Protection of public beaches in Gibraltar by stabilisation of quarried cliffs using rock anchors

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1.0 INTRODUCTION

Cliff stabilisation has to date been more commonly carried out using rock bolting systems of varying quality with respect to corrosion protection. The severity and potentially fatal consequences of a cliff collapse at either Camps Bay or Little Bay inlets, which provide recreational areas in Gibraltar, demanded the use of double©protected high quality rock anchors complying with BS8081. These bay areas had originally been created by extensive quarrying activities carried out to win stone for local construction. Crude excavation and blasting techniques had left steep and shattered rock faces up to 75m in height.

120 rock anchors with working loads up to 500kN and lengths up to 20m, were required to enhance the stability of large buttresses of rock, some partially separated from the main cliff. Specially designed cliff face drilling rigs were winched into position and fixed to the face with dowels during drilling and grouting operations. All operatives were secured independently, using abseil sit harnesses and dual rope safety systems. All construction operations in this potentially hazardous area were executed in accordance with a well defined safety related method statement.

2.0 PRELIMINARY GROUND STABILISATION

Above the cliff, other geotechnical operations were initially required to ensure the stabilisation of colluvium infill and broken rock under and around the high level Europa Road. Europa Road passes within 2m of the edge of the gully from where rock fall had occurred, and the road at this location had been temporarily spanned by a Bailey bridge after the rock fall, in an effort to reduce ground loading. A diesel powered tracked drilling rig carried out vertical and raked drilling, followed by ascending or descending stage grouting. Grout take within the colluvium was high, even with a 2:1 sand/cement mix, and finally required tertiary grouting in some areas. Furthermore, the encounter of a large voided area within the rock below the colluvium, from 7m below road level to a depth of 25m, initially demanded high take. However, stability analysis suggested the road stabilisation by full soil and rock grouting of the six metre depth immediately below the road was satisfactory, and that the enormous grout take requirements to fill the major voids would be unnecessary.

3.0 ANCHOR DRILLING OPERATIONS

The impressive operations involved the winching of one tonne pneumatic drilling rigs into various locations on vertical and even overhanging cliffs (Photo 1). These specially designed cliff face rigs were further secured during drilling to local mechanical bolt placements. The rigs operated down©the©hole hammer drill strings, resulting in 110mm diameter boreholes to depths of 20m using air flush. All rig operatives utilised roped access systems that are approved by the Health and Safety Inspectorate and are independently certificated to the Industrial Roped Access Trade Association (I.R.A.T.A.) codes of practice and safety. The roped access systems were supplemented by narrow articulating work platforms, attached to the rig chassis itself.
Photo 1: One tonne pneumatic drill rig suspended while operatives utilise roped access system

Photo 2: Continuous prefabricated strand tendons lowered and installed without interruption for coupler application
4.0 WATER TESTING AND GROUTING

The original specification directed the use of a water test to prove boreholes' integrity, but this was superseded, under engineer's instruction, by the use of the more realistic and representative Falling Head grout test (BS8081, Clause 10.4.2.3).

On completion of drilling of a hole to the specified depth in which air flush was totally or partially lost, then a sand/cement grout was pumped in to waterproof the hole. After initial set, the hole was reamed out and normal neat cementitious grout pumped in.

On completion of drilling to the specified depth and if no loss of flush was detected, then the grout was pumped into the bore in one continuous operation. The level of the grout was monitored. When the level remained constant or with a tolerable fall within an observation period of 15 minutes, the borehole was deemed to have passed and the tendon was homed.

The grout was mixed using a water cement ratio of 0.45 in a Colcrete 4/10 colloidal mixer system.

Of the 120 anchorages, 31 required waterproofing, or some supplementary ground improvement, and this involved a total of 304 tons of grout. This was, in some holes, well in excess of three times hole volume as outlined in BS8081 for anchoring operations.

The grout itself was subjected to three types of test: initially, slump and bleed tests on the mix and subsequently daily cube tests. The characteristic strength of 40N/mm² at 28 days was generally achieved without difficulty, albeit occasional poor results were exhibited due, not to grout quality, but to cube making, stripping or handling problems under the site conditions.

5.0 ANCHOR TENDONS AND INSTALLATION

Anchor tendons consisted of up to four 15.2mm dyform prestressing strands, complete with double plastic corrosion protection layers for their entire length. These protected tendons (Ref 1) were fully fabricated in Keller Colcrete works in Yorkshire and transported to the site. The rigid 3m encapsulation lengths, followed by the flexible tendon free length were carefully lowered down the cliff face and fed into the borehole (Photo 2). The continuous factory applied corrosion protection ensured that no holdups for fitting of couplers and subsequent application of corrosion protection were necessary, thus easing the operation in these rope suspended locations. The encapsulations were spaced in the borehole to ensure 10mm cover during grouting operations.

6.0 ANCHOR TESTING AND STRESSING

The installed anchorages were subjected to two types of test: 12 as to on-site suitability, and the remainder to acceptance tests.

The anchorages were stressed using monostrand loading techniques, utilising hydraulic bottle jacks with internal grippers.

All the tested anchorages were within acceptable tolerances as outlined in BS8081, conforming with load/extension criteria and load loss criteria at proof load and working load.

On completion of approval of results, strands were cropped to length. The galvanised steel anchor caps were filled with grease and bolted to the anchor head plate. This operation by individual operatives, although fully protected with the double rope system, was certainly not for the faint hearted! (Photo 3).

7.0 SUPPLEMENTARY WORK
In addition to the major anchoring and grouting works, a considerable scope of other geotechnical techniques was employed. Boulders up to 5 tons in weight were removed in a controlled manner, and larger potentially loose blocks were secured with dowelling and galvanised cable restraints. Avalanche fences were sited at the outfalls of loose gullies, and a total of 200 rockbolts up to 3m long were used in conjunction with sprayed concrete to give structural stability to large areas of exposed and high angle breccia slopes. Finally in certain areas, the random stone walls of old defensive works sited right on the cliff face crestline, were showing signs of distress. These were stabilised using various permutations of reinforced concrete dentition works, pressure pointing with grouting, and reinforced sprayed concrete.

Photo 3: Fitting of grease filled anchor caps on overhanging rock face

8.0 SUMMARY
Whilst the contract works were under way, the entire area of Camp Bay and Little Bay was closed to the public. The construction operations in this potentially hazardous area were executed in accordance with extremely well defined safety related method statements. Any cliff access required to inspect the works fell under the precise guidance of the cliff access contractor, in order to ensure that full coordination was continually maintained. These extensive soil and cliff stabilisation works, utilising quality anchor of double protected prestressing strand tendons, were completed within a six months winter period. This then allowed safe and risk free future utilisation of the Camp Bay and Little Bay leisure facilities.

10. ACKNOWLEDGMENTS

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REFERENCES