BGA Annual Conference 2022

GFRP anchoring systems for soft-rock geostructures with high cultural and environmental value

L. Sandrini, M. Ciantia, R. Castellanza, I. Bridi, D. Grassi, G. Balconi, P. Perrone
2432125@dundee.ac.uk

Introduction

The stability of geostructures composed soft rocks such as chalk and calcarenite is a serious problem especially when failure mechanisms interfere with inhabited centers. The areas affected by such threat often coincide with cultural heritage sites because of their evocative landscape. A novel anchoring system aimed to overcome limitations such as corrosion weathering and negative visual impact typical of steel bars is proposed. The performance of the new anchoring system is demonstrated by an intensive field-testing campaign. Pull-out tests on Glass Fiber Reinforced Polymers (GFRP) anchors installed with various types of consolidants, are compared with test results on DYWIDAG steel bar anchors.

Site investigation and field location

The field-testing campaign was performed in two different locations on the Polignano a Mare coastline (Southern Italy). Both locations were chosen to be close to two large caves which experienced partial collapses in the past and that require urgent in safety measures (Figure 1). The first (FT1) is in the proximity of the *Grotta Palazzese* cave, where both Calcarenites of Gravina (CG) and Calcare di Bari (CB) limestones are outcropping. In filed test 2 (FT2), which is in correspondence of the *Grotta dell'Arcivescovado* cave, only the Calcare di Bari (CB) limestone is outcropping.

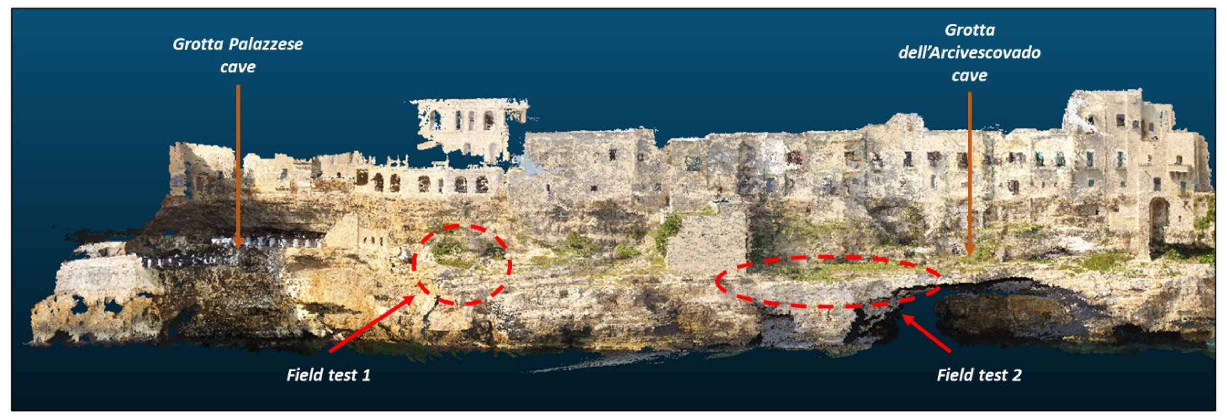

Figure 1 Field tests location. Image reconstruction from drone acquisition

Pull test characteristics

As mentioned previously, two types of bars were used in this field-testing campaign. On one side GFRP bars of variable diameter were used to determine their pullout capacity performance and exploit their lightweight and corrosion resistance properties. On the other classic DYWIDAG bars are used as benchmark to compare the performance of the GFRP bars. Whist DYWIDAG bars are already threaded, one extremity of each of the GFRP bar used had to be modified to allow a proper anchoring of the pulling system. Depending on the bar type a threaded steel tube was attached to the external or internal (for hollow bars) surface of the GFRP at one extremity using an epoxy resin. Table 1 and table 2 summarise the mechanical and geometrical characteristics of the DYWIDAG and GFRP bars used.

Table 1. DYWIDAG bar details

Type	Diameter (mm)	Yield stress (MPa)	Yield load (kN)	Ultimate load (kN)	Young Modulus (GPa)
Y1050H	26.5	950/1050	525	580	205

Table 2. GFRP bar details

Type	Diameter (mm)	Guaranteed Tensile Strength (MPa)	Min guaranteed ult. tensile force (kN)	Young Modulus (GPa)
Glasspree Ø16	16	850	> 170	46
Glasspree Ø25	25	800	> 392	46
GFRP Hollow Bar	32	800	> 350	40

Consolidants

In FT1 two types of consolidants were used to anchor the bars in the CB limestone and only one type for the tests in the CG calcarenite. A bi-component organo-mineral and thixotropic resin, MasterRoc RBA 380, and a premixed cement mortar, MasterEmaco T 1200 PG, were used in the limestone, as both materials have low hardening times. For the tests in the calcarenite a lime-based mortar, MasterInject 222, was used instead, as the holes were made with an inclination of 45 degrees upwards and the use of resins resulted to be impractical. In FT2, on the other hand, the 8 different types of consolidants listed in Table 3 were used:

Table 3. Details of the consolidant materials used

Consolidant	Fabricant	Chemical composition/ characteristics	Compressive Strength (MPa)	Interface shear strength (MPa)	Young Modulus (GPa)
Masterinject 222	Master-Builders Solutions	pozzolanic lime grout	> 10	> 4	6 ± 1
MasterEmaco T 1200 PG	Master-Builders Solutions	reinforced cement mortar	> 80	> 25	43
MasterRoc RBA 380	Master-Builders Solutions	TIX polyurea silicate resin	> 35	/	/
MasterEmaco A 640	Master-Builders Solutions	expansive cement mortar	> 40	> 15	30 ± 2
MasterEmaco S 1120 TIX	Master-Builders Solutions	TIX cement mortar	> 35	/	22
MasterRoc 710 TIX	Master-Builders Solutions	TIX cement mortar	> 40	/	22
Stabilcem T	Mapei	TIX cement mortar	> 40	> 17	30
Silicajet EXP/4	Mapei	two-component polyurea silicate resin	/	/	/

Positioning and bars grouting

In FT1 12 bars were installed (4 in CG and 8 in CB limestone) and pulled to failure or to the maximum capacity of the jacking system (100 Tons). Of the 4 bars installed in the calcarenite, 2 were Ø32 GFRP hollow tubular bars and 2 were Ø26.5 DYWIDAG bars.

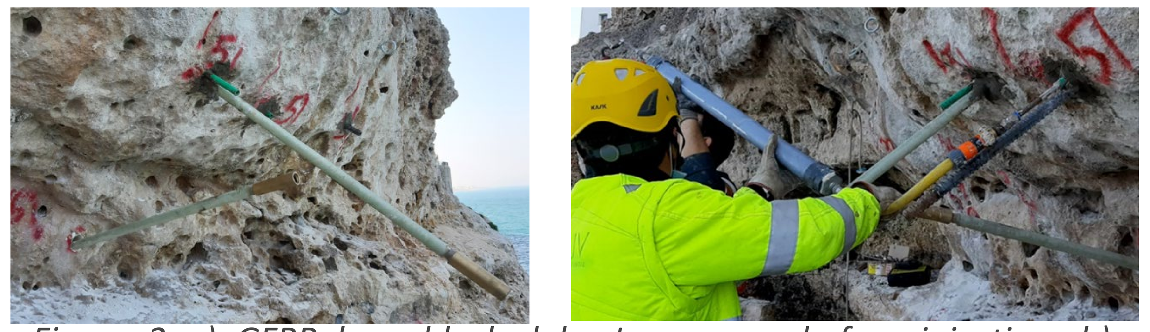

Figure 2 a) GFRP bars blocked by Lampocem before injection; b) injection of MasterEmaco 222 through injection tube in CG

Figure 3 pouring to two different materials (MasterEmaco T 1200 PG and MasteRoc RBA 380) in CB

In FT2, 12 anchors were installed (all in CB limestone), with 8 different types of consolidating materials. Except for the CB1/2 and CB2/2, where the consolidant material was injected with the same bespoke method used in FT1 (see Figure 2b), all the other bars were grouted by casting the chosen material .

Pull-out tests

All the pull-out tests were performed using Hallow piston Hydraulic cylinder Jack brought under pressure by a manual pump, connected to a load cell to measure the applied tensile force. Depending on the estimated capacity a 100ton capacity or 30ton capacity hallow piston was used. Data acquisition was carried out digitally, using 3 digital displacement transducers connected to a data logger to which a connection to the pump was also added to view the applied force. By connecting the data logger to a portable PC, it was possible to view and record in real time the displacement and force signals of the transducers.

Figure 4 a)Pull test with 1000 kN capacity Hallow piston; b) pull test with 300 kN capacity hallow piston

As detailed in Table 4 some tests were performed after 18 hours of curing time. Others were performed after 40 days.

Table 4. Anchors pull test details

ID test	Bar type	D (mm)	D_h (mm)	Consolidant	Curing time	F_{max} (kN)	Comments
CA-2/1	DYWIDAG	26.5	55.3	*Masterinject 222*	40 (days)	400	failure looked to appear at interface rock-binder
CB-1/1	GFRP	16	35.4	*MasterEmaco T 1200 PG*	18 (hours)	> 140*	failure pull test bar attachment system
CB-2/1	GFRP	16	35.3	*MasterRoc RBA 380*	18 (hours)	100	failure at interface rock-binder
CB-4/1	GFRP	25	54.1	*MasterRoc RBA 380*	18 (hours)	120	failure at interface rock-binder
CB-5/1	GFRP	25	54.4	*MasterEmaco T 1200 PG*	18 (hours)	340	failure looked to appear at interface rock-binder
CB-6/1	DYWIDAG	26.5	34.4	*MasterEmaco T 1200 PG*	18 (hours)	> 300	Hallow piston max load
CB-7/1	GFRP	16	34	*MasterEmaco T 1200 PG*	18 (hours)	> 140*	failure pull test bar attachment system
CB-8/1	GFRP	16	34.2	*MasterRoc RBA 380*	18 (hours)	> 120*	failure pull test bar attachment system
CB-1/2	DYWIDAG	26.5	33.6	*MasterEmaco A640*	40 (days)	> 430**	Hallow piston max load
CB-2/2	GFRP	25	53.7	*MasterInject 222*	40 (days)	> 100*	failure pull test bar attachment system
CB-4/2	DYWIDAG	32	46	*Silicajet EXP/4*	40 (days)	235.7	failure looked to appear at interface rock-binder
CB-6/2	GFRP	16	33.8	*MasterRoc 710 TIX*	40 (days)	> 122.4*	failure pull test bar attachment system
CB-8/2	GFRP	25	52.6	*MasterEmaco A640*	40 (days)	> 511**	Hallow piston max load
CB-9/2	GFRP	25	54.1	*MasterEmaco S1120 TIX*	40 (days)	340	failure looked to appear at interface rock-binder
CB-10/2	GFRP	16	34.2	*MasterEmaco A640*	40 (days)	> 128*	failure pull test bar attachment system
CB11/2	DYWIDAG	26.5	53	*MasterEmaco A640*	40 (days)	> 488**	Hallow piston max load

Discussion

The results of the pull test of the CB8/2 and CB11/2 anchors are reported in Figure 5. In the figure the failure loads related to rock-consolidant shear failure, bar consolidant shear failure and yielding of the bar are also reported. For the anchoring length of 1m and for tests in CB limestone, failure is expected to occur because of the yielding of the bar. The two tests reported could not reach failure as the maximum load of the piston was reached in both cases. The main difference observed is a much stiffer response of the DYWIDAG bar compared to the GFRP one.

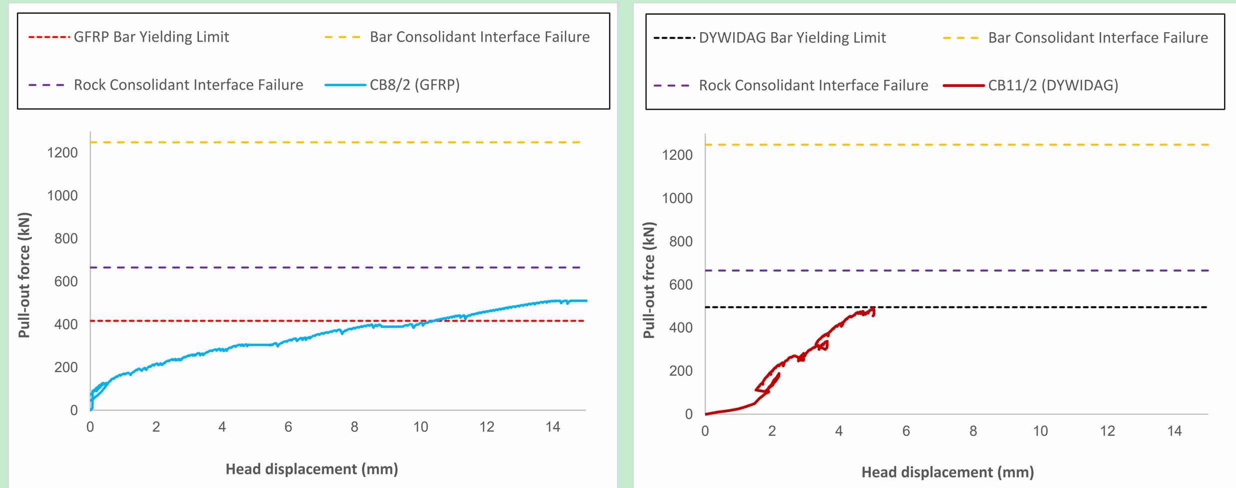

Figure 5 pull-out force vs head displacement curves for CB8/2 (a) and CB11/2 (b).

The main results of the 16 pull test performed in the two sites in the proximity of the *Grotta Palazzese* cave show that GFRP bars are a good alternative to DYWIDAG as they can provide similar capacity with a more ductile behaviour. Such feature is important when stabilising rock masses prone to brittle failure mechanisms.

References