by the molecular weight Mw and by the carboxyl end group (CEG) of the polymer used to make the fibres. The higher the Mw and the lower the CEG, the better the yarn performance.

## 3.2 ARTER® AND MACRIT®

Alpe Adria Textil is the first Italian producer of geogrids and geotextiles based on high tenacity PET yarns. Alpe Adria Textil geosynthetics range presently includes the following products:

- ARTER®: is a D.O.S. (Directionally Oriented Structure) textile geogrid manufactured by means of warp knitting technology with weft insertion (*Fig. 6*). In the D.O.S. structure the elongation is only due to the yarns used, while there is no practical elongation of the geogrid structure, since the yarns are straight and parallel. ARTER geogrids are differentiated between ARTER® GTS (*Fig. 5.A*), which is coated with EVA polymer, and ARTER® GT (*Fig. 5.B*), which is uncoated.



A) B)

Fig. 5:ARTER® geogrids: A) ARTER® GTS; B) ARTER® GT

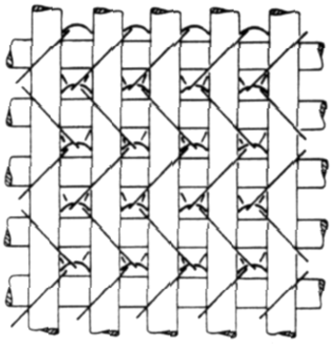
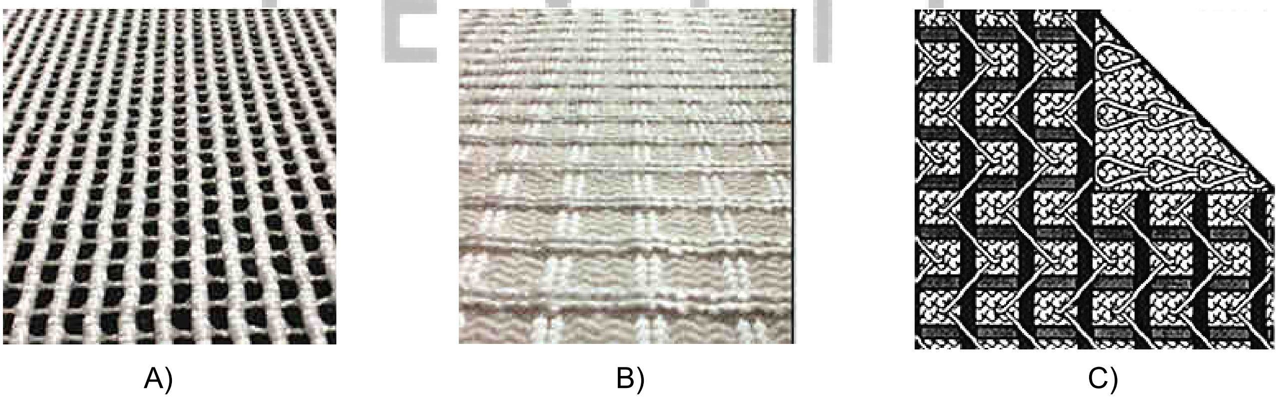


Fig. 6:The D.O.S. structure

- MACRIT®: is a geocomposite consisting of a nonwoven geotextile coupled to a monoaxial or biaxial D.O.S. geogrid reinforcement (*Fig. 7*); the geogrid has the same characteristics of ARTER® GTS, while the nonwoven geotextile provides drainage, separation, and filtration features.



A) B) C)

Fig. 7:MACRIT® geocomposites: two of the available products (A and B) and the structure (C)

- ARTER® GTS, ARTER® GTS A, and MACRIT® GTS V: are both coated with EVA (Ethylene vynilacetat) polymer (*Fig. 8*) and were specifically developed for asphalt reinforcement applications.

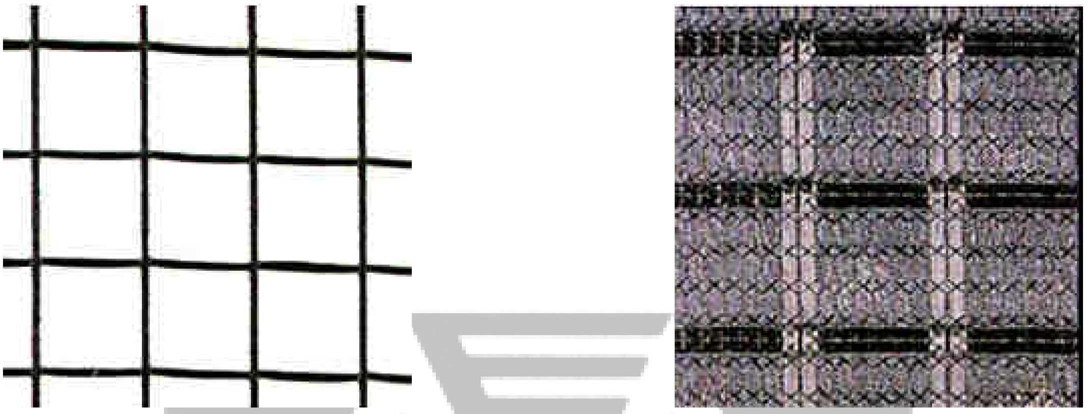


Fig. 8: ARTER® GTS and MACRIT® GTS V are specifically developed for asphalt reinforcement

- MULTIAXIAL: is a D.O.S. multiaxial textile geogrid, manufactured by warp knitting technology (*Fig. 9*); it is a unique product, the most technologically advanced geogrid presently on the market; thanks to the othogonal and diagonal ribs it yields multiaxial reinforcement capability and dimensional stability.

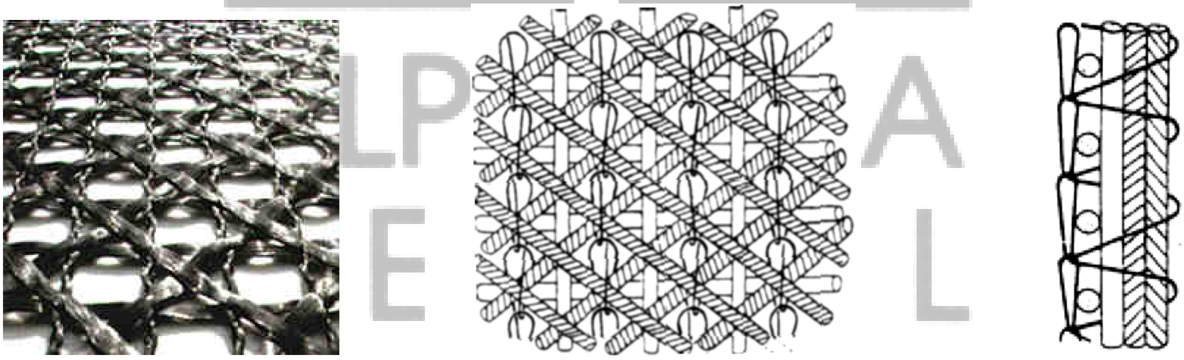


Fig. 9: MULTIAXIAL is a geogrid with both orthogonal and diagonal ribs

All Alpe Adria Textil geogrids and geocomposites are manufactured with the highest quality components. In particular, the high tenacity Polyester yarns ensure the best technical characteristics.
The high creep resistance of Alpe Adria Textil geosynthetics was demonstrated by creep and creep rupture testing performed on the high tenacity yarns through the Stepped Isothermal Method (SIM).

SIM creep test starts with a constant load applied to the yarns at a reference temperature. After a specified time exposure and without releasing the applied load, the temperature is increased rapidly. This procedure is repeated for several temperature steps. The number, height and duration of the temperature steps are designed to produce a master curve of creep strain and creep modulus over a long period. Extrapolation of results up to 1,000,000 hours (115 years) is possible and it allows to determine the creep properties of the polyester yarns over the entire design life of a civil engineering structure. The master creep modulus curves of the yarns are shown in *Fig. 10*, for a creep load equal to 60 % of the ultimate tensile load. It can be noted that, even at such high sustained load, the strain at 100 years never exceed 9 %.

Moreover the CEG of the PET used for the yarns is always in the range of 15 - 25 meq/kg and the Mw is always higher than 50,000 g/mol, thus ensuring the highest chemical resistance.
This confirms the high technical characteristics of Alpe Adria Textil geosynthetics and their suitability for all kind of reinforced soil structure.

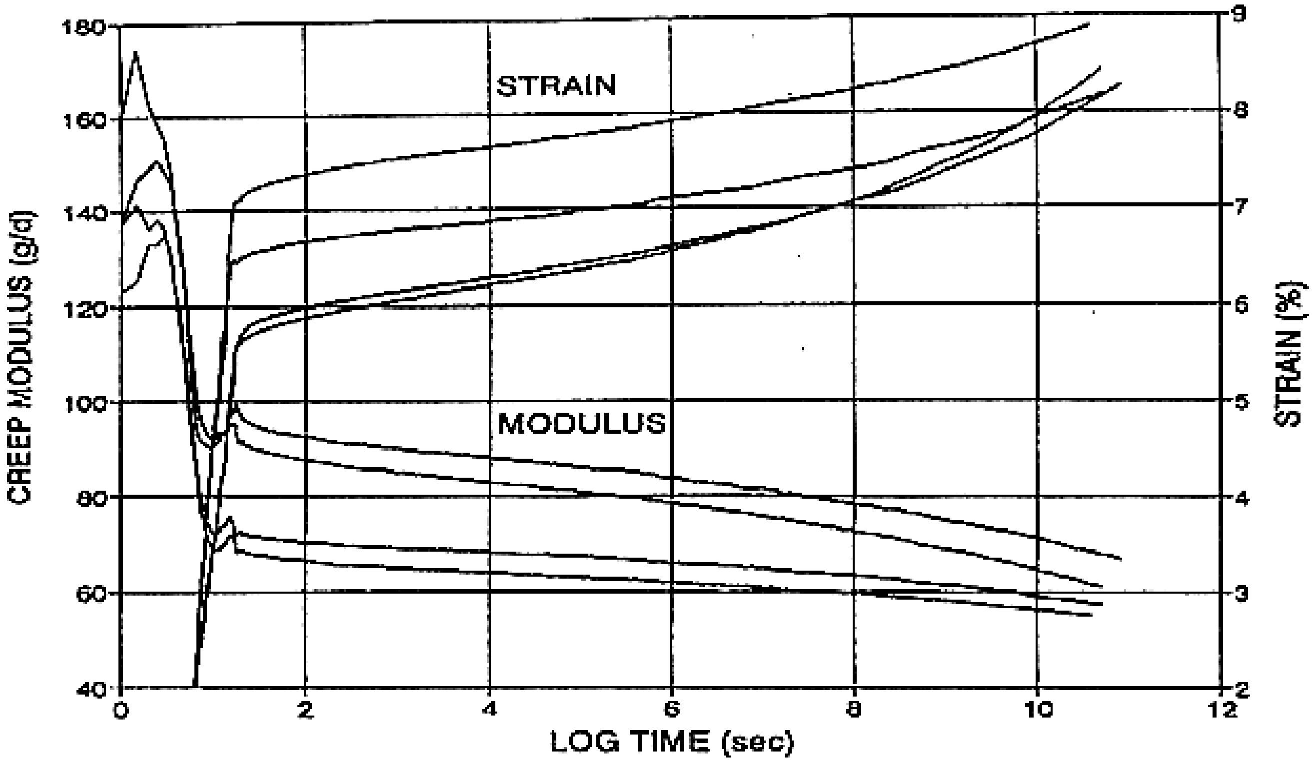


Fig. 10: Results of SIM creep tests on PET yarns used in  Alpe Adria Textil geosynthetics

# 4 REINFORCED SOIL SLOPES AND WALLS

Reinforced soils slopes and walls are internally stabilised structures. An externally stabilised system uses an external structural wall against which stabilising forces are mobilised. An internally stabilised system involves reinforcements installed within and extending beyond the potential failure mass. Within this system, shear transfer to mobilise the tensile capacity of closely spaced reinforcing elements has removed the need for a structural wall and has substituted a composite system of reinforcing elements and soil as the primary structural entity.

The stiffness of the reinforcement influences the soil shear deformation required to mobilise the reinforcement force. Axially stiff reinforcement will experience little strain before taking up load. The stress in the reinforcement can accumulate rapidly and may occur at lower strains than those required to mobilise peak soil shear strength. Flexible reinforcement requires greater deformation before taking up the stress imposed by the soil. This may lead to higher strains and the peak shear strength of the soil may be approached or exceeded.

As well as the intrinsic properties of the soil and the reinforcement, the properties of their interaction is also a key consideration for reinforced soil. Bond strength is generated by friction, adhesion or bearing stresses between soil and reinforcement, but the relative movements of soil and reinforcement are different from those occurring in direct sliding.

For soil on either side of strip or sheet reinforcement, the interaction between soil and reinforcement is the same as in direct sliding and bond forces may be measured or calculated in the same way. With grid reinforcement, bond is induced by shear along the surfaces of the reinforcing element and by bearing of transverse or anchor members of the grid against the soil.

The development of polymeric reinforcements has allowed the possibility of using indigenous soils and waste fills in reinforced soil structures, thus providing the possibility of realising significant savings in construction costs.

The acute lack of conventional frictional fill in some countries, such as Hungary, has lead to the use of cohesive soils in major reinforced soil structures in these countries. It has also been shown that geosynthetic reinforced soil structures formed using cohesive or cohesive frictional fill are potentially more stable than structures formed from purely frictional fill.

## 4.1 DESIGN OF STEEP REINFORCED SLOPES AND REINFORCED WALLS

For a uniform fill soil there is a limiting slope angle $\beta_{\mathrm{lim}}$ to which an unreinforced slope may be safely built. For the case of non cohesive and dry material, the limit angle of the slope equals the friction angle of the soil.

$$\beta_{\mathrm{lim}} = \phi$$

A slope with a greater angle than the limiting slope angle is a steep slope; to build an embankment with a steep slope it is necessary to add some addictional forces to maintain equilibrium.

The easiest method is to place horizontally some reinforcing layers in the slope so that the reinforcements can resist the horizontal forces, thus increasing the allowable shear stresses. The forces which must be applied to the soil to maintain equilibrium can be added up in a gross force that works in a horizontal direction, that is the direction of the reinforcements.

The gross force T may be expressed with the following formula:

$$T = 1/2 \cdot K \cdot \gamma \cdot H^2$$

where:

- H = height of the slope[m]
- $\gamma$ = unit weight of the soil [kN/m3]
- K = equivalent earth pressure coefficient, depending on the angle of the slope ß, the soil strength parameters c and $\phi$, and the pore pressure coefficient $r_u = u/(\gamma \cdot z)$.

For the case of vertical face, the coefficent K equals the coefficent of active earth pressure $K_a$; when $\beta$ is between $\Phi$ and 90°, K has a value between 0 and $K_a$.

The earth pressure coefficient K can be evaluated with a stability analysis based on a two-part wedge mechanism, as shown in *Fig. 11*. Through the systematic application of such analysis it is possible to obtain design charts, like the one shown in *Fig. 12*, which allow to obtain the coefiicient K and the required reinforcement length at the base of the slope (where direct sliding is the critical mechanism) and at the top of the slope (where pull-out of reinforcement is the critical mechanism).

These design charts allow to take into account the inclination of the slope, the friction angle of the soil, and the pore pressure parameter $r_u$. With the charts an easy and fast design of the reinforced slope can be achieved. Obviously more sophisticated methods and analyses can be used, particularly in case of complicated geometries and layered soils of different characteristics, including finite elements or finite differences analysis. But for most cases the design charts provides a sufficient tool for getting the layout of the reinforcement layers and their required characteristics.

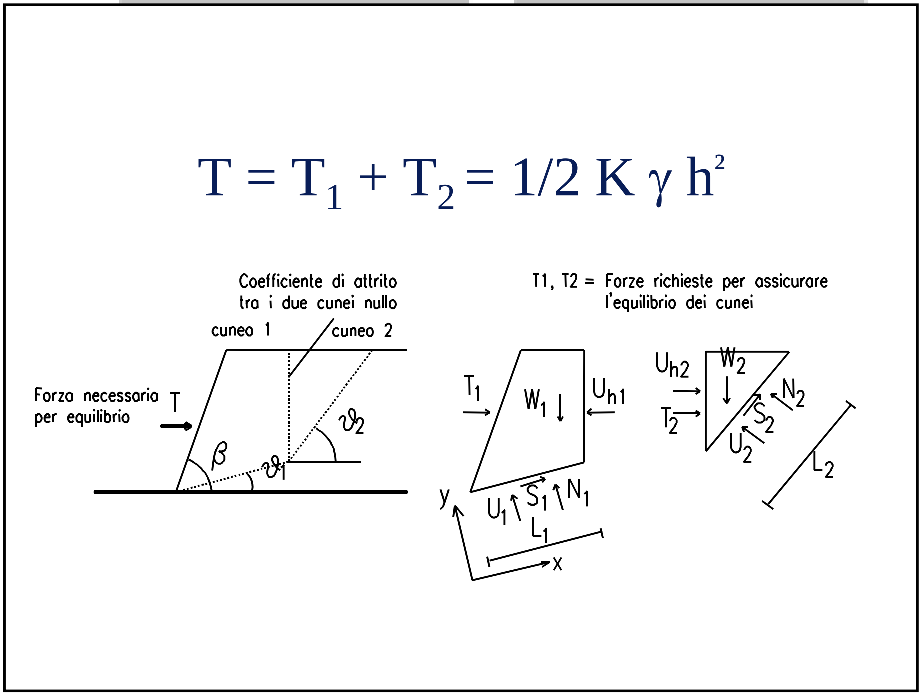
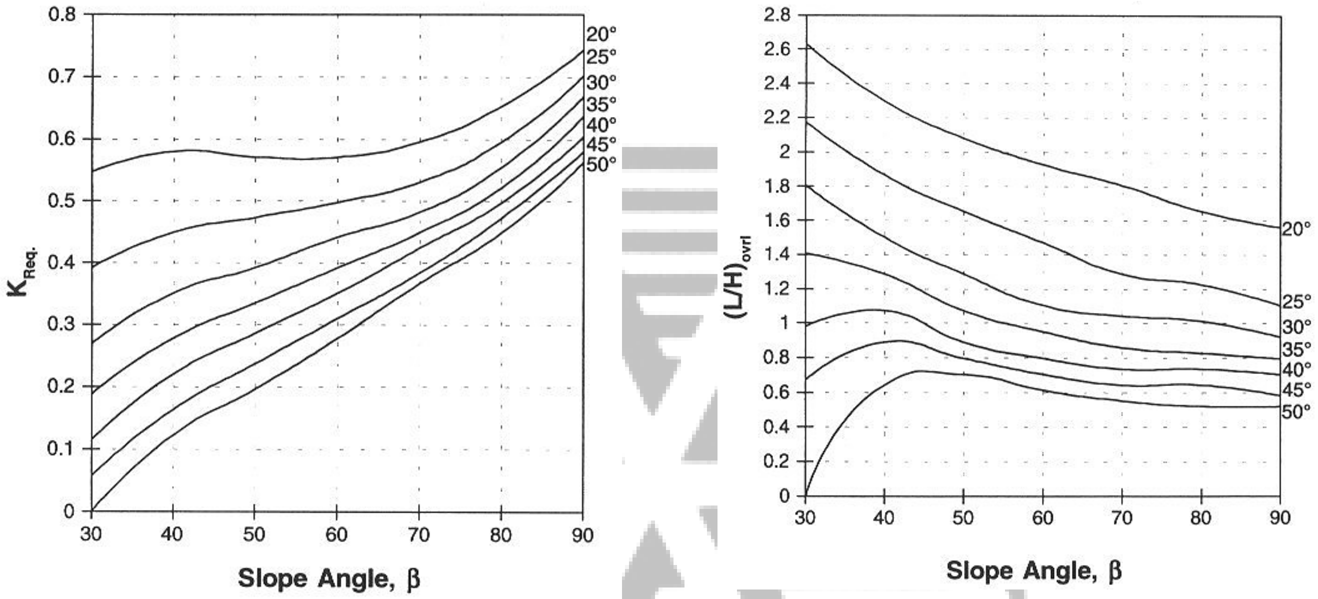


Fig. 11: The two part wedge failure mechanism.

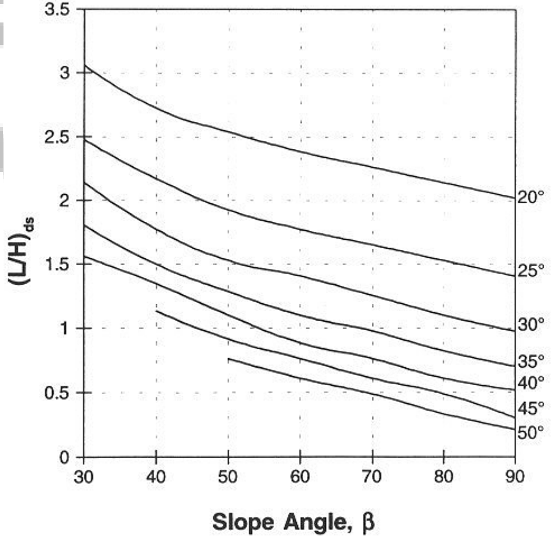
# Steep Reinforced Slope Design Charts (Jewell, 1991)



**Minimum Required Force $K_{Req}$ Lenght.**

**Minimum Required Length Overall Stability**

**Minimum Required Direct Sliding**



$$R_u = u/(\gamma z) = 0.50$$

Fig. 12: Design charts for steep reinforced slopes, for $R_u$ = 0.50

Reinforced soil walls are designed through three separate analyses (*see Fig. 13*):

- external stability, where the reinforced soil block is considered as a rigid body: direct sliding, rotation around the toe, and bearing capacity analyses allow to define the minimum length of reinforcement layers;
- internal stability: the reinforcing layers are designed in terms of vertical distribution, design strength and length, in order to afford a proper Factor of Safety against tensile failure and pull-out of reinforcement layers;
- global stability, where all the possible failure surfaces are investigated, including those passing beneath and beyond the reinforced block.

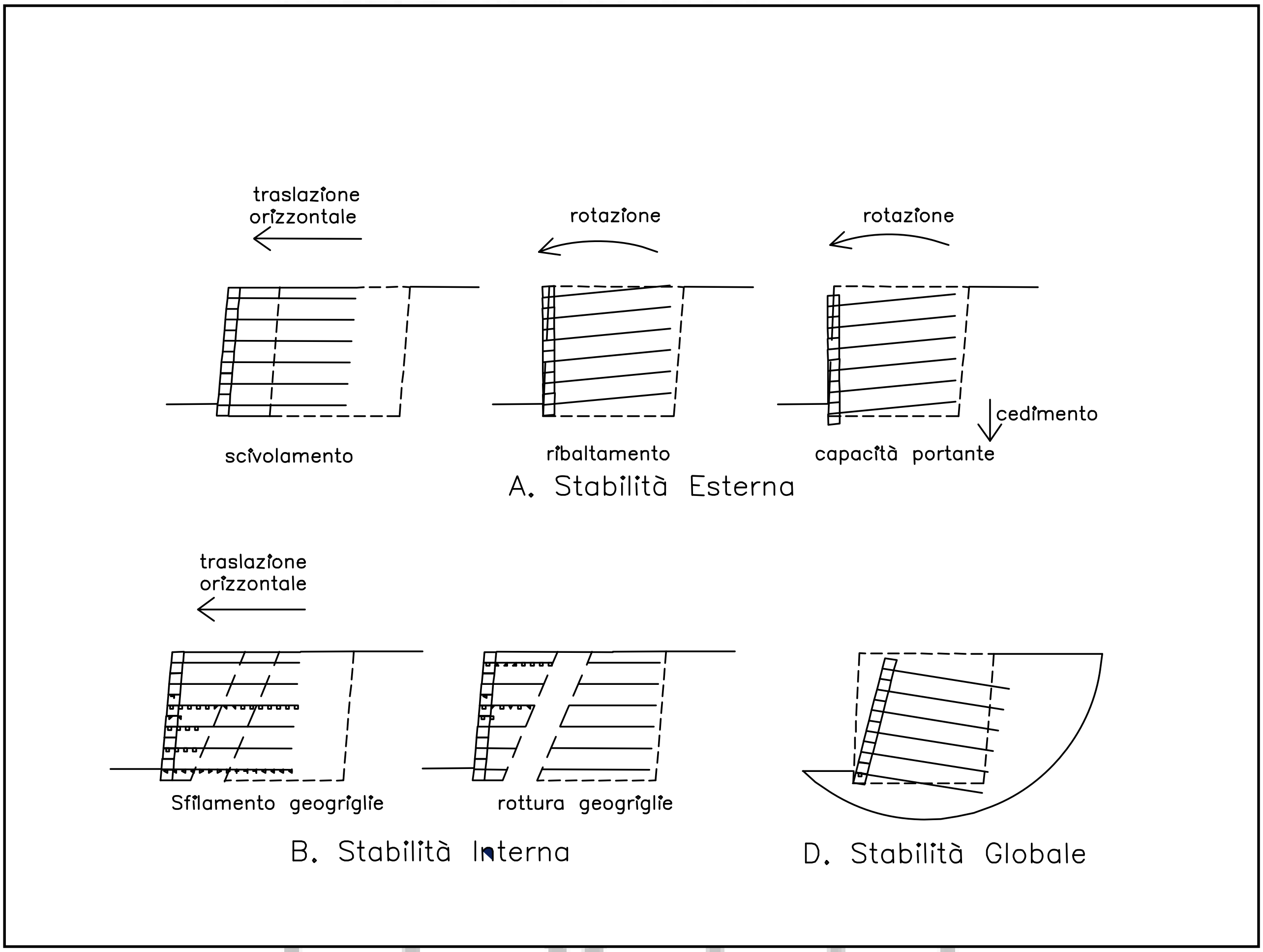


Fig. 13: Stability analyses for reinforced soil walls: A) external stability; B) internal stability; D) global stability

The design of reinforced soil slopes and walls requires the definition of the Allowable Long Term Strength $T_{allow}$ of the selected geogrids or geotextiles. $T_{allow}$ is obtained, for any given geosynthetic, through the following equation:

$$T_{allow} = \frac{LTDS}{FS_{damage} x FS_{chemical} x FS_{bio\log ical}}$$

The Long Term Design Strength LTDS is determined from accelerated creep tests, performed at different temperatures and extrapolated to 1,000,000 hours (120 years).

The proper Safety Factors $FS_{chemical}$ and $FS_{biological}$ can be determined by comparing the Ultimate Strength of a Reinforcement before and after exposure to a chemically or biologically aggressive environment.

The value of $FS_{damage}$ can be found as the ratio of the original Ultimate Strength of the geosynthetic to its Ultimate Strength tested on samples exhumed after installation.

The Design Strength $T_{des}$ is finally found by applying a further $FS_{design}$ (or the so called $f_n$, which takes into account the economical ramification of failure) depending upon the difficulty and importance of the project, to the Allowable Long Term Strength $T_{allow}$:

$$T_{des} = T_{allow}/FS_{design}$$

$FS_{design}$ ranges typically between 1.25 and 1.50.

ARTER® geogrids and MACRIT® geocomposites manufactured with PET fibers are available in strengths up to 600 kN/m.

*Tab. 1* shows the data sheet of one of these reinforcing geosynthetics.

ARTER® and MACRIT® present excellent low creep characteristics, high chemical and biological resistance, and good resistance to compaction damage. Tab. 1 and Tab. 2 shows the suggested values of the partial factors of safety for these two products.

The LTDS for all ARTER® geogrids and MACRIT® geocomposites can be safely assumed as:

$$LTDS = 0.66\ T_{ult}$$

where $T_{ult}$ is the ultimate tensile strength measured in Wide Width Tensile Tests (EN 1S0 10319), as reported in the data sheets of the products.

**Dati Tecnici** (valori nominali) **Technical data sheet** (nominal data listed) **Technische daten** (Nennwerte)

## ARTER GTS 200-30-30

|  |  |  |  |  | **TEST** |
|---|---|---|---|---|---|
| Struttura | Structure | Struktur |  | **K D.O.S.** |  |
| Composizione | Composition | Zusammensetzung |  | **PET EVA** |  |
| Massa areica | Mass per unit area | Masse pro Flächenneinheit | **$g/m^2$** | **480** | **UNI EN 965** |
| Resistenza a trazione longitudinale | Tensile strenght M.D. | Zugfestigkeit längs | **kN/m** | **200** | **UNI EN ISO 10319** |
| Deformazione longitudinale | Elogation M.D. | Dehnung längs | **%** | **12** | **UNI EN ISO 10319** |
| Resistenza a trazione trasversale | Tensile strenght C.D. | Zugfestigkeit quer | **kN/m** | **30** | **UNI EN ISO 10319** |
| Deformazione trasversale | Elongation C.D. | Dehnung quer | **%** | **12** | **UNI EN ISO 10319** |
| Resistenza longitudinale al 2% di deformazione | Strenght at 2% elongation | Festigkeit längs bei 2% Dehnung | **kN/m** | **50** | **UNI EN ISO 10319** |
| Resistenza longitudinale al 3% di deformazione | Strenght at 3% elongation | Festigkeit längs bei 3% Dehnung | **kN/m** | **75** | **UNI EN ISO 10319** |
| Resistenza longitudinale al 5% di deformazione | Strenght at 5% elongation | Festigkeit längs bei 5% Dehnung | **kN/m** | **135** | **UNI EN ISO 10319** |
| Resistenza longitudinale al 10% di deformazione | Strenght at 10% elongation | Festigkeit längs bei 10% Dehnung | **kN/m** | **<200** | **UNI EN ISO 10319** |
| Apertura di maglia | Mesh size | Maschenweite | **mm** | **30** |  |
| Larghezza del rotolo | Roll width | Rollebreite | **m** | **4,4** |  |
| Lunghezza del rotolo | Roll lenght | Rolleläange | **m** | **100** |  |

Tab. 1: The data sheet of ARTER® GTS/200-30-30 geogrid

| **Type of soil** | **Particle size** | **$FS_{damage}$ for ARTER** | **$FS_{damage}$ for MACRIT** |
|---|---|---|---|
| Silt and clay | < 0,06 mm | 1,00 | 1,00 |
| Pulverized fuel ashes |  | 1,00 | 1,00 |
| Fine and medium sand | 0,06 - 0,6 mm | 1,10 | 1,15 |
| Coarse sand and fine gravel | 0,6 - 6 mm | 1,20 | 1,25 |
| Crushed gravel, ballast, sharp stones | 6 - 60 mm | 1,30 | 1,40 |

Tab. 2: $FS_{damage}$ for different types of soil

| **pH of the soil** | **FSbiological** | **FSchemical** | **FSchemical for MACRIT** |
|---|---|---|---|
| PH < 2 | 1,00 | 1,30 | 1,40 |
| 2 < PH < 12 | 1,00 | 1,00 | 1,10 |
| PH > 12 | 1,00 | 1,30 | 1,40 |

Tab. 3: $FS_{chemical}$ and $FS_{biological}$

The main difference between the two products is that MACRIT® includes a nonwoven geotextile, which provides separation, filtration and drainage capacity. When the reinforced slope or wall is made up of self draining soil, ARTER® geogrids are the favourite reinforcing elements; while when the soil is fine or with low permeability, MACRIT® geocomposites provide both reinforcement and internal drainage of the soil, thus ensuring a higher degree of stability.

*Fig. 14* show examples of reinforced soil slopes and walls built with ARTER® geogrids and MACRIT® geocomposites.

Fig. 14: Examples of reinforced soil walls and slopes with ARTER® geogrids and MACRIT® geocomposites

# 5 GEOSYNTETHICS IN ROADWAYS AND RAILWAYS BASES

Roadways and railways may fail due to structural deficiencies, which can occur expectedly at the end of the design life or prematurely. The development of permanent strain in the base and subgrade materials with continued traffic loading can eventually result in an excessive rut depth. In this case, geosynthetic reinforcement of the roadway system could be used to enhance structural characteristics. In another case, the mixing of the subgrade with the base course would lead to a deterioration of the mechanical properties of the base course layer. In this situation, use of a geosynthetic separator/filter would ensure the structural integrity of the base aggregate and the capacity of the roadway.

Geosynthetics can be used to reduce the design cross-section of the roadway such that a roadway of equal life results. Alternatively, geosynthetics can be added to the original design cross section to extend the life of the roadway and to decrease maintenance costs. Geosynthetics can also be used to great advantage during the construction of a roadway over soft soils where separation and reinforcement can aid in the construction of a working platform for the remaining construction.

Geosynthetics (geogrids and geotextiles) in roadways play functions that fall into four categories: reinforcement, separation, filtration and drainage.

- Reinforcement: the function of reinforcement pertains to the ability of the geosynthetic to aid in supporting vehicular traffic loads, where these loads may be due to construction traffic or daily operating traffic. Reinforcement plays the function of lateral base course restraint and the tensioned membrane function.
- Lateral Base Course Restraint: the reinforcement function of lateral base course restraint develops through shear interaction of the base aggregate with the geosynthetic contained in or at the bottom of the base layer (*Figure 15*).

  The development of shear interaction at the base-geosynthetic interface potentially results in four reinforcement mechanisms commonly lumped together under the heading of lateral base course restraint.

  As illustrated in *Figure 16*, vehicular loads applied to the roadway surface create a lateral spreading motion of the base aggregate. Tensile lateral strains are created at the bottom of the base as aggregate moves down and out away from the applied load. Lateral movement of the base aggregate allows for vertical strains to develop leading to a permanent rut in the wheel path. Placement of a geosynthetic layer or layers in the base aggregate allows for shear interaction to develop between the base and the geosynthetic as the base aggregate attempts to spread laterally. Tensile load is in effect transmitted from the base aggregate to the geosynthetic layer.

  Since the geosynthetic is considerably stiffer in tension as compared to the base aggregate, far less lateral tensile strain develops in the system. This first reinforcement mechanism results from less lateral strain being developed in the base, which results in less vertical deformation of the roadway surface. The shear stress developed between the base aggregate and the geosynthetic provides an increase in lateral stress within the bottom portion of the base. This increase in lateral confinement leads to an increase in the mean hydrostatic normal stress in the aggregate.

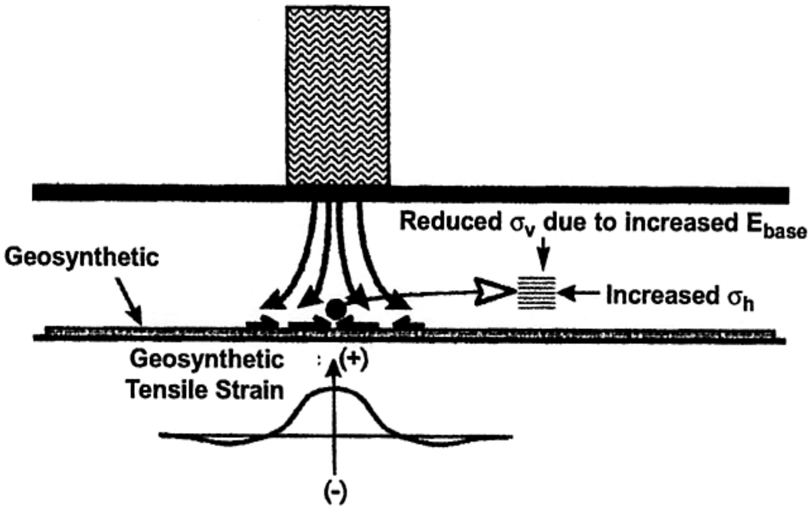


Fig. 15: Lateral base course restraint mechanism

Granular materials generally exhibit an increase in elastic modulus with increasing mean stress, meaning that the base aggregate becomes more stiff when adequate interaction develops between the aggregate and the geosynthetic. This second reinforcement mechanism, an increase in modulus due to lateral confinement of the base, also results in less vertical strain being developed in the base aggregate. While this mechanism controls the development of rut depth, it might also be expected that an increase in modulus of the base would result in lower dynamic, recoverable vertical deformations of the roadway surface, meaning that fatigue of an asphalt concrete layer in a flexible pavement would be reduced by this mechanism.

For layered systems, where a weaker, less stiff subgrade material lies beneath the base aggregate, an increase in modulus of the base also means that this layer will aid in distributing load on the subgrade. This third reinforcement mechanism reduces vertical stress in the base and in the subgrade beneath the centerline of the wheel. A reduction of vertical stress results in lower vertical strain in these layers. As a result of an improved load distribution, the deflected shape of the roadway surface would have less curvature.

The presence of a geosynthetic layer in the base course layer can also lead to a change in the state of stress and strain in the subgrade material. As noted above, the increased stiffness of the base layer leads to a reduction of vertical stress in the subgrade. It is also expected that shear stress transmitted from the base aggregate to the subgrade would be reduced. Hence, this fourth reinforcement mechanism results from less shear stress being developed in the subgrade, which, when coupled with lower vertical stress, results in a less severe state of stress leading to lower vertical strain in the subgrade.

- Tensioned Membrane: the function of the geosynthetic to act as a tensioned membrane has been described in terms of subgrade confinement or restraint, increased subgrade bearing capacity and membrane support. For applied wheel loads causing impending shear failure of the subgrade and resulting in relatively large rut depths, the deformed shape of the geosynthetic would be as shown in *Fig. 16*. The deformed shape of the geosynthetic and the resulting tension developed in the material creates an upward deflection of the wheel load and a downward confinement on the subgrade.

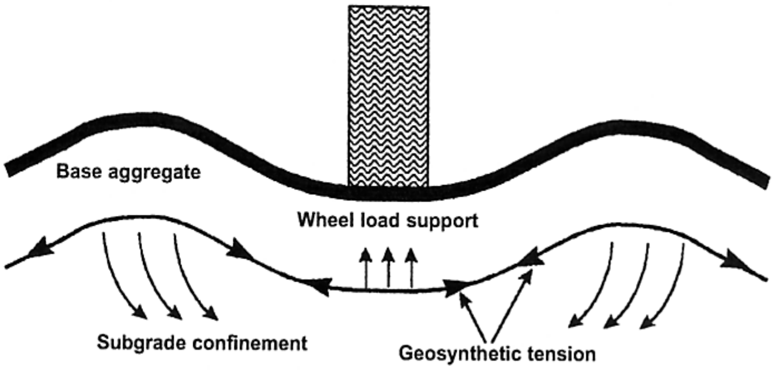


Fig. 16: Tensioned membrane function.

Membrane support of the wheel load reduces the vertical stress applied to the subgrade. Confinement of the subgrade increases its resistance to shear failure (i.e. bearing capacity). The reinforcement process is dependent on the rut depth developed. Initially, the load applied may exceed the subgrade strength, which allows rutting to occur. As rutting progresses under the condition that the applied load exceeds the strength of the subgrade, the geosynthetic begins to carry more load. This process continues until the stress on the subgrade is equal to a permissible level. At this point the system becomes stable and the rut depth reaches a constant value. To develop this mechanism, significant deformation of the roadway surface is necessary, which generally requires that the subgrade soil is weak and/or the traffic loads are heavy. Traffic must also be channelized (i.e. operating in the same travel path) for situations where a critical rut depth is reached after a series of traffic passes.

- Separation: in many situations, fines from the underlying subgrade can contaminate the base course layer of a paved or unpaved road and may happen during or after construction. Contamination of the base course layer leads to a reduction of strength, stiffness and drainage characteristics, promoting distress and early failure of the roadway. Fines contamination also makes the base course layer more susceptible to frost heaving. The contamination process is far heavier in railways where the fast cyclic load of the trains wheels produce a “pumping” action which promotes the fast upward movements of fine particles into the base and even the ballast layers, thus producing a fast decrease of their supporting capacity.

The function of separation refers to the ability of the geosynthetic to provide physical separation of subgrade and base materials both during contruction and during the operating life of the roadway or railway. It is illustrated in *Fig. 17*. The function is defined by a prevention of mixing, where mixing is caused by some type of mechanical action. Mechanical actions causing mixing generally arise from physical forces imposed by construction or operating traffic and may cause the aggregate to be pushed down into the soft subgrade and/or the subgrade to be squeezed up into the base aggregate. If the subgrade is weak at the time of construction, then the combination of relatively thin initial base course lifts combined with heavy construction equipment generally means that the potential for mixing is greatest during construction. A properly designed geosynthetic separator allows the base course aggregate to remain “clean”, which preserves its strength and drainage characteristics.

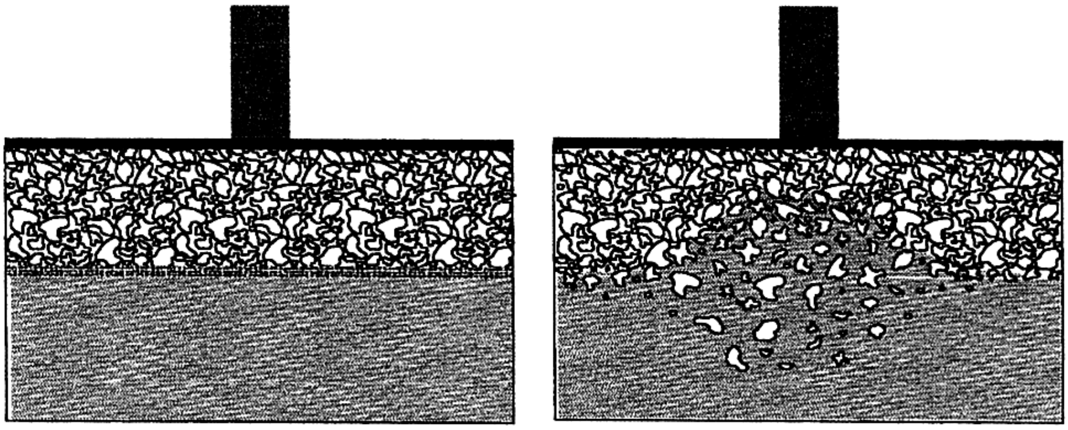


Fig 17: Geosynthetic separation function.

The strength and modulus of the separating geosynthetic is important only to ensure survivability of the material during contruction and operation of the roadway. The addition of a geosynthetic separator ensures that the base course layer in its entirety will contribute and continue to contribute its intended structural support of vehicular loads; the geosynthetic separator itself is not viewed to contribute structural support to the roadway.

- Filtration: filtration refers to the ability of the geosynthetic to filter fine soil particles from the subgrade from intruding into the base when water flows from the subgrade into the base. Water flow is most likely produced by the generation of excess pore water pressures in the subgrade as a result of repetitive traffic. Fine soil particles that become suspended in the pore fluid are filtered by the geosynthetic as water passes through it into the base. If filtration is needed, then a suitable geotextile having characteristics which prevent clogging while serving as a filter should be selected.

Available literature clearly demontrates the ability of both geotextiles and geogrids to reinforce unpaved roadways through the operation of the tensioned membrane effect. There is also evidence that indicates that for relatively small rut depths, the function of lateral base course restraint is important in providing improvement of unpaved roads. Experimental data suggests that this mechanism is viable for geotextiles but is more predominant when geogrids are used.
The need for reinforcement increases as the strength of the subgrade decreases, the vehicle weight and passes increases and as the expected performance of the roadway becomes more stringent. The thickness of the base aggregate and whether the traffic is channelized or random will indicate the type of reinforcement function most appropriate for design. A thick base course section that can be placed in such a way as to minimize separation problems will develop as much as 50% of the surface rut depth through vertical strain in the base. For this situation, geogrid reinforcement providing a lateral base course restraint mechanism will be most appropriate. For random traffic, it is unlikely that sufficient rut depth in any given spot will develop to mobilize the tensioned membrane reinforcement function. For this case, geogrid reinforcement providing a lateral base course restraint mechanism will again be most appropriate.

For situations where the base is relatively thin, traffic is channelized and relatively large rut depths are permissible, the tensioned membrane reinforcement function is most appropriate. Both geogrids and high modulus geotextiles are potential candidates for this application.

For situations where geogrid materials are more appropriate for reinforcement, a geogrid would need to be used in combination with a geotextile for required separation, filtration and drainage functions.

*Fig. 18*, which reports the results of experiments made in USA on 1996, clearly shows the advantage and savings that can be achieved through the inclusion of a geogrid and of a geogrid-geotextile geocomposite in a road base.

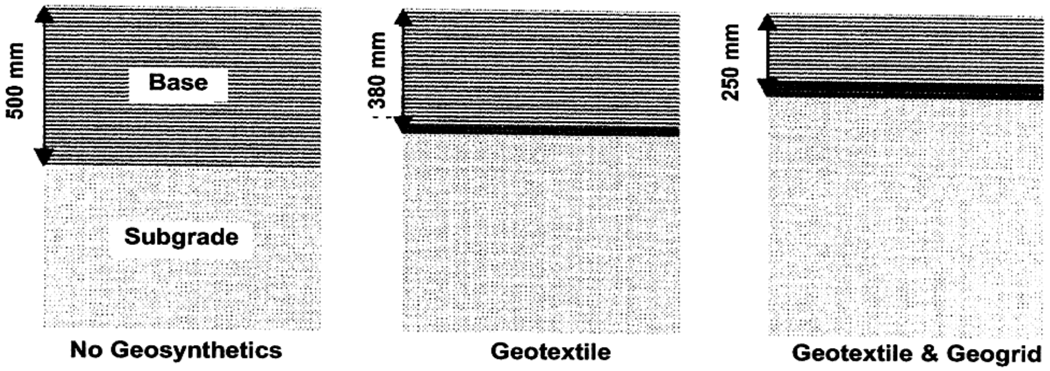


Fig. 18: Unpaved test section geometry constructed in USA in 1996. Each section reached a rut depth of 75 mm after 2000 passes of a veichle having a gross weight of 185 kN

ARTER® geogrids and MACRIT® geocomposites, with their high technical properties, provide an excellent solution in both situations. *Fig. 19* shows the use of ARTER® and MACRIT® as ballast reinforcement in a railway.

Fig. 19: ARTER® geogrids and MACRIT® geocomposites for railway base reinforcement

# 6 CONSTRUCTION OF EMBANKMENTS WITH REINFORCEMENT AT THE BASE

Reinforcement is used in the foundation to enhance the resistance of embankments to avoid failure through excessive deformation or shear in the foundation.
Much of the design and analysis of reinforced soil foundations have utilised a limit equilibrium approach where a global Factor of Safety is required to be satisfied. Because these methods are based on equilibrium considerations they can be simply restated in a limit state format by increasing the soil weight and live loading by appropriate partial load factors and reducing the soil properties and reinforcement strength by appropriate partial material factors.
The reinforcement material factor is applied to the ultimate tensile strength strength of the reinforcement and should have a value consistent with the type of reinforcement to be used and the design life over which the reinforcement is required.
There are also two soil/reinforcement interaction parameters which require consideration:

- soil sliding across the surface of the reinforcement;
- pull-out of the reinforcement from the soil.

## 6.1 REINFORCED EMBANKMENTS OVER SOFT AND VERY SOFT FOUNDATION SOILS

For the construction of reinforced embankments over soft and very soft foundation soils, the techniques in use can be divided into one of two categories:

a) Those techniques where the reinforcement is used to control initial stability of the embankment, without controlling settlement (*Fig. 20, a,b,c*). Techniques include basal reinforcement alone; basal reinforcement with vertical drains; and basal mattress reinforcement.
b) Those techniques where the reinforcement is used as part of a foundation stabilisation system to control stability and prevent settlement of the embankment (*Fig. 20 d*).

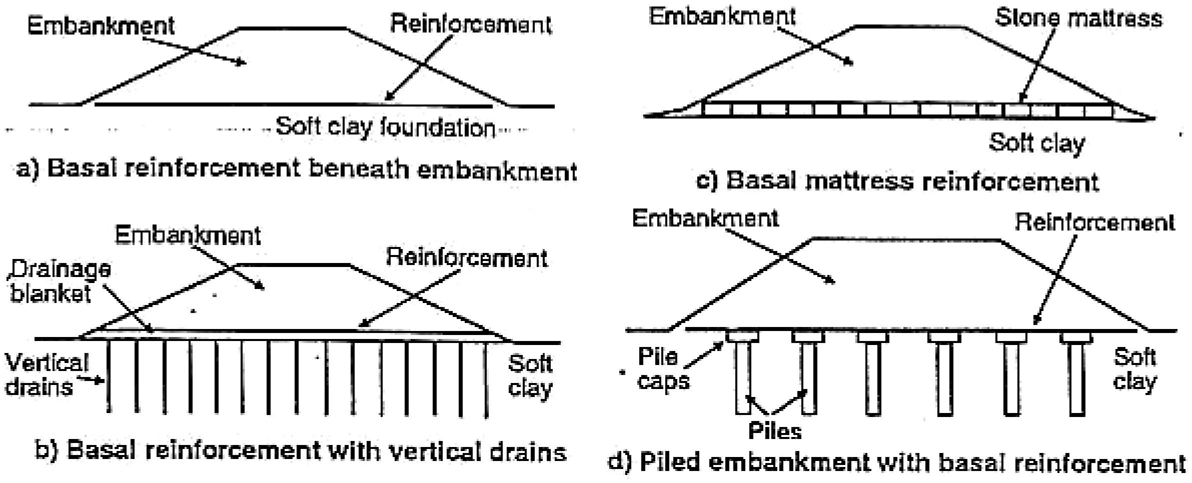


Fig. 20: Techniques used for reinforcement of embankments on soft soil

## 6.2 REINFORCEMENT USED TO CONTROL EMBANKMENT STABILITY

The stability of an embankment constructed on soft soil is governed mostly by the shearing resistance of the foundation, and the construction of an embankment on soft soil is a problem of bearing capacity. Reinforcement may be placed at foundation level to prevent shear failure both in the embankment fill and in the foundation soil, any reduction in differential settlement is of secondary importance. An important consideration is that the stability of an embankment on soft soil is most critical during construction. This is because the relatively low permeability of the soft foundation does not permit full consolidation in the normal time scale of construction. At the end of construction the embankment loading has been applied, but the gain in shearing resistance of the foundation due to consolidation may be insufficient for stability.

Once consolidation has occurred, the resulting improvement in shearing resistance in the foundation will usually remove the need for the reinforcement to improve stability. Thus during the period between the end of construction and consolidation of the foundation the fundamental strength requirement of the reinforcement is that at any instant of time the factored reinforcement design strength must equal or exceed the design load.

Basal reinforcement stabilises an embankment over soft ground by preventing lateral spreading of the soil, extrusion of the foundation and overall rotational failure.

This stabilising force is generated in the reinforcement by shear stresses transmitted from the foundation soil and fill which place the reinforcement in tension.

The ultimate limit states which must be considered (*Fig. 21*) are as follows:

- local stability of the embankment fill;
- rotational stability of the embankment;
- lateral sliding stability of the embankment;
- foundation extrusion stability;
- overall stability.

The serviceability limit states which must be considered (*Fig. 21*) are:

- excessive strain in the reinforcement;
- settlement of the foundation.

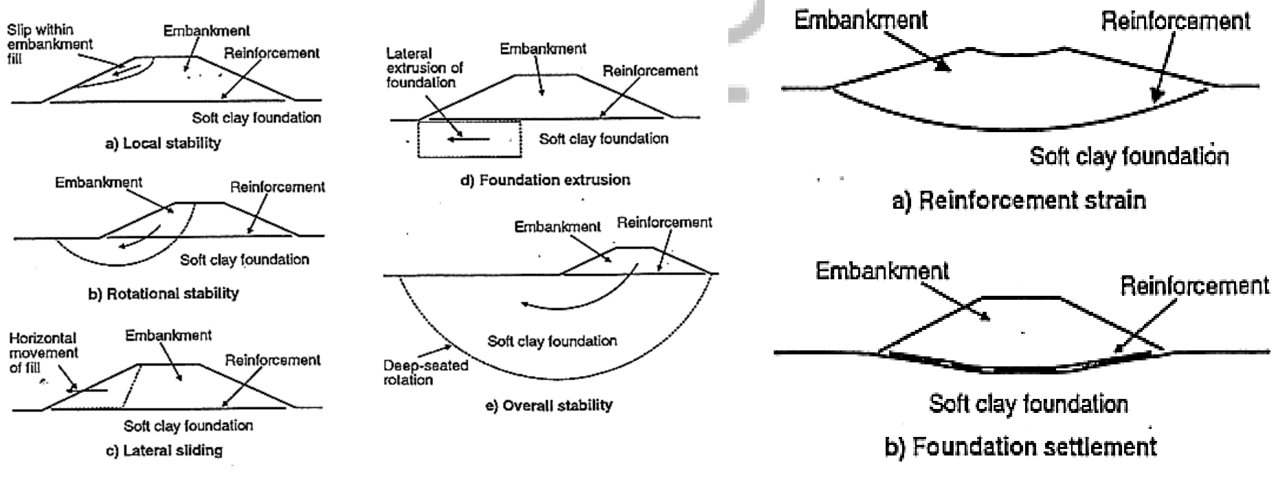


Fig. 21: Ultimate and serviceability limit states for the design of reinforced embankments on soft soil

## 6.3 REINFORCEMENT USED TO CONTROL EMBANKMENT STABILITY AND SETTLEMENT

Various techniques exist to increase the effective shear strength of soft foundation soils, and to control their post-construction consolidation. These techniques include drainage, grouting, piling, and complete soil replacement One technique which enables embankments to be constructed to unrestricted heights (assuming the fill is suitably stable), at any construction rate, with subsequent controlled post-construction settlements, is piling. Basal reinforcement may be used to bridge across the tops of pile caps to distribute the load, and maximise the economic benefits of piles installed in soft foundations (*figure 20.d*).

It is normally assumed that all of the embankment loading will be transferred through the piles down to a firm stratum. Consequently, the performance of the embankment, and the characteristics of the soft foundation soil, have to be considered only with regard to the type of piles used and their installation. Basal reinforcement spanning across the pile caps may be used to transfer the embankment loading onto the piles. The reinforcement permits the spacing of the piles to be increased and the size of the pile caps to be reduced. In addition the reinforcement counteracts the horizontal thrust of the embankment fill and the need for raking piles along the extremities of the foundation can be eliminated

The ultimate limit states which must be considered (*Fig. 22*) are as follows:

- pile group capacity;
- pile group extent;
- vertical load shedding onto the pile caps;
- lateral sliding stability of the embankment fill;
- overall stability of the piled embankment.

The serviceability limit states which must be considered (*Fig. 22*) are:

- excessive strain in the reinforcement;
- settlement of the piled foundation.

The maximum ultimate limit state tensile load, Tr, per metre 'run', in the basal reinforcement should be the following:

a) In the direction along the length of the embankment the maximum tensile load should be the load required to transfer the vertical embankment loading onto the pile caps, Trp.
b) In the direction across the width of the embankment the maximum tensile load should be the sum of the load required to transfer the vertical embankment loading onto the pile caps, Trp, and the load required to resist lateral sliding, Tds.

Trp can be calculated taking into account the soil arching effect between two adjacent piles, according to the scheme shown in *Fig. 23.A*; Tds can be calculated based on the scheme shown in *Fig. 23.B*.

To ensure the ultimate limit state governing reinforcement rupture is not attained over the design life of the reinforcement the following condition must be observed:

$$T_D / f_n > T_r$$

where $T_D$ is the design strength of the reinforcement, and $f_n$ is the partial factor governing the economic ramifications of failure.

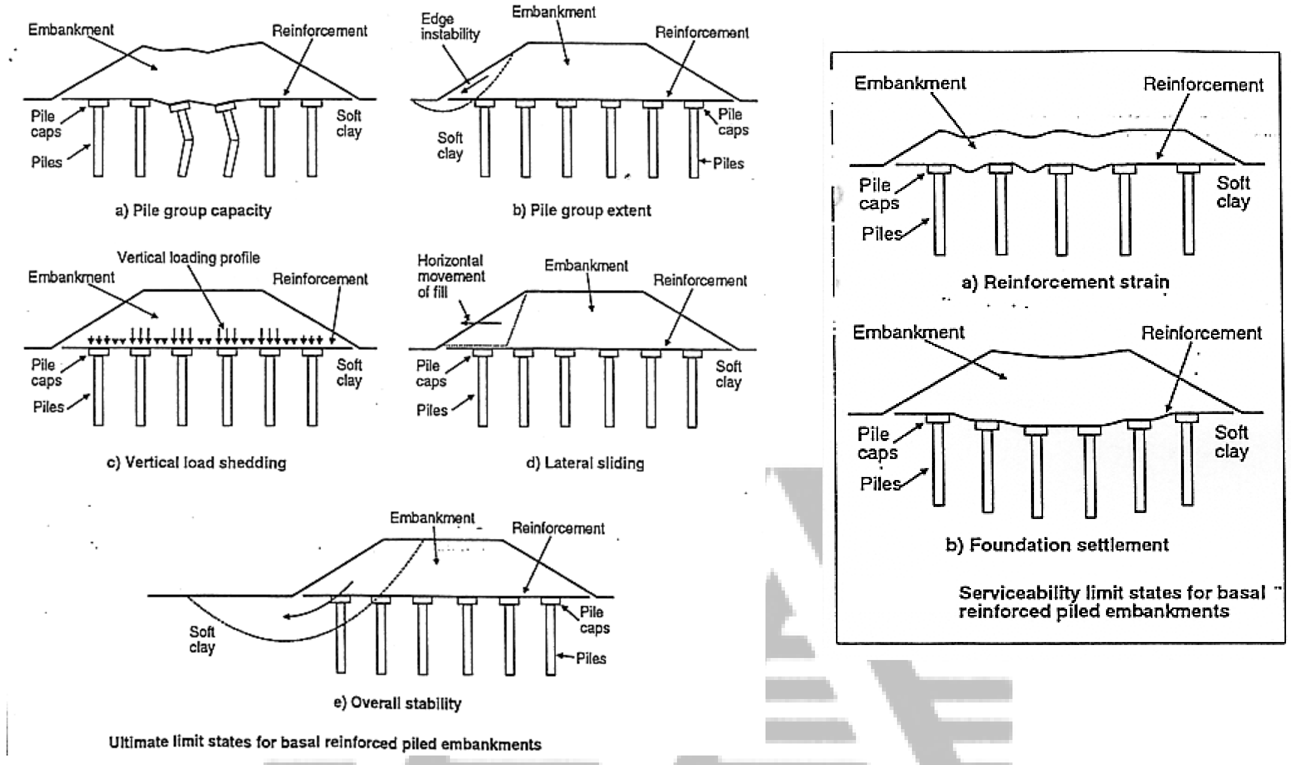


Fig. 22: Ultimate and serviceability limit states for basal reinforcement over piles

The ultimate tensile strength required to provide the desigh strength $T_D$ resulting from the above calculations can be very high, even in excess of 1,000 kN/m.

Hence the reinforcing geosynthetics must be of the highest quality and with the highest technical characteristics.

MULTIAXIAL and ARTER® geogrids and MACRIT® geocomposites can be produced with high tenacity PET fibers, with ultimate tensile strength up to 600 kN/m and related design strength up to 400 kN/m.

When these strengths are not enough according to the calculations, MULTIAXIAL, ARTER® and MACRIT® can be produced with liquid crystals polimers fibers (Vectran), reaching extremely high ultimate tensile strengths, up to 1,650 kN/m, and with practically no creep. The resulting design strength of these geosynthetics can reach therefore the level of almost 1,200 kN/m, representing the present upper limit of the geosynthetics technology.

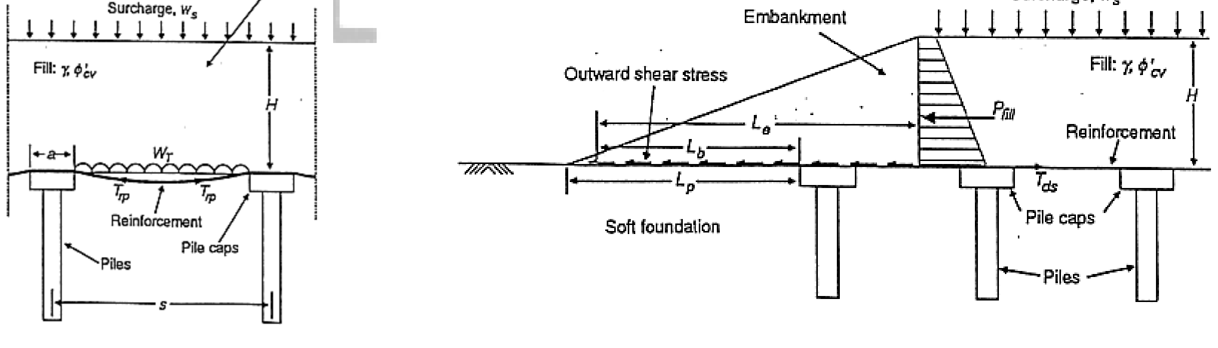


Fig. 23: Schemes for the calculation of Trp (A) and of Tds (B)

# 7 ASPHALT REINFORCEMENT

Asphalt is a proven material for the construction and maintenance of roads and runways. However, even in new asphalt layers, there is recurring evidence of reflection cracking. Such cracks are produced mainly by excessive thermal and/or traffic induced forces within the asphalt.
In an asphalt layer over a concrete roadway, reflection cracks may be caused by horizontal movement of individual concrete slabs, as they expand or contract under the influence of daily or seasonal temperature fluctuations. These movements produce high strain in the asphalt layer directly above a concrete joint, most likely resulting in cracks.

Asphalt reinforcement is used for upgrading existing roads and for construction of new roads (especially on a soft ground). The reinforcing grid increases the tensile strength of the asphalt layer, and under load ensures even distribution of horizontal stresses over a wider area.
Damage in asphalt layers can be significantly delayed or entirely prevented by using ARTER® K geogrids and MACRIT® K geocomposites.

These flexible asphalt reinforcement geosynthetics are designed to prevent cracks in asphalt layers by redistributing asphalt tensile stresses. The grid is made of high-modulus, heat-resistant PET fibers, while the EVA coating ensures excellent adhesion to the asphalt.
Flexible pavements generally consist of a prepared subgrade layer which is the roadbed soil or borrow material compacted to a specified density. A subbase course is constructed on top of the prepared roadbed, and may be omitted if the subgrade soil is of a high quality. The base course is constructed on top of the subbase course, or if no subbase is used, directly on the roadbed soil. It usually consists of aggregates such as crushed stone, or crushed gravel and sand. On top of the base course is the surface course that typically consists of a mixture of mineral aggregates and bituminous materials.
Paved road surfaces must be maintained when they develop significant cracks and potholes. The rehabilitation of cracked roads by simple overlaying, or placing an additional layer of asphalt over the old paved surface, is rarely a durable solution. The cracks in the old pavement eventually propagate through to the new surface. This is called reflective cracking.
A geosynthetic can be placed over the distressed pavement prior to the overlay to create an overlay system. The MACRIT® geocomposites are fixed to the bottom surface through a bituminous tack coat which is sprayed on the old road surface to enhance the bond between the old and new pavements. The resulting geosynthetic interlayer, impregnated with the bitumen from the tack coat, can enhance the life of the overlay via stress relief and/or reinforcement.
A stress relieving geosynthetic retards the development of reflective cracks by absorbing the stresses that arise from the damaged pavement. And, since it is impregnated with tack coat, it also prevents seepage through the pavement when the old cracks eventually reflect through.
Reinforcement occurs when a geogrid is able to contribute significant tensile strength to the pavement system. The reinforcement attempts to prevent the cracked old pavement from moving under traffic loads and thermal stress by holding the cracks together.

While ARTER® geogrids can provide substantial reinforcement, MACRIT geocomposites can provide both stress relief and reinforcement.
The benefits of geosynthetic interlayers include:

- saving 30 - 50 mm of overlay thickness;
- delaying the appearance of reflective cracks;
- lengthening the useful life of the overlay.

The nonwoven geotextiles included in the MACRIT® geocomposites have relatively high elongation and low tensile strength. They are commonly used for stress relief. When impregnated with tack coat, the fabric allows considerable movement around a crack but nullifies or at least lessens the effect the movements have on the overlay. This type of interlayer also waterproofs the road structure.

To reinforce, a geosynthetic interlayer has to hold the underlying crack together and dissipate the crack propagation stress along its length. If the interlayer elongates under stress, it will allow the crack to open. Consequently, the interlayer must have high axial stiffness so that little elongation takes place. In order to stop the crack from opening, the interlayer also needs to control horizontal movement of the asphalt. A stiff interface between the interlayer and asphalt is therefore required. The resistance of the reinforcement and the asphalt to move relative to each other is called pullout. The interlayer should have appropriate strength/stiffness and pullout resistance.

ARTER® GTS and GTS A geogrids and the grids included in the MACRIT® GTS V geocomposites are made of high tenacity PET fibers, hence they provide all the strength, stiffness and pull-out resistance needed to positively reinforce asphalt layers.

On site and laboratory experiments confirm the excellent performance of ARTER® GTS A and MACRIT® GTS V in bituminous paving reinforcement.

Aa an example, an independent research program performed in Slovakia has evaluated 15 different geosynthetics for asphalt reinforcement, including nonwoven geotextiles, woven geotextiles, extruded geogrids, woven geogrids, and geocomposites. An important part of such evaluation was the test aimed at measuring the bond strength between the asphalt and the geosynthetics. Hence samples of reinforced asphalt were bored and the resulting specimens were tested in direct shear mode along the asphalt - geosynthetic interface, with the apparatus schematically shown in *Fig. 24*.

Results of such tests indicated that ARTER® 40 - 35 (30 mm x 30 mm mesh) by far had the highest bond resistance of all the 15 tested geosynthetics.

Such excellent bond strength derives from the EVA coating of ARTER® GTS, which melt when asphalt is laid down, thus “glueing” the geogrid to the bottom layer and to the new asphalt layer being laid.
Hundreds of successful installations prove that ARTER® GTS and MACRIT® GTS V are presently the state-of-the-art asphalt reinforcing geosynthetics.
*Fig. 25* shows phases of ARTER® and MACRIT® installation in asphalt overlays.

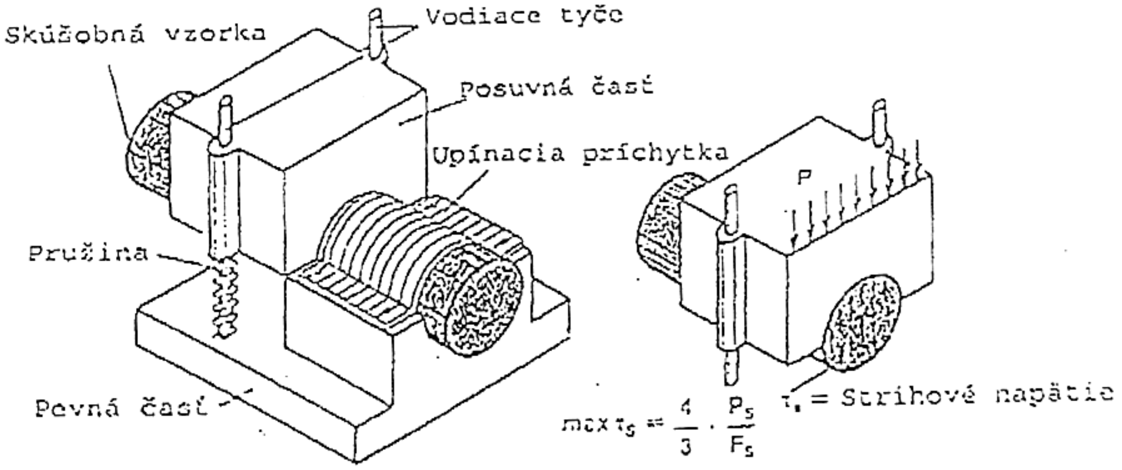


Fig. 24: Scheme of the bond strength test on asphalt - geosynthetic interface

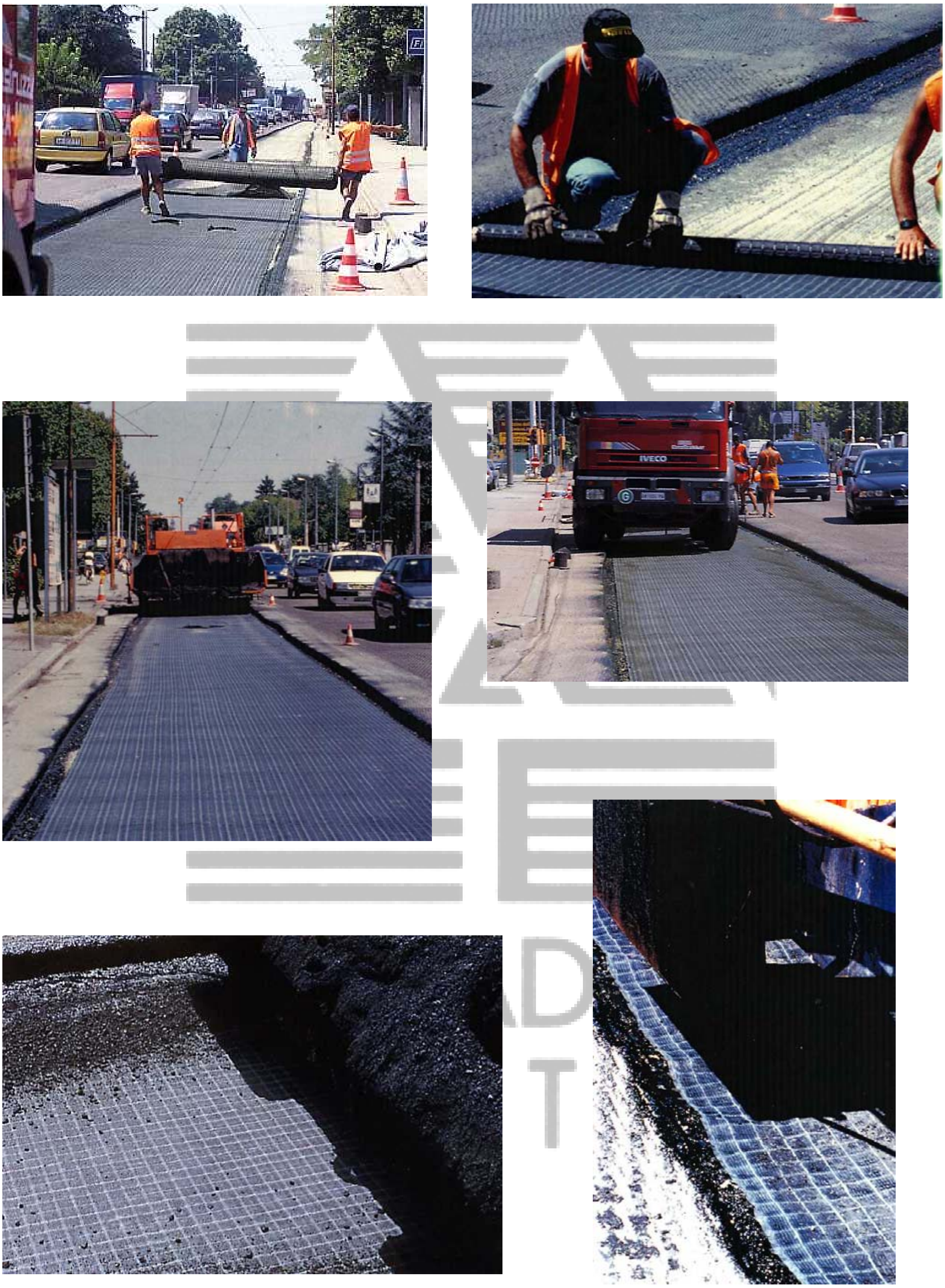


Fig. 25: Phases of the installation of ARTER® K geogrids and MACRIT® K geocomposites in asphalt overlays

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