RESULTS OF THE SITE CHARACTERISATION OBTAINED AT THE TARIFA EXPERIMENTAL GALLERY

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ABSTRACT

The 570 m long Tarifa Experimental Gallery has allowed the investigation of three of the five flysch units involved in the future tunnel of Gibraltar. This Tunnel will have a length of 38 km approximately and will cross the Strait.

For this reason, the results obtained from in situ testing, instrumentation measurements and laboratory tests are presented.

INTRODUCTION

The Tarifa Experimental Gallery is a major geotechnical experiment carried out within the ongoing process of studies by the Spanish SECEG (Sociedad Española para la Comunicación Fija del Estrecho de Gibraltar) and by the Moroccan SNED (Societe Nationale d'Etudes du Detroit) into the feasibility of a tunnel across the Strait of Gibraltar. In **Figure 1** are shown the location of the future tunnel as well as the location of the gallery.

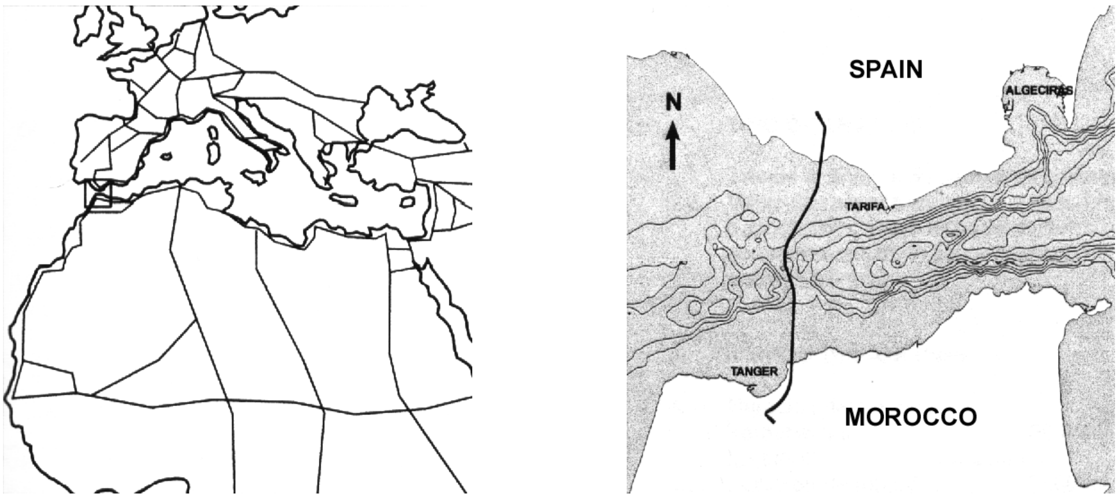

Figure 1 : Location of the future tunnel.

The terrain expected to be encountered in the selected route consists of five types of flysch units. These were formed by either overconsolidated clay strata (the Almarchal unit and basal portions of some other units) or by clayish formations with interbedded hard layers, mostly of sandstone and calcarenites, with thickness ranging from a few centimetres to a few metres.

All five types of flysch occur actually in chaotic, heavily tectonised and micro-tectonised massifs with no knowledgeable spatial organisation for practical purposes, either for lithological or tectonic inferences. Thus, it can be roughly summarised that the picture we have of the geological environment of the tunnel route is a massive, highly impervious clayish formation, sometimes armoured –sometimes not- with hard

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slabs, mostly of sandstone, unpredictably oriented. This particular situation led us to investigate the geotechnical behaviour of the terrains involved in the project by relatively large experimental works located on both shores of the strait at representative sites. To this end, the 300 m-deep Malabata Shaft (Jan. 94-Dec. 95) was sunk in the Moroccan shore and the 75m-deep Bolonia Shaft (Jul.93-Oct.93) as well as the 570m-long Tarifa Gallery (Feb.95-Aug.95) have been built in the Spanish shore of the strait. All of them are now completed in that sense that the civil work and auscultation during construction is finished and that different instrumentation programmes of significant duration have already been carried out: however, further different observations and complementary testing are under way or expected to start in the future.

MAIN CHARACTERISTICS OF THE TARIFA GALLERY

The location of the Tarifa Gallery (**Figure 2**) is highly satisfactory from the geological-geotechnical point of view, since, with a length of only 570 m, representations of three of the five flysch units involved in the project are exposed. For practical purposes, this covers the entirety of the geotechnical problematique, including the very peculiar one presented by Almarchal unit –and Almarchal-like formations-, which is the project's weakest from the tunnelability viewpoint. Furthermore, it is also worth recalling that the gallery cuts through one of the most important faults known in the project area, i.e. a double fault involving a wedge of Almarchal in contact with harder units (Algeciras and Bolonia), a circumstance that has provided the rare opportunity of observing directly the fault-sealing effect of plastic Almarchal behaviour under tectonic pressure.

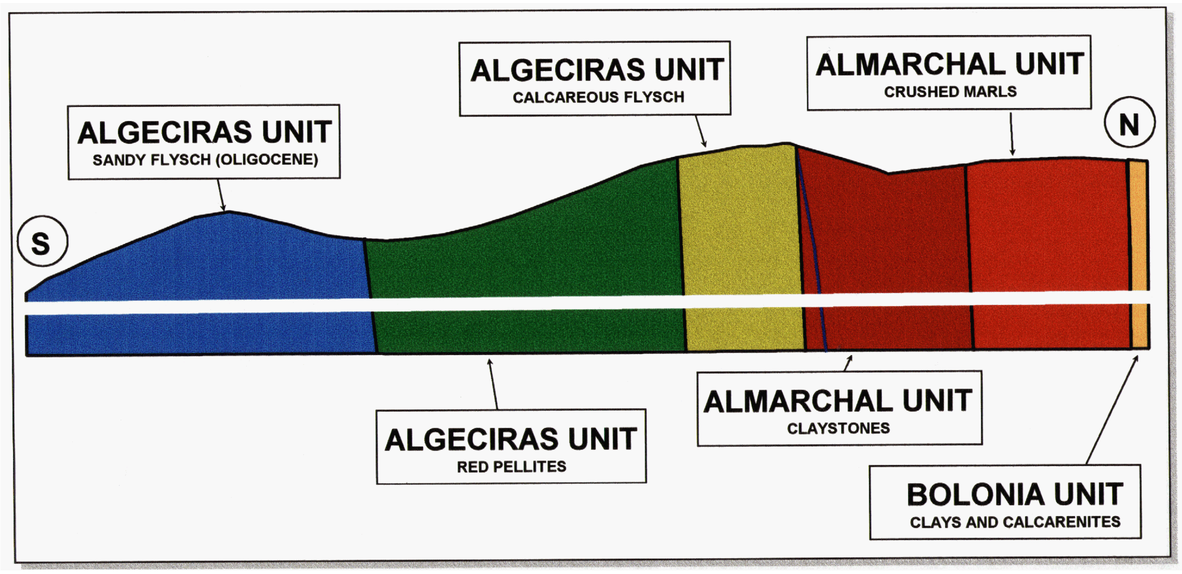

Figure 2 : Elevation profile of Tarifa Experimental Gallery.

In terms of overburden, the representativeness of the Tarifa Gallery is less satisfactory, since its maximum 2 MPa overburden pressure is only about one third of that maximum water+earth load in the envisaged tunnel under the strait.

The Tarifa Gallery, located at about 6 km east of the city of Tarifa, is a 3.8 m-diameter, 570 m-long, 80 m-deep, one-portal gallery, built with a Robbins unshielded TBM in the period February 1995 through August 1995. The gallery was provided with "strict supporting" compatible with safety, but light enough so as to favour observation of significant convergence (and, at a lesser extent, confinement). In hard terrain (Algeciras), mainly 6-10 cm slightly reinforced shotcrete was used, while in soft ground (Almarchal) steel circular supports spaced at 1.5 m were preferred.

GEOTECHNICAL PROGRAMME

In order to make a satisfactory site characterisation of the described units, several tests and measurements were performed.

These tests have been as follows:

- **convergence measurements**, with 62 stations spaced at 10 m measuring vertical and horizontal closure.
- **confinement measurements**, in five 5m long rigid sections including each one 4 stress cells and 4 extensometers embedded in the lining.
- **pressuremeter tests**, 21 tests carried out at the Algeciras and Almarchal units.
- **load tests**, 13 tests performed with TBM grippers.
- **laboratory tests**, some hundreds of lab tests over representative samples of both units.

The results of these tests and measurements are briefly described below.

Convergence measurements

62 convergence stations (generally spaced at 10 m) were instrumented for horizontal and vertical near-diameter measurement with tape-extensometers. At each station, the first measurement was regularly taken at a distance of 2.85 m from the current excavation face and further measurements were systematically made at increasing time intervals ranging from a few hours to a few months in accordance with the observed evolution of the convergence process. Normally, convergence bolts were anchored at a depth of 30 cm and, exceptionally in Almarchal, "triple convergence stations" with 2x3 pairs of bolts anchored at 30, 120 and 200 cm were installed in an attempt to observe radial deformation both vertically and horizontally.

Some of the stations have been measured for more than two years (Feb. 95 to Feb. 97). In **Table 1** the average values of total convergence are shown.

Table 1 : Convergence average values.

	Algeciras Unit		Almarchal Unit	
	mm	% of diameter	mm	% of diameter
Horizontal	6	0.18	61	1.7
Vertical	4	0.12	67	1.9

These values seem to depict a good average geomechanical behaviour of both Algeciras and Almarchal flysch units, in spite of the fact that, as obviously expected, the latter proves to be far more deformable, although convergences taken at deep-anchored conditions (120 cm form the surface instead of 30 cm) sharply decrease to 50 %. The favourable impression from these measurements is however to be considered with some reserve, since significant rate of residual convergence (about 1 mm/month) is still detected in Almarchal, a circumstance needing further analysis and monitoring.

In **Figure 3** is shown the ratio between the convergence at 20 m from the tunnel face and the final convergence. As it can be observed from 400 m (Almarchal Unit), the average of this ratio is about 75 %, which indicates that after an elastic-plastic behaviour some creep behaviour can exist.

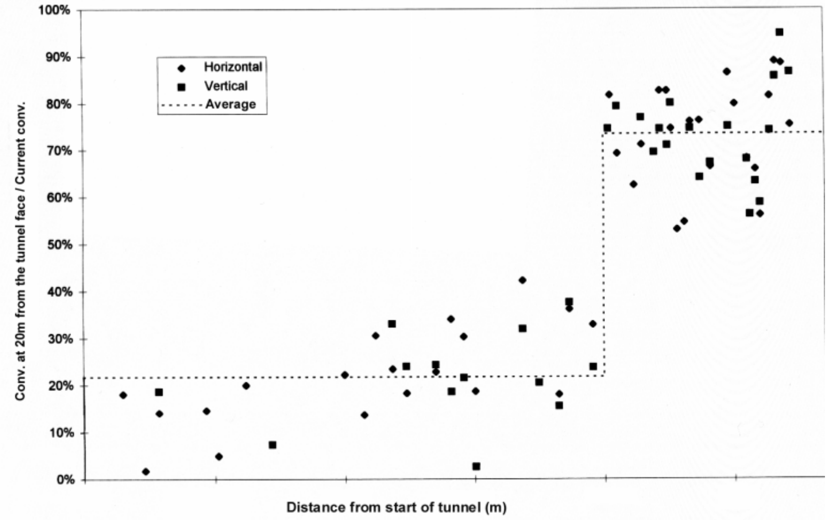

Figure 3 : Ratio between the convergence at 20 m from the tunnel face and the final convergence.

Confinement measurements

In order to assess long-term differed effects, five 5 m-long “rigid sections” heavily supported with a 20 cm-thick reinforced shotcrete lining were installed in the gallery, three of them in Algeciras unit and two in Almarchal Unit. Each of these sections was instrumented with four stress cells and four extensometers embedded in the lining and were only intended to observe quite residual effects, since for operational reasons the sections were built and instrumented well behind and after (over about 30 m and three days) the face of the tunnel. In spite of some inconsistencies observed in measurements, the relatively small readings (average 0.06 MPa and 0.14 MPa in Algeciras and Almarchal respectively) and their fairly stabilised values tend to indicate that total stabilisation is reached after 4-6 months under the moderately rigid confinement of 20 cm of shotcrete.

Pressuremeter tests

21 pressuremeter tests were performed (10 in Algeciras, 11 in Almarchal) with an OYO ELASTMETER-200 applying pressures of up to 20 MPa. Here again, the values of deformation modulus reflect the weakness of Almarchal (average 500 MPa) as compared to Algeciras (1.75 GPa). More than that, more detailed analysis shows that in the Almarchal unit, two stretches can be considered, one of them, highly clayish with an average modulus of only 240 MPa, the other one, clearly more marly, with an average modulus of 750 MPa. This different behaviour has also been observed in convergence measurements.

Load tests with TBM grippers

In an attempt to test geomechanically large portions of the rock massif, a systematic loading test was envisaged using the grippers of the TBM properly equipped with strain-stress measuring devices. 13 tests were performed, with effective pressures of up to 2 MPa in the Almarchal and up to 10 MPa in the Algeciras through grippers of 1.14 m^2 effective contact area, generally in 1.5-cycle experiments (loading-unloading-loading) of about 1 hour duration, as shown **in Figure 4**.

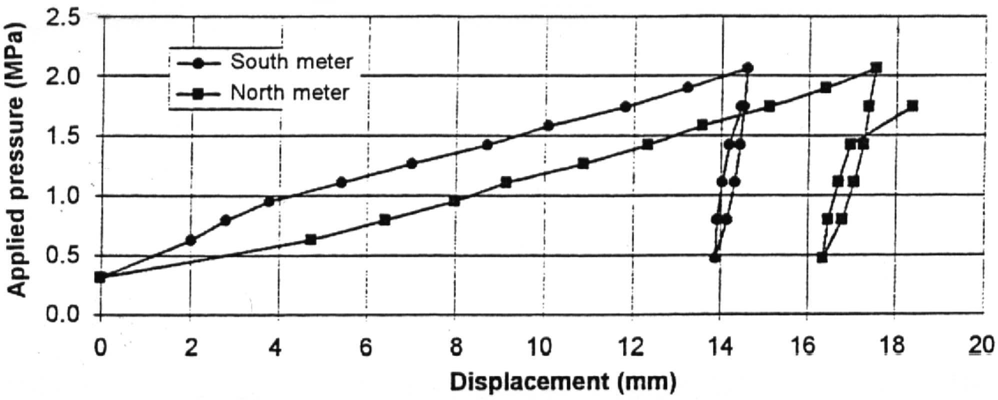

Figure 4 : Example of a load test with TBM grippers.

As shown in **Table 2**, average values of the deformation modulus obtained from gripper tests are as follows:

Table 2 : Results of the load tests.

	Algeciras Unit (MPa)	Almarchal Unit (MPa)
1^{st} loading run	1500	900
1^{st} unloading run	4000	2400

This suggests the following: (1) results from the loading run of the experiments are, although higher, still comparable with the pressuremeter results; (2) results from the unloading branch are much better in both units, this possibly reflecting the effect of initial deformation and stress relief in the contact adjustment; and (3) the unloading branch values –definitely more appropriate to assess the geomechanical behaviour of the massif under TBM-tunnelling-, would perhaps reflect the effect of involving a large mass of rock in the experiment, neglecting the scale effect existing in rock masses.

Laboratory tests

A campaign of some hundreds of lab geotechnical tests was associated to the in situ experimentation, in order to provide information for later comparison and modelling. In **Table 3** is shown a summary of lab results, many of them subject to the diversity of materials encountered in the highly heterogeneous, anisotropic Algeciras unit or to the difficulty of coring and cutting undisturbed samples in soft Almarchal.

Table 3 :Mechanical properties of intact rock.

PROCEDENCE OF TESTED CORES				σc (MPa)	γ (t/m³)	H_2O (%)	E (MPa)	ν	σt (MPa)	mi	MOHR-COULOMB ($0{,}5 < \sigma_3 < 6$MPa) Φ (°)	MOHR-COULOMB ($0{,}5 < \sigma_3 < 6$MPa) c (MPa)
ALGECIRAS UNIT	OLIGOCENE	Flysch	Marls	15.9	2.52	2.8	6,204	0.25	2.4	8.8	40.4	3.9
			Siltstones	25.3	2.60	2.7	9,313	0.24	3.2	14.7	46.1	5.3
			Sandstones	35.8	2.66	1.6	11,345	0.24	4.0	16	49.9	6.5
		Red Pellites	Pellites	3.6	2.14	7.4	655	0.2	1.2	9.6	31.6	1.5
			Sandylimestones	11.2	2.36	4.6	4,611	0.21	2.6	9.2	37.5	3.0
			Sandstones	10.4	2.45	4.9	3,420	0.27	1.2	12	42.6	2.4
			Sandylimestones (roof)	11.2	2.52	4.6	4,611	0.21	-	8.4	35.6	3.3
	EOCENE	Lime-stone Flysch	Sandylimestones (basal)	29.7	2.54	1.2	69,296	0.26	-	7.4	45.2	5.6
			Limestones	76.7	2.41	0.4	74,263	0.33	6.2	8.8	47.9	13.1
	CRET.	Al-mar-chal	Claystones	0.43	2.52	12.1	25	-	-	8.7	26.7(*)	0.26(*)
			Crushed marls	0.42	2.54	7.6	41	-	-	-	-	-

It is however noticed that, as shown in **Table 4**, the comparison of average values of Almarchal shear parameters from pressuremeter measurements and from lab tests, is roughly consistent, leading to similar undrained shear strength.

Table 4 : Comparison between lab and pressuremeter tests.

Almarchal Unit

	Cohesion, c (MPa)			Friction angle, φ (°)		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Values from lab tests	0.17	0.20	0.26	19	28	37
Values from pressuremeter tests	0.10	0.30	--	14	18	25

CONCLUSIONS

It is stressed that the data briefly presented above correspond to a first testing campaign performed in the gallery, upon which geomechanical back-analyses have been attempted with only partial success. A second campaign of complementary in situ and lab tests is now under way intended to better characterise Almarchal, either by extensive dilatometer testing and laboratory tests on deep-cored, undisturbed samples focusing shearing, edometric as well as swelling and water related parameters. Although new back-analyses of the so enriched database are expected to provide a good geomechanical modelling of the Straits tunnel, additional testing will be probably performed in the Tarifa Gallery in the years to come –including the boring of lateral galleries-, in order to progressively improve the geotechnical knowledge of –specially- the Almarchal flysches, taking advantage of the unique access to highly representative terrains provided by the gallery.