TUNNEL CONSTRUCTION IN HIGH SWELLING CLAYS

CONSTRUCTION D'UN TUNNEL DANS DES ARGILES TRES GONFLANTES
СТРОИТЕЛЬСТВО ТУННЕЛЯ В СИЛЬНО НАБУХАЮЩЕЙ ГЛИНЕ

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SYNOPSIS. The construction of a tunnel in Southern Italy has given the opportunity of studying the swelling properties of soils with high bentonite content. The development of pressures, up to 35 Kg/cm^2, on provisional lining have been investigated by means of laboratory and in situ tests. Usual correlations between swelling pressures and geotechnical parameters have been proved inadequate to quantitatively define this phenomenon. Laboratory determined pressures did not reach the field test values: in situ tests seem to be the most adequate way of measuring such pressures in planning the most appropriate tunnel driving method and in designing the tunnel lining in such soils.

1. FOREWORDS

The "Consorzio per la Bonifica della Capitanata" Foggia, Italy, has recently completed a very large irrigation project including the Fortore river diversion. Works consist of an earth dam holding a 330 x 10^6 m^3 available storage capacity reservoir, a 16 Km diversion tunnel and the primary and secondary channels network irrigating a 138,000 ha area. The tunnel has a horseshoe section, ranging from 26 to 30 m^2, and discharges 30 m^3/sec and has been excavated starting from 4 adits. This paper deals with geotechnical properties of the soils met in tunnelling, particularly the swelling soils, and with the soil pressures on lining.

2. GEOLOGY

The soil stratigraphy along the tunnel is as follows, see Fig. 1 (V. Cotecchia 1960):

- Lower Pleistocene-Upper Pliocene: blue silty marly clays.
- Medium Miocene: Daunia Formation composed of three types of flysch: marly limestone. marly clay and clay with bentonite layers.
- Oligocene(?):motley-clays formation.

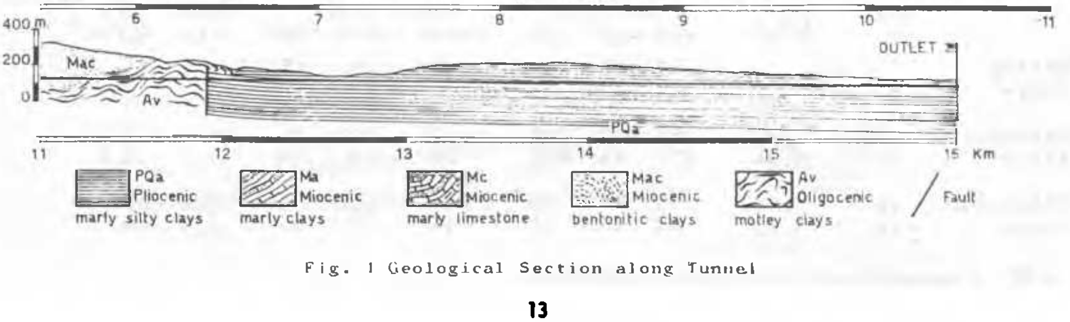

Fig. 1 Geological Section along Tunnel

Plio-pleistocenic soils have been found along 3.7Km of the tunnel near the outlet. They show low tectonic disturbande and a quasi-horizontal stratification. Miocenic soils, through which the major part of the tunnel has been driven, appears composed of the three types of flysch alternating. It is higly tectonized, jointed and faulted and has variably thick layers and variable attitude. Motley clays have a "scagliosa" (laminated) structure that allows water inflow; they lay under the miocenic flysch as well as tectonically intruded into them; sometimes bentonite layers are present.

3. MINERALOGICAL AND GEOTECHNICAL PROPERTIES

Usual laboratory geotechnical test and mineralogical semiquantitative analysises using X rays have been performed(A. Piccio and L. Meisina 1971). The results reported in Table I concern some Miocenic and Pliocenic samples.

TAB.I-PERCENTAGE MINERALOGICAL COMPOSITION

	MIOCENIC CLAYS		PLIOCENIC	
SAMPLE N°	1	2	3	4
Montmorillonite	-	-	70-75	-
Interbedded Mont./Illite	10	10	-	-
Talc	10	<5	-	-
Kaolinite	-	10	-	10-15
Quartz	15-20	15-20	10-15	40-45
Feldspars	-	-	<5	<5
Calcite	45-50	45-50	10	25-30
Illite	<5	<5	<5	10

The variable mineralogical composition of the Miocenic formation even in a single lithitype, explains, at least partially, their variable geotechnical properties, see Table II. Pliocenic soils are more uniform;motley clays show properties similar to those of the most plastic Miocenic samples.
The occurrence of high bentonite contents and high unit weight and plasticity values in Miocenic and motley clays, forecasted the development of swelling pressures on the lining. Laboratory tests on samples carved from large blocks taken at the advancing face were performed, in order to find the maximum swelling pressures.The usual testing techniques have been used (G.Baldovin and G.Lorenzini 1967)consisting of preventing any swelling in the oedometer, by gradually increasing the load on the sample . Fig. 2 shows the swelling pressures obtined from the above mentioned tests:they range from 3 to 10 Kg/cm^2, 6 Kg/cm^2 being the most frequently value recorded in Miocenic clays, and 5 Kg/cm^2 in Pliocenic clays.

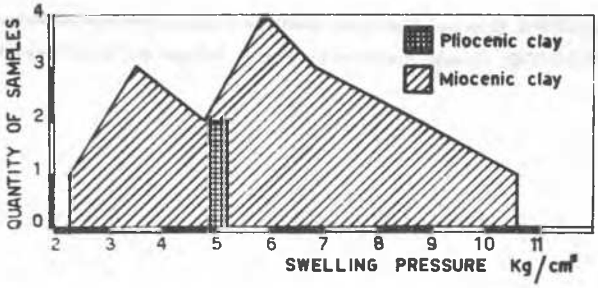

Fig. 2 Distribution of Pressure

As far as the uniaxial-free-swelling versus time relation is concerned, the tested samples did not show any appreciable stabilization after 1000÷1600 hours, as reported in Fig.3, in accordance with the results obtained by other Authors (A.Mislivec 1969)

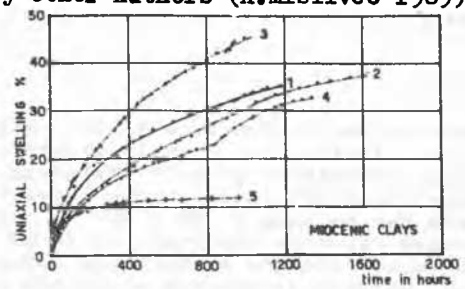

Fig. 3 Free Swelling in Time

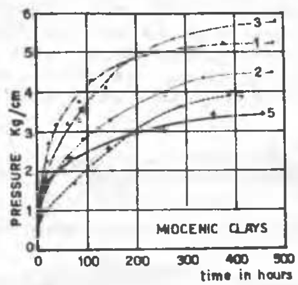

Fig. 4 Swelling Pressure in Time

TAB. II - GEOTECHNICAL PROPERTIES RANGE

	Wn %	γ_d t/m^3	Plasticity w_L%	w_P%	I_P%	Grain Size Sand%	Silt%	<2μ%	Activity	σ_f (*) Kg/cm^2
Motley clays	-	-	61	25	30	0	24	45	1,1	-
			119	39	87	5	50	76	1,5	
Miocenic clays	11	1,32	66	22	42	1	27	26	1,2	1,2
	32	2,16	436	39	408	26	73	72	5,0	2,8
Pliocenic clays	12	1,92	49	14	32	9	56	31	0,9	28.
	13	1,93	52	16	38	13		35	1,1	44.

(*)σ_f = unconfined compressive strength

As shown in Fig. 4 the maximum swelling pressure is reached about 400 hours after the beginning of the test. For construction purposes, it would had been very useful finding a direct quantitative correlation between swelling pressure and geotechnical properties, such as liquid limit, unit weight and mineralogical composition. Research in this direction did not show any useful correlation probably because all the above factors contribute together in different proportion to this phenomenon. Only qualitative correlations have been found. The following formula proposed by A. Komornik and D. David (1969):

$$\lg P = \bar{2},132 + 0,0208 w_L + 0,000665 \gamma_d - 0,0269\, w_n$$

where P = swelling pressure (Kg/cm^2)
w_L = liquid limit (%)
γ_d = unit weight of dry soil (Kg/m^3)
w_n = natural water content (%)

did not give any good correlation, probably because, as the Authors admit, it does not take into adequate consideration the initial clay "structure" which is likely to play a major part in the swelling phenomenon.

Fig. 5 Deformations of Tunnel Prelining

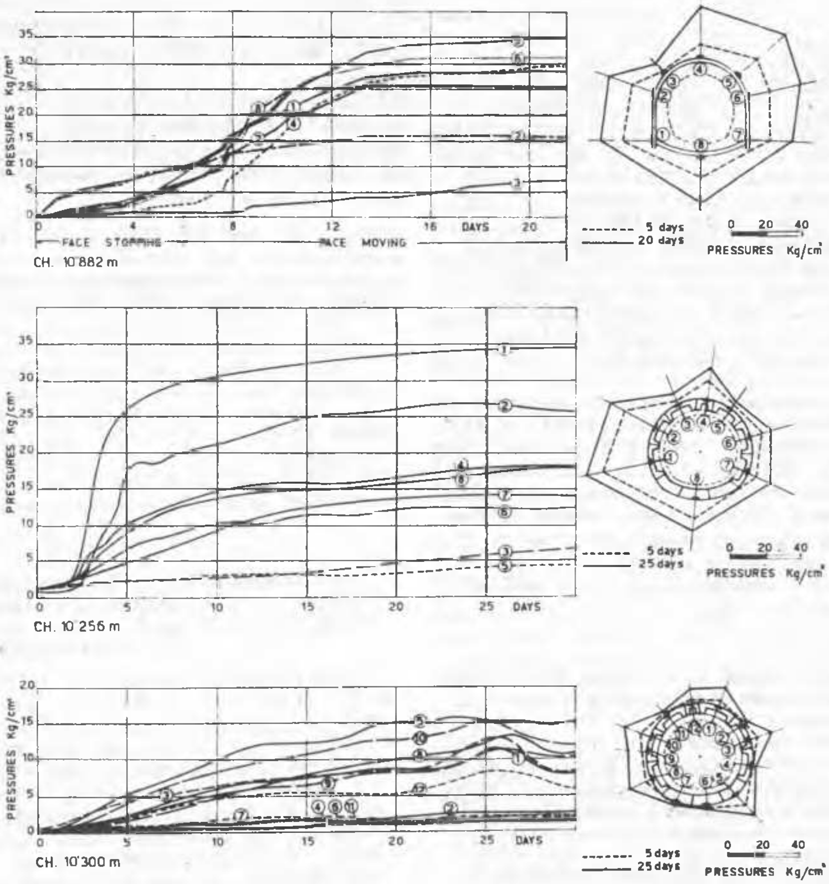

Fig. 6 Pressures on Lining in Miocenic Clays

So far it appears that the best laboratory test to evaluate swelling pressure is the direct measurement on "undisturbed"samples, even if this method gives lower value than field tests, probably owing to the fact that the samples are never really undisturbed.

4. FIELD TESTS AND CONSTRUCTION TECHNIQUES

In Pliocenic clays, that did not generally give any construction trouble, the excavation has been carried out full section using the blasting-mucking method. Miocenic and motley clays underwent swelling, as forecasted: a shield has been consequently used; the temporary support was achieved by means of steel supports and reinforced concrete lagging. Between ch 10,000 and 11,000 exceptionally high uniform pressures developed on the supports. In this stretch the soil is composed of about 50% bentonite clay and about 50% interbedded stratified limestone frequently jointed and water bearing. Increasing soil pressure caused incontrolled deformations, Fig. 5: immediatly adopted remedies such as steel supports with high moments of inertia sections, closer spacing (0.40m instead of the previously adopted 0.60m),the adoption of the invert and of lateral concrete walls 1 m thick, did not prove adequate to prevent the development of dangerous deformations. Laboratory swelling tests were performed on the above mentioned soils:the results have been reported on Fig. 2,3 and 4. In order to achieve a more accurate control and soil pressures evaluation,a measuring station has been installed at ch 10,882m as shown in Fig.6, consisting of 8 Gloetzl hydraulic cells. At this section, pressures up to 35 Kg/cm^2 have been measured,uniformly distributed around the tunnel perimeter.On this account it has been decided to adopt a circular section instead of the previously used horseshoe.The prelining has been built using reinforced concrete blocks followed by the reinforced concrete final lining. Two measuring stations have been placed here, at ch 10,256 and at ch 10,300. At ch 10,300 the rock is highly jointed and contains few bentonite layers:low pressure values have been recorded here,which can be essentially regarded as caused by the overbunden. At ch 10,256 and at the above mentioned ch 10,882, bentonite clay is prevalent: very high pressure values have been recorded. It is then apparent, from these results,that the exceptionally high pressure values recorded have been caused by swelling phenomena taking place in the bentonite clayey soils.

5. CONCLUSIONS

- The exceptionally high pressures recorded at Fortore tunnel seem essentially caused by swelling of clayey soils.
- Some trials have been done in order to forecast the field pressure conditions by means of laboratory tests. Laboratory correlations, based on Atterberg limits and mineralogical composition, proved inadequate to yield a quantitative evaluation. Swelling laboratory tests did not reach the maximum swelling pressures recorded in the field.
- Field tests, only, can nowday guarantee the measurement of the real pressures developing on tunnel linings due to expansive soils, whose knowledge is of primary importance to ensure tunnel stability in the above considered soil conditions.
- The rate of swelling is of major importance in designing and building tunnels in expansive soils. Where high pressures develop shortly after the excavation, like in the above mentioned instance, unusually strong provisional supporting sistems are required.

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