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A green solution for the design and construction of steep slopes and embankments

OVER THE YEARS since the company began in Italy in the late 19th century to solve problems regarding the impact of civil engineering works on the surrounding environment, Maccaferri has always used innovative ways to introduce new and improved methods and systems. Some of the biggest challenges faced were in the realm of retaining walls and steep embankment slopes. Experience gained with mass gravity gabion retaining structures prepared the way for further development, incorporating the principles of soil reinforcement.

BACKGROUND

The first structure to use the Terramesh™ (TM) system was a 14,0 m high embankment in Sabah (Malaysia). This structure was built in 1979 in a very confined space to support a road embankment. It consisted of a vertical "skin" of rock-filled gabion mesh units that were anchored to the structural fill in the embankment using horizontal steel strips.

Following on from this experience, the design was improved and steel wire in the form of a double twist (DT) hexagonal mesh reinforcement system replaced the steel strips. Independent TM units consisted of a gabion unit and reinforcement section (to the required lengths) made from a continuous panel of DT mesh (Figures 1 & 2).

To meet the need to reduce environmental impact by incorporating vegetation into the front face of the structure, it was possible to plant cuttings in the vertical face.

The versatile nature of gabion construction made it possible to "batter" or step back the front face, making allowance for the incorporation of topsoil to support the vegetation.

Further research and development using the stepped-back or sloping wall principles led to the establishment of the Green

1 Close-up view of GTM face showing PVC-coated DT mesh, biodegradable erosion control blanket and the vegetation

2 Vertical face Terramesh™ System showing soil reinforcement in cross-section

3 Stepped-back face to facilitate sloped profile of embankment

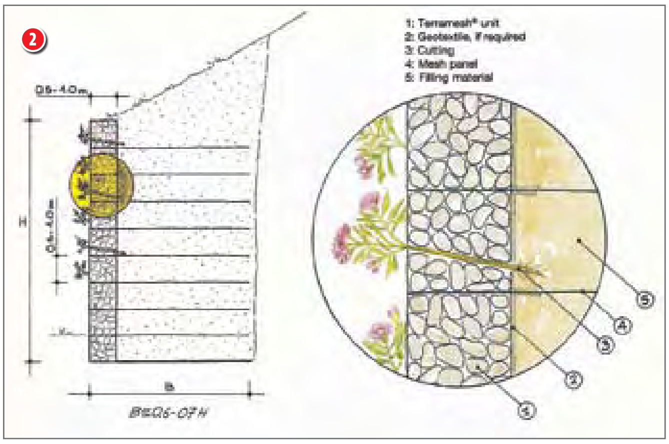
4 Gabion face units replaced by vegetative topsoil to form the Green Terramesh™ System

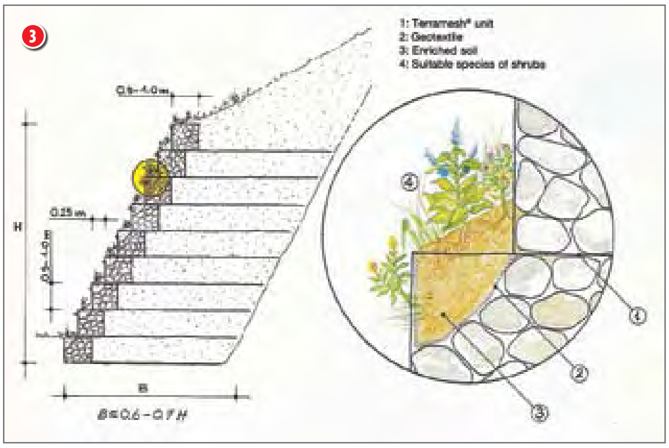
5 A single hexagon on which the DT mesh principle is based

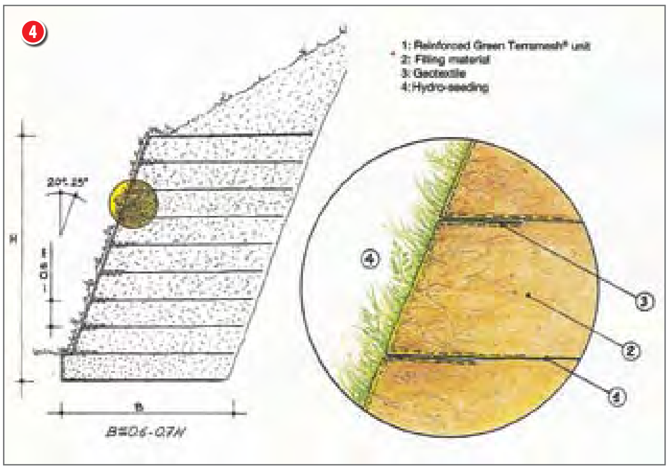
6 BioMac erosion-control blanket

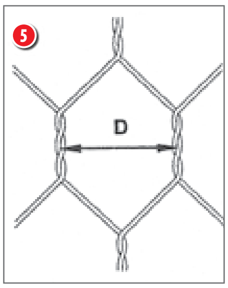
7 Mechanical interlocking properties of the structural fill

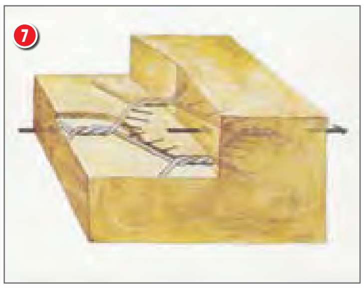
8 Standard GTM unit showing the extended mesh "tail" that is embedded into the soil as reinforcement

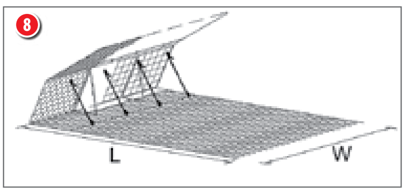












Terramesh™ reinforced unit (GTM) as a "Water" or "Soil" type (Figures 3 & 4). The GTM Soil type is used for retaining embankments and slopes, while the Water type, which utilises different geosynthetic components, is used for river bank protection and the lining of water courses.

MATERIALS USED

The standard GTM unit consists of a heavily galvanised 2,2 and 2,7 mm diameter steel wire which is PVC-coated before going through the DT process to form the mesh panels. An improved Galfan coating replaces the traditional zinc method. Galfan is classed as a zinc-alloy system with 5% aluminium and significantly extends the life of the mesh in industrial, coastal and other harsh environments. The coated steel wire is sourced from a local supplier in Gauteng and Maccaferri performs the extrusion of the PVC at its own factory in KwaZulu-Natal. All materials conform with relevant SANS specifications.

The PVC coating conforms with the requirements of appearance, specific gravity, hardness, tensile strength, modulus of elasticity, resistance to salt spray and to exposure to ultraviolet rays, abrasion resistance and brittleness temperature in terms of applicable ASTM standards.

To facilitate the process of vegetation a biodegradable erosion-control blanket (BioMac), made of 100% coconut fibre, is attached to the inside of the inclined front facing. A welded steel panel and preformed triangular brackets, shaped to fix a 45°, 60° or 70° slope angle, are set behind the BioMac to support the facing while holding the blanket in place during construction. In the Soil type system the erosion-control blanket protects the topsoil filling behind the face and permits a vegetative cover to establish itself rapidly.

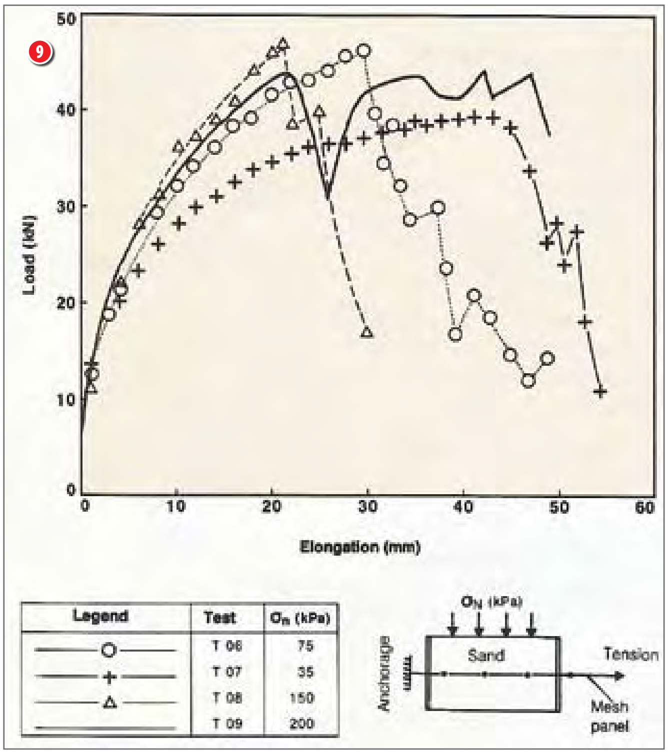
ADVANTAGES OF THE DT MESH

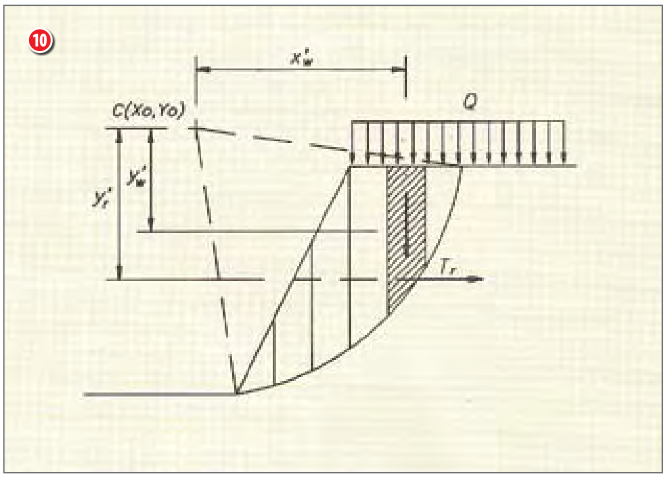
The use of the mesh exploits the friction on the surface of the wire and, more importantly, the mechanical interlocking properties of the structural fill. This phenomenon is due to the large size of the openings in the mesh (D = 80 mm with H = 100 mm) in relation to the diameter of the wire (2,7 mm or 3,7 mm and 2,2 mm and 3,2 mm when coated with PVC). The end-result is an increase in the total strength of the reinforcement, which would be impossible for other materials whose strength is derived from surface friction alone. The panels of double-twist mesh ensure that the reinforcement is continuous along the whole length of the structure, and not just in line with a limited number of tie points. The front end forms a "wrap panel" folded back from the face to bind in with the upper layer. (See Figures 5 to 8.)

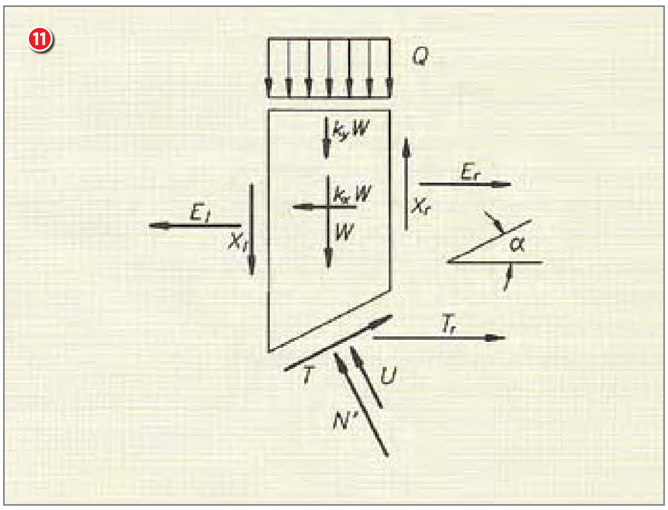
9 Resistance to pull-out of DT steel wire mesh embedded in a 1,0 m x 1,0 m section of compacted sand at increasing normal stress

10 Vertical slices analysis according to Bishop

11 Forces on a slice computed by Bishop's method







STRUCTURAL FILL

The structural fill is the carefully selected soil material that is used directly behind the Terramesh unit and placed and compacted in layers, with the reinforcement (mesh or grid or a combination of both) embedded into the layers at set vertical intervals, as specified in the design. This soil must have a low fines content and low plasticity, be relatively free-draining and have a fairly high angle of internal friction. It should not contain large sharp-edged particles which could damage the reinforcement during construction. Compaction must be done in layers not greater than 250 mm in depth and normally to 95% Mod. AASHTO.

RETAINED BACKFILL

The retained backfill forms the wedge of soil behind the structure that the GTM wall has been designed to support in addition to any external surcharge loads. This soil must also be well compacted, preferably to the same degree as the structural fill. Ideally, this section will be constructed at the same time as the structural fill so that the whole works will consist of continuous layers. Where necessary, a vertical subsoil drain can be used to separate this soil from the structural fill block.

VEGETATIVE TOPSOIL

The soil to be used directly behind the facing panel should be either a sandy clay or clay-like sand with 3 to 20% of organic material. This soil should be fertile and friable and be excavated from 200 to 300 mm depths in the field. It should be free from wood and stones larger than 50 mm in maximum dimension. A 500 mm wedge of the topsoil is placed behind the facing and compacted in 200 mm lifts using a light hand-held compactor. This process is carried out in conjunction with the laying and compaction of the adjoining layers of structural fill.

VEGETATION PROCESS

Where possible, the GTM face should be vegetated during construction or relatively soon afterwards to minimise or prevent erosion due to rainfall and runoff on the face. Vegetation requirements vary by geographic and climatic regions and are therefore project-specific. The steepness of the facing limits the amount of water retained by the soil before runoff occurs. Once the vegetation has been established on the facing, it should be protected. An initial irrigation plan and long-term maintenance programme may be required to ensure its survival. This system allows flexibility in the choice of vegetation, including herbaceous vegetation (grass) applied by hydroseeding or sod plugging, or woody plants cultivated in a nursery on site. The selection and choice is an integral part of the overall long-term erosion control plan and attractiveness of the solution.

REINFORCEMENT STRENGTH

Extensive research has been carried out on the properties of the 2,7 mm diameter DT steel wire mesh in a soil-reinforcement system. Specimens 1 m wide were used in a study at the University of New South Wales in Canberra, Australia, and the Federal Highway Administration carried out full-scale tests on a site at Chicago, USA. The anchorage capacity of the soil-reinforcement interface was studied, as well as reinforcement resistance. The results were used for various analyses, especially the load-extension relationship. In the design, partial factors of safety are applied to ensure that the ultimate tensile strength of the mesh is not exceeded under the working loads. It is also ensured that the horizontal strain under load does not lead to excessive deformation.

CONSTRUCTION OPTIMISATION

To optimise construction time, the GTM units are manufactured in a range of sizes with varying unit heights, tail lengths and tail widths.

ADDITIONAL REINFORCEMENT

In situations where a greater reinforcement resistance than the allowable tension in the mesh is required, it is possible to use other types of reinforcement, such as the MacGrid range of polymeric grid reinforcements.

This product can provide tensile strengths of 60 to 200 kN/m. Other materials, such as ParaLink and ParaGrid, are also suitable with strengths up to 1 000 kN/m.

In the process of selecting an alternative system, a short "tail" of the mesh (2,0 to 3,0 m long) could be used from the face to overlap the additional reinforcement so that the frictional

12 The GTM embankment at King Shaka International Airport at 80% of the final height, showing the initial growth of vegetation

resistance to "pull-out" is effective, or a separate layer of mesh or grid could be inserted between the GTM units to achieve adequate "bond" at the front end of the reinforcement where it connects to the face of the wall (Figure 9).

The polymeric or geosynthetic grid types consist of a dense formation of high-strength polyester tendons encased in either durable PVC or polyethylene sheathing.

TECHNICAL EVALUATION REPORTS

Maccaferri obtained certified reports evaluating the GTM system from the British Board of Agrément (BBA) in January 2000, and the Highway Innovative Technology Centre (HITEC) in the USA in April 2005.

DESIGN PRINCIPLES

Stability analysis during the design is carried out by means of limit equilibrium theory using either the Bishop or Jambu methods. In the process the reinforced soil mass is modelled using rigid equilibrium conditions along curvilinear slip planes so that computations based on the method of displacement can be used to analyse the effects of the force system at the intersection between the reinforcement and the surface defined by the slip plane. A system of linear equations, which take into account the resisting moment due to the shear forces which oppose sliding, and the overturning moment due to the destabilising forces, is developed for each slice. The contribution of the mesh reinforcement is introduced into the calculation only where it intersects the slip plane and is assumed to act horizontally. The magnitude of these forces is the lower value of the tensile strength of the mesh and the pull-out resistance of the mesh embedded in the soil. The first value is a constant and is fixed by the mesh characteristics, while the second value varies linearly with the depth, in terms of the reinforcement length beyond the slip surface. Each of these is reduced using adequate partial factors of safety in accordance with the particular standards applied by the designer.

One of the main limitations of limit equilibrium analysis is the difficulty in modelling the strain effect on the generation of force in the reinforcement, especially in respect of geosynthetic reinforcing material. This criterion has been incorporated into the software program developed by Maccaferri, through including an up-to-date database of each type and grade of reinforcement used. This information includes all the elastic characteristics required to model the strain behaviour of the reinforcement at the point where the displacement is generated, the displacement being a variable which depends on the geometry of the surface under analysis and on the check conditions fixed by the designer.

Elementary manual calculations can be used to assess computed design outputs using analysis based on the Rankine or Coulomb failure wedge theory.

APPLICATIONS OF GTM IN SOUTH AFRICA

The GTM system has been used for various applications in South Africa to date, as illustrated by the following two projects.

GTM embankment at the South Gate: King Shaka International Airport KZN

The embankment was designed by Maccaferri in conjunction with PD Naidoo and Associates. Construction was carried out under the Ilembe Civils Joint Venture by the subcontractor CivFin (Figures 12 & 14).

The structure consists of two walls at right angles to each other intersecting at the highest point, which is approximately 12,9 m (including 1,0 m foundation embedment). The total length is 210 m and the area of the GTM face is 1 520 m^2. The foundation was excavated into a hard shale formation and the first 4,0 m of the structural fill consists of an imported G4 dolerite material having an internal friction angle of 45°. The upper 8,0 m of structural fill is of the local silty sand, Berea Red soil, friction angle 29°. The retained backfill is also the Berea Red local soil found on the site.

The initial proposal was to construct the entire embankment using the imported dolerite. However, in order to economise, the alternative combination using Berea Red was chosen. The quantities of soil are as follows: dolerite 1 800 m^3; Berea Red (structural) 7 500 m^3; and retained backfill (Berea Red) 7 000 m^3. Construction was completed in October 2009.

The embankment has been designed to support a levelled terrace that houses an industrial section at the new airport. A road network traverses this built-up section and heavy vehicles are expected to utilise this area. A surcharge load of 50 kN/m^2 was applied in the design from a position 7,0 m back from the face. For reinforcement in the lower dolerite block, a 110 kN/m (ultimate strength) geosynthetic grid was used in conjunction with the standard mesh "tails" to a length of 7,0 m. The upper block in the Berea Red is reinforced by the mesh alone to a length of 6,0 m and based on an allowable tensile strength of 38 kN/m.

13 One of the embankments under construction at Le Grand Golf Estate viewed from another position on the site

14 Aerial view of the GTM embankment at King Shaka International Airport with the embankment at approximately 50% of the final height

In order to monitor movement during construction and under the final loaded condition, survey beacons were implanted at various positions along the face on both sides. Observations taken at the highest section over a period of nine months from December 2008 have indicated some movement: settlement ≈ 12 mm and tilt-back of face ≈ 25 mm. During this period there was higher-than-average seasonal rainfall on the site and the tilt readings varied from + 25 to –25 mm, indicating that the soil below the surface of the face may be causing a localised effect on the beacons. Ongoing observations should make this clearer.

The vegetation recommended for this application was: (a) green: *Cynodin*; and (b) plants: *Aptenia*, *Bulbine* and *Carpobrotis edulis*.

A nursery was established on site to prepare plugs of these species for insertion at the correct time. Hydroseeding of a grass type was also used to some effect.

Le Grand Golf Estate, George

The first phase of this project was designed by MVD Consulting Engineers (South Cape) (Pty) Ltd. Maccaferri assisted with design reviews and construction details.

Construction was carried out by the contractor Loyiso-Henra Construction. The works consisted of the construction of a number of GTM embankments ranging in height from 3,0 to 14,0 m on steep side slopes and from the lower portions of a deep valley that runs through the property (Figure 13). The total length is approximately 1 300 m and the full area of the face is 3 320 m^2. The approximate volume of structural and retained fill is 47 280 m^3. The structural fill consists of a greyish G7 sandy soil with an internal angle of friction of 30°.

A geosynthetic reinforcing grid with a 60 kN/m ultimate tensile strength was used in conjunction with the mesh tails. On the highest sections of the wall the reinforcement had lengths of 8,0 m at the base.

A kikuyu grass type, which is very common in this region, was used to vegetate the face. Irrigation of the face presented various challenges. In addition to this, the extremely dry conditions in that region at that time made it difficult to nurture the early growth of the vegetation.

CONCLUSION

The Green Terramesh™ System is a versatile solution for the design of steep slopes that are stable in confined spaces. The inclusion of high-strength geosynthetic grid reinforcement makes it possible for the system to carry relatively high loads for the full design life, at strains within serviceability requirements. Careful attention to the natural vegetative processes makes it possible to blend the structure in with the surrounding environment. The contractor should be fully competent in normal civil engineering works such as material selection, setting out and compaction control, and also be capable of working harmoniously with nature to take care of and improve the environment, where possible.

ACKNOWLEDGEMENTS

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