FRP applications in geotechnical engineering

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ASCE 4th Materials Conference

1996

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Abstract

What shall be the role of composite materials in geotechnical engineering. This new technology has already found important applications in aerospace, military and sports industry. The pace in civil engineering has been slower, but it has been used to replace steel in reinforced or pre-stressed concrete structures. Fibre reinforced plastics are produced by a process named pultrusion. High strength, low unit weight and high corrosion resistant bars, tubes and shapes are obtained through this process. Geotechnical applications are important where corrosion is of concern, such as permanent ground anchors or reinforcement bars and tubes. Anchor head for high loads are not simple to design, although solutions exist. FRP have straightforward applications in soil nailing walls and in tunnelling reinforcement.

Introduction

The technology of composite materials has produced new products that have found application in the aerospace, military, sports and civil engineering industry. They are generally named fibre reinforced plastics or simply FRP. The stealth fighter and the US Army Composite Armoured Vehicle (CAV) are two recent examples of FRP intensive use. Military applications are sought because of high strength and low weight. The US Army research program for the CAV plans to obtain a 30% weight reduction in the today's 50 ton heavy tank (CCM, 1994).

In sports, FRP is used to protect the pilot in F-1 and Indy car racing. There is no grand slam without the use of a carbon reinforced racket.

The civil engineering industry benefits from a variety of applications from reinforced and pre-stressed concrete, ground reinforcement for walls and tunnels and also beams, grades, etc. But the type of composites to be dealt herewith are high strength geosynthetic bars,

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tendons and tubes that can be used for soil and rock reinforcement and anchors. They will be called FRP *geobars* and *geotubes*.

Composite materials are developed in multi-disciplinary research centers by scientists and engineers with different backgrounds encompassing chemical, materials, textile, mechanical and even civil engineers.

This type of geosynthetic is still rather expensive. But can these new composite materials replace steel? This is a question for each type of project balancing the assets summarised in Table 1 with high cost.

Table 1 Main assets of FRP (Rostásy, 1994)

High and adjustable tensile strength
High and adjustable Young's modulus
High dynamic strength
Excellent corrosion resistance
Low unit weight
Magnetic and electric neutrality

These new geosynthetic products are strange to the geotechnical engineer, therefore a short discussion on the manufacturing process will take place in the beginning of this paper. We will discuss types of fibres, the pultrusion process and how to control strength and deformation properties of the final product. Afterwards we will show a variety of applications in geotechnical engineering.

Fibres

Manufacturer's catalogues show up to three fibres used in the manufacturing process: carbon (*C*), aramid (*A*) and glass (*G*). These are the only types capable of giving the final product the high tensile strength it deserves. Their properties are summarised in **Table 2**. Fibres are very thin and flexible. They should be cast in a polymeric matrix resin. Most common resins are polyester and epoxy.

Strength and deformation properties of final products can be adjusted by varying the fibre content according to the formulae (Cogumelo, 1994):

$$E = v_f\, E_f + 3/8 \times M\, E_f + P\, E_p \quad (1)$$

$$T = E\, \varepsilon_f \quad (2)$$

Table 2 Mechanical properties of fibres and their products (adapted from Rostásy, 1994)

Brand name	Fibre	Resin	Volume of fibres V_f (%)	Tensile strength (GPa)		Young's modulus (GPa)		Strain at failure (%)
				Fibre	FRP	Fibre	FRP	
Polystal	*G*	*P*	68	2.65	1.80	75	53	3.3
Polygon	*G*	*E*	60	2.99	1.79	93	56	3.1
Arapree	*A*	*E*	45	3.00	1.35	123	55	2.3
CFCC	*C*	*E*	64	3.29	2.12	213	137	1.6

G = glass, *A* = Aramid, *C* = Carbon, *P* = Polyester, *E* = Epoxy

Where: E is the composite Young's modulus, E_f is the Young's modulus of the glass fibre, equal to 73 GPa, E_p, the Young's modulus of the polyester resin, equal to 4 GPa, V_f is the fibre content, in percent, and M is the fibre textile content (used in laminates, but not in bars). T is the tensile strength and ε_f the strain at failure of the fibres.

Even if the encapsulating resin matrix does not contribute significantly to stress-strain behavior of the final FRP product, it is of great importance, for it protects the fibres against chemical attack, abrasion and lateral pressure.

Pultrusion

Pultrusion is a manufacturing process developed in early seventies and patented by Goldsworthy (1971). It is a one step continuous raw material conversion system for reinforced plastics, which is the exact analogue of an extrusion machine in aluminum or thermoplastic.

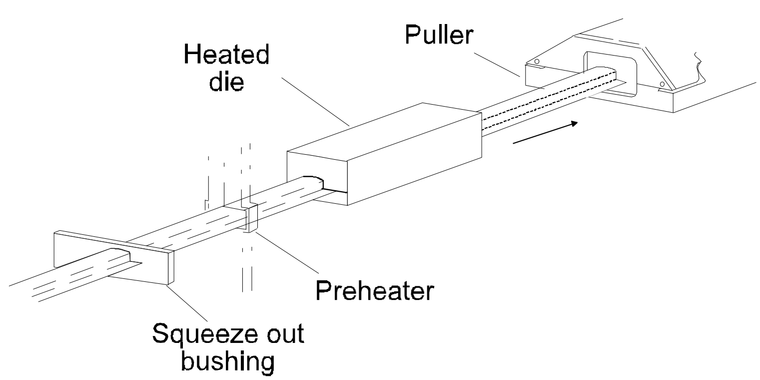

Figure 1 Pultrusion machine (Goldsworthy, 1994)

As raw materials (fibres and resins) are pulled through a heated die, polymerisation of the resin takes place and forms a rigid cured profile corresponding to the die orifice shape. The emerging product is a constant cross-sectional shape of infinite length. No further process is required, except to cut the stock at the desired length and size.

Figure 1 illustrates the process schematically. The first step is to wet fibres in resins (Figure 2), then, draw into the system by squeezing and removing the excess resin. The surface veil is a set of fibres used to protect the surface of pultruded shape. At the same time, the product can be pre-heated by microwave or radio frequency. The resin impregnated and heated reinforced roving enters the curing die and is pulled out by suitable devices.

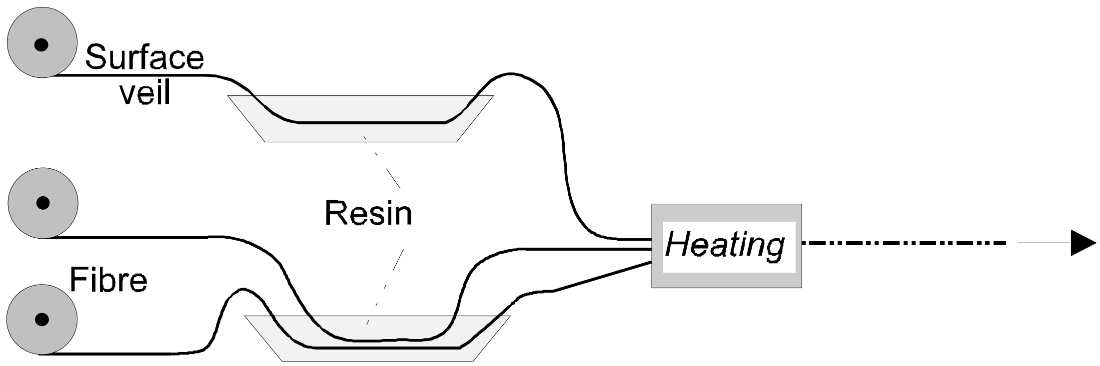

Figure 2 Pultrusion process

Properties

Figure 3 and Figure 4 present a summary of stress-strain properties of FRP’s. Tensile strength reaches values above two to three times steel’s strength and they behave linear-elastic up to failure. The most common type used in geotechnical applications is the glass fibre and its properties are summarised. Alike other types of fibres it presents low unit weight, high strength and low (adjusted) modulus.

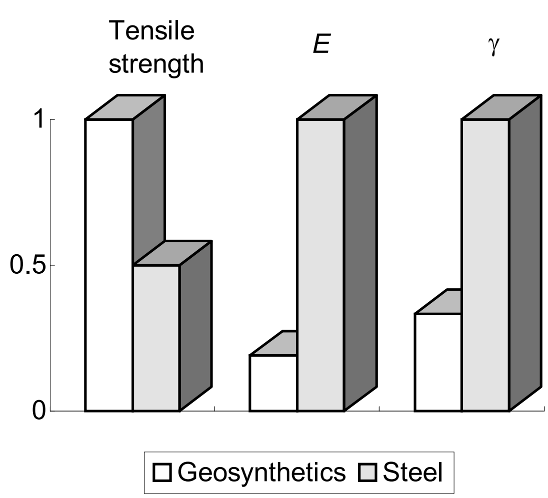

Figure 3 FRP geobars versus steel

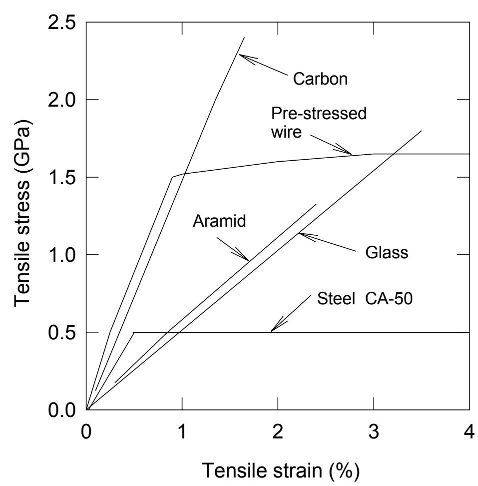

Figure 4 Tensile stress-strain properties of FRP's (adapted from Rostásy and Budelmann, 1994)

Corrosion

The life of a reinforced concrete structure is directly related to corrosion in the reinforcement. Corrosion rates can be a major problem in aggressive environment and waterfront structures.

Corrosion can be of concern in buried soil anchors and nails, and this has prevented the use in permanent structures in some countries. The City of Rio de Janeiro no longer permits the use of permanent multi-strand soil anchors. This is due only to corrosion concern.

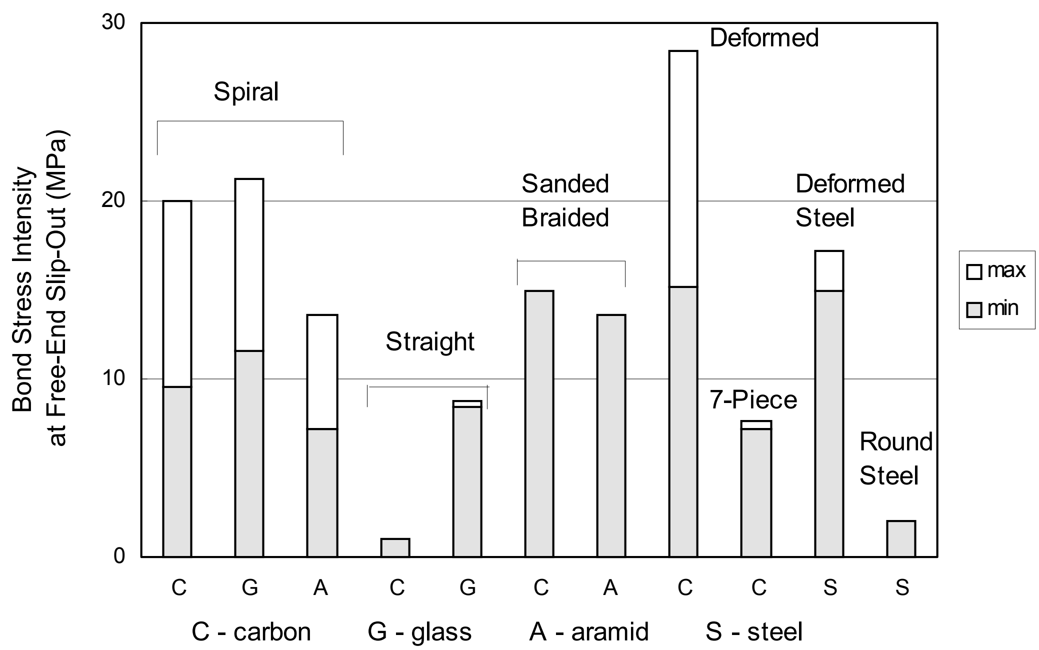

Figure 5 Relationship of raw materials types and surface conditions (Yamasaki et al, 1994)

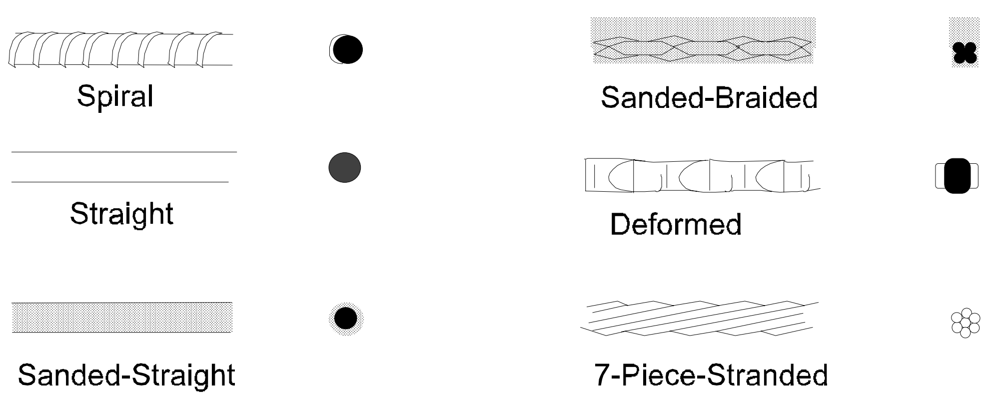

Figure 6 Types of surface finishing (Yamasaki et al, 1994)

It is expected that FRP nails and anchors, presenting high corrosion resistance, will overcome this problem.

Geobar-grout interface

Geobars can have different types of surface finishing as indicated in **Error! Reference source not found.**

The interaction with concrete was studied in detail by Yamasaki et al (1994) and the results of their bond tests are presented Figure 5. It is concluded that the bond shear strength between bars and concrete is low in carbon fibre geobars. The most common geobars are made with glass fibres and can have its bond strength significantly improved just by roughing the geobar surface by applying sand particles.

Anchorages for FRP

FRP products are anisotropic by nature. They have high tensile strength along the its axis, but are very sensitive against lateral pressure and surface injury. Anchor systems used for steel bars, like threads or *clavettes*, *i.e.*, the Freyssinet anchor type systems used

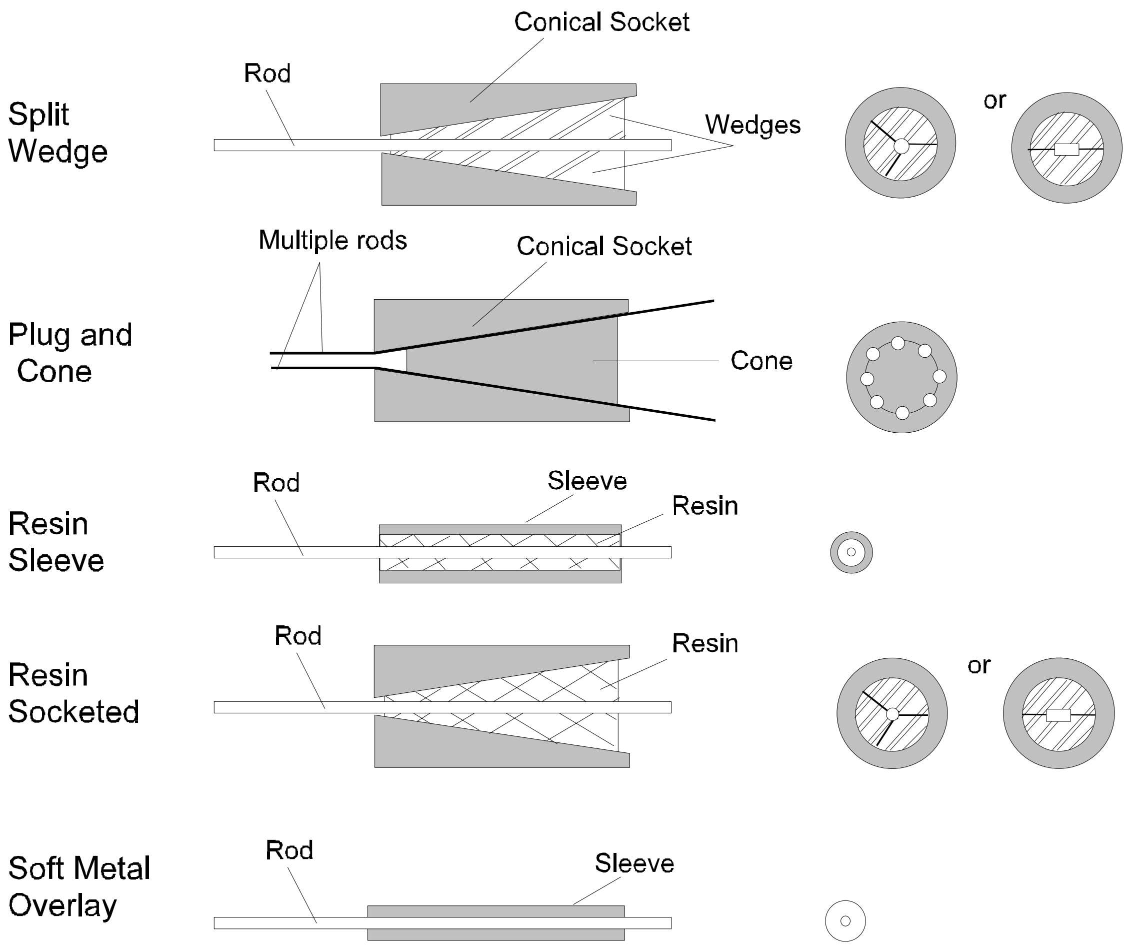

Figure 7 - Anchor head designs (Holte et al, 1994)

for pre-stressed concrete, are out of question. One can only take advantage of the full tensile strength if anchor systems are carefully designed. Research on this particular and important issue has led FRP to be used in pre-stressed concrete (*e.g*, Rostásy et al, 1994, Erki and Rizkalla, 1993, and Holte et al, 1994).

Figure 7 presents different types of anchor systems. It is expected that a satisfactory design for a multi-strand and high load ground anchor will evolve from FRP manufacturers.

Soil nailing applications

Applications of geobars in permanent soil nailing walls will certainly assure long life to the structure. The technique is discussed elsewhere (*e.g*., Ortigao et al, 1995). Soil-nail interactions takes place mainly by friction along the grouted annulus around the bar. Consequently, nails are subjected to low head load, *i.e.,* less than 50 kN, therefore, anchoring systems are relatively easy to design.

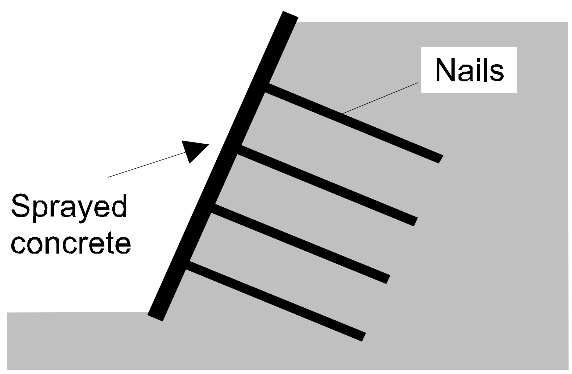

Figure 8 Soil nailing wall

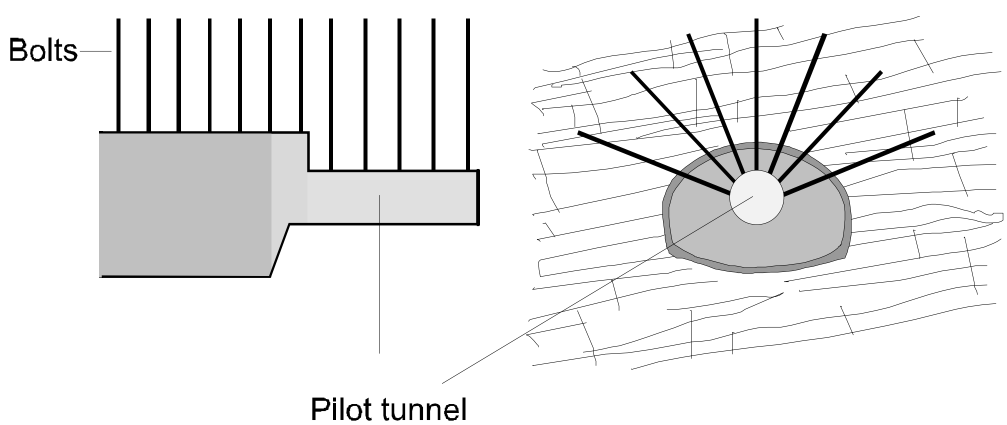

Figure 9 Rock bolting from a pilot tunnel

Tunnelling and mining applications

Geobars and geotubes present a significantly advantage in tunnelling applications when demolition is going to take place. This is the case of tunnels in rock (Figure 10), when a pilot tunnel is designed to investigate rock quality and to provide drainage and ventilation. Geobars do not pose any difficulty to cutting, when the secondary excavation takes place.

Geobars present good performance during dynamic loads or shock waves from blasting (Hagedorn, 1991) and have been successfully applied at Pirapora Dam in Brazil (Mello et al 1994 and Nieble, 1994).

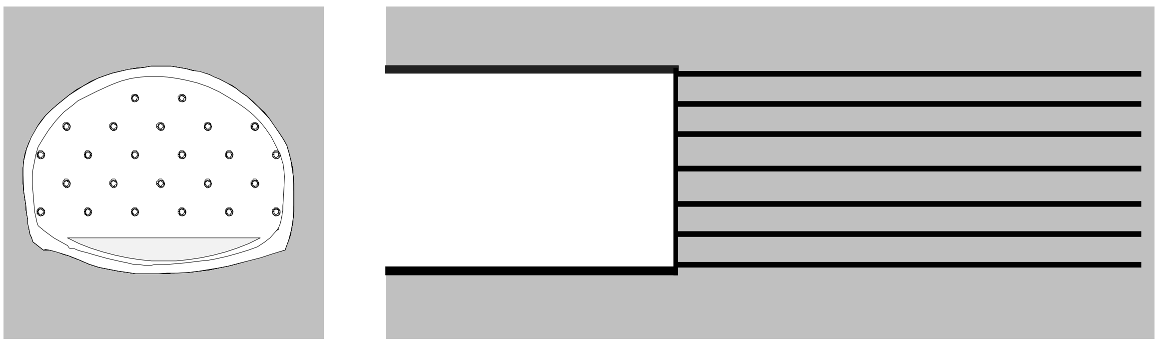

Figure 10 Soil nailing at the face of the excavation in soft ground tunnelling

Rock bolting in mining and in tunnelling in fractured rock can take advantage of the high corrosion resistance of FRP bars. This is specially advantageous in aggressive environments such as in salt and coal mines where steel bolts deteriorates in a matter of days, rather than years.

Since 1988 a new technique of nailing the face of tunnels has evolved in Europe (Lunardi, 1991, 1994). It consists in reinforcing the soil plug ahead of the excavation by nailing with geobars. Up to 30 m long nails are horizontally installed in 100 mm boreholes and grouted in a similar pattern shown in Figure 10. Three-dimensional deformational analysis and field measurements on several tunnels in Italy demonstrate the advantage of this technique in poor ground conditions to stabilise the excavation face and to reduce ground movements. This method enables full face excavation and high

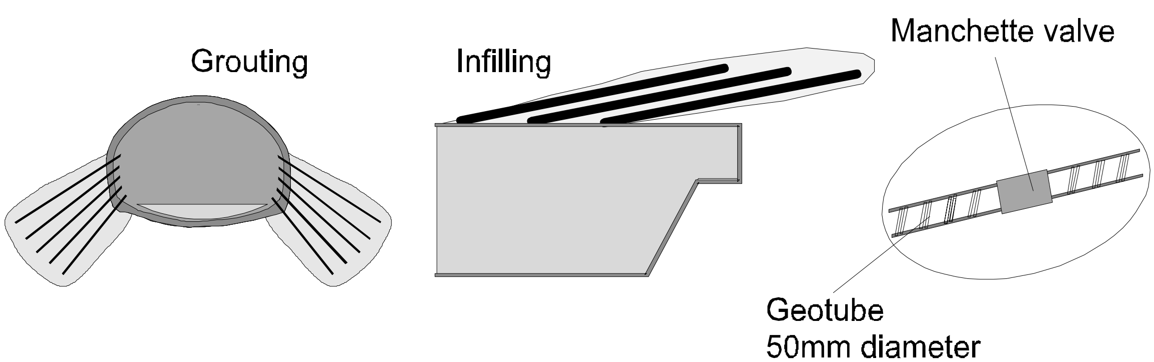

Figure 11 Geotubes with manchette valves for grouting and infilling

production rates of 3 m per day, even in poor ground conditions.

Geotubes with manchette valves can be used for soil stabilisation by grouting and for infilling for roof support, as indicated in Figure 12.

Conclusions

FRP geobars and geotubes present high tensile strength, low unit weight, high resistance to corrosion, easy cuttability, but the cost is high as compared to steel. Its replacement will occur where corrosion or demolition is a major concern.

Applications of geobars in soil or rock reinforcement, where head loads are small (*i.e.*, less than 50 kN) are straightforward.

On the other hand, high load ground anchors pose severe difficulties to the anchoring head design. Simple solutions like those used for steel are nor applicable, due to the inherent anisotropy of FRP bars. Special solutions exist but require careful design and extensive for creep and deterioration testing effort.

Acknowledgements

The author is indebted to several people and their organisations who shared their time and expertise and sponsored technical visits to Italy, Switzerland and the US, namely Messrs G Pilz and A Catunda of Cogumelo Ltda, Rio de Janeiro, Drs A Giamundo and L Giamundo of ATP srl, Italy, Mr H Helbling of H Weidmann AG, Switzerland, and Dr P F Castro, on sabbatical at the Center of Composite Materials of the University of Delaware, and Drs M Chajes and H Ling from the University of Delaware. Mrs L Alves and T Moreira were instrumental in the preparation of this paper.

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