# Technical Solutions for Soil Nails in Tunnel Face Reinforcement and Drainage

Carla L. Zenti[1], Giovanna Cassani[2], Donatella Sterpi[3]

[1] Elas Geotecnica S.r.L., Segrate (Milan), Italy
[2] Rocksoil S.p.A., Milan, Italy
[3] Department of Structural Engineering, Politecnico di Milano, Milan, Italy

## ABSTRACT

Tunnelling in soft ground conditions requires the adequate stabilization of the tunnel face. To this target, the soil nailing is one of the most effective techniques. In this paper, some innovative technical solutions are discussed, purposely devised to improve the reinforcing action and to couple it with an additional drainage action. In particular, a new fibreglass pipe is described, characterized by a preformed corrugated surface which improves the mechanical interaction with the injected grout. Some comments about its performance are drawn from the results of pull out tests. In addition, details on a new type of soil nail for coupled reinforcement-drainage action are given.

## 1 INTRODUCTION

The soil nailing is considered as one of the most economical and effective provisions for ground improvement in the stabilization of natural and engineered slopes (Juran and Elias, 1991) and of underground excavations (Mair, 2008). In tunnelling works, the soil nailing was introduced for the long term reinforcement around the excavation and for the temporary stabilization of the tunnel face. Its use has become integral part of design methods, its effectiveness being recognized in the control and reduction of the tunnel pre-convergence and face extrusion (Lunardi, 2008).

In the years, improvements have been made in technological aspects of nailing systems and in analytical and computational procedures, nowadays able to take into account their mechanical action at the design stage (e.g. Wong et al., 2000; Ng and Lee, 2002).

At the same time, efforts have been devoted to reach a better understanding of the mechanical behaviour of new materials and equipments adopted for these techniques. Pipes made of Glass Fibre Reinforced Polymer (GFRP) are adopted since the nineties in all the applications where their characteristics could represent an advantage (Ortigao, 1996). The GFRP pipes offer high tensile strength, low unit weight, high resistance to corrosion and can be easily cut. The latter property is particularly relevant whenever an excavation of the already nailing stabilized ground mass has to take place, such as during the tunnel face advance.

A new soil nail typology has been recently introduced for the stabilization of the tunnel face in soft ground conditions. Its characteristics have been discussed on the basis of pull out field tests in natural deposits of coarse soil and highly weathered rock, by comparing the pull out strength of improved nails with the one offered by standard nails (Zenti et al., 2008).

In the present paper, details are given on these innovative technical solutions for soil nailing, in particular on the features of a nail used for simple reinforcement or for coupled reinforcement-drainage action and on the structural characteristics of GFRP pipes. Standard pipes and pipes obtained with an alternative production technique were subjected to pull out laboratory tests. The results are discussed, giving insights into the more effective mechanical action that the new element is able to provide.

Do date, the performance of the new soil nail typology has been tested in a few very recent construction sites. In the paper a reference is made to a tunnelling case in Southern Italy, where the poor quality rock mass associated with high pore water pressures induced to adopt a coupled reinforcing and draining action for the tunnel face stabilization.

## 2 TECHNICAL ASPECTS ABOUT SOIL NAILING

Specific details are given on innovative soil nailing systems: first on a new kind of fibreglass pipe characterized by an external corrugated profile and secondly on a soil nail consisting of an internal fibreglass pipe and an external textile sheath devised to contain the injected cement grout. Both products are patented by Elas Geotecnica S.r.L. (Segrate-MI, Italy).

### *2.1 Glass fibre reinforced pipes*

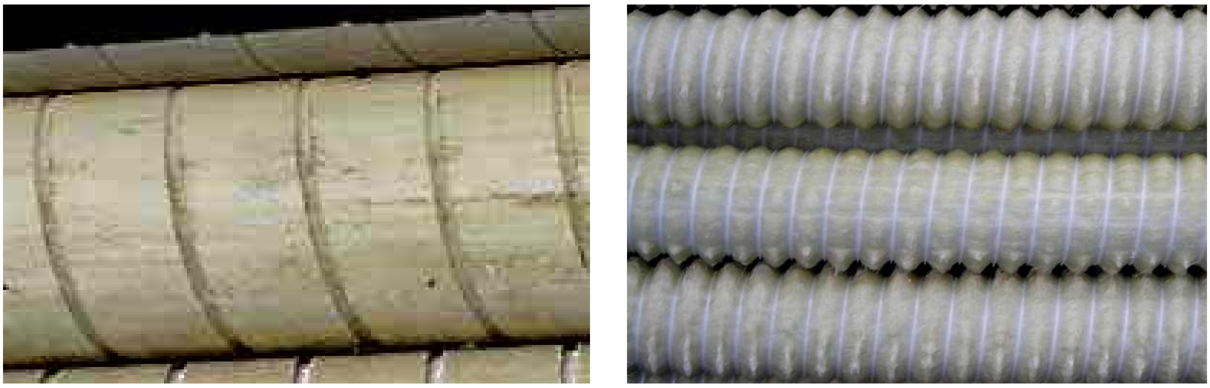
The pipes used for soil nailing at the tunnel face are made of Glass Fibre Reinforced Polymer (GFRP) through an industrial manufacturing process called pultrusion, from the contraction of words “pull” and “extrusion” (Goldsworthy, 1971). The pultrusion of reinforced polymers is similar to extrusion process of metals, with the addition of a tensile force applied to the glass fibres to guarantee their alignment before the polymerisation of the matrix polyester resin. The final product is characterized by uniform distribution of perfectly aligned fibres.

The fibre content is expressed as percentage by weight (or volume) of reinforcing fibres with respect to the total weight (or volume) and it is considered as reference parameter for the prediction of the mechanical properties of the pipe. In particular, the higher the fibre content the higher will be the tensile strength, according to a roughly linear relationship. The pultrusion process enables the production of pipes having a fibre content ranging between 50 and 60%, which is almost twice the content that can be reached by other manufacturing techniques.

Together with the tensile strength of the GFRP pipe, the resistance to pull out is another parameter used to identify the soil nail performance. In fact, in the soil nailing the GFRP pipes are driven or grouted inside drilled boreholes and remain unstressed until the soil movements, such as those induced by the tunnel face extrusion, mobilize tensile forces which are transferred to the ground through friction along the interface. For a better performance the lateral surface of the pipe needs to be treated so to increase the adherence with the surrounding mass.

The GFRP pipe with improved adherence is traditionally obtained by etching a spiral groove along the external surface (Figure 1.a). The depth of the etching could be equal to 2 mm in a 60/40 pipe, having 60 and 40 mm respectively as external and internal diameters. The unavoidable consequence is the cutting of external glass fibres and the content of continuous fibres actually bearing tensile actions decreases. Therefore, also the pipe tensile strength is reduced with respect to the case of pipe with smooth surface.

Alternatively a new product is proposed, named “Corrugated” GFRP pipe (VTR-CRG® by Elas Geotecnica S.r.L.) and obtained introducing in the production process a phase of preforming, before the polymerisation of the resin. This phase creates a corrugated external profile, thus reaching the target of improving the bonding adherence while maintaining at the same time the longitudinal continuity of the glass fibres (Figure 1.b). The depth of the shrinkage could be equal to 1.7 mm in the 60/40 pipe. Further details on the mechanical interaction between the corrugated pipe and the surrounding cement grout will be given in Section 3, on the basis of the pull out test results.



(a) (b)

Figure 1 Fibreglass reinforced pipes: (a) 60/40 AM pipe with spiral groove and (b) 60/40 CRG corrugated pipe (60 mm external diameter and 40 mm internal diameter)

Another non negligible consequence of this new preforming technique, with respect to that involving the groove etching, concerns the great reduction of waste in the form of glass dust in the processing plant. In fact in this case the cut of fibres producing the glass dust is limited to the cut of the pipe edges. The glass dust, if not properly removed by exhaust fans, is highly dangerous for the workers' health.

The glass fibre content by weight can be measured after heating treatment at 800°C for 8 hours. In the case of pipes with spiral groove it is also possible to distinguish between the total content of glass and the content of glass from longitudinal continuous fibres only. Figure 2 shows the assembly of fibres from the different pipe samples after heating: the presence of cut fibres is evident in the standard pipe (Figure 2.a).

*2.2 Standard and innovative soil nails*

In standard soil nails used for the tunnel face reinforcement the fibreglass pipe is inserted in a previously drilled borehole, which is later filled by cement grout injected at low pressure using a small tube at the pipe side.

The innovative soil nail differs from the standard one for the presence of an external expandable geotextile sheath, which wraps the fibreglass pipe for the whole of its length and is sealed at the head and at the tip (Figure 3).

(a) (b)

Figure 2 Glass fibre mass after heating treatment: from (a) 60/40 AM pipe with spiral groove and (b) 60/40 CRG corrugated pipe, as in Figure 1

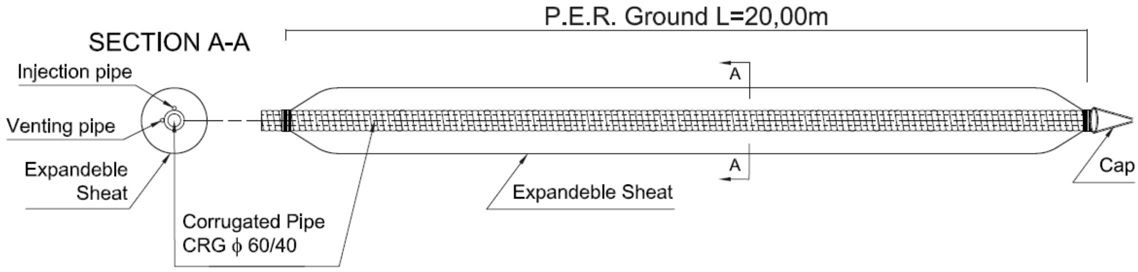



Figure 3 Soil nail for the tunnel face reinforcement (PERGround®, Elas Geotecnica S.r.L.)

Through a small tube a low shrinkage cement grout is injected between the pipe and the sheath, so that the sheath inflates till the gap within the borehole is closed. This new system is named Pressure Element Reinforcement Ground (PERGround®, Elas Geotecnica S.r.L.). The internal pipe is the 60/40 corrugated model described in the previous section. To date, 24 m is the maximum length of these soil nails used in tunnelling applications.

In general, high adherence between the nail and the soil can be reached by high pressure grout injections. While in the standard soil nail the maximum allowable pressure of injection is limited in order to prevent soil fracturing (claquage) and consequent grout dispersion, in the innovative soil nail the external sheath confines the grout and injection pressures up to 15 bars can be reached, the injection volumes being under control.

The result is a highly homogeneous reinforcement, characterized by high skin friction and continuous adherence at the interface between the bar and the borehole surface. During the high pressure injection, the surrounding ground mass undergoes compaction and the associated increase of radial compression stress increases its load bearing capacity. In addition, the soil treatment is less affected by the site conditions (water content, soil density, presence of large voids), by the characteristics of the grout and by the quality of injection.

The performance of the PERGround® technique was assessed by preliminary on site pull out tests carried out at the face of tunnels under construction in soil and rock masses of various nature and conditions (Zenti et al, 2008, Renda et al., 2012). The pull out load can reach values 10 times higher than those measured with the standard soil nailing systems.

### *2.3 Coupled reinforcement and drainage*

The PERGround® soil nail can also be equipped with a coaxial drain, meant to reduce the pore water pressures occurring at the tunnel face (Figure 4). The drain is a micro slotted HDPE pipe, protected by a non woven fabric geotextile. The water collected from the deepest portion of the nail is drained out within the corrugated pipe. The drainage can be also improved through the use of pumps. In this alternative configuration, the simple reinforcing effect is coupled with a drainage effect, thus realizing a more effective stabilization action in water bearing ground.

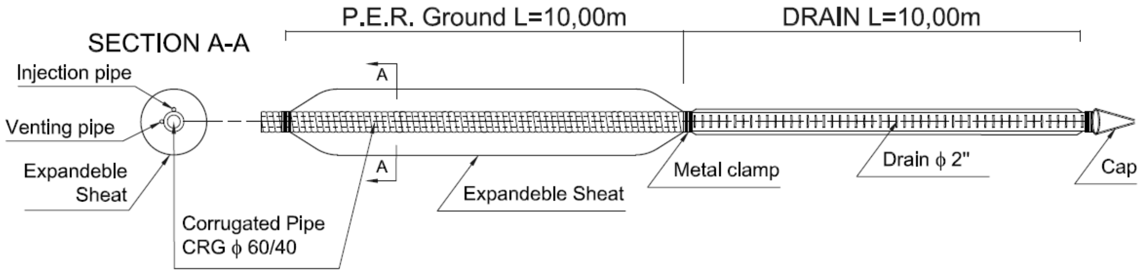



Figure 4 Soil nail for the coupled tunnel face reinforcement and drainage, as a modification of PERGround® shown in Figure 3

An application of this soil nailing technique was required during the excavation of a tunnel in Southern Italy, with cross section area between 150 and 170 $m^2$ and maximum overburden of 65 m, in a highly weathered rock mass consisting of phyllitic schists with a relevant presence of clay. The low permeability and the high water content were the cause of local aquitards, with consequent high pore water pressures. The umbrella arch made of steel reinforced micropiles and the traditional fibreglass nailing did not sufficiently stabilize the excavation and eventually a huge face collapse occurred, probably also due to high water pressures. The need to adequately reinforce the tunnel face and simultaneously reduce the water pressures far ahead of the tunnel face led to the adoption of these improved soil nails. In particular, the section type comprised an average of 50 nails for reinforcement and 4 nails equipped with coaxial drain, having sub-horizontal direction, 20 m length and superposition of 10 m along the tunnel axis.

Details about this case history are discussed in (Renda et al, 2012). A review of the stability analysis accounting for the effect of soil nail reinforcement, based on the concept of equivalent effective cohesion (Grasso et al., 1989), is also included.

## 3 STANDARD AND CORRUGATED GFRP PIPES

With reference to standard improved adherence and corrugated GFRP pipes described in Section 2.1, a laboratory testing program will be briefly described, aimed at assessing and comparing their performance in terms of pull out resistance. In both kind of pipes the glass percent by weight is equal to 60%, the tensile strength and the tangent modulus of elasticity are approximately equal to 600 N/$mm^2$ and 25000 N/$mm^2$ respectively.

### *3.1 Set up of pull out tests*

The laboratory testing program involved 12 pull out tests on 60/40 GFRP pipe samples (Figure 5), in particular on 6 samples of standard improved adherence pipes (AM in the following) and 6 samples of corrugated pipes (CRG).

For both kind of pipes, 3 samples were tested 24 hours after the grout pouring and the other 3 samples 48 hours after. The grout is obtained by mixing ordinary cement and water, in the ratio 100:50 by weight, and a chemical additive to improve fluidity. The uniaxial compression strength of the grout was found to be equal to 19.3 N/$mm^2$ after 48 h setting.

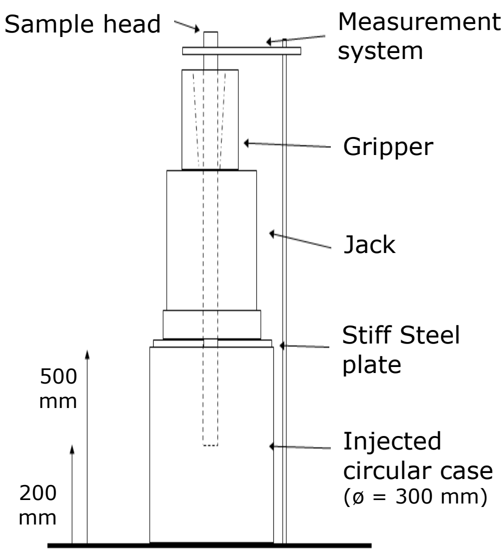



Figure 5 Set up for laboratory pull out tests on GFRP pipe samples

The samples are vertically installed in circular cases, having 300 mm diameter and 500 mm height, so that the samples have a 300 mm deep embedment (Figure 5). The sample head is inserted into a protective cylindrical case, used as gripper for the load application, which reduces the risk of damage to the pipe by increasing the surface along which the axial load is transferred by friction. The load is applied by an electrically operated hydraulic jack and controlled by an analog manometer. A steel plate, with a central hole at the position of the pipe, uniformly distributes the vertical load to the surface of the cement grout. An optic differential levelling is used to measure the pipe displacement.

The pull out test is carried out by applying the axial load by steps, each of them equal to 10 bars, and by recording the vertical movement of the sample head one minute after the application of each load step. The final condition of pulling out is inspected by measuring the residual displacement after the unloading of the hydraulic jack.

*3.2 Results of pull out tests*

The results of 12 pull out tests are shown in Figures 6 and 7, respectively representing the behaviour 24 hours and 48 hours after grouting. In both cases the corrugated pipes (CRG in the figures) offer a resistance against the pull out higher than the one offered by the standard improved adherence pipes (AM).The values of pull out tangential stress and pull out force per unit length of pipe, reached in the tests at the ultimate condition of pull out, are summarized in Table 1 in terms of average and maximum values. The tangential stress is calculated as the stress, uniformly distributed over the lateral surface of the embedded pipe, which equilibrates the pull out force.

The particular mechanical interaction between the GFRP pipes and the surrounding cement grout is highlighted also by the fracture pattern observed in the grout after the pull out tests. In the case of standard improved adherence pipe (Figure 8.a), the cylindrical block of grout seems unaffected by the pull out of the pipe, the fractured zone being localized around the pipe surface. On the contrary, in the case of corrugated pipe (Figure 8.b), the fracture pattern shows the involvement of the surrounding grout in bearing compression stresses transferred by the pipe. The particular corrugated surface allows the pipe to activate compression stresses within the grout, thereby providing a better pull out performance than standard pipes.

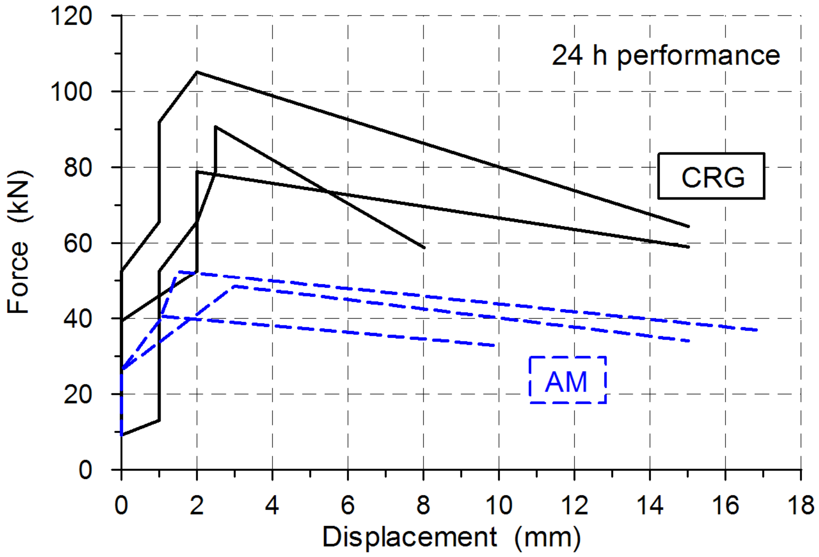



Figure 6 Results from pull out laboratory tests on standard improved adherence (AM, dashed lines) and corrugated (CRG, solid lines) pipe samples, 24 hours after grout injection (sample length = 300 mm, external diameter = 60 mm, internal diameter = 40 mm)

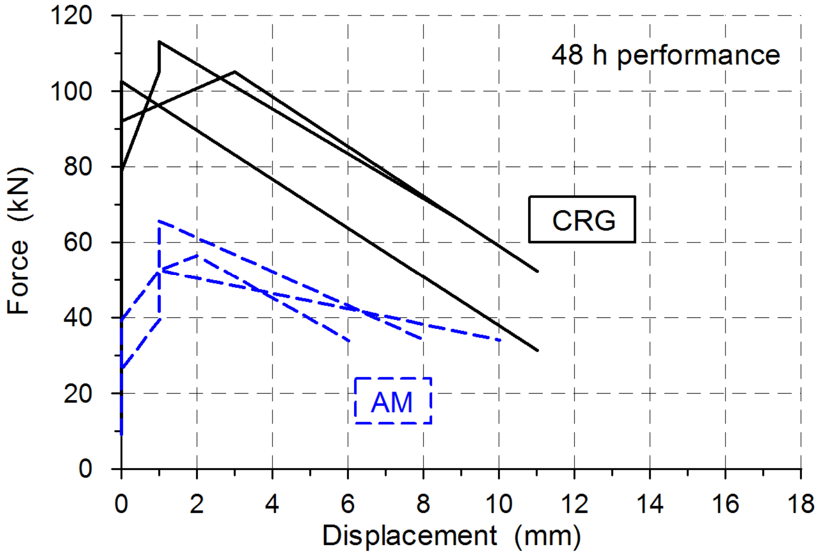



Figure 7 Results from pull out laboratory tests on standard improved adherence (AM, dashed lines) and corrugated (CRG, solid lines) pipe samples, 48 hours after grout injection (sample length = 300 mm, external diameter = 60 mm, internal diameter = 40 mm)

## 4 CONCLUSIONS

Innovative systems for soft ground reinforcement have been described and compared with traditional ones. The new soil nailing technique provides high pull out strength, due to the possibility to apply high injection pressures without soil fracturing and loss of grout, and to create homogeneous nails with uniform adherence to the borehole surface. In addition, it provides the possibility to combine the reinforcing action with in depth drainage, thus resulting in a more effective stabilizing action, especially in water bearing ground. The first applications to tunnel face stabilization seem promising.

The new kind of fibreglass pipe is obtained by a particular forming process which creates a corrugated external profile while avoiding, at the same time, the cutting of the glass fibres. The resulting pipe offers high bond properties with the surrounding cement grout, as it was shown by the results of pull out tests. Some finite element analyses on the interaction between the pipe and the surrounding grout are currently going on, to highlight the role of the geometry of the external surface on the mechanical behaviour of the reinforcing element.

Table 1 Tangential stress and force per unit length of pipe at the condition of pull out

| | | 24 h performance | | 48 h performance | |
|---|---|---|---|---|---|
| | | Pull out tangential stress (N/mm$^2$) | Pull out force per unit length (kN/m) | Pull out tangential stress (N/mm$^2$) | Pull out force per unit length (kN/m) |
| Standard improved adherence pipe (AM) | Maximum value | 0.93 | 175. | 1.16 | 219. |
| | Average value | 0.84 | 158. | 1.03 | 194. |
| Corrugated pipe (CRG) | Maximum value | 1.86 | 350. | 2.00 | 377. |
| | Average value | 1.62 | 305. | 1.89 | 356. |

(a) (b)

Figure 8 Pictures showing the different mechanical interaction between pipes and cement grout from laboratory pull out tests on (a) standard improved adherence (AM) and (b) corrugated (CRG) pipe samples

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