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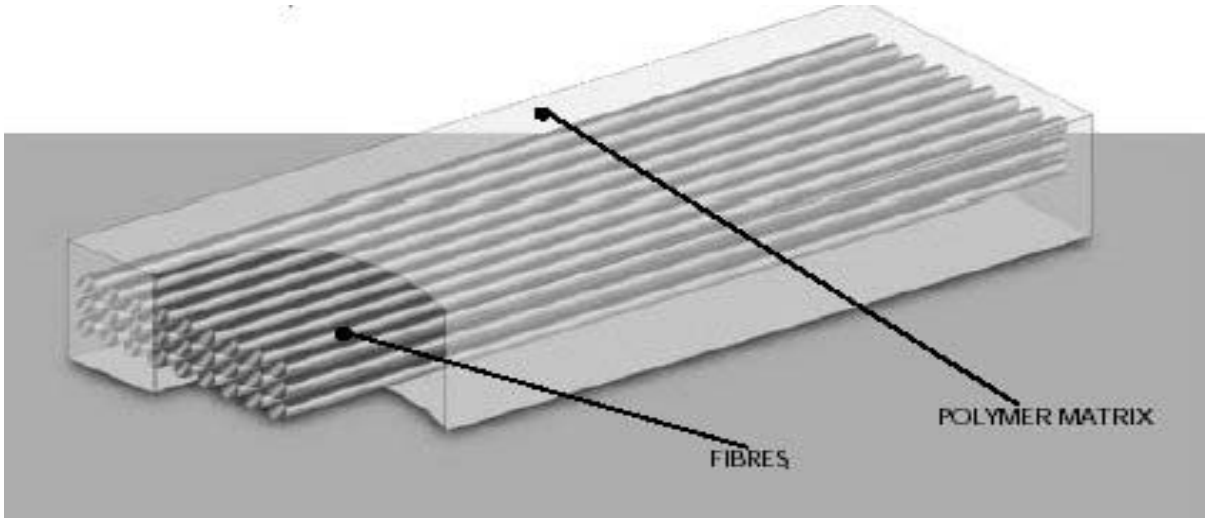
FIBER REINFORCEMENT MATERIALS: NEW DEVELOPMENT IN POST-TENSIONED ANCHORS

ABSTRACT
In this paper will be shown the application of GFRP and CFRP materials in post tensioning. and soil nailing. FRP materials have some advantages in respect of steel that will be analysed here. Some real applications are mentioned with support of pictures. Here we will limit to speak about the use of these materials in geotechnical applications.

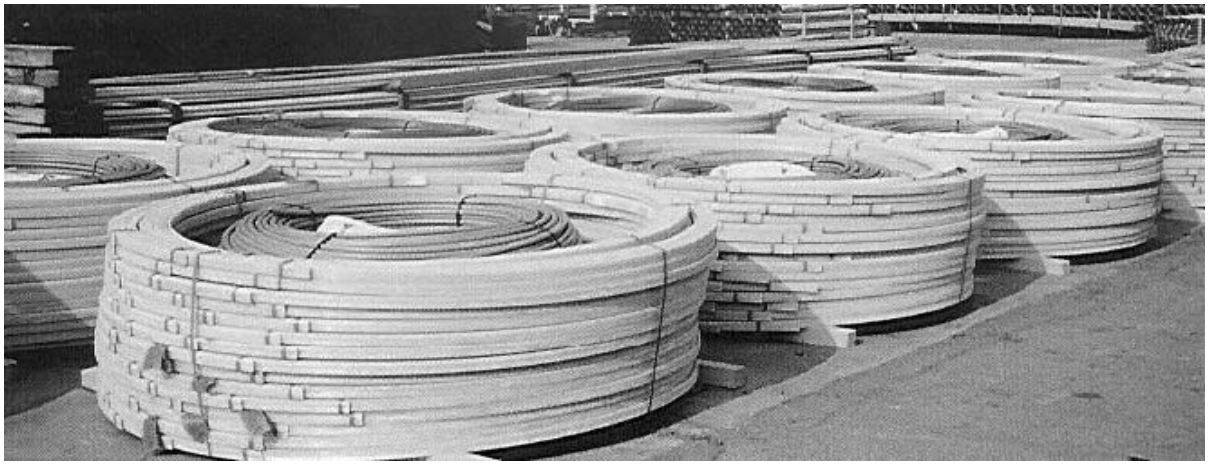
INTRODUCTION
When we talk about GFRP and CFRP we usually mean Glass Fibre Reinforced Plastic and Carbon Fibre Reinforced Plastic materials. Briefly this indicates material composed by fibres immersed in polymeric matrix.



The matrix, in this case, has the function of protection for the fibres, but above all act as interface with external materials and fibres, helping to transmit uniformly the forces from the outside to the fibres. Here a first problem appeared to the users: the matrix used is smooth and so the product adherence with the external material is very low. The adherence, or better the bonding, is very important in geotechnical applications, so first of all the manufacturer focused to eliminate this problem. At the beginning was followed the path used for steel, it means giving corrugation to the external surface of the product (mainly rods); this opened other problems of which the most important was the looseness of tensile strength applying the corrugation. Now there are different cross sectional shapes (square, round, solid hand hollow) and deformation system (exterior qound fibres, sand cotaings, corrugation).Sireg opted for the way of using quartz sand during manufacturing process so that the matrix looked like something rough. After different adjustment and test a perfect roughness was found and the rods, so treated, give the best bonding with the external material to which they are applied.
After solving this issue the use of FRP rods started above all in tunnelling, where Glass FRP rods were and are still used as nails to support the front excavation. Sireg, which is a leader in

production of FRP materials for this kind of application, decided to add something new starting to manufacture flat bars. In respect of rods flat bars have more surface for adherence giving a better bonding and till certain thickness they are quite flexible to be rolled. This opened widely the market of tunnel core reinforcement where very often the length of nails is around 20-24 meter. With flat bars rolled and delivered in coils all transport problem were solved and the door, for using this material in tunnelling, opened. The long flat bars solved also the problem of coupling, as coupling represent always the critical point for FRPs. This because to thread a rod (obviously it is not possible with a flat bar) means to cut part of it, in other words cut some fibres that are cast in the matrix longitudinally. This causes a loose of strength of the rods, as parts of the fibres, which give the tensile resistance, are broken. Then the coupler acts on the thread, which is composed of series of cut fibres, which don't have any resistance. The coupler usually doesn't support more than 100 kN, so it is possible to understand that couplers are the weakest point of a series of rods joined together.

Raticosa tunnel – Italy High Speed Railway



Flat bars rolls

Carbopree® rods 16mm –Sunderland (UK) soil nailing

ADVANTAGE AND DISAVANTAGE IN USING GFRP AND CFRP

Now the latest application of these materials, despite of in civil engineering application for concrete strengthening, are post-tensioning and soil-nailing. Here will be explained the reason which would lead the contractors and engineers towards the use of GFRP and CFRP.

The advantages are different if we refer to Glass FRP or Carbon FRP.

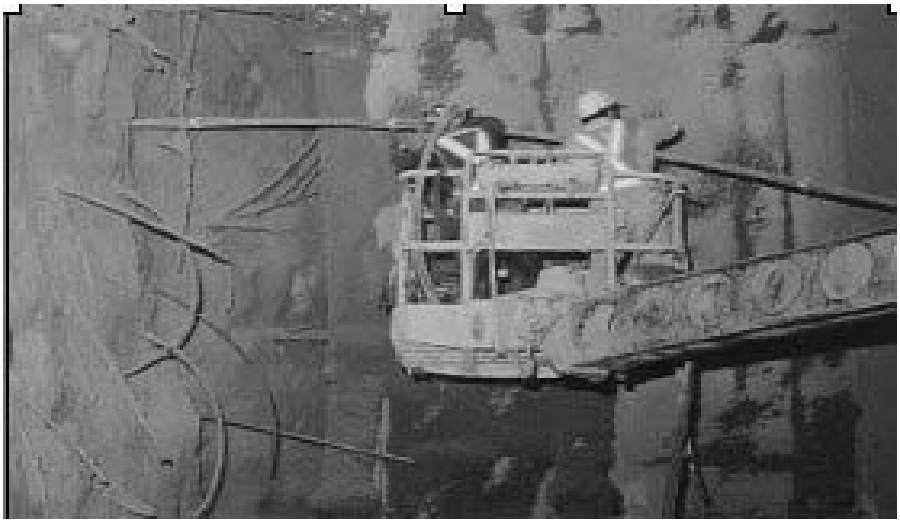
Mainly Glass FRP rods/bars are used as temporary because of creep problem that limit the durability. They have the advantage of being very light compared with a similar resistant steel rods and above all, very important in temporary anchors, could be crashed very easily after their use is finished. Sometimes, today always more often, in temporary anchoring is required something removable because further excavation could be done afterwards. This is very frequent in project performed in the city, where the space is always more limited. Using steel rebar means use removable anchors, very expensive and requiring additional removing work for the workers, with lost of additional time and more expenses for the client. Using Glass fibre rods/bars this wasting time is not necessary as, once placed, they could be left in place and in case of future excavation they could be crashed with normal means of excavation (excavators, roadheaders, blasting etc.). Than you can imagine the advantage of handling an anchor 24mt long weighing 64 kilos and having 900kN of breaking load, with one in steel which as, for the same resistance, a weight of approximately 160Kg! The limit of GFRP is the durability: it is limited to temporary use, or better, some reduction factors, should be considered in relation to the duration of the project, ground condition and stressing ratio.

Carbon FRP has its main features in durability: there is no acid, alkali or other solutions that can corrode this material; even the electricity, that could affect in time the steel, doesn't cause any change in the characteristic of CFRP. The potential of this material is very very high.

Consider one Sireg Carbopree ® rod ∅ 16mm has a tensile strength of 460 kN and a weight of 340 gr/mt: even better than glass fibre products. This material is foreseen to have a durability of more than 100 years.

The main issues using FRP in these applications are related to the way of tighting and pulling the FRP and to the lack of acknowledgement, from the side of engineers, of the design principles that should be used for these materials. Yes because you cannot simply substitute the steel with glass or carbon fibre elements as different material with different behaviour and different characteristics (modulus of elasticity, stiffness, creep shear strength etc). So the

calculation should be done on different basis considering different safety factors. We can rely for design, on the ACI440 guidelines, which speaks about the characteristics and behaviour of FRP materials, but more much in relation with concrete reinforcement; then we have a draft from JSC, CHBD of Canada, FHA of USA and Eurocode. The main problem is that there is a lack of real application apart from test conducted by Universities and Authorities. A consegquence is a certain scare from the engineers to specify the material in the project papers: is quite difficult to change from well known product used for long time, such as steel, to another quite unknown which don't still have, above all in term of durability, lot of done project as witness of its good performances.



Handling of Durglass® 24mt long structural element - Tartaguille tunnel (FR)

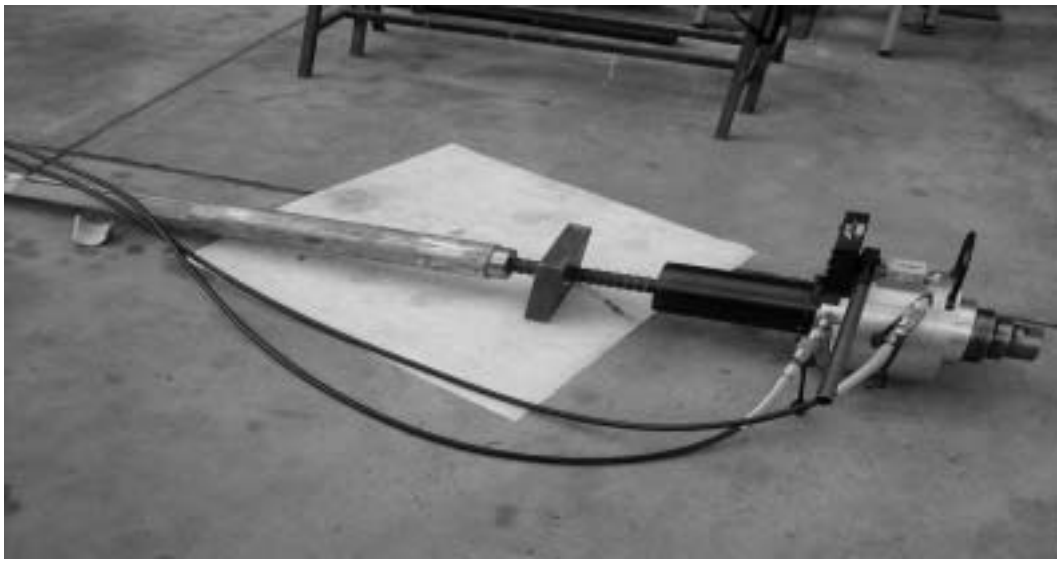
The big issue in post-tensioning with FRP materials is the blocking system. This because the FRP materials cannot be treated like a normal steel anchor rebar or strand. In case of rebar there is a nut that allow the stressing of the bar and has the function of blocking the rebar to the needed load too. In case of strands usually there is a bearing plate, which has lodgement for conical wedges system for each strand.

Conical wedges system with carbon fibre flat bar 40x5mm - London soil nailing

Applying this two system to FRP rods/flat bars means limiting very much their potential; because in the first case is needed a threaded rod (not possible on the flat bar) and as explained before this reduce a lot the resistance of the rods; in the second case the conical wedges system act in compression on the rods/flat bars crashing in that way the fibres when a

certain load is achieved. This because the resistance of FRP materials in compression is about 1/5 of the total tensile strength. Usually conical wedges system is used in case of soil nailing with no post-tensioning or in post-tensioning when the load to be achieve is limited: till now Sireg was successful to reach load of about 30tons with conical wedges system, but this with the bigger rods/flat bars, as the resistance to the compression vary in relation to the thickness.
To avoid this problem Sireg decided to follow another way. The FRP materials best performances are obtained in traction, so Sireg designed a blocking system following the principle of the anchors: try to create a bulb outside the soil in which the FRP are cast. In that way the FRP always work in traction and the friction with the cast material grant the blocking of the FRP rods/bars. At the end of this, that we can call tube, there is an adaptor for a steel rebar which will be used to pull the system, by means of a hydraulic jack.

Blocking system with Glasspree® flat bars system: Ultimate tensile strength 800 kN



Pulling system in connection with new blocking system

This system is very suitable above all considering the weight of the anchor and the pulling system that is the same used for steel rebars. Another advantage of this kind of anchors is flexibility, which allows moving also in place where the space is limited.

APPLICATION

Till now Sireg did about ten application of which the most important is the soil nailing of Sunderland in England, where about 45km of Carbopree® rods 16mm were applied. In this case no stressing was applied to the nail because its function was only the stabilisation of slopes aside an ancient and dismantled rail track. The formation level had to be one meter lower to allow the overhead electrification. It was decided to construct steep sided slopes, but as their angle was too great than the angle of friction of the natural material, a certain slope stabilisation have to be provide. Another concern was the durability required: more than 100 years, obtained in presence of currents induced by the metro tracks. This require a double corrosion protected steel rebars very heavy, expensive and requiring a bigger hole for placing. The client decided for carbon fibre because it didn't act as unwelcome earth for the currents; the contractor was very happy to have something to handle very light: one 7mt carbon nail should be handled on an hand, without requiring crane or excavator to raise it up till the 8mt of the nails upper line. So the workman power required was also limited and the insertion of the nails was very fast and the cost finally was half the one foreseen in case of steel nail!

Inserting 7mt Carbopree® 16mm rod – Sunderland (UK)soil nailing

Another soil nail, in different soil, was the one performed in Mahon isle, where some rock stabilisation should be done in face of the turistic harbour. The job had to be done near the high season, very quickly and above all without spoiling the landscape with enormous machines and mess that a job site can take with it. The carbon fibre in this case was again the best solution: scaffolding with little drilling machine and resin cartridges for injection

Inserting of Carbopree® rod 16mm in the rock – Mahon island (ES) soil nailing

For what concern the FRP post-tensioned anchors, Sireg already supplied some job sites: the most important were in Russia and Greece. In both cases the main reasons of using FRP post-tensionable anchors, had to be looked into the need of having something that could be crashed afterwards. In Russia they used post-tensionable anchors in glass fibre on the side of the tunnel. A second tube aside should be done afterwards, so was necessary to use something removable, if in steel, or something easy to be crashed. Glasspree® flat bar seemed to be the best solution, but a certain stressing had to be applied to the anchor. Sireg proposed its system and prepared the anchors 24mt long with an ultimate load of 800kN in its factory.

Anchor 24mt long preparing

In Greece the customer had to secure, temporary, the slope during the work of preparation for the tunnel entrance. Here also the main requirement was something that should be crashed without any problem during future excavation. Sireg proposed a system similar to the previous with an alternative for the pulling. In the following picture you can see that the steel tube is threaded outside so that a bolt could be used to pull and tight the anchor.

Anchor with nut for stressing and blocking

The same blocking system was used to secure the steel ribs during the Iselle elichoidal tunnel (within Italy and Switzerland) enlargement.

Anchor testing – Elichoidal tunnel – Iselle (Italy)

CONCLUSION

As could be seen, some important steps have been done on the way of post-tensionable anchors in FRP materials, but it is true that some more have to be done. Like for all new technology at the beginning the process is quite slow, the lackness of information obliged the manufacturers to make lot of test before achieving the correct acknowledgements about the behaviour of the new material in different conditions. Sireg in this field has the advantages to be one of the first that began to work with FRP materials in geotechnic. Our acknowledgement of these materials come from a long experience and this help us for example in introducing in Italy the use of FRP materials for concrete reinforcement.

FRP materials should be, for sure, very suitable, for their characteristics, in construction and geotechnic, but their acknowledgement is quite new so the applications are, very often, due to the more open minded engineers which, attracted from new technology, see the occasion of doing a innovative and prestigious project. Sometimes the clients consider these materials only very expensive because used mainly in Aerospatial construction, without seeing the advantages in applying them on their projects.

Finally we can say the main aim, at the moment, is to take to the eyes of the engineers and clients the advantages of using FRP materials; being sure they understand very well their characteristics.

Guidelines for using of FRP are becoming more popular; University are investing lot of money in doing test and growing up the students, so it is reasonable to say in brief time we will be able to see more and more real application of these materials.

Finally we can say that some steps more should be done before FRP reach the same utilisations they have in other field: Aerospatial, Automotive, Naval and Sport.