GEOTECHNICAL SITE CHARACTERISATION OF THE PERTHUS TUNNEL

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ABSTRACT

The tunnel across the Pyrenees, joining by a high speed train Barcelona (Spain) and Montpellier (France), will have a total length of 8200m.

In order to characterise the rock mass, several site investigations, in situ and lab tests have been performed. Also, a full scale gallery has been built at the weakest part of the predicted profile.

INTRODUCTION

In the liaison by a High Speed Railway between Barcelona (Spain) and Montpellier (France), the cross of the Pyrenees is projected to be done throughout the “Le Perthus Tunnel”, with an approximated length of 8200m.

The studies for this tunnel are included in the binational stretch: “Figueres-Perpignan”, approximately 42km long, and conducted by the European Group of Economical Interest AEIE/GEIE Sur Europa Mediterráneo/ Sud Europe Mediterranée, co-ordinated by technicians of the Spanish and French National Railway Companies RENFE and SNCF, as well as from the Ministry of Transport in both countries.

The studies of the Perthus Tunnel have their background on the projects successively conducted by SNCF and FGC (Ferrocarrils de la Generalitat de Catalunya) between 1989 and 1994.

Several locations and lengths for this tunnel have been considered, but finally the cross of the Pyrenees will be done under Le Perthus village, between the villages of La Jonquera in Spain and Le Boulou in France. The final location of the tunnel is shown in **Figure 1**.

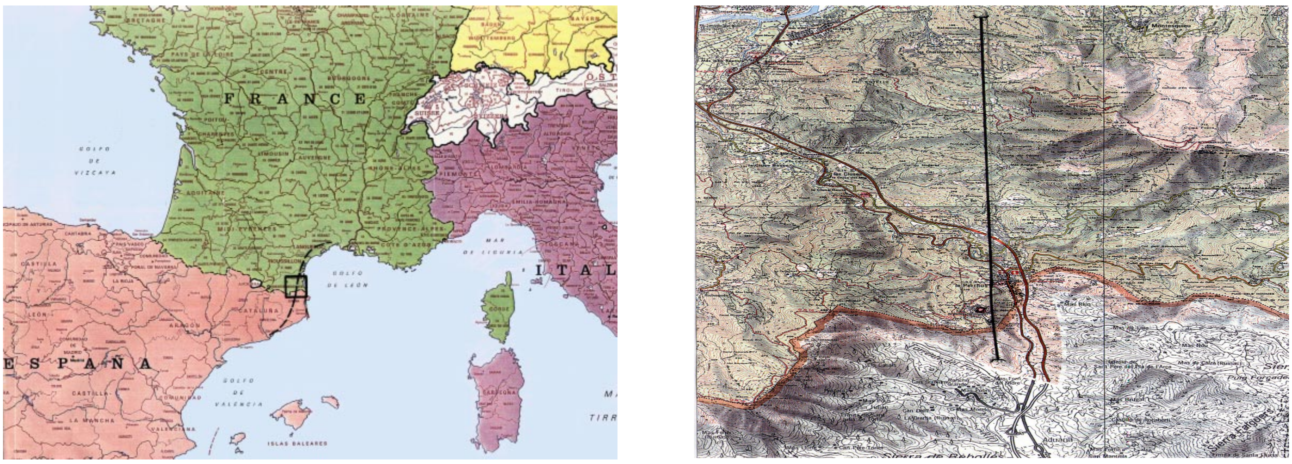

Figure 1 : Location of Le Perthus Tunnel.

As it has been said before, several geological and geotechnical studies have been carried out (SICSOL, 1989, 1994; BURGEAP, 1994; GEOCONTROL, 1989, 1990), but the definitive study was done in 1996 by GEOCONTROL S.A. This study can be summarised by the following figures:

[1] BOCABARTEILLE, A. and GONZÁLEZ, A.; GEIE-SEM Sud Europe Mediterranée, 21, Bd. Saint Assiscle – B.P. 2000 – 66011 Perpignan Cedex, France.

[2] CELADA, B. and GALERA, J.M.; Geocontrol S.A., c/ Alenza, nº 9, 2º izq. 28003 Madrid, Spain.

- Detailed geological mapping.
- Geophysical investigation (132ml refraction seismic, 3030m electrical and EM profiles, 3 electrical sounding, and 6340m VLF-R survey).
- 7795m cored boreholes.
- 387m pressuremeter boreholes.
- 208 ut pressuremeter and dilatometer tests.
- 30 ut hydrofract tests on 4 boreholes.
- 1527 ut laboratory tests.

From these studies it can be concluded that the geology of the tunnel is reasonably well known.

As for the geotechnical model, several in situ and lab tests were carried out and more recently (GEOCONTROL, 1998) the construction of an experimental shaft and gallery at Le Boulou (France) was made, crossing some weak silurian ampellites and the myllonites of Le Boulou fault, making several complementary tests and an extensive instrumentation programme (borehole slotter, extensometer, convergence, stress sensors, etc.).

All this information has been analysed in order to estimate the strength and deformability properties of rock mass. For this analysis different approaches have been used including numerical modellisation.

Finally, the hydrogeology of the tunnel has also been studied in order to determinate the water table position and the rock mass hydraulic conductivity. In this way, from November 99 to January 00, further boreholes and measures are planned.

GEOLOGY OF THE TUNNEL

The Le Perthus Tunnel is situated on the Axial Zone of Eastern Pyrenees formed by metamorphic Paleozoic rocks and granites of the hercynien cycle.

As it is shown in **Figure 2**, the geological profile of Le Perthus Tunnel can be divided as follows:

- 0 to 0+800 m: Black slates of Montesquieu Le Boulou fault.
- 0+800 to 1+830: Gneiss of Les Alberes.
- 1+830 to 2+130: Green schists and amphibolic gneiss. Diorites and marble subordinated.
- 2+130 to 3+290: Diorites and quartz-diorites with quartz and pegmatites dykes.
- 3+290 to 5+630: Green schists, affected by abundant granodiorites bodies (Sant Martí de La Albera Granitoid). Myllonites.
- 5+630 to 8+200: Le Perthus granodiorite, affected by a late hercynic schistosity. Myllonites.

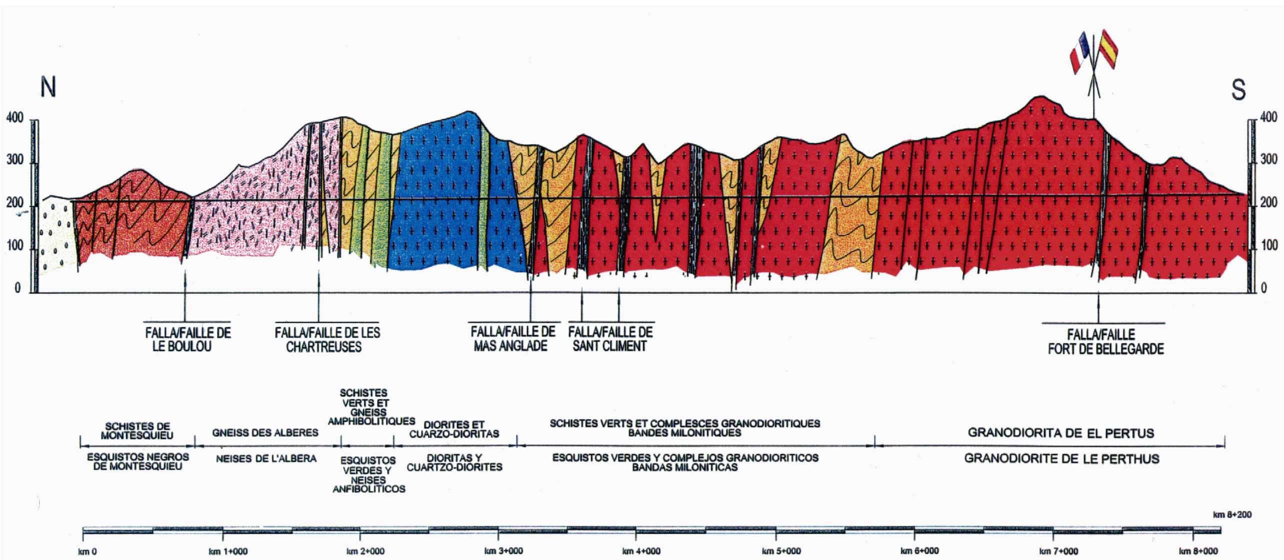

Figure 2 : Geological profile of Le Perthus Tunnel.

GEOTECHNICAL CHARACTERISATION

All the present lithologies have been characterised with in situ and lab tests, obtaining an estimation of the strength and deformability parameters of each one.

For the strength values, each lithology has been tested in order to obtain the intact rock value of m_i. Afterwards and considering the RMR, the values of the intact rock have been decreased, in order to take into account the scale effect in rock masses.

In **Figure 3** is shown an adjustment of both failure criteria (Mohr-Coulomb and Hoek-Brown), while in **Table 1** all the strength and deformability parameters for rock mass are presented.

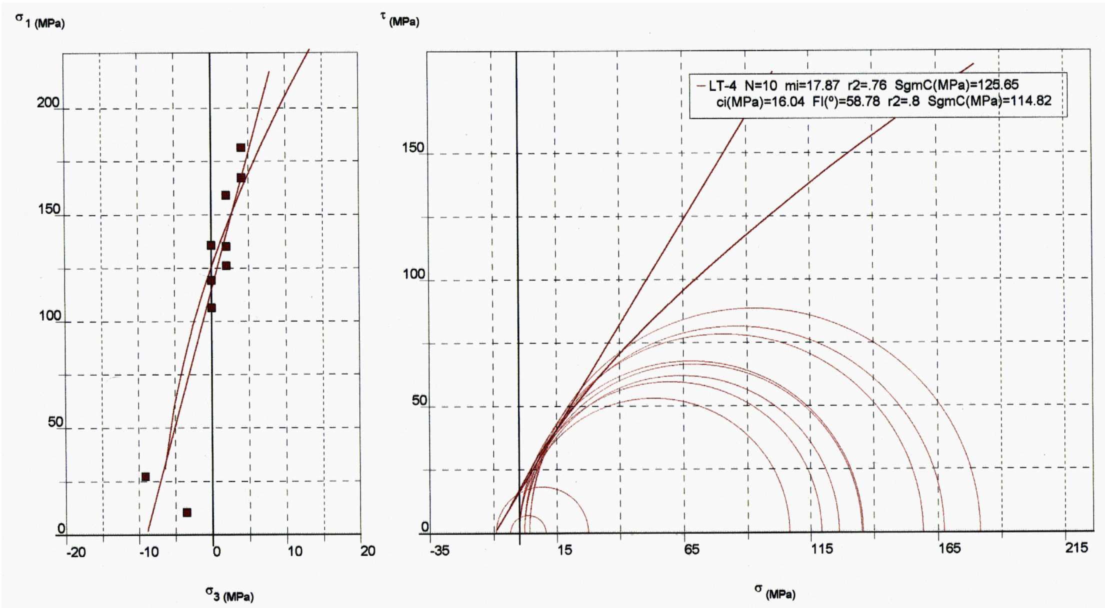

Figure 3 : Mohr-Coulomb and Hoek-Brown adjustments.

Table 1 : Rock mass mechanical properties.

		σc (MPa)	mi	RMR	C (MPa)	ϕ (°)	m	s	E (MPa)	AVERAGE OVERBURDEN (m)
SCHISTS OF MONTESQUIEU	Black schists	17.6	5.63	27 (30-25)	0.08 0.09	30 27	0.415	0.0003	1267	50 80
GNEIS OF LES ALBERES	Gneis	48.7	19.66	50 (53-45)	0.62 0.55	45 50	3.296	0.003865	7878- 16375	200 100
SCHISTS OF MAUREILLAS-LES CLUSES	Green schists	58.2	5.63	41 47-42(35)	0.56 0.6	35 32	0.684	0.001422	6486	125 200
	Sandy green schists	70	7.83	43 50-42(35)	0.67 0.72	41 37	1.022	0.001776	6486	125 200
	Amphibolic gneiss	80.9	17.87	61 64-57	1.6	51	4.438	0.013123	30765	175
	Marble	51.8	7.14	61 65-57	1.42	38	1.773	0.013123	32208	175
GRANITOIDS OF SANT MARTÍ DE LES ALBERES	Diorite	132.2	14.91	57 (62-52)	2.15	51	3.21	0.008414	29323	200
	Granodiorite	96.4	20.0	54 (59-49)	1.25	53	3.868	0.006029	7067	150
	Foliated granodiorite	52.2	18.0	42 (46-37)	0.42	45	2.268	0.001589	3383	150
	Granodiorite/Myllonite	9.4	16.0	27 (29-25)	0.05	26	1.179	0.0003	815	150
GRANODIORITE OF LE PERTHUS	Granite grain medium size	108.1	29.0	65 (72-62)	2.3 2.15 2.10	57 58 61	8.308	0.020468	11396	200 140 50
	Granite grain large size	80.7	20.0	61 (72-62)	1.62 1.53 1.40	51 53 56	4.967	0.013123	21674	200 140 50
	Orientated granite	67.3	18.0	47 (51-38)	0.7 0.66 0.55	46 48 56	2.711	0.00277	9707	200 140 50
	Foliated granite	43.1	16.0	44 (48-35)	0.43 0.41 0.34	41 43 51	2.165	0.001984	3383	200 140 50
	Granite/myllonite	11.9	16.0	30 (35-24)	0.07 0.07 0.06	27 29 38	1.313	0.000418	1090	200 140 50

For this estimation dilatometer and pressuremeter tests have been very decisive.

According to this characterisation, the following geotechnical classification of the Tunnel has been established:

- Geotechnical Class II (80 > RMR $\geq$ 60): 2455m (29.8%)
- Geotechnical Class III (60 > RMR $\geq$ 40): 3910m (47.7%)
- Geotechnical Class IV (40 > RMR $\geq$ 20): 1835m (22.5%)

For the determination of the in situ stress field, hydrofract tests have been done, in four boreholes, in order to measure stress regarding different kinds of structural units:

- Metasedimentary paleozoic rocks (Gneiss and schists).
- Granitoids.
- Granodiorite of Le Perthus.

These measurements have consisted in 30 points with the determination of S_v, S_H and S_h. In **Figure 4** is shown the stress wireline profile in borehole SC-322 S, drilled in granodiorite.

The maximum $k_0 = \sigma_H / \sigma_v$ measured ranges from 1.5 to 2.5.

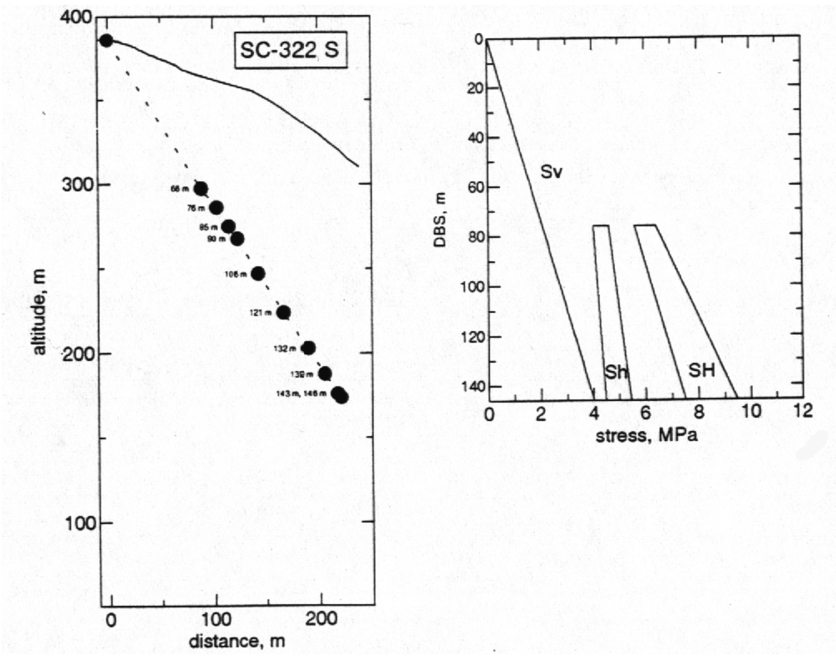

Figure 4 : Natural stress field profiles for borehole SC-322 S (Granodiorites of Le Perthus).

HYDROGEOLOGY OF THE TUNNEL

Several permeability tests, piezometric measurements and water analysis have been done in order to obtain the hydrogeological model.

In general, the charge is done by infiltration, and the water moves through weathering and by fractures and faults. In this way, the faults with E-W strike have higher permeability in gneiss, while in granite the higher values are associated with N-S fractures.

The measured permeabilities change from 10^{-5} to 10^{-8} m/s depending on lithology and the existing gouge on fractures.

WEAKER ZONES OF THE TUNNEL

After all the investigation undertaken, it can be concluded that the weaker zones of the future tunnel are:

- Ampellites. (Black slates of Montesquieu).
- Le Boulou fault.
- Mas Anglade and Sant Climent faults and tectonic zones.
- Fort de Bellegarde fault.

In order to characterise these weak zones, it was considered the construction of an experimental shaft and gallery at Les Chartreuses of Le Boulou, which has allowed to investigate the full scaled behaviour of ampellites and myllonites of Le Boulou Fault.

THE EXPERIMENTAL SHAFT AND GALLERY OF LE BOULOU

In **Figure 5** the characteristics of this experimental gallery are shown.

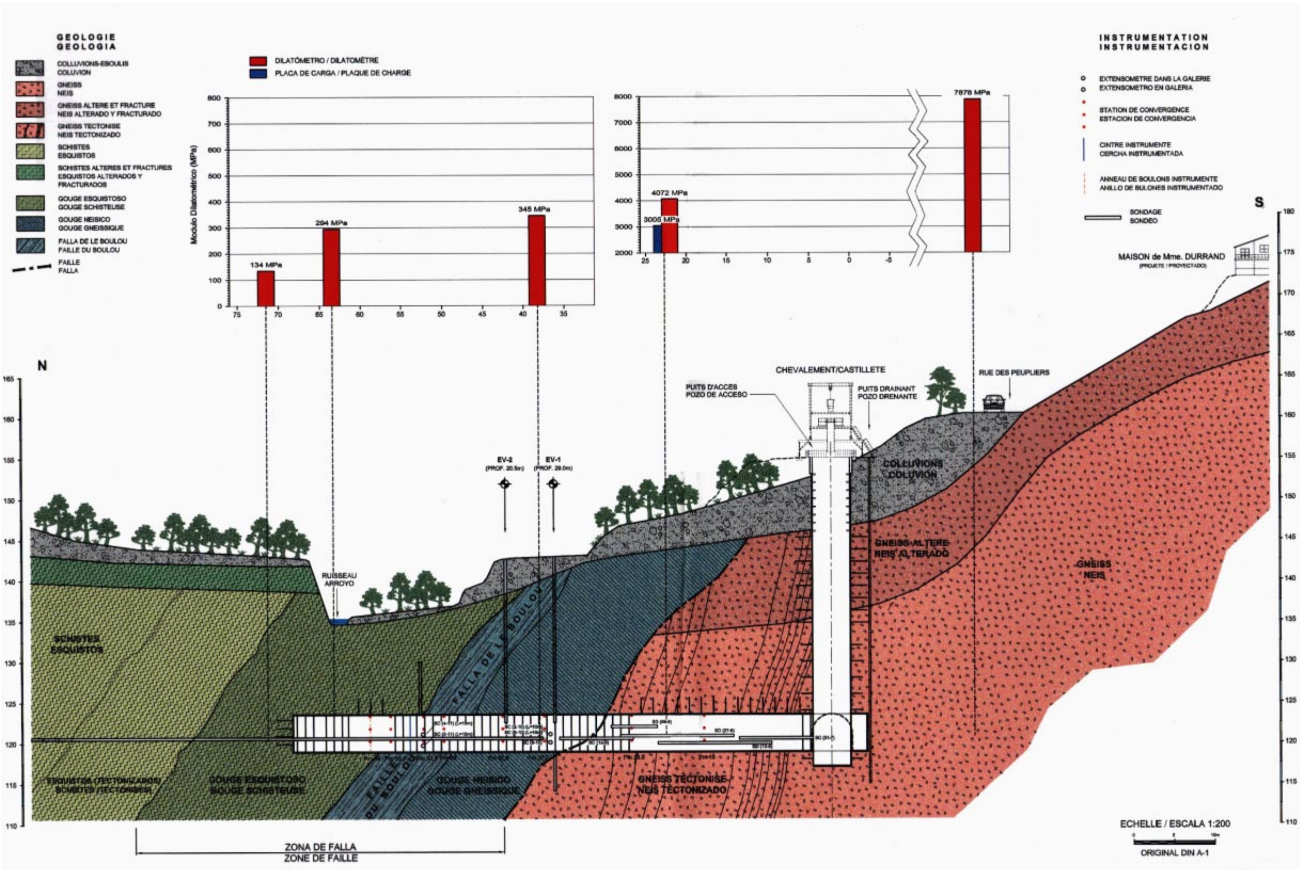

Figure 5 : Geotechnical profile of Le Boulou Experimental Gallery.

The tasks carried out have been, basically:

- instrumentation programme: two vertical incremental extensometers from surface and one horizontal drilled from the face.
- convergence measurements.
- 5 dilatometer tests.
- 54 laboratory shear tests.
- 3 borehole slotter measurements.
- 7 bearing plate tests.
- 2 shear strength in situ measurements.

In order to define the position and type of instrumentation, a blind prediction using a stress-strain 3D calculation solved with FLAC 3D codes was done.

After the measurements of the instrumentation and characterisation programmes, final calculations were done for a better understanding of ground behaviour.

In **Figure 6** the numerical model used is shown. This model has been solved using several stress conditions in both directions N-S (gallery strike) and E-W. In **Table II** the results of the seven hypothesis considered are shown. Finally, it has been concluded that better results are obtained with a value of k_0 in E-W direction of 1.6. In **Figures 7**, and **8** are shown the results derived when comparing the instrumentation measured and calculation values. As it can be observed, a good correlation has been obtained.

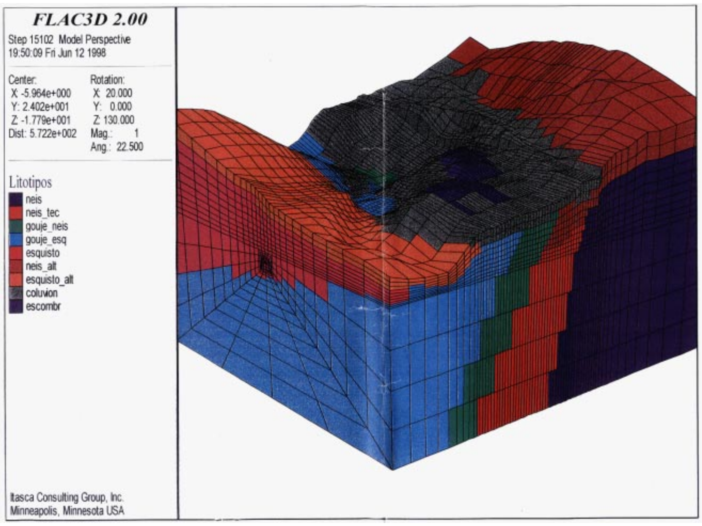

Figure 6 : Numerical model.

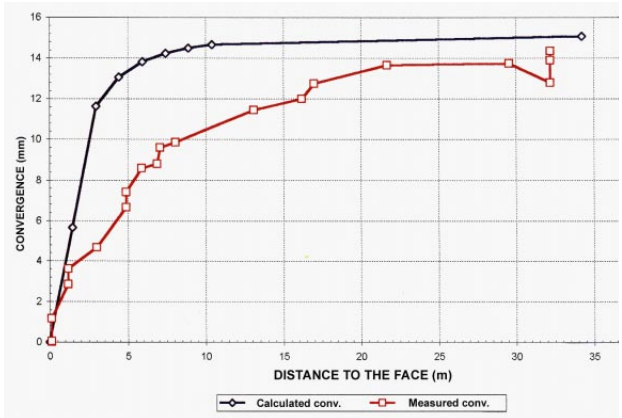

Figure 7 : Correlation between the measured and the calculated convergence.

Table II : Calibration of the numerical model.

CASE	STRESS STATE		RESULTS OBTAINED[1]		REMARKS
	K_0 (N-S)	K_0 (E-W)	TOTAL CONVERGENCE (mm)[2]	TOP DESCENT (mm)	
1	0.8	2.0	19.4	3.0	
2	1.1	1.4	12.0	1.7	
3	1.1	2.0	19.0	3.0	
4	1.5	0.8	6.5	3.0	
5	1.5	2.0	19	3	
6	1.5	2.0	23	4	Adjustment of elastic properties for gouge and gneis.
7	1.5	2.0	27	7	Simulation of steel-arches is not introduced in the model.

(1) The results obtained refer to a gouge section equivalent to monitoring station C-3.

(2) It has been considered the total convergence of the section, which is about 30 to 40% higher than the one measured.

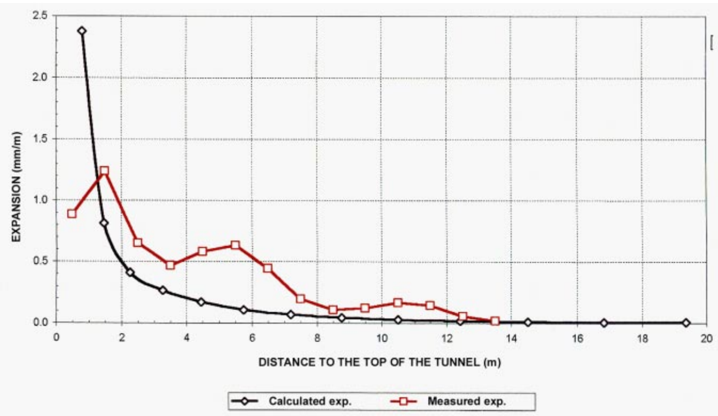

Figure 8 : Correlation between the measured and the calculated expansion at extensometer EV 1.

CONCLUSIONS

The previous studies carried out at Le Perthus Tunnel have allowed to know its critical and weaker zones. Therefore, it can be concluded that:

- the location of the mechanical weaker zones of the tunnel is known.
- the characterisation based on geotechnical classifications and in situ and laboratory tests have allowed to define a range of mechanical properties on all the existing lithologies, the stress field and the hydrogeology of the tunnel.
- a further investigation based on the instrumentation programme of the Experimental Shaft and Gallery of Le Boulou, and further modelling, has allowed to understand fully scaled the stress-strain behaviour of the black slates and myllonites that constitute the weaker lithologies.
- no water has been found associated to Le Boulou fault. Therefore, further investigations are needed in order to know the source of Le Boulou thermal aquifer, probably related to minor faults of Mas Anglade tectonic zone.