ROCK MASS CHARACTERISATION OF THE WEAK ZONES AT THE PERTHUS TUNNEL

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ABSTRACT

In this paper it is presented the methodology used to characterise the weaker zones of Le Perthus Tunnel. This methodology has two phases. The first one is based on geotechnical classifications and in situ and laboratory tests, while the second one has consisted in the construction of the Le Boulou Experimental Gallery, extensively instrumented, and in the numerical modelling of all the measured data.

1 INTRODUCTION

In the Liason by a High Speed railway between Barcelona and Montpellier, the cross of the Pyrenees is projected to be done by the "Le Perthus Tunnel", that with an approximated length of 8200 m, will cross the range situated between Spain and France.

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

2 BACKGROUND

The studies of the Perthus Tunnel have its background, in the jobs successively conducted by SNCF and FGC (Ferrocarril's de la Generalitat de Catalunya) since 1989.

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

As 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 on 1996 by GEOCONTROL.S.A.. This study can be summarised on the following figures:

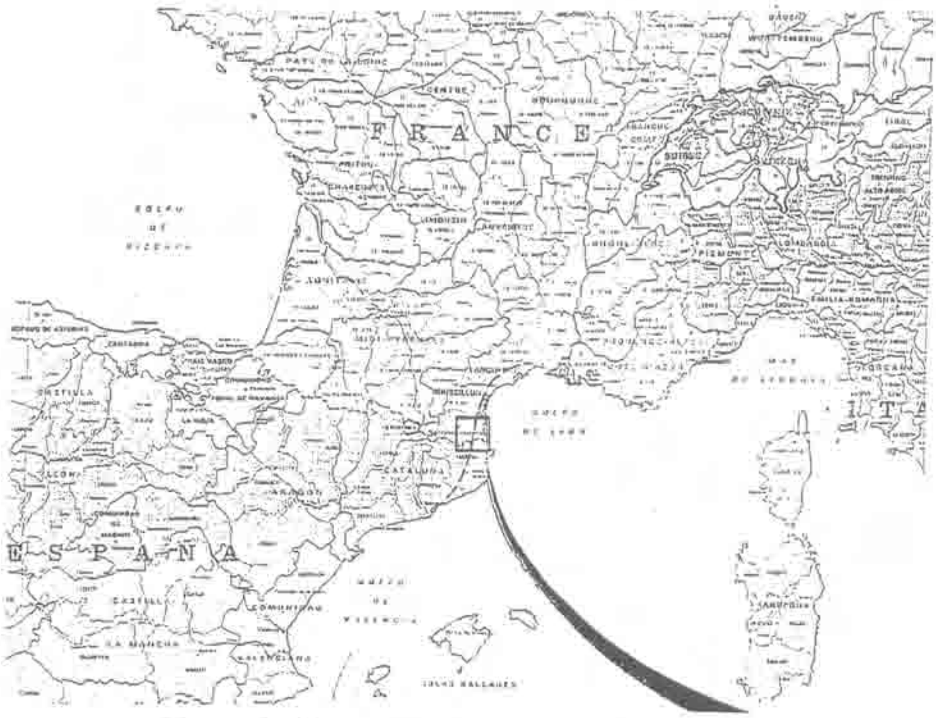


Figure 1.- Location of Le Perthus Tunnel

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

It can be concluded that the geological model of the tunnel is well known, as it is shown on **Figures 2 and 3**.

Also the geotechnical model considering the strength and deformability properties of rock mass and water table position and conductivity are known. As an example on the **Figure 4** it is shown the data of stretch of the tunnel.

3 GEOLOGICAL SUMMARY OF THE TUNNEL

As it can be seen on Figure 3 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: Les Alberes neises

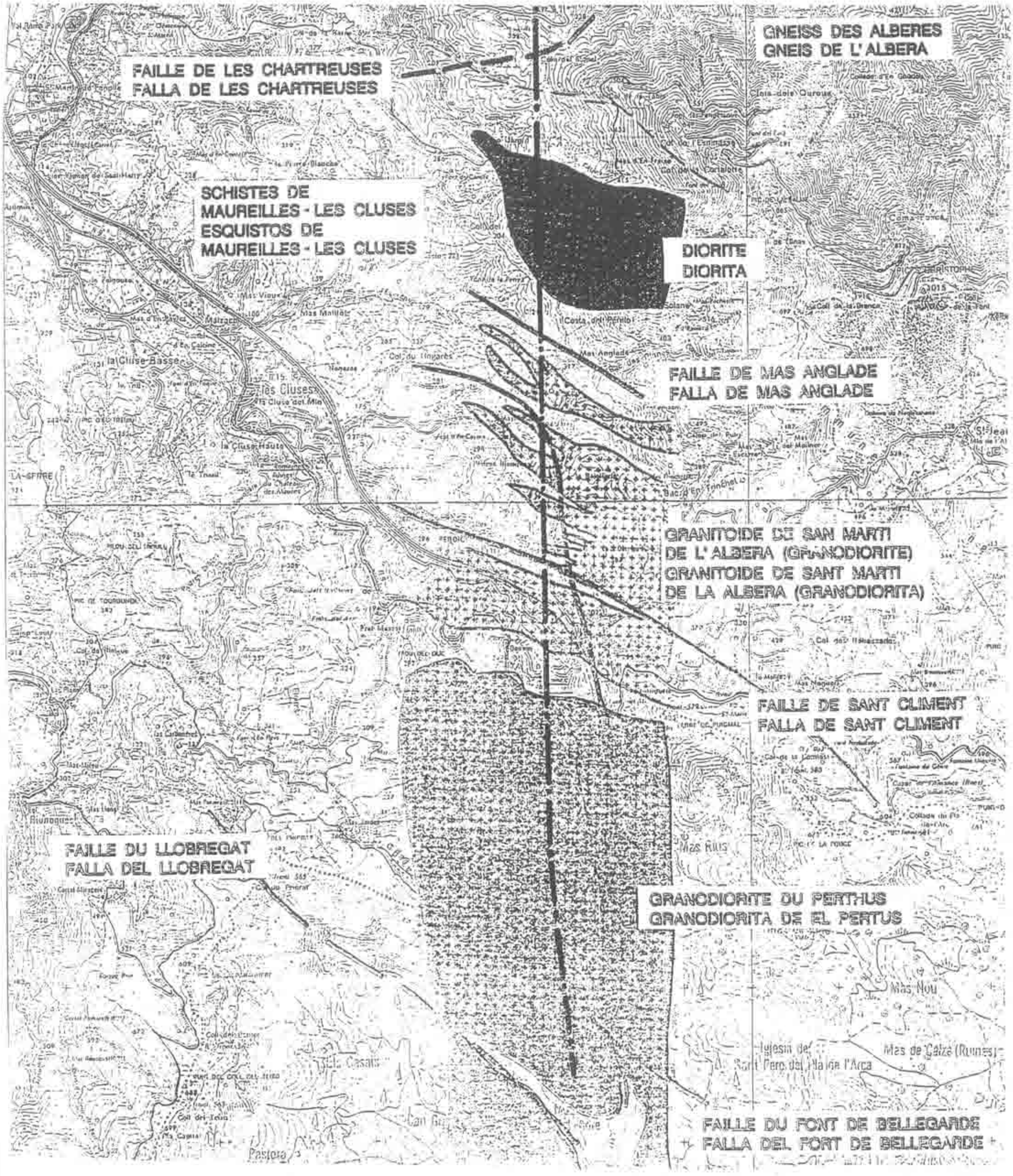


Figure 2.- Geological map of Le Perthus Tunnel

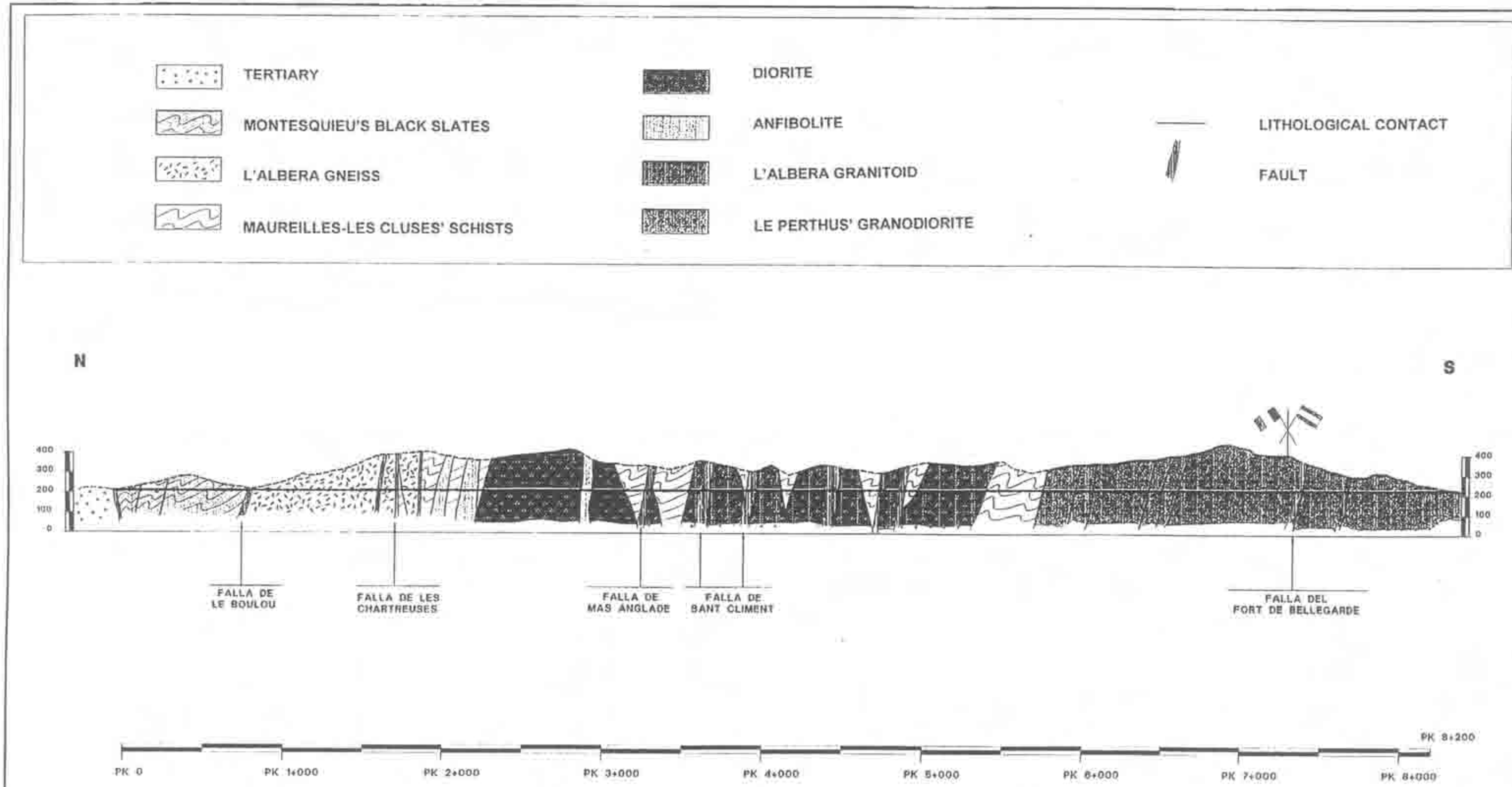
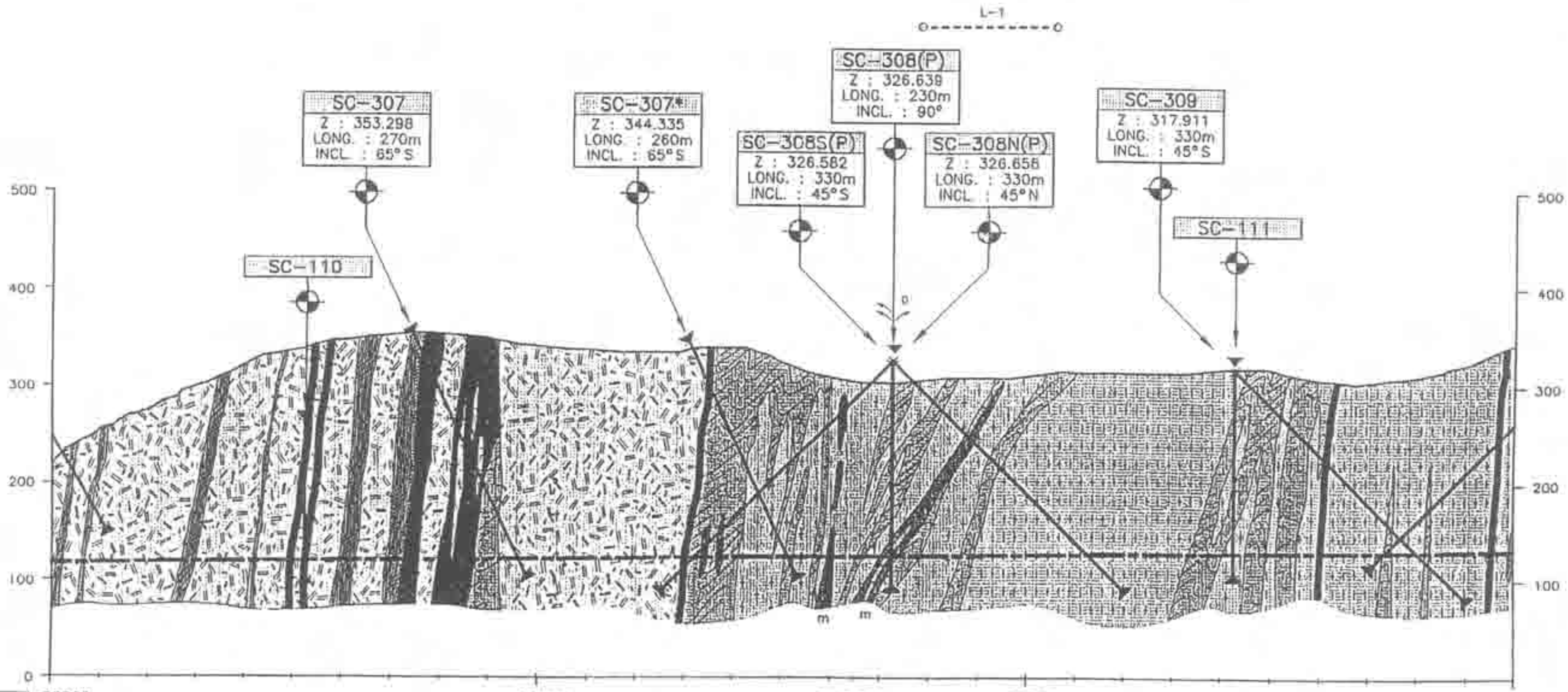


Figure 3.- Geological profile of Le Perthus Tunnel



P.K.	23500		23000		PK.2,000	22500		22000
COTE TERRAIN/COTA TERRENO	294.6	361.0	335.0	315.0	310.0	320.0	310.0	
COTE PROYECT/COTA PROYECTO	117.6	118.8	119.7	122.0	124.1	127.0	129.1	
RECOUVREMENT/RECUBRIMIENTO	177.0	242.2	215.3	193.0	185.9	193.0	180.9	

PROPIETES MECANIQUES DU MASSIF ROCHEUX/ PROPIEDADES MECANICAS DEL MACIZO ROCOSO																
R.M.R.		50(53-45)	35-24	43	50(53-45)	43	61(64-57)	61	43	61	43	57(62-52)	43	61	43	57(62-52)
Densité/Densidad d(t/m³)		2.72	2.72	2.75	2.72	2.75	2.88	2.0	2.75	2.88	2.75	2.87	2.75	2.88	2.75	2.87
T.eau/Humedad ω(%)		0.26-0.3	10	0.33	0.28-0.3	0.33	0.1	0.1	0.33	0.1	0.33	0.1	0.33	0.1	0.33	0.1
Mod.Young E(MPa)		16376	1904	7878	16376	7878	30765	20323	7870	30765	7878	29323	7878	30765	7878	29323
Coef.Poisson ν		0.3	0.3	0.24	0.3	0.24	0.22	0.2	0.24	0.22	0.24	0.2	0.24	0.22	0.24	0.2
Cohésion/Cohesión C(MPa)	0.55	0.62	0.07	0.72	0.62	0.72	1.6	1.42	0.72	1.6	0.72	2.15	0.72	1.6	0.72	2.15
Ang.Friction/Ang.Fricción φ(°)	50	55	27	37	55	37	51	38	37	51	37	51	37	51	37	51

CLASSIFICATION AFTES / CLASIFICACION AFTES													
RESISTANCE/RESISTENCIA	R3	R4		R3	R3	R2	R3	R2	R3	R2	R3	R2	R3	R2
DISCONTINUITES/DISCONTINUIDADES	RQD(RQD4-RQD2)	RQD5		RQD3	RQD3	RQD2-RQD1				RQD2	RQD3			RQD2-RQD3
C. HYDRAULIQUE/C. HIDRAULICA	H2	H3												
PERMEABILITE/PERMEABILIDAD	K2													

Figure 4.- Example of the geotechnical profile

SEIII Sud Europe	G.E.I.E. SUD EUROPE – MEDITERRANNEE A.E.I.E. SUR EUROPA – MEDITERRANEO	GEOCONTROL S.A.	TUNNEL TRANSFRONTALIER DU PERTHUS ETUDE GEOLOGIQUE-GEOTECHNIQUE DU TERRAIN TUNEL TRANSFRONTERIZO DE PERTUS	ECHELLE/ESCALA E. 1:5.000	TITRE/TITULO PROFIL GEOLOGIQUE-GEOTECHNIQUE PERFIL GEOLOGICO-GEOTECNICO	DATE/FECHA AOÛT/AGOSTO NO/NUM 7

- 1+830 to 2+130: Green schists and amphibolic neises. 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 Marti de la Albera Granitoid). Myllonites.
- 5+630 to 8+200: Le Perthus granodiorite, affected by a late hercynic schistosity Myllonites.

According with this profile the following geotechnical classification of the Tunnel has been established.

- Geotechnical Class II (80 > RMR ≥ 60): 2455 m (29,8 %)
- Geotechnical Class III (60 > RMR ≥ 40): 3910 m (47,7 %)
- Geotechnical Class IV (40 > RMR ≥ 20): 1835 m (22,5 %)

4 WEAKER ZONES OF THE TUNNEL

After all the investigation done it can be concluded that the weaker zones of the future tunnel will be:

- 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 this weak zones, it has been considered the construction of an experimental shaft and gallery at Les Chartreusses de Le Boulou, that will allow to investigate the full scaled behaviour of the ampellites and of the myllonites of Le Boulou Fault, not only consider the mechanical behaviour but also the hydrogeological behaviour as Le Boulou Fault is the source of an important mineral water industry and of a medical thermal baths.

In this paper the methodology for the mechanical characterisation of those weak zones is presented.

5 CHARACTERISATION PROGRAMME

The aim of the characterisation programme that is been carried out is to know the hydromechanical behaviour of the experimental gallery of Le Boulou, based on instrumentation and numerical modelling.

5.1 INSTRUMENTATION PROGRAMME

On the **Figure 5** the instrumentation considered is shown. Basically it consists on:

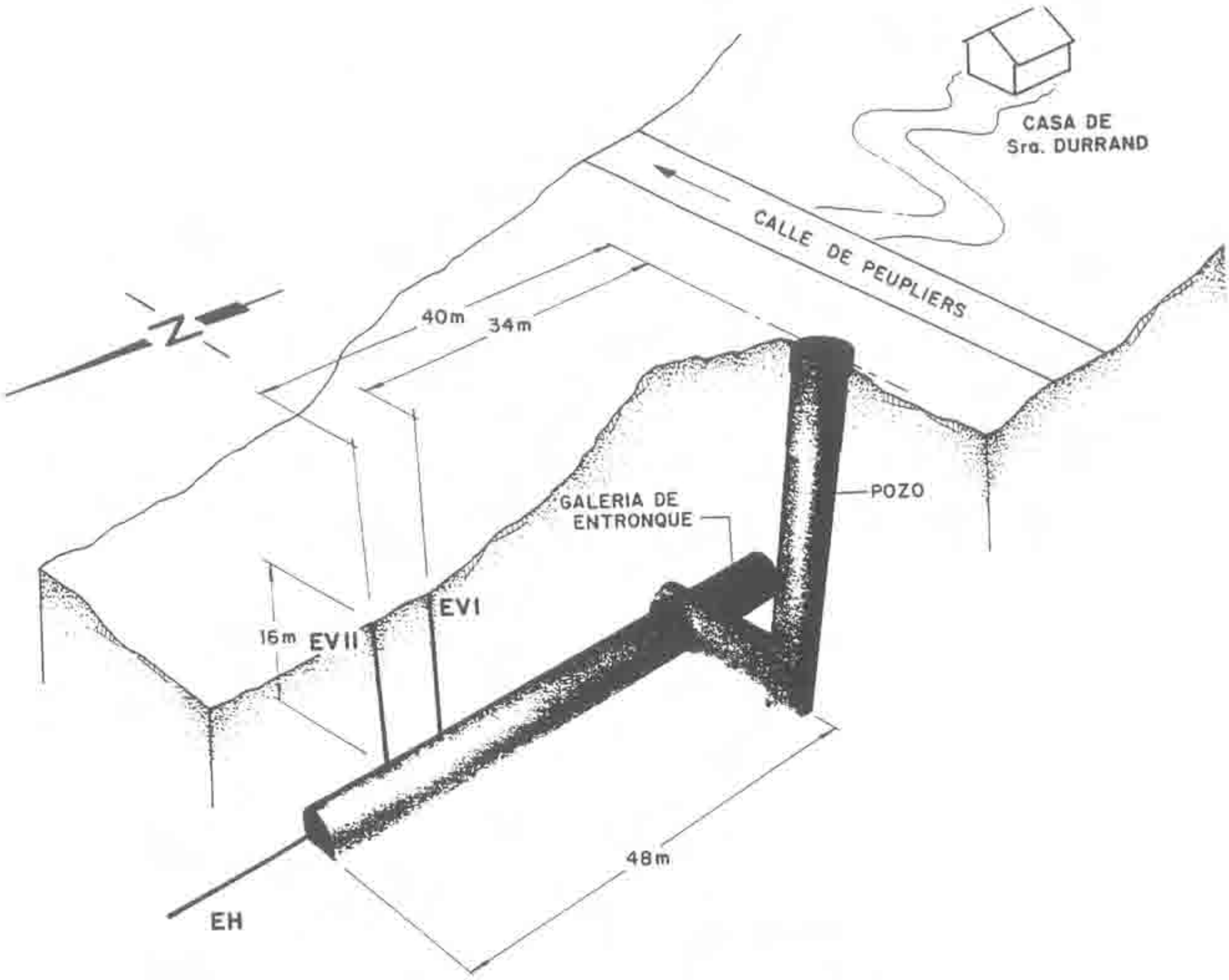


Figure 5.- Instrumentation proposed

- Two boreholes drilled from surface, for deformability measures using an EXTENSOFOR incremental extensometer.
- On borehole drilled from the face of the gallery equipped with the same extensometer.
- Convergence stations for measuring the gallery clousure.

5.2 BLIND PREDICTION

In order to define the range and kind of the instrumentation, a blind prediction has been conducted.

This blind prediction has been done using a 3D-numerical model solved by the FLAC^{3D} v. 2.0 code.

On the **Figure 6** the 3D model is shown. considering eight rock mass classes: neis, black slates, fractured neis and slates, fault, weathend neis and slates. The mechanical properties of these terrains are included on **Table I**. The model has been solved using K_o (horizontal stresses/vertical stresses) equal to 0,7, 1 and 2.

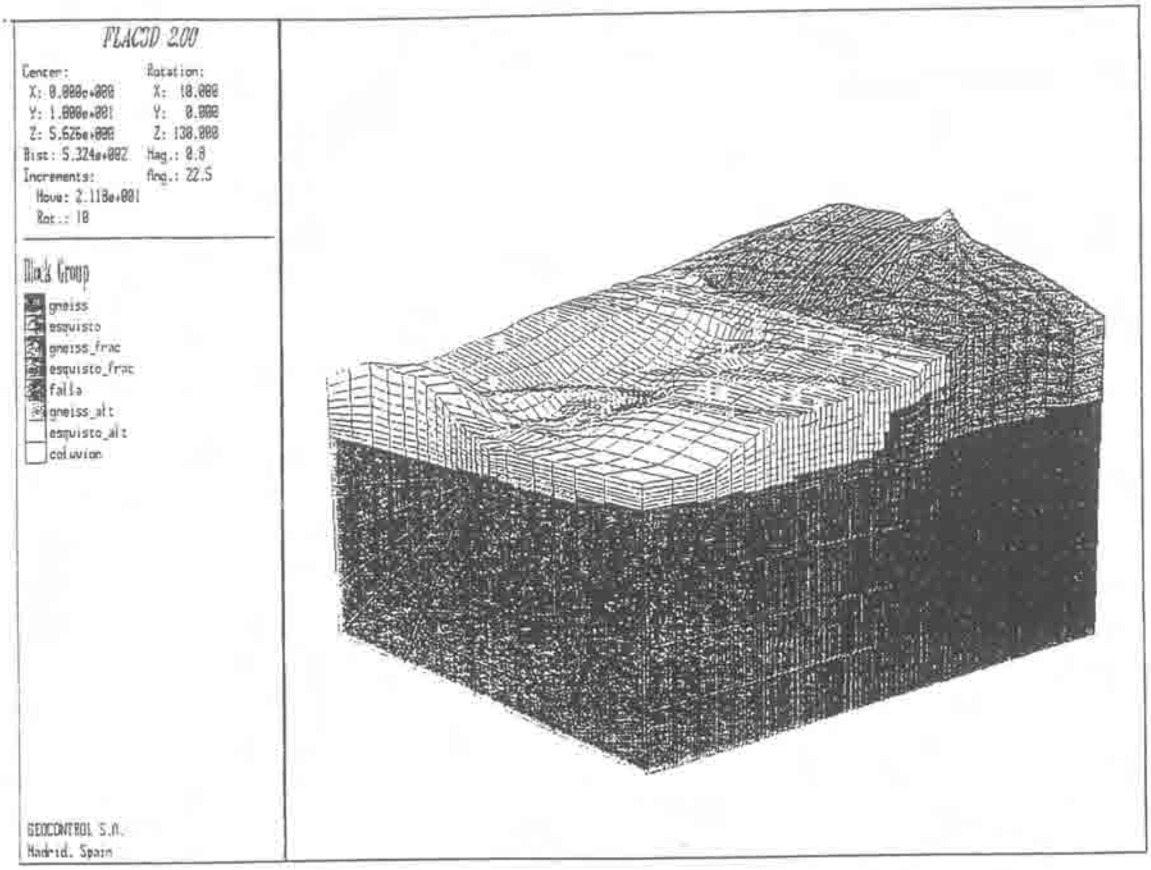


Figure 6.- Numerical model of Le Boulou Gallery

TERRAIN	DENSITY (g/cm^3)	YOUNG'S MODULUS (MPa)	POISSON'S COEFFICIENT	COHESION (MPa)	FRICTION ANGLE (°)
GNEIS	2.69	7878	0,3	0,5	50
BLACK SLATES	2.60	1267	0,3	0,08	30
TECTONIZED GNEIS	2.69	1904	0,3	0,3	48
TECTONIZED SLATES	2.50	383	0,3	0,05	25
FAULT	2.60	500	0,3	0	26
WEATHERED GNEIS	2.69	1904	0,3	0,3	48
WEATHERED SLATES	2.50	383	0,3	0,05	25
COLUVIAL	2.00	30	0,33	0,03	22

Table I

The following results have been obtained:

- **Subsidence**: the highest subsidence, 0,5 mm, is obtained for $K_o = 0.7$, while for $K_o = 4$ the expected subsidence is only 0,3 mm. In any case this is not consider that can be measured properly.
- **Convergence**: on the **Figure 7** it is shown the convergence for $K_o = 1$, and on the **Table II** the maximum expected convergences are shown. Considering that the real measured converge can be approximately 60 % of the one calculated, it can be concluded that in the black slates and fault, these measurement will proportionate a big amount of information about the mechanical behaviour and the natural stress field.

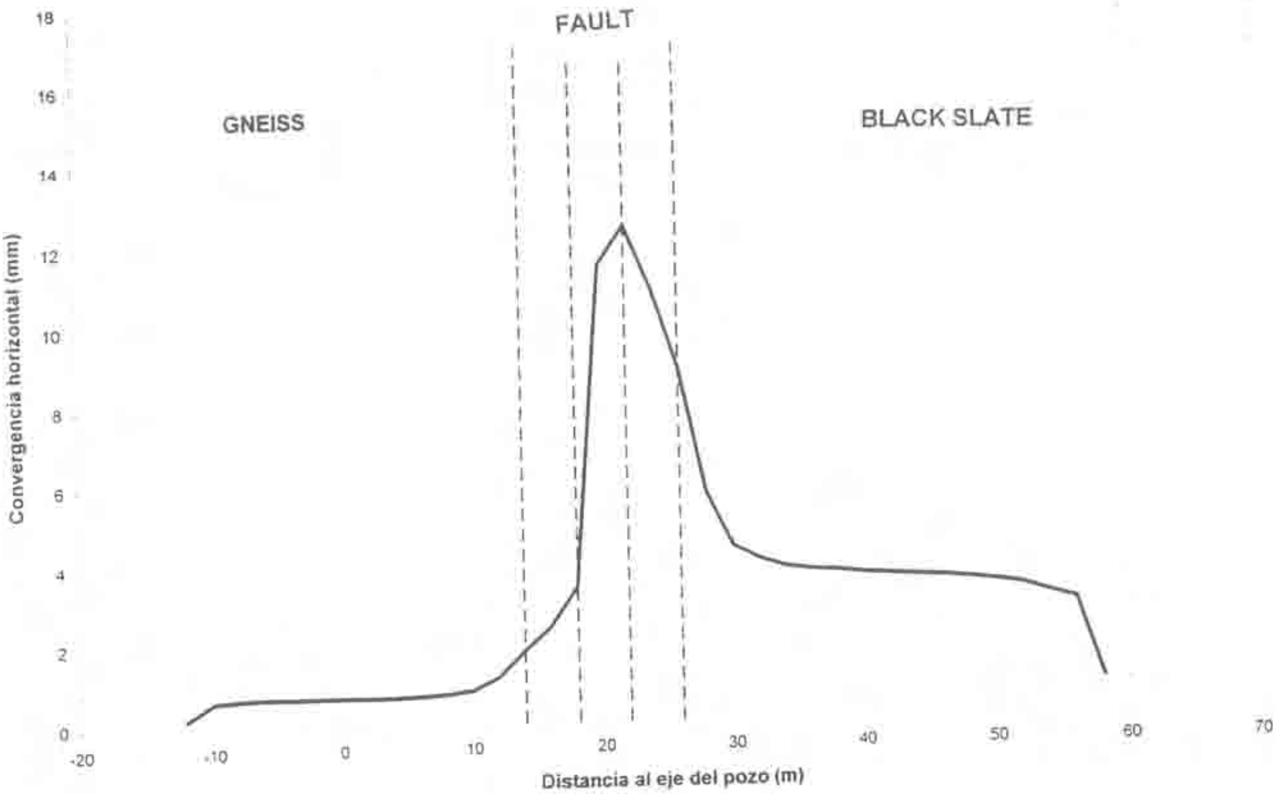


Figure 7.- Convergence profile for K_o= 1

GALLERY ZONE	MEASURE'S DIRECTION	VALUES OF CONVERGENCE (mm)		
		Ko=0,7	Ko=1	Ko=2
GNEIS	HORIZONTAL	0,4	0,7	1,6
	VERTICAL	0,9	0,9	0,8
FAULT	HORIZONTAL	9,1	12,4	28,9
	VERTICAL	12,5	15,4	38,8
BLACK SLATES	HORIZONTAL	2,4	3,8	10,8
	VERTICAL	3,6	3,8	7,3

Table II

- **Vertical extensometer**: with the data of the 3D model, the **Table III** shows the strains in the vertical extensometer EV-I, while in the **Figure 8**, the profile in case of K_o = 0,7 is shown.

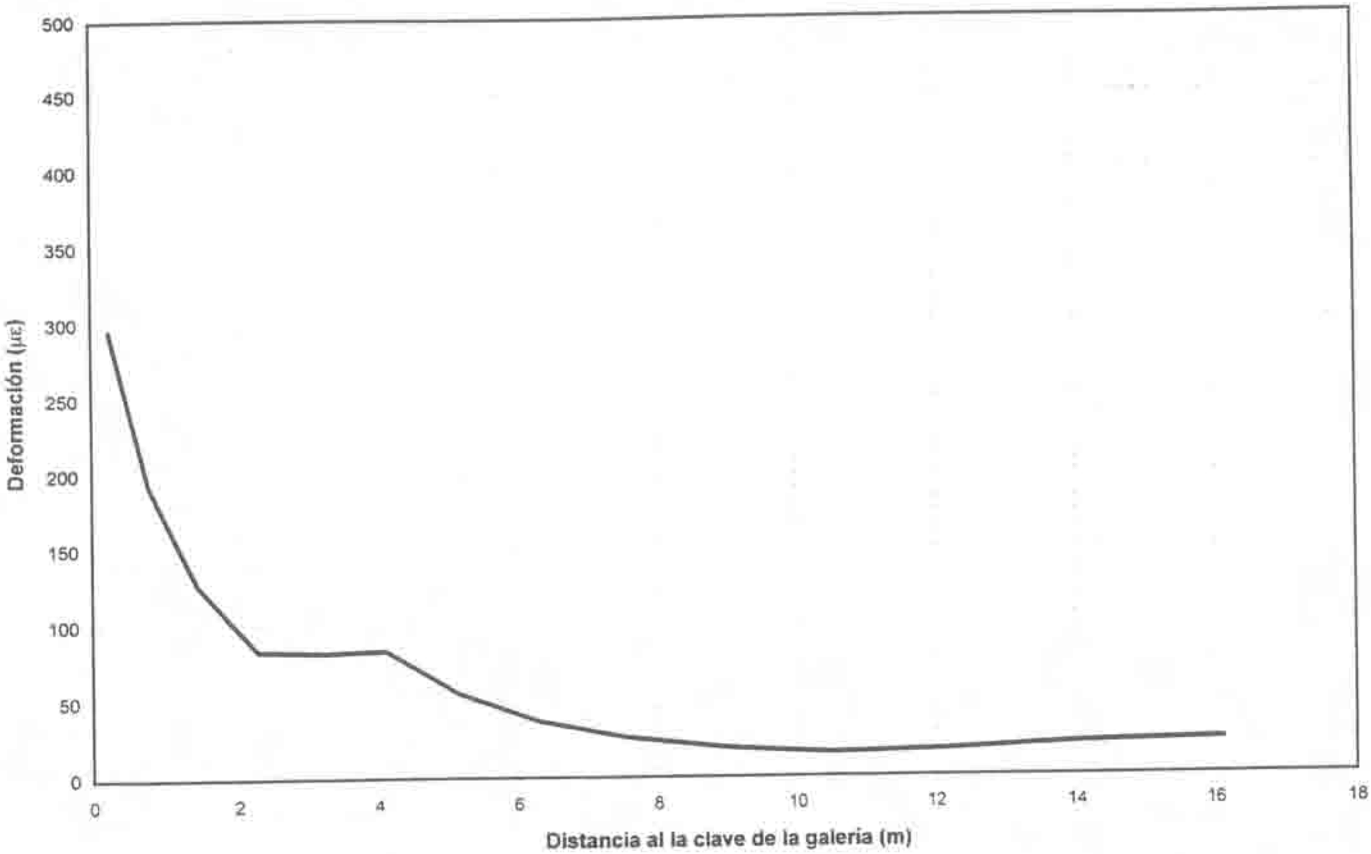


Figure 8-. Profile of strain for the vertical extensometer for K_o= 0,7

DISTANCE TO SHAFT (m)		MEASURE LENGTH (m)	STRAIN (μΣ)		
INICIAL	FINAL		K_0=0,7	K_0=1	K_0=2
2,30	2,80	0,50	296	430	1016
2,80	3,41	0,60	193	198	275
3,41	4,13	0,72	127	119	105
4,13	5,00	0,87	84	75	78
5,00	5,91	0,91	82	64	22
5,91	6,91	1,00	83	52	-46
6,91	8,01	1,20	55	33	-38
8,01	9,21	1,21	37	22	-28
9,21	10,54	1,33	26	16	-16
10,54	12,01	1,46	19	13	-5
12,01	13,62	1,61	15	12	5
13,62	15,38	1,77	17	15	11
15,38	17,33	1,95	21	16	-1
17,33	19,47	2,14	23	20	6

Table III

The same prediction has been carried out for the extensometer EV-2.

- **Horizontal extensometer**: on the **Table IV** it is shown the strains for the horizontal extensometer while on **Figure 9** it can be observe the strain versus distance to the shaft in the case of $K_o = 1$.

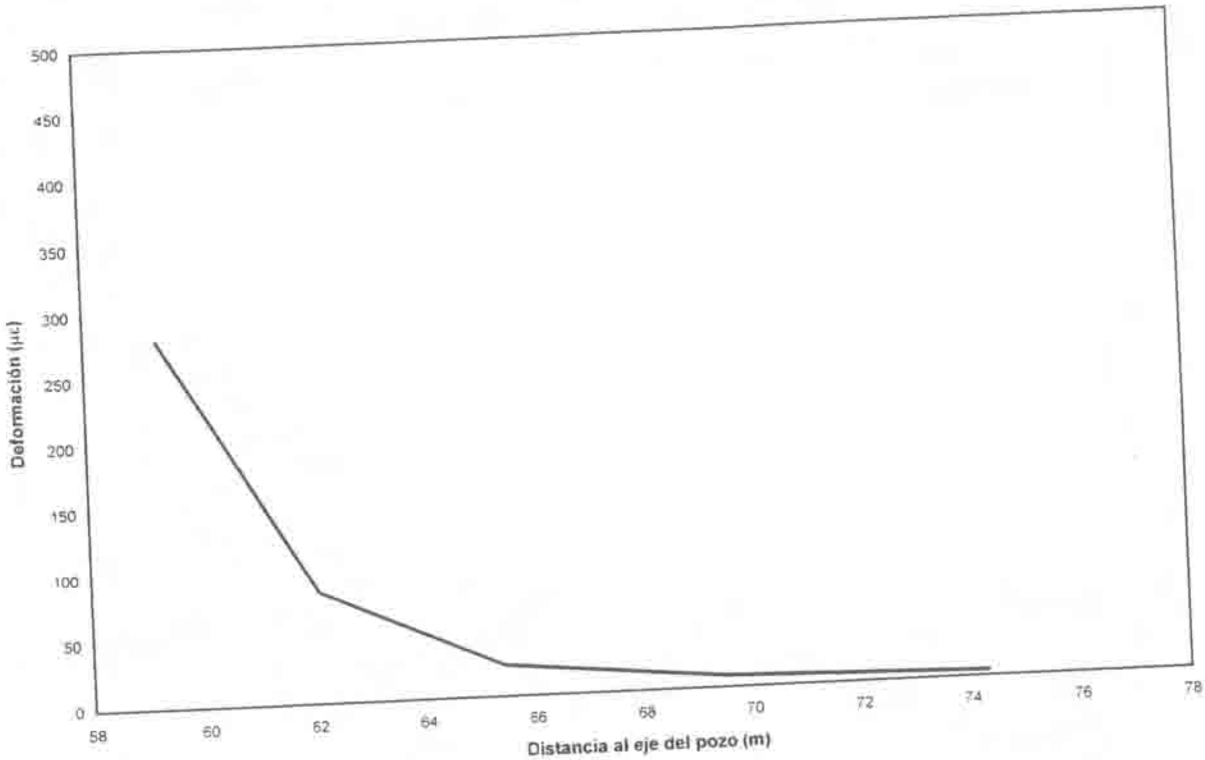


Figure 9.- Strain vs distance for the horizontal extensometers

DISTANCE TO SHAFT (m)		MEASURE LENGTH (m)	STRAIN (µ Σ)		
INICIAL	FINAL		K_0=0,7	K_0=1	K_0=2
58,00	60.55	2.55	194	279	679
60,55	63.60	3.05	51	84	237
63.60	67.27	3.67	12	24	84
67.27	71.67	4.40	4	9	34
71.67	76.94	5.28	2	4	17

Table IV

5.3 MAIN PREDICTIONS

- Subsidence is not a critical parameter to be measured.
- Convergence will be significative in the black slates and specially in the Le Boulou Fault.

- The elastic-plastic transition takes place 5,6 m in front of the gallery face.
- The range of predicted strains for the vertical and horizontal extensometers can be accuratly measured.
- The strains are very sensible to the K_o value.

5.4 NUMERICAL MODELLING

After the gallery is built up and all the instrumentation programme finished, the numerical presented model will be updated in order to feed back all the calculations already done.

This will allow to know more about the strength and deformability behaviour of the rock-mass and about the values of the natural stress field around Le Boulou Shaft and Gallery.

6 CONCLUSIONS

The previous studies carried out at Le Perthus tunnel have allowed to know the critical and weaker zones of it. So the following can be concluded:

- The location of the mechanical weaker zones of the tunnel are known.
- The characterisation based on geotechnical classifications and in situ and laboratory tests, had allow to define a range of mechanical properties of the existing black slates and myllonites.
- A further investigation is being carried out based on the instrumentation programme of the Experimental Shaft and Gallery of Le Boulou, and further numerical modelling.
- A blind prediction has been done to define the parameters and range of the measurements of these instrumentation.
- After these jobs are finished, a precise knowledgment of the stress-strain behaviour and of the natural stress field around the Le Boulou Gallery, is expected.