GEOSTRAP® & ECOSTRAP™ REINFORCEMENTS FOR MSE STRUCTURES. A NEW APPROACH TO GEOSYNTHETIC SOIL REINFORCEMENT.

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ABSTRACT

This paper discusses the use of new geosynthetic solutions for soil reinforcements reviewing the whole process from design through to the construction stage.

Recent developments in high strength polyester (PET) GeoStrap® and polyvinyl alcohol (PVA-L) EcoStrap™ soil reinforcements, combined with GeoMega® Sleeve, a new method for connecting geosynthetic reinforcements to concrete facing panels, offers durable design solutions for Mechanically Stabilized Earth (MSE) structures located in sea water and aggressive environments.

1 INTRODUCTION

Geosynthetic soil reinforcement has many benefits over traditional metallic reinforcement in that a wider range of backfill material is available for use as select fill. Geosynthetic reinforcement is also more suitable for use in marine environments due to its high durability when exposed to salts.

This paper discusses:

i) Reinforced Earth Pty Ltd (RECO) designed MSE walls that use GeoMega® connection system with segmental concrete facing panels.
ii) The different types of geosynthetic reinforcement used by RECO and the benefits of each.
iii) The research & development (undertaken & ongoing) which has been carried out into the properties of geosynthetic materials and their behaviour when employed as reinforcement in an MSE structure.
iv) The parameters used in the design of the geosynthetic reinforced MSE wall.
v) The construction procedure for a MSE wall using the GeoMega® connection system.

2 TECHNOLOGY

RECO's geosynthetic system includes the reinforcement materials itself, new materials research, plus both laboratory and on site tests performed to determine their physical properties and how they will behave when used as a soil reinforcement.

2.1 ELEMENTS

The following describe the two types of reinforcement together with GeoMega® Sleeve connection.

2.1.1 GeoStrap® reinforcing strips

GeoStrap® reinforcing strips consist of discrete channels of closely packed high tenacity polyester fibres encased in a polyethylene sheath. They are manufactured by extrusion-coating.

The polyester (PET) fibres are selected to comply with the most demanding up to date standards and demonstrate excellent durability in standard environments ($pH<9$). GeoStrap® strips are not sensitive to backfills with high concentrations of salts and are suitable to marine applications. Design parameters are determined according to the environment and the desired service life of the structure.

The polyethylene continuous sheath ensures a very efficient protection against potential installation damage. This makes the GeoStrap® reinforcing strip a particularly strong geosynthetic reinforcement.

The current range of available GeoStrap® reinforcing strips is shown in Table 1.

Table 1: GeoStrap® Range of reinforcements.

GeoStrap®		
GRADE	Nominal Width	Characteristic strength
	mm	kN
37.5	50	37.5
50	50	50.0
65	50	65.0

GeoStrap® reinforcing strips are compatible with all backfill with a pH under 9. They do not impose any limitation in salt concentration.

2.1.2 EcoStrap™ reinforcing strips

EcoStrap™ reinforcing strips are made of compact bundles of polyvinyl alcohol (PVA-L) yarns protected by a polyethylene sheathing. They are manufactured by extrusion-coating.

The selected PVA-L yarns conform to the strictest standards, thus providing excellent durability in all types of conditions and environments, including very alkaline environments (pH up to 13). EcoStrap™ reinforcements are not sensitive to the presence of salts in the backfills and are particularly adapted to applications in which the fill material is potentially highly alkaline, as it is the case with lime and cement-treated fills, or fills made of recycled aggregates containing crushed concrete. A detailed Research and Development program demonstrated that the PVA-L yarns do not exhibit any degradation in the types of environments and for the service duration expected from MSE structures. Also, they do not show any sign of sensitivity to high temperatures, such as those in tropical and equatorial areas.

PVA-L yarns are twice as stiff as high tenacity polyester yarns (GeoStrap®). This leads in practice to lower deformations during construction of MSE structures (compared to GeoStrap® reinforced structures).

The current range of available EcoStrap™ reinforcing strips is shown in Table 2.

Table 2: EcoStrap™ Range of reinforcements.

EcoStrap™		
GRADE	Nominal Width	Characteristic strength
	mm	kN
37.5	50	37.5
50	50	50.0

EcoStrap™ reinforcements do not impose any limitation on the concentration of salts nor of on the pH level of the fill or the environment where the structure is constructed

Table 3 below, presents a decision chart for RECO's geosynthetic reinforcement type according to environment and application.

Table 3: Reinforcement type according to environment and application.

		Environment / Type of Fill				
		Low Chlorides and Sulphates High resistivity	High Chlorides and Sulphates. Marine Applications	Fine soils treated with cement or lime	Recycled Concrete	Acidic fills
				$9<pH<12$	$9<pH<12$	$2<pH<5$
PET	GeoStrap®	120 years according to temperature $2<pH<9$		NO		YES
PVA-L	EcoStrap™	YES				

2.1.3 **High adherance GeoStrap® / EcoStrap™** reinforcing strips

Recently a new synthetic reinforcement has been developed by RECO. It is called a High Adherence GeoStrap®/EcoStrap™ reinforcement (HA GeoStrap®/EcoStrap™).

This strap is ribbed along its edges (as shown in Figure 1) in order to provide higher soil/reinforcement friction.

HA GeoStrap®/EcoStrap™ is highly efficient in fine-grained soils, uniform sands, lime or cement-treated soils (HA EcoStrap™ only) and in seismic areas due to its greater friction capacity so the strips length can be significantly reduced.

That higher friction capacity provided by HA GeoStrap®/EcoStrap™ improves the strip performance in terms of reinforcement quantities, structure stability and constructability thanks to lower deformation during compaction compared to others geosynthetic reinforcements.

Some samples of RECO geosynthetic reinforcements are shown in Figure 1 (from top to bottom: GeoStrap®-50kN, EcoStrap™-37.5kN and HA GeoStrap®-50kN).

Figure 1: RECO's geosynthetic reinforcement samples (Plan view).

Figure 2 shows the way the PET or PVA-L yarns are encapsulated and coated by a continuous protective LDPE sheath.

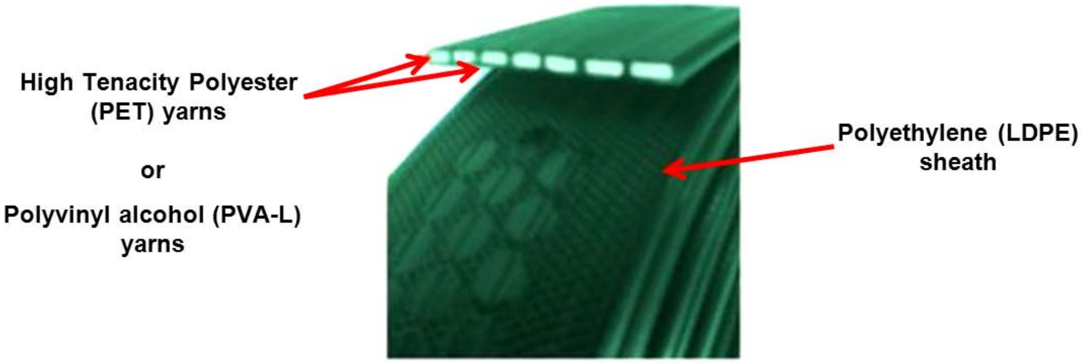

Figure 2: GeoStrap®/EcoStrap™ (cross section)

2.1.4 GeoMega® sleeve connection

GeoMega® Sleeve is a fully synthetic connection which is partially embedded into the concrete facing panels. These panels are used to form the outside face of the MSE retaining wall.

The GeoStrap®/Ecostrap™ reinforcing strips are connected to the concrete panels by inserting them through the GeoMega® Sleeve connection previously cast into the facing panel.

This system gives mechanical protection to the connection by providing a smooth surface of contact between the concrete panel and the straps and at the same time chemical protection against the concrete alkaline environment, isolating the polymeric reinforcing strips from the concrete panel.

To guarantee the durability of GeoMega® sleeve when exposed to alkaline conditions (when in contact with concrete) the sleeve is manufactured from 100% high density polyethylene (HDPE). Black carbon is added to the base plastic during manufacture to increase the resistance to UV and heat exposure of the sleeve.

The “Omega-loop” shape (as shown in Figure 3) provides a high anchorage capacity of the GeoStrap® /EcoStrap™ to the concrete facing panel connection.

Figure 3: GeoMega® Sleeve, (prior casting into facing panel).

2.2 RESEARCH & DEVELOPMENT

Several studies including testing campaigns, numerical modelling and site monitoring have been carried out to determine the properties of the materials and predict their behaviour. Some of the studies are still ongoing.

The following summarises the more important findings.

2.2.1 Exhaustive long-term study on hydrolysis of high-tenacity polyester

The hydrolytic degradation of high-tenacity polyethylene terephthalate (PET) yarns has been investigated during a long-term experimental study (Nait-Ali K.L. *et al.,* 2009). The aim of this work was to understand and model the chemical resistance of high-tenacity polyester yarns used in MSE structures. Thus, an experimental program, divided in three parts, was carried out: (1) Immersion of high tenacity fibres for 3 months in 27 different media at 95°C; (2) Exposition of 5 different yarns at 80°C to 3 media (water pH 7, hydrochloric acid pH 1 and caustic soda pH 12) for more than 500 days; (3) Experiments on high tenacity yarns exposed at 23 and 50°C in four different media (water pH 7, hydrochloric acid pH 1, caustic soda pH 12 and saturated lime pH 13) were run for 15 years. The evolution of strength loss was studied, comparing the effect of media and time on PET hydrolytic degradation rate. The results suggested a new approach for the modelling of PET hydrolytic degradation in water: a time-lag before actual loss of strength starts can be considered, followed by a constant degradation rate as presented in Figures 4(a) and 4(b).

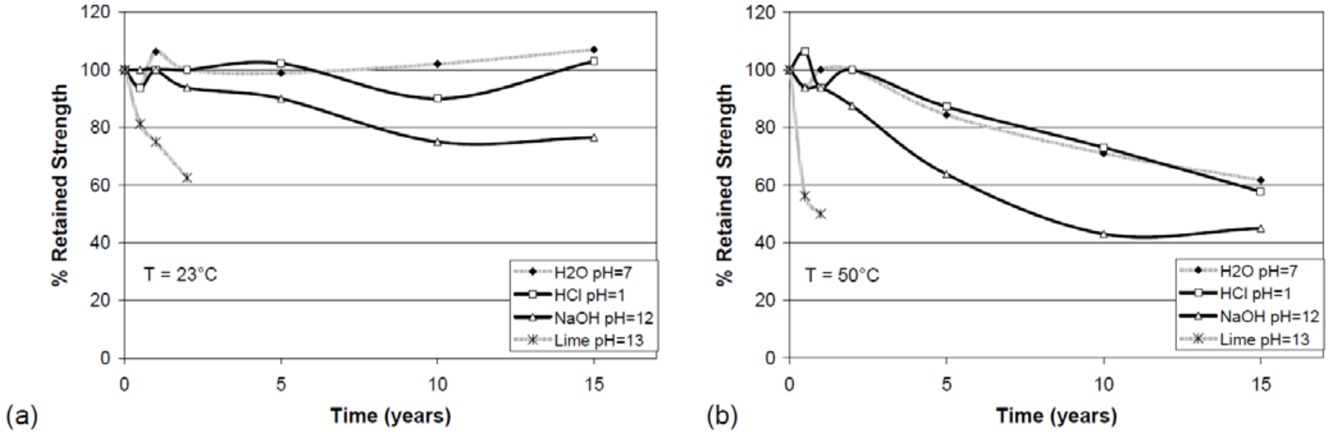

Figure 4: Hydrolitic degradation of PET yarns in various media (1<pH<13) at (a) 23ºC and (b) 50ºC during 15 years.

Considering the previous curves, hydrolysis over time can be described in 3 parts, as shown in Figure 5:

- Phase 1: (time-lag): the polymer tensile strength is stable or sometimes increases slightly because of chemicrystallization (Allen N.S. *et al.*, 1991)

- Phase 2: the hydrolytic degradation rate is stable until about 50% of strength loss.

- Phase 3: beyond approximately 50% strength loss, the degradation rate decreases.

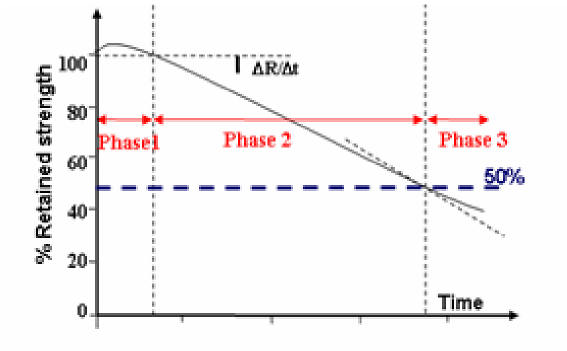

Figure 5: General hydrolytic degradation evolution.

2.2.2 Pull-out tests to assess soil/reinforcement behaviour

The classical friction models used for the analytical and numerical modelling of metallic reinforcements cannot be used with synthetic reinforcements due to their intrinsic extensibility.

The behaviour modelling of the geosynthetic reinforcement anchored in the ground requires a complex friction model. Several parameters have to be taken into account, which directly relate to the extensible reinforcement behaviour or its interaction with the soil mass. The main parameters, relating directly to the reinforcement, concern its elongation. However, most of the friction models used in the design of synthetic reinforced structures are based on a linear elastic strap behaviour. The reality is more complex and the elongation modulus of the geosynthetic can be obtained by a nonlinear function. The second parameter that is necessary to take into account in the tensile-strain model relates to the confinement stress level. Indeed, the elongation modulus of the geosynthetic is also a nonlinear function of the confinement stress level.

A modified tensile-strain model can be used to simulate the elongation of the synthetic straps and their delayed mobilisation. To check the validity of this modified analytical model, several pull-out tests were carried out in a three-dimensional physical model by *Terre Armee International*® (Abdelouhab A. *et al.*, Eurogeo4). These tests allowed for the interaction parameters between the soil mass and the reinforcement to be defined and for the behaviour of the synthetic reinforcement to be analysed. The tests were carried out in a 2m^3 test tank filled with dense sand. To perform the tests the strip was anchored in the sand at the centre of the tank and an airbag placed between the top of sand and the cover plate of the tank. This airbag allows a surcharge to be applied to simulate the vertical stresses applied at various depths of a real MSE structure.

To monitor the strap behaviour in the tank it was instrumented by displacement and force sensors. The installation of various sensors in the test tank permitted not only the analysis of the strip behaviour but also the study the influence of various parameters and test conditions on the reinforcement.

To allow for accurate modelling of the strip behaviour by analytical calculation, the reinforcement characteristics and friction model parameters were determined from the experimental tests. After establishing of all the parameters, displacements along the reinforcement can be calculated by the analytical equations. Comparing the theoretical and experimental results shows that the analytical method makes it possible to accurately reproduce the delayed displacement of the reinforcement (Figure 6).

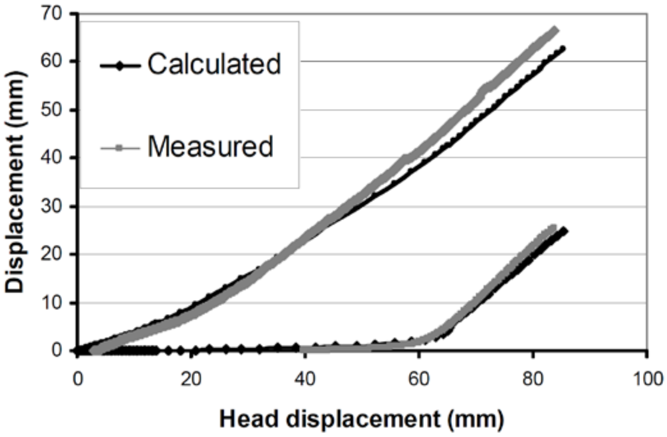

Figure 6: Displacement at the rear and at the centre of strip versus displacement at the head, (vertical stress: 100 kPa).

The results of various tests show that the behaviour of the synthetic reinforcement is highly influenced by the confining stress. In fact, when this is low, the strip behaves as a stiff reinforcement and exhibits elasto-plastic behaviour and its far end is mobilised after a small displacement of the head (connected to the facing). However, when the confining stress is significant, the reinforcement first starts to move slowly at the head, this stage corresponds to the beginning of the frictional mobilisation along the strip. Then, the displacement increases when the friction is fully mobilised on a section of the strip. Finally, when the friction is fully mobilised over the entire strip, it behaves as a stiff reinforcement. This behaviour is presented on Figure 7.

Figure 8 shows that the reinforcement at the rear only moves after a large displacement (50 mm) at the head due to its elongation behaviour.

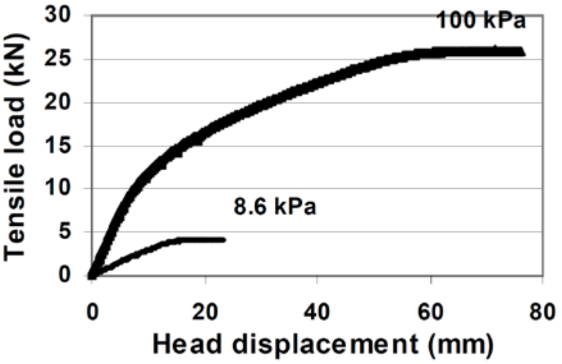

Figure 7: Strip behaviour at the head under different confinement stresses.

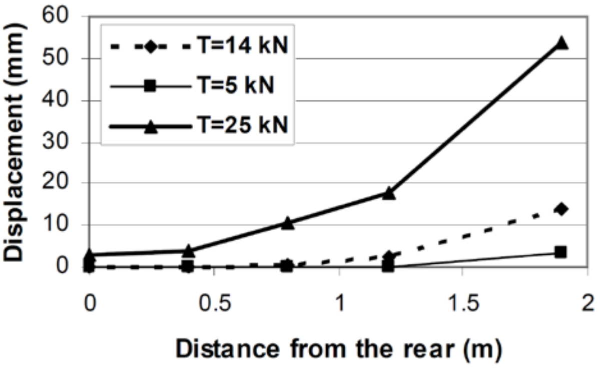

Figure 8: Mobilised strip length under different applied tensile-load (confinement stresses = 100 kPa)

3 DESIGN

Both laboratory and field test studies have been conducted by RECO to select the parameters necessary for internal design of a MSE wall using GeoStrap®/EcoStrap™. From these studies, results have been developed using GeoStrap®/EcoStrap™ for the line of maximum tension, lateral earth pressure coefficients and apparent coefficient of friction in MSE wall applications. The discussion of those results is not in the scope of this paper.

The following briefly describe the coefficients and parameters taken into account in order to determine the ultimate tensile strength of the reinforcing strip during design stage:

At the time of design, the engineer should know the following parameters:

- Design temperature and Service life duration.
- The following reduction factors will be taken into account to carry on the design:

  A.- Installation damage. This parameter relates to the effect of installation (and compaction) of GeoStrap®/EcoStrap™ strips on the design strength of the reinforcing strips.

  B.- Creep-rupture. It represents the rupture under constant load converted in static maximum load, applicable during the design life of the structure.

  C.- Chemical degradation:

    a) In the case of PET chemical degradation represents its hydrolysis (degradation by water). Temperature and pH of the soil can accelerate hydrolysis and consequently reduce the tensile strength.

    b) PVA-L is not sensitive to hydrolysis even in extremely acidic or alkaline media. Due to its chemical structure this polymer shows a water affinity than can lead to a slight increase of its elongation under constant loading. The consequence of this additional elongation due to contact with water is a reconsideration of the design tensile strength calculation by adding a new reduction factor

4 CONSTRUCTION

4.1 COMPONENTS OF THE SYSTEM

The various components used to construct a GeoMega® connection system MSE wall are detailed bellow:

Concrete Levelling Pad – Cast-in-situ or precast unreinforced concrete levelling pad serves as a smooth, firm, working surface for setting the first level of panels. Generally this pad is 150 mm thick and 350 mm wide.

Precast Concrete Facing Panels (Cruciform or Rectangular)

Full size panels are used for the majority of the facing

Half size panels are used alongside full size panels in the initial course, alternating between the two (as can be seen in Figure 9).

A similar arrangement is used for the upper course.

Specially cut, bent or sloping panels are cast as required by the geometry of the structure.

Facing Panel Joint Material

Rubber Bearing Pads are placed in the horizontal joints between all panels to prevent concrete-to-concrete contact. The pads are 20 mm. Rubber shims are used as needed to adjust for minor variations in panel height.

Geofabric is applied with adhesive to the backfill side of the panels to cover all the horizontal and vertical panel joints. The geofabric widths vary from 300 mm to 450 mm depending on the panel type used.

Synthetic reinforcements

Grade 37.5 kN, 50 kN and 65 kN GeoStrap® or 37.5 kN and 50 kN EcoStrap™ reinforcements are supplied in a 50 mm width and varying lengths as required by the design of the structure.

GeoMega® Sleeves

The sleeve arrives on site cast into the concrete facing panel, ready for strips installation. The sleeve provides a smooth, protective surface for the insertion of the synthetic strip.

Select Granular Backfill

Backfill conforming to RECO's specifications is used throughout Mechanical Stabilised Earth mass

Polymeric GeoStrap® or EcoStrap™ reinforcing strips used as reinforcements are robust, and suffer very little damage in common fill materials. If a freshly crushed stone with sharp edges is used, with particle sizes greater than 50 mm, a specific study of the potential installation damage should be done prior to finalising the design.

4.2 CONSTRUCTION PROCEDURE

The construction of a GeoMega® connection system MSE wall is similar to the construction of a metallic reinforced MSE wall. It is not the purpose of this paper to provide a detailed construction manual. However, the following briefly describe the standard construction procedure and provide some specific techniques for the GeoMega® system.

The basic erection sequence for a GeoMega® connection system MSE wall can be summarised in these steps:

1. Prepare the site, including excavation and installation of drainage systems, if required
2. Form and pour unreinforced concrete levelling pad.
3. Set and brace the initial course of facing panels, which consists of alternating half and full-height panels. Use wood wedges and clamps to hold panels in position. Attach geotextile with adhesive. (See Figure 9)

Figure 9: Initial course of facing panels set up.

4. Once the first row of panels is set in-place, thread the GeoStrap® strips through recess in the GeoMega® Sleeves.
5. Spread and compact backfill up to the lowest level of the GeoStrap® strips. At the same time dig a trench near the far end of the strips as a way to tension the GeoStrap® reinforcing strips during compaction.
6. Lay the GeoStrap® strips flat on backfill and perpendicular to facing then secure far end of GeoStrap® reinforcing strips by driving a metallic pin into the soil prior backfilling.
7. Begin placing select backfill over far end of GeoStrap® reinforcing strips and tamp down with the excavator bucket to ensure the strips are locked in place.
8. Backfill the trench before any fill is placed between the trench and the facing. (See Figure 10)

Figure 10: Backfilling operations (trench section).

9. Continue spreading and compacting backfill towards the facing panels, taking care to ensure no strips become twisted during the process. Spread and compact backfill in lifts of 200 mm or less up to 75 or 125 mm of the top of the half panels. Place bearing pads and set the second course of panels.
10. Repeat cycle of backfilling and compacting in lifts, inserting GeoStraps®, placing geofabric and bearing pads and setting panels until design height is reached.
11. As each course is completed, remove the wooden wedges from the panels in the course three levels below. Set top panels; place GeoStraps®, complete backfilling and compaction. Remove all wedges and clamps. Install concrete coping, traffic barriers, or any other cast in situ concrete element if required, as shown in Figure 11.

Figure 11: Marine MSE wall (GeoMega® connection system).

5 CONCLUSIONS

Where conventional steel reinforcements are not suitable, “geosynthetic solutions” enable a wider range of soils to be used as a fill material for MSE structures.

The availability of these synthetic reinforcements allows the designer to use waste or recycled fill materials. This allows for the use of backfill soils that have a high alkalinity (pH up to 13), or when high concentrations of chloride or sulphate are present. Steel reinforcement often cannot be used in such conditions.

High strength GeoStrap® & EcoStrap™ exhibit greater tensile capacity and lesser extensibility than other geosynthetic reinforcement used in MSE wall applications.

6 REFERENCES

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