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Glass Fiber for Underground Projects

Recent Applications

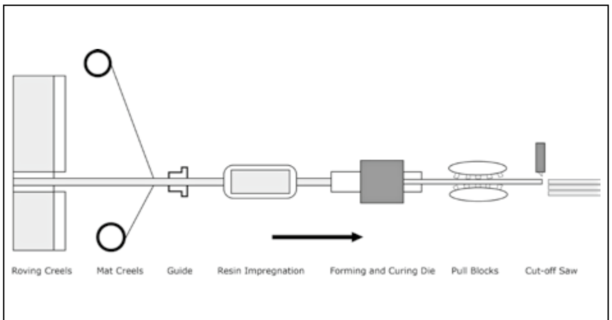
The following paper wants to give an overview about the features, performances and examples regarding the use of Glass Fiber Reinforced Rods/Profiles (GFRP) on underground projects. Chapter 1 is about rod features and advantages, focusing on tensile strength and on the necessary surface-bonding requirements. The following chapters represent a short report, as to introduce different case-stories.

1 GFRP main features for engineering purposes

GFRP belongs to the class of so called fiber composite materials. Such glass fiber composites are fabricated by a pultrusion line (Fig. 1): the plant is basically pulling single continuous fibers from roving creels, kept straight while combined with other materials to achieve improved properties and synergy effects. The properties of the resulting material are variable according to the specific fibers chosen and by varying the resin type and content as the fabrication process features.

One of the best known composites is glass fiber reinforced polymer (GFRP). It is being used to fabricate light weight, high strength components and as a pultruded product has been showing new potential in the world of underground excavations and projects.

The new combination of materials like "GFRP pultruded rods and structural elements" with conventional steel technology can be beneficial for the special demands of modern underground projects. The following pages will focus on the state-of-the-art technology used by some manufacturers. As the use of the material is becoming more and more widespread, selected examples about the topic are presented, regarding temporary face bolting on tunnelling projects, about reinforcement-cages of "Continuous Flight Auger" piles and complex structures, about recent models of actively-tensioned anchors.



1 Pultrusion Line

1.1 Material overview: surfaces and high strength

The use of an efficient process of pultrusion can give way to a GFRP unidirectional high strength profile product (for bolts and reinforcement purposes), which consists of fine, unidirectional glass fiber-reinforced wires. For geotechnical applications a dedicated production process was developed, in order to obtain a product characterized by high tensile strength and modulus in the main direction along profile. Such High Performance product is a composite material composed by maximum glass to resin ratio. All the single and continuous glass fibers, which sum up for the 65 to 75 % of total weight, are kept together by a polyester resin: this matrix, in a percentage of 25 to 35 %, is responsible for the stresses "spreading" among all the single fibers. Process result is a compact section, with a high tensile strength compared to a conventional steel product (Fig. 4). Strength performances are variable according to the fabrication process features: Unidirectional reinforced GFRP rods and flat bars show values of tensile strength in the range of 800 to 1,000 MPa and Elastic modulus 40 GPa, a good standard nowadays.

This method of fabrication is already well-known on several application-industries: in the specific field of underground and concrete works, a great importance has to be paid to the external surface of the elements too.

Typical geometric and mechanical properties are completed by a density of GFRP around 1.9 g/cm^3, which is roughly a

2 Glass fiber rod, with example of an enhanced bonding surface. A cm-scale boudinage is visible (Source: Sireg S.p.A.)

Glasfasern für unterschiedliche Untergrund-Projekte

Derzeitige Anwendungen

Der folgende Beitrag soll anhand von Beispielen einen Überblick über Eigenschaften und Leistungsfähigkeit von glasfaserverstärkten Trägern/Profilen (GFK-Träger/-Profile) bei unterschiedlichen Untergrund-Projekten liefern. Kapitel 1 erklärt die Eigenschaften und Vorteile der Träger in Bezug auf Zugfestigkeit und die erforderlichen Anforderungen der Oberflächenanhaftung. Die folgenden Kapitel stellen einen Kurzbericht mit verschiedenen Fallbeispielen dar.

Fibres de verre pour projets en souterrain

Recentes applications

L´article suivant veut donner une vue d´ensemble des caractèristiques, des performances et des exemples d´utilisation de barres et armatures en fibre de verre dans des projets en souterrain. Le chapitre 1 est consacrè la description des caractèristiques et des avantages des fibres de verre en matiêre de rèsistance la traction et des prescriptions concernantes l´adhêrence des surfaces. Les chapitres suivants prèsentent des diffèrents exemples d´applications.

Fibra di vetro per progetti in sotterraneo

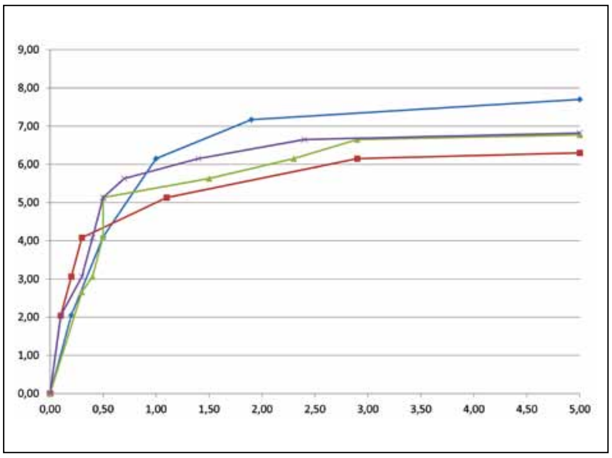
Applicazioni recenti

Il seguente articolo fornisce, basandosi su degli esempi, una visione d'insieme sulle caratteristiche e sull'efficienza di elementi e barre in fibra di vetro (GFRP) per progetti di scavo in sotterraneo. Il capitolo 1 si occupa delle caratteristiche e dei vantaggi delle barre, in particolare riguardo alla resistenza a trazione e alle esigenze di adesione delle superfici del materiale. I capitoli successivi presentano vari casi di studio sul tema.

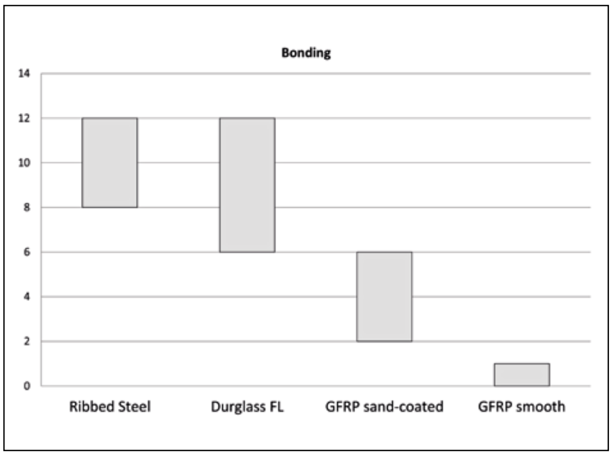
25 % of the density featured by a standard steel. The single rods can be coated by a quartz sanding portion during the fabrication process, and the rod shows an external strong spiral wire and boudinage (Fig. 2). This is realised in order to control the bond performance of rods with conventional concrete mixtures. A reference tau value is reported to be in a range between 6 and 12 MPa, depending on rod diameters (Fig 3, left + right).

Alternative methods to increase surface bonding have been reported by other authors: they are mainly based on spiral cuts on the external fibers or high-scale waved portion of rod sections. The authors of this paper do think these are not efficient solutions, as they lower down the contribution of fibers, with a variability-effect which can not be kept under control.

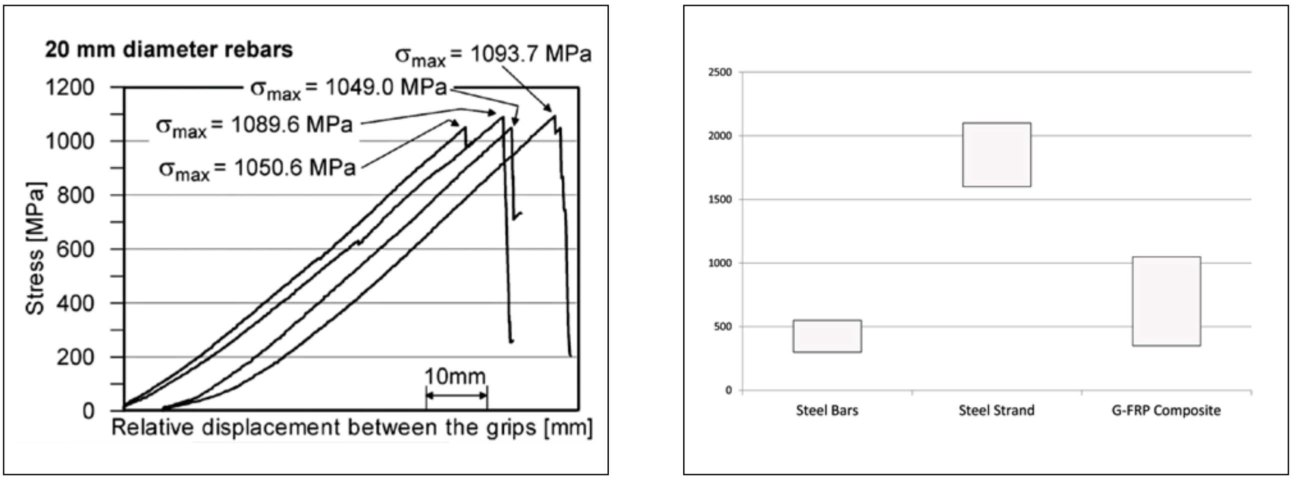
Among the advantages of pultruded GFRP rods there is an immunity to corrosion in practically all relevant media, even in the presence of high mechanical stresses. Together with this it is possible to mention its lightweight, high tensile strength, elastic behaviour (with no yielding), low thermal and electric conductivity, non-magnetic behaviour. A milestone is represented by the low shearing strength: such a constitutive detail is important on underground projects, as the glass fiber profiles are easy to be cut through by conventional cutters, shovels, tunnelling machines. This is a reference feature for all the applications reported in this article. Glass fiber profiles can be considered as an efficient alternative to steel elements, every time a reinforcement or anchor/dowel bar has to be installed. All the profiles can subsequently be cut-through with ease, not harming conventional cutting tools. An example of high-strength GFRP 20 mm rod on a tensile test [3] is reported in Fig. 4.



3a Tau [MPa]/Slippage [mm] comparison, Durglass 16 mm rebar



3b Bond [MPa] comparison chart



4a+b Results example of Tensile tests on a stress/strain plot: Durglass fiber rod diameter 20 mm (left, [3]) and Tensile Strength Comparison Chart [MPa] (right)

2 Sappanico Tunnel/I case story

2.1 Face dowels on a soft ground tunnelling project

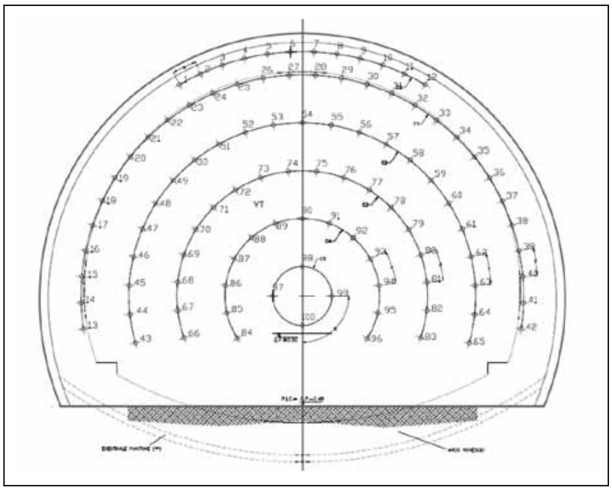
The first example is reported from one important worksite on the new section of the A14, the main Highway along the central part of Italian east coast. Lot with name Ancona Nord- Ancona Sud is positioned on this important road axis, and it is featured by the presence of a total 32 km tunnel portions. The whole system of tunnels, which includes the Sappanico Tunnel, is cutting through the Eastern Appenine deposites, and it is currently under excavation stages.

2.2 Geological data and excavation method

Starting from the basic geological audits, the geometrical constraints for the new section underground and from the cost analysis, construction method for the focused tunnel has been chosen. The length of the tunnel is about 900 m, the section of excavation had the huge value of 190 m^2. The field geological sections are reporting the main litological units, which are grouped under the Pliocene-Pleistocene Appenine sedimentary sequence. They are mainly formed by marly clays, with heterogenous grain size, featured by arenaceous lenses: main part of the excavation has been cutting through Pliocene Blue Clays formation.

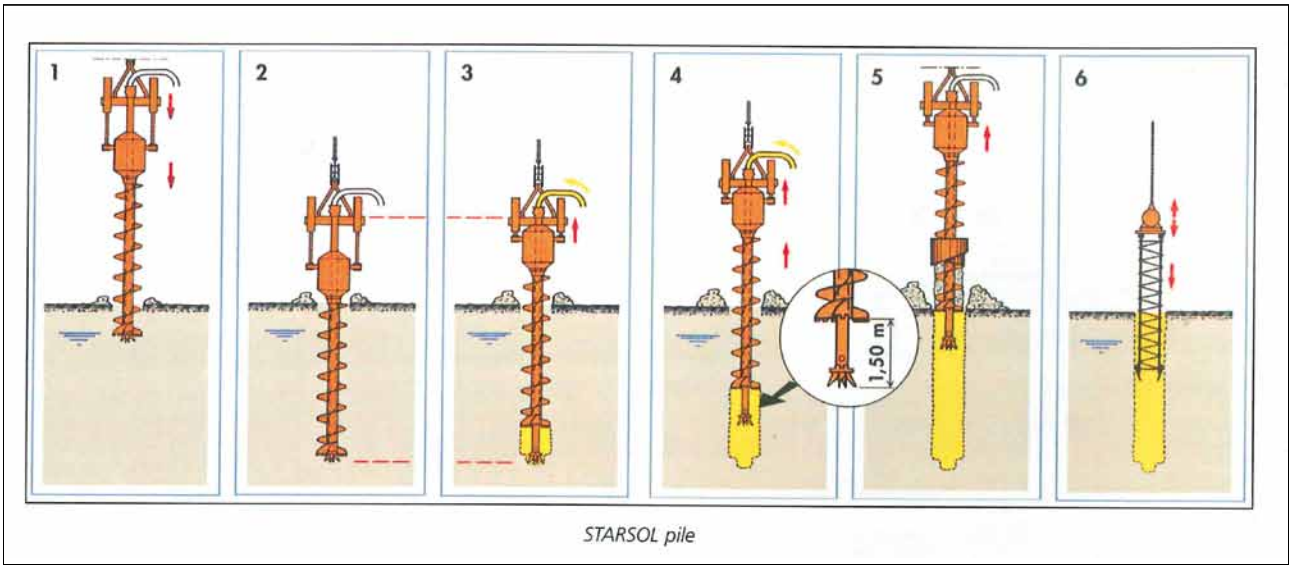
Excavation, featured by conventional method and in a Full-Section [5] with no partial mining or sequential excavation, has been designed in accordance with the section reported.

Bolting of the face consists in the installation during advancement of fiberglass structural elements or pipes in the longitudinal direction, integrally connected to the surrounding ground by a cement grouting. Single length used was 24 m, overlapping 12 m and main density from 80 to 120 glass fiber dowels (Fig. 5, 6). The Durglass dowels are placed in concentric circles with a regular geometry. The quantity (density) is calculated step by step considering geotechnical conditions of tunnel face such as its strains and core extrusions during excavation. A higher quantity of face bolts (220 Durglass dowels, equivalent to more than 1 dowel each m^2 of tunnel front) was necessary next to the breakthrough at the midpoint of the tunnel.



5 Section of Sappanico Tunnel with GFRP face dowels design

6 Tunnel face during excavation



7 CFA pile excavation sequence, Starsol model [7]

Thanks to the Durglass anchors the plastic deformations of the rock in the nucleus have been kept under control and the tunnel front extrusion has always been less than 20 mm.

The excavation was performed on both fronts by the same method and timing (northern front and southern front): the borehole diameter to install the Durglass dowels was 130 mm wide. As regards positioning and grouting, the drilling speed was between 80 to 100 m per hour.

Advancing work was done by hammers and shovels, and it was followed by the installation of a sprayed concrete layer. Anchors for the ground strengthening of portals has been glass fiber structural elements too. During the preliminary excavation stages, several testing rounds have been faced by the contractor, with support of Sireg S.p.A., about the GFRP tensile strength and behaviour.

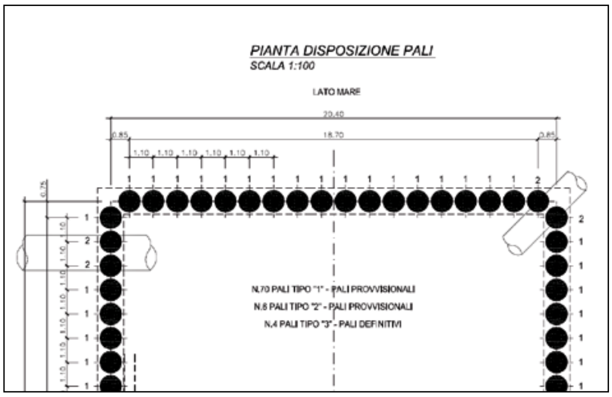
The 900 m length Sappanico Tunnel excavation was finalised in 9 months on the 18th December 2013, with a saving of 2 months, in advance on the scheduled tunnelling program. The average speed was 50 linear meter bored per month on each single excavation front. Considering that the tunnel section is 190 m², the contractor bored safely more than 170,000 m³ of poor ground (clays) in just 9 months, which is an important result.

3 Napoli Port/I – Dry dock renewal case story

3.1 Temporary glass fiber cages applied on CFA piles

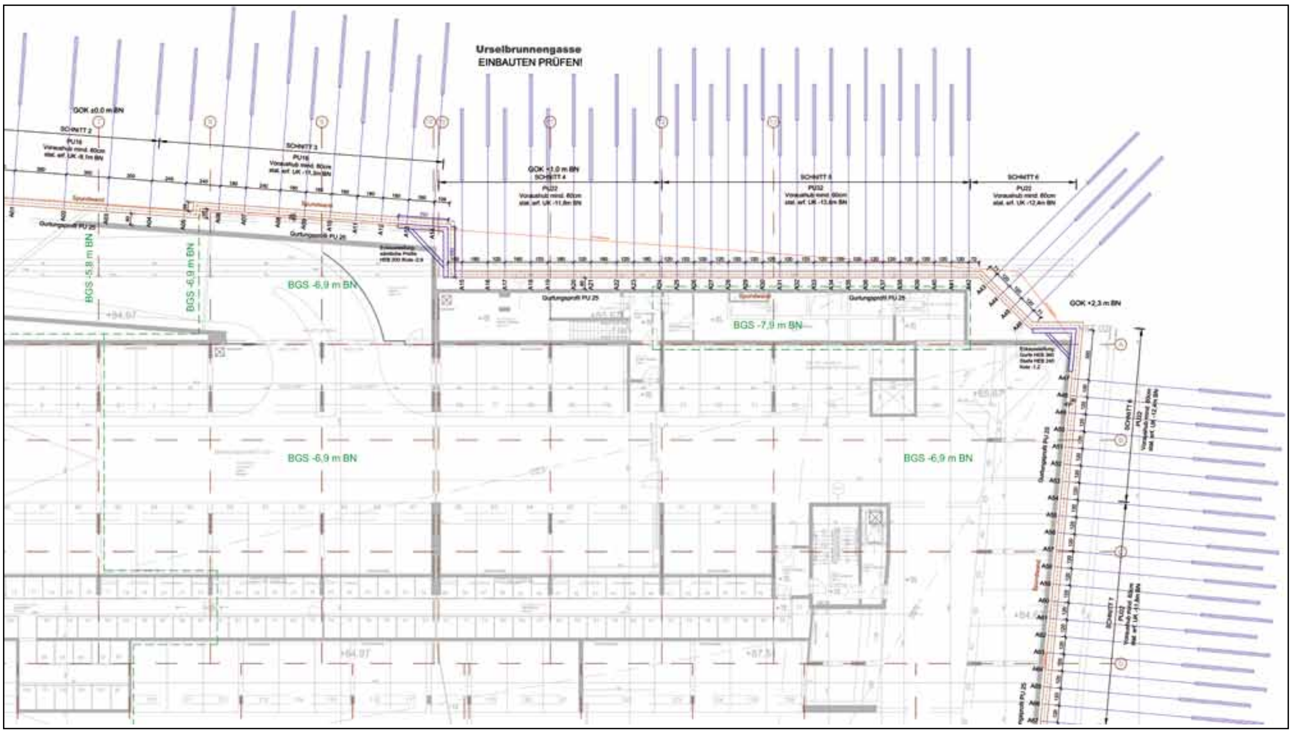
Second example is the renewal of a dry dock at Napoli Port, which is still under construction by the company Società Italiana per Condotte d'Acqua S.p.A.. Final Client is the local Port Authority in Napoli. A system of CFA piles was designed for the basic retaining structure, along the border of the new dock, as visible in Fig 7 and 8. CFA piles, which are excavated by a Continuous-Flight Auger, are a bored pile subset [7], as a reinforced cast-in-situ concrete piling work.

Under these specific conditions, concreting operation was executed immediately after pile boring, during the lifting of the screw equipment tool, by an extendible tremie pipe. Concrete compressive strength has been C28/35 (cylinder/cube). Conventional steel reinforcement for the major part of



8 Napoli Port – Dry dock renewal plan (Source: Società Italiana per Condotte d'Acqua S.p.A.)

9 Napoli Port – GFRP pile cage during lifting operations (Source: Società Italiana per Condotte d'Acqua S.p.A.)



10 *Monte Laa foundation plan, sheet piling and anchors overview (Source: Porr Bau GmbH)*

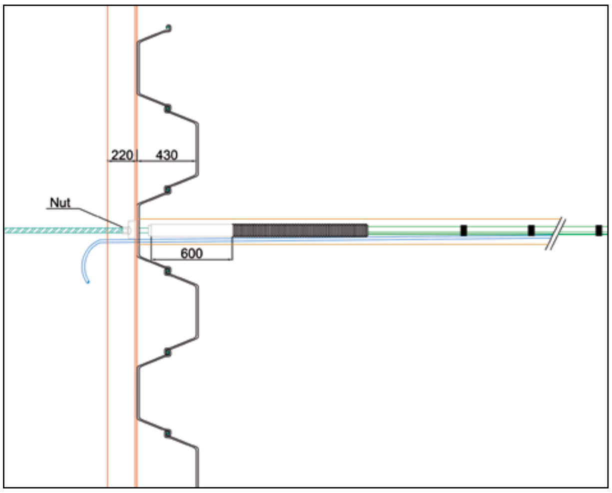
this retaining structure was installed inside the bored profile, immediately after concreting process, inside a soft cement mixture.

Some of these piles (pile family number 2, Fig. 8) were designed as temporary structures: they had to guarantee a static function for a temporary time span (< 2 years), to be cut through by a system of water outlet tunnels, supposed to be excavated by microtunnelling machines. Intermediate portion for these piles was realised by a glass fiber reinforcement, composed of GFRP vertical rods and shear rings. All the GFRP structure was connected to the steel permanent portions positioned on top and bottom (Fig. 9) and consequently inserted inside the borehole. Glass-Steel connection was realised according to the prescriptions of CNR recommendations: an overlapping of the single rod steel-glass was executed and they were gripped through a conventional cable U-bolting system.

4 Wien Monte Laa/A case story

4.1 Temporary glass fiber anchors with pre-stressing tension applied

The third case story is about the use of new GFRP temporary anchors, which were applied in a wide foundation project during the last 2 years. The first attempts and ideas for the



11 *Section detail of the sheet piling – glass fiber anchor (Source: Sireg S.p.A.)*

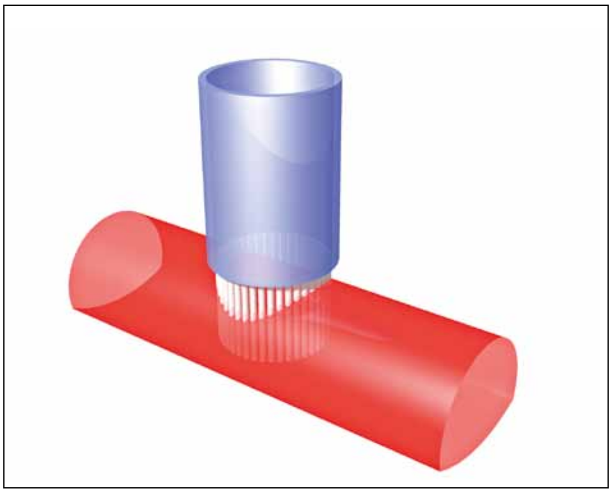
12 *Example of the anchor installation during tensioning by an hydraulic jack and strain measurement (Source: Porr Bau GmbH)*

Monte Laa buildings in Wien are dating back to the early 1960s. The project consists of 2 towers of 90 m height over which a horizontal structure of 30 m hovers, thus creating a second level and activity zone in the urban landscape. Monte Laa foundation portion, executed by Austrian company Porr, was featured by the use of extensive sheet piling, together with temporary non-metallic anchors. Such retaining structures were designed as foundations for the first construction stages of this important and new building site. An overview from the main plan design is reported in Fig 10.

The interest of designers and contractors was focused on an anchoring technology specifically studied for worksites on "crowded" urban patterns. In fact, among the total number of approx. 100 ground anchors, a high percentage was to be installed in a public domain ground portion. There was a specific request, sourcing from the final client side, to avoid a permanent steel anchor system applied on all foundation edges. The designer had to secure the wall stability by a system of anchors alternative to removable steel anchoring systems, which were evaluated as a potential solution too. Several input data were used to compare the options, and among them installation costs, "removing-operation" costs, potential risks during the removal of the free length part. After such a stage, a solution based on glass fiber anchor flat bars was chosen, as the more efficient one in the costs/performances balance count. An additional advantage of the GFRP option was that no steel part, even small, had to be left inside ground. After construction of the final slab structures, all the anchors have been left as sacrificial parts inside boreholes, and they will be easy-to-be-cut by any future foundation work or tunnel.

The whole anchor length was composed by a system of glass fiber flat bars. Such 40 x 9 mm bars were mounted as strands in a unique structural element, and connected to a blocking system by an adhesive mixture, as shown in Fig. 11. A working tensile load between 370 and 400 kN was guaranteed, with a durability time span of 2 years, to be considered as a temporary one. Borehole diameter on the sheet piling structure was limited to 90 mm, with a spacing of 1.8 m in horizontal span. A picture about the tensioning stage is reported in Fig. 12.

13 Marchand shaft during Jet-Grouting (Source: Consolidations Suisse)



14 Schematic model of one of the deep shafts (blue) and its relationship with the new tunnels to be excavated (red)

5 Toulon/F – Marchand shaft and tunnel case story

5.1 Face anchors on a tunnel face from deep narrow shafts

On the Toulon Underground Crossing, which was a tunnel project executed during the period from 2007 to 2010, a milestone is represented by the Marchand shaft. Such structure was designed in the intermediate point of the second road tunnel across the city, as to create 2 new starting front-faces for the underground works, in addition to the side portals. The project

15 Tunnel face with drilling machine during the first excavation and installation of GFRP flat-bars anchors. A portion of the vertical shaft border is visible in the upper part (Source: Consolidations Suisse) was designed with a system of vertical shafts, with a diameter of 16 m, retained by diaphragm walls. From – 25 m level, a first work was the execution of jet-grouting columns, followed by excavation down along the vertical direction, through a zone with increased ground mechanical features (Fig. 13).

From such circular shaft-structures, at a depth of – 37 m, several tunnels in eastern and western direction were started (Fig. 14, red tunnel). A system of 60 steel canopy tubes for each tunnel was designed, together with front face non-metallic anchors. Because of the space constraints, imposed by the shaft dimensions, special drilling mast on C6 and C8 Casagrande rigs were modified, as to realise all the drilling operations with requested inclinations.

The poor ground conditions led to the choice of GFRP face bolts, which were studied to have a length of 18 m with a 9 m overlapping. A number of 80 full-length dowels, composed by 2 continuous flat bars to guarantee a tensile strength of 600 kN, were installed directly from the narrow shaft. This was possible thanks to the elastic behaviour and to the geometry of the glass fiber structural elements, which were easily bended inside the narrow shafts and tunnel spaces. Such operations, as well as the ones of shaft and tunnel excavations, were executed by a Consolidations Suisse team (formerly Presspali France). All single tunnels were quickly and safely excavated by this method in the highly alterate Phyllitic and Pelitic rocks of Toulon.

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