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'Argille Scagliose' complex in Northern Italy: The geotechnical characterization

Le complexe de 'Argiles Scagliose' dans l'Italie septentrionale: La caractérisation géotechnique

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ABSTRACT: Outcrops of the "Argille Scagliose" complex, which from a lithological point of view consists of extremely heterogeneous marl-claystones with calcareous inclusions, are common in the Norther Apennines. Three important road and rail tunnels are to be cut through this complex in the near future.

Knowledge of the geotechnical features of these materials is very important for the planning and design of the excavations, support and lining structures. At present existing data concerning the "Argille Scagliose" is scarce and at times contradictory.

The authors, beginning with a specific investigation for one of the tunnels in question, have gathered together and processed all the data already available in the literature.

The result is an overall picture of the geotechnical features of the "Argille Scagliose". The statistical importance of this picture becomes fundamental when the scattered nature of the data collected by the authors is considered.

RESUME: Le complexe des argiles écailleuses lithologiquement constitué d'argilites marneuses fortement hétérogènes affleure largement dans les Apennins nord. Dans un proche avenir il accueillera trois importants tunnels autoroutiers et ferroviaires.

La connaissance des caractéristiques géotechniques de ces matériaux est très importante pour la conception des excavations et des ouvrages de soutènement. A l'heure actuelle, les données relatives aux argiles écailleuses sont éparses voire contradictoires.

Partant de l'enquête spécifique d'un des tunnels en question, les auteurs ont collecté et traité toutes les données disponibles déjà publiées.

Il s'en dégage un tableau général des caractéristiques géotechniques des argiles écailleuses dont la signification statistique acquiert de l'importance face à la dispersion des données recueillies par les auteurs.

1 INTRODUCTION

The "Argille Scagliose" complex, which from a lithological point of view consists of clays and shale, is very widespread throughout the Apennine Chain. Its importance, for an understanding of the dynamic evolution of the Apennines, has induced numerous researchers to study the stratigraphic and tectonic relations of the complex with other units. Despite the fact that the complex extends over a very wide and important area as far as land development is concerned (development of major transport routes, landslide prevention, urban development), present knowledge of its geotechnical features is scarce and at times insufficient. The "Argille Scagliose" are important because several transport construction projects, currently planned, in Italy pass through them.

The authors felt that it would be extremely useful to collect, process and interpret data and information available from the numerous works that have been carried out, with particular reference to the specific works for the Bologna-Florence motorway. It is the purpose of this paper to summarise our present knowledge of the "Argille Scagliose".

2 SOURCE OF DATA

Outcrops of the "Argille Scagliose" in the Northern Apennines are considerable and widespread; the stratigraphic and tectonic features are complex and varied and consequently not easy to map.

Current Italian transport planning involves contruction on three important Apennine routes (Fig. 1) (from East to West):

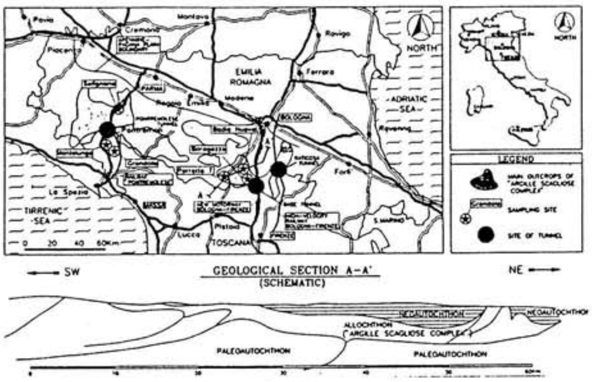

Fig. 1 - Geographical setting.

- a high speed Bologna-Florence railway line;
- the new Bologna-Florence motorway;
- the new Parma-La Spezia railway line.

In these works the crossing of the Apennines is effected by the construction of tunnels of considerable length (Fig.2):

- "Raticosa" tunnel
  10,400 m approx.length
- "Base" tunnel
  8,700 m approx.length
- "Pontremolese" tunnel
  21,000 m approx.length

Geological forecasts show that the "Argille Scagliose" will appears in these works for a total length of approximately 12 km which is equal to 25-30 % of the overall length of the tunnels.

The presence of "Argille Scagliose" with high lithostatic overburdens (400-600 m max approx.) means that it is important to study the behaviour of the rock mass during the works for excavation and construction of the temporary and final support structures.

In order to obtain a detailed picture of the "Argille Scagliose", data from surveys carried out for the construction of the "Base" tunnel was examined (Bologna-Florence motorway in the "Vidiciatico Clays" formation ("Argille Scagliose" Complex)). Data coming from other works involving the "Argille Scagliose" was also examined in order to obtain statistically valid data.

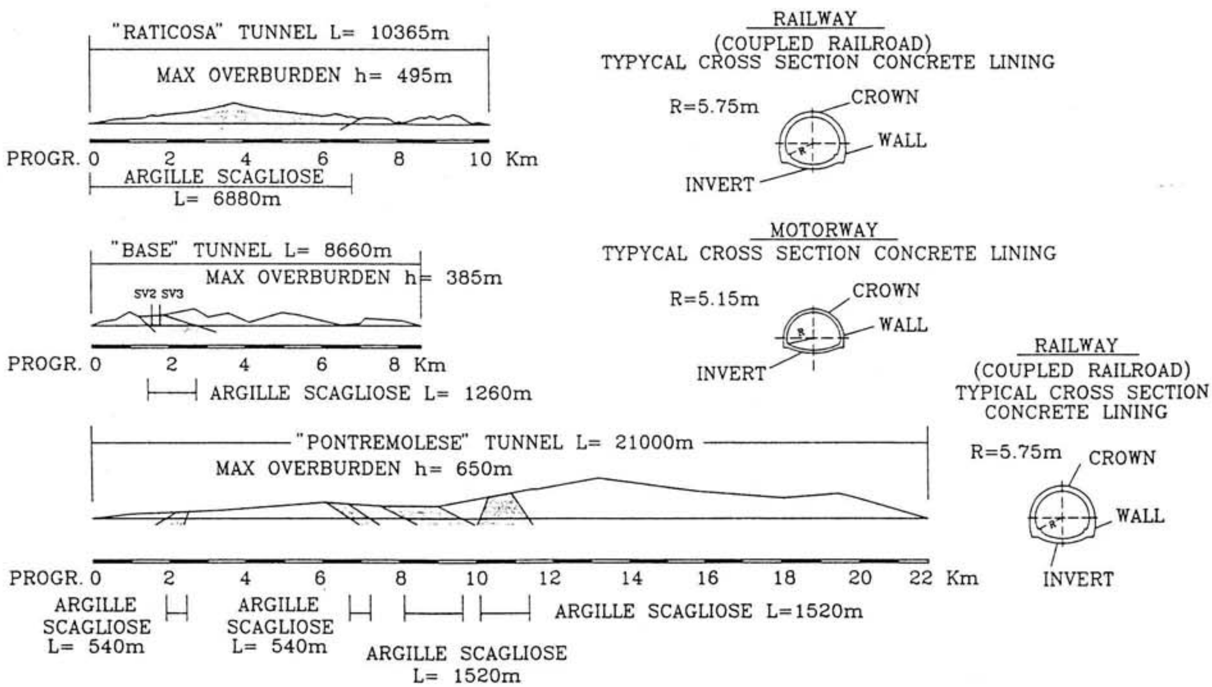

Fig. 2 - Geological sections of tunnels.

3 GEOLOGICAL SETTING

The Northern Apennines form a mountainous chain, the end points of which are given by the Piedmontese tertiary basin (NW) and the Lazio volcanoes (SE). Two main parallel zones with different paleogeographic and structural features can be identified from the evolutionary relationships (Fig.3) (CNR, 1982):

- External Range (Tuscany-Umbria-Marche Units):
  this consists of a limestone series forming the overlay, partly autochthonous and partly separate, of an ancient paleoautochthonous bed;
- Internal Range (Internal and External Ligurid Units):
  this consists of a completely allochthonous series formed in oceanic areas.

The "Argille Scagliose" belong to the completely allochthonous Internal Range and run over onto the external Tuscan-Umbrian group.

The Internal Range appears to be completely chaotic due to considerable dislocations undergone mainly in the Eocene period.

The dislocation undergone was favoured by a flowing plastic level and the clayey nature of the Ligurid Units which gave rise to enormous gravitational flows.

The gravitational plastic masses include disjointed strip formations, at times in ordered sedimentary layers of considerable extension.

The main features of the "Argille Scagliose" (Esu, 1977; AGI, 1979) are as follows:

- complexity of strata and tectonic relations with other formations and irregular area distribution;

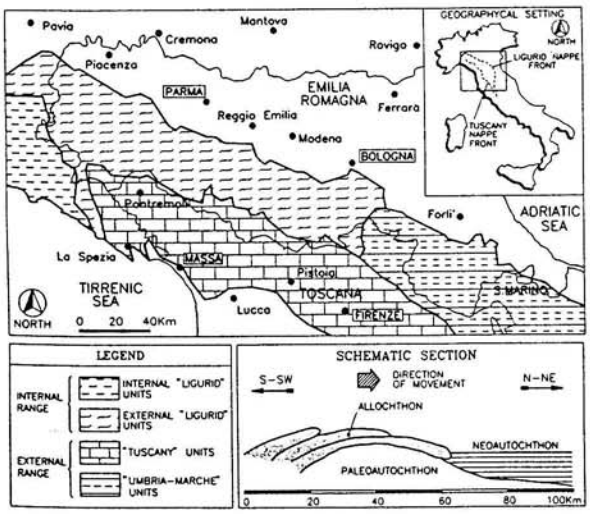

Fig. 3 - Geological-structural setting.

- lithological complexity and heterogeneity;
- presence of olistostrome bodies and strip formations that maintain their original sedimentary configurations;
- complex structure with phenomena of stretching, lamination and short radius folding; frequent convolutions and the presence of prismatic and/or flat scales with translucent surfaces. Lithoids contained are lithologically varied but mainly calcareous showing a dense network of fractures filled with calcite.

4 INVESTIGATIONS AND SURVEY

The surveys carried out on the "Argille Scagliose" of the motorway "Base" tunnel (BOL-FLO Motorway) are as follows:

- 4 No. geognostic drillings - continuous bore drilling with depth varying from 90 m to 270 m approx. obtaining 17 No. undisturbed and disturbed samples;
- 17 No. pressiometric tests in borehole (Menard type);
- laboratory testing:
  - physical and chemical properties;
  - mineralogical and petrographical properties;
  - mechanical properties.

5 CLASSIFICATION OF ARGILLE SCAGLIOSE

Macroscopic analysis of the cores showed that the lithological nature of the material consisted mainly of a marl-claystone mass with a chaotic scaly structure, greenish grey in colour with numerous intercalations of small blackish clayey levels. There were frequent occurrences of material of a polygenic nature contained (sandstones, limestones, clays) and also calcareous levels sometimes up to a few metres in thickness.

According to the classification system for "Structurally Complex Formations" (Fig. 4) (Esu, 1977; AGI, 1979), which is based on the heterogeneity of the mineral, lithological and structural characteristics of the rock, the material examined could be attributed to class B3. Group B comprises formations originally consisting of more or less regular alternations of lithological heterogeneous materials (in our case claystones and marls).

Type B3 in particular includes formations with a completely chaotic structure (chaotic clays), caused by intense and repeated tectonic stresses, and includes elements of a more or less stone-like nature (D'Elia, 1977; D'Elia et al, 1982). In this particular case, the material of a marl-claystone

GROUP	CLASS	DESCRIPTION
A	A1	BEDDED CLAY OR SHALE, OFTEN FISSILE, MORE OR LESS FISSURED AND/OR JOINTED
	A2	COMPACT BODY OF CLAY OR SHALE "SCAGLIA"
B	B1	REGULAR BEDDING SEQUENCE OF ROCK AND CLAY OR SHALE, MORE OR LESS FISSURED OR JOINTED
	B2	CHAOTIC BEDDING BODY OF CRACKED ROCK AND CLAY OR SHALE, FROM FISSURED OR JOINTED TO VERY HIGHLY FRACTURED
	B3	FRACTURED CLAY OR SHALE, WITH ROCK FRAGMENTS DUE TO HIGH AND REPEATED TECTONIC SHEAR STRESSES
C	C	ROCK BLOCKS OR FRAGMENTS, MORE OR LESS WEATHERED, WITH CLAYEY-SILT MATRIX OF HETEROGENEOUS NATURE

Fig. 4 - Classification of the "Structurally Complex Formations".

nature shows a high level of structural instability which for various reasons (variation in the tensional state, weathering, soaking and drying), may lead in a short space of time to the breakdown of the diagenetic bonds and the formation of loose rocks.

From the granulometric point of view, laboratory determinations identified a material which, according to BS 5930/1981 (British Standard Code of Practice for Site Investigations), can be classified as Mudstone. The granulometric curves (Fig.5) are very

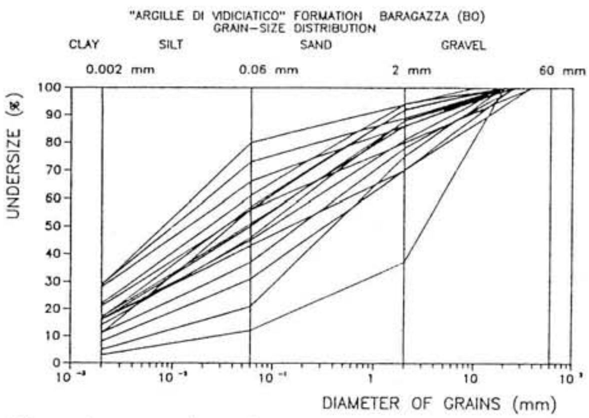

Fig. 5 - Grain-size distributions.

scattered due to the abundant presence of stone-like bodies. If the fine fraction only is considered the material can be more correctly identified as siltstone (Hawkins and Pinches, 1992).

An interpretation of the granulometry results should take into consideration the objective difficulty of separating claystone fractions due to the intra-particle bonds of clayey minerals. The consistency of these is sometimes the same as that of a diageneticized material.

No significant variations were found in granulometric composition at different vertical levels (e.g. bore drilling SV3, Fig.6) and this confirms

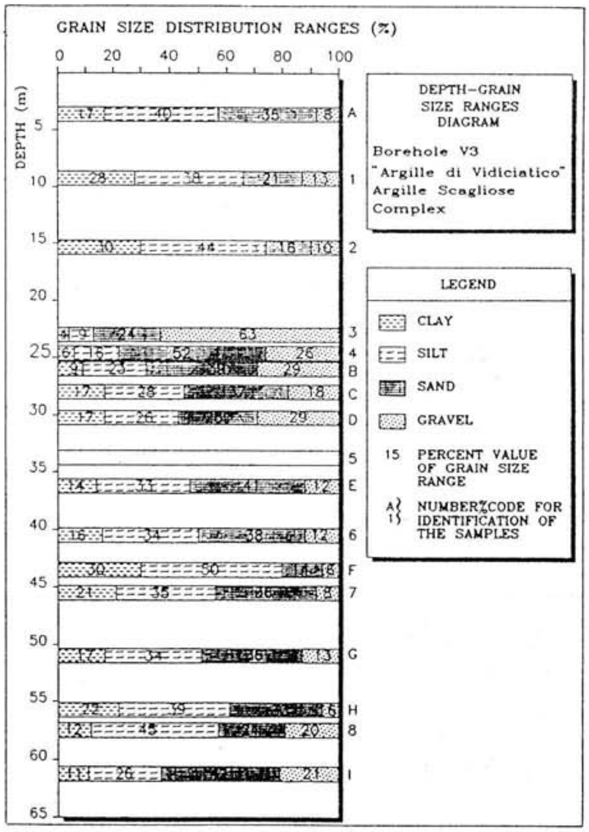

Fig. 6 - Grain-size distribution ranges versus depth.

the extreme chaotic nature of the mass under study. The presence of a greater percentage of clay and silt in the samples from the surface level (max. depth: 25 m) gives confirmation of better separation in the laboratory due to less litification of the material. It is only possible to classify the clayey matrix of the "Argille Scagliose" complex since the presence of stone-like bodies can heavily distort a classic granulometric analysis of the weighted type.

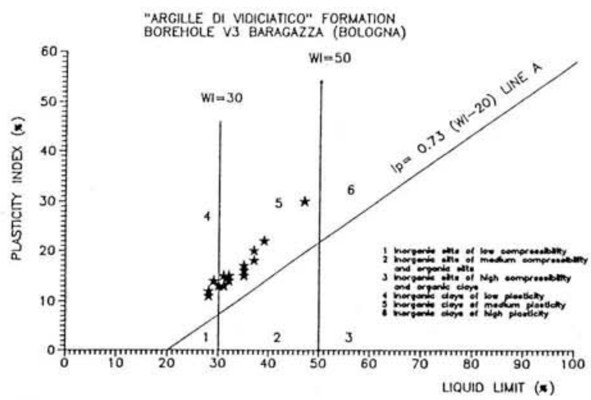

Fig. 7 - Casagrande Chart.

The Atterberg limits made it possible to classify the material within the Casagrande plasticity diagram; it is on average an inorganic clay with medium plasticity (Fig.7).

The material was classified according to the calcium carbonate content (Fig. 8); this is more prevalent in the field of the marl-clays. It was noted that the percentage of $CaCO_3$ was often concentrated inside threads and veins of secondary calcite in fissures.

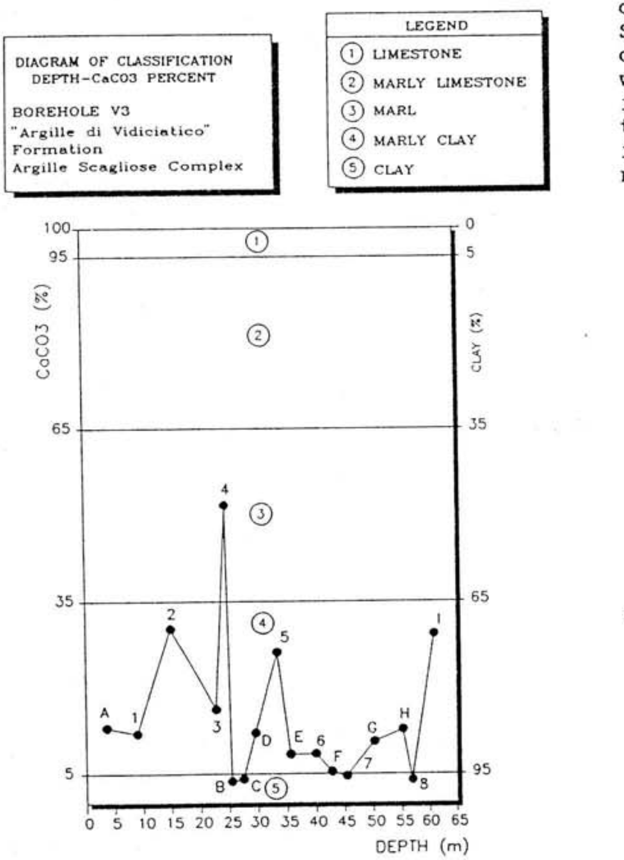

Fig. 8 - Percentage of $CaCO_3$ versus depth.

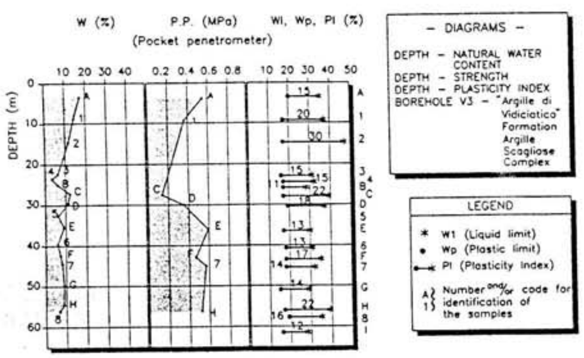

Fig. 9 - Logs of the main physical properties.

The natural content of water generally varies from between 5% to 15% and shows a slight tendency to diminish with depth (Fig. 9).

The plastic index varies from 10% to 20% and slows a slight decrease with depth (Fig.9).

The material always shows a consistency index greater than one.

6 DEFORMABILITY

Seventeen pressiometric tests were carried out in the boreholes SV2 and SV3 in order to determine the deformability of the material. The tests were carried out with MENARD (MPM) instruments using a tricellular APAGEO type 100 bar (ϕ 60 mm) probe and low inertia (0.05-0.1 MPa) sheaths with metallic blades.

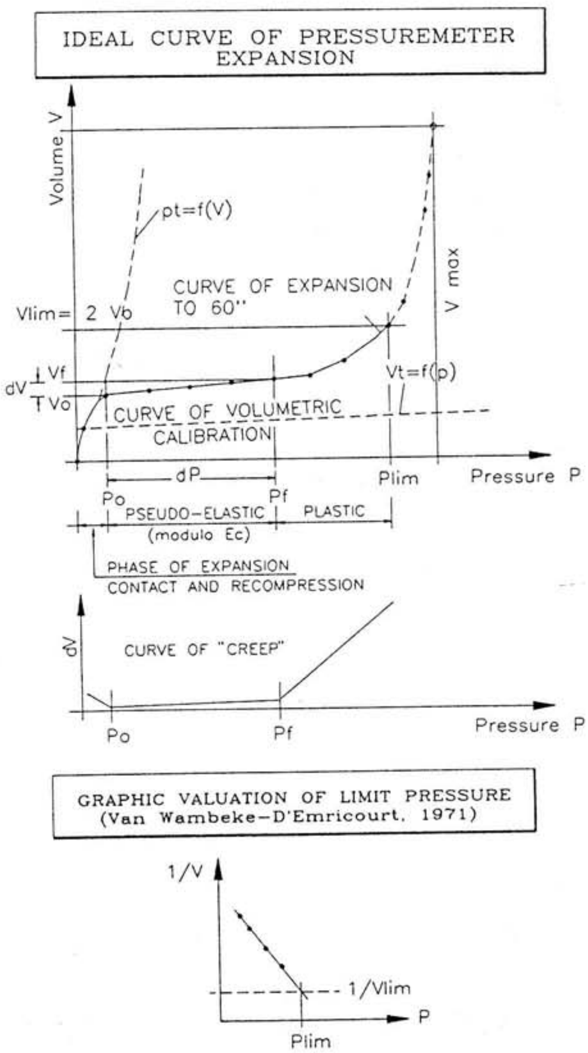

Fig.10 - Interpretation of the Menard pressuremeter tests.

Processing of the test data (Cassan, 1978) made it possible to construct pressiometric curves and to identify pressiometric parameters (Deformation modulus, "Creep" pressure, Limit Pressure). Figure 10 show the typical pressiometric curve and his ideal interpretation.

The processing of real pressiometric curves showed that at levels near the surface (depth: 25-30 m from surface) complete development of pressiometric curves was obtained with clear identification of the expansion phase of the probe and recompacting of the ground, of the pseudoelastic phase and of the plastic phase (Fig. 11). At greater depths the maximum pressures applied did not allow, due to the more stony characteristics of the material, the development of a complete pressiometric curve (Fig. 12). The deformation characteristics of the lithotype, which depend on the lack of lithological homogeneity and the anisotropic behaviour, show that:

- in the distinctly clayey facies the elastic moduli fall within the range of from 100 to 500 MPa;
- in the marl facies the values are more scattered (500-3500 MPa), with maximum values the same as those for the distinctly stony facies (5800 MPa in bore drilling SV3 and 16800 MPa in bore drilling SV2).

Despite the wide scattering of the deformation values an increase in the values for the elastic modulus was found with increased depth (Fig.13). Average values equal to 1600 - 1700 MPa approx. were found at a depth of 80 m.

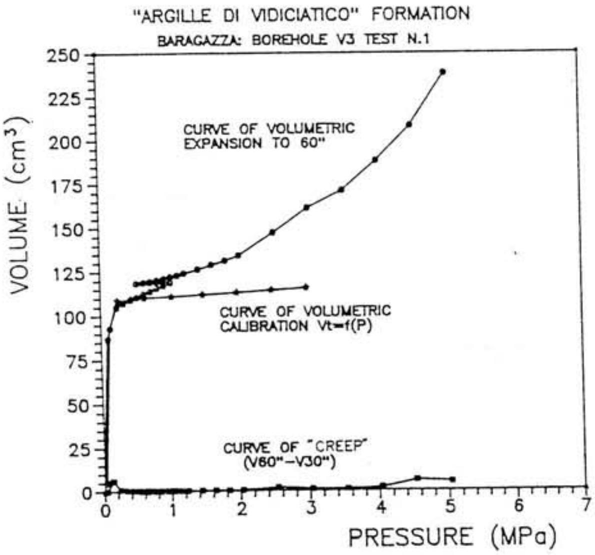

Fig.11 - Pressuremeter tests in the argillaceous level.

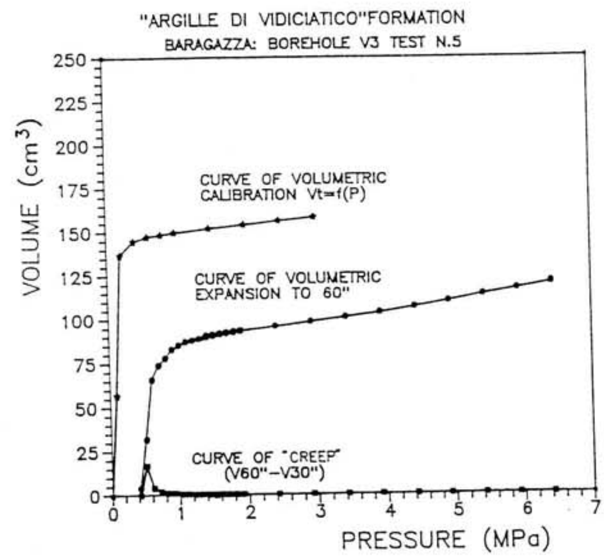

Fig.12 - Pressuremeter tests in the marlaceous level.

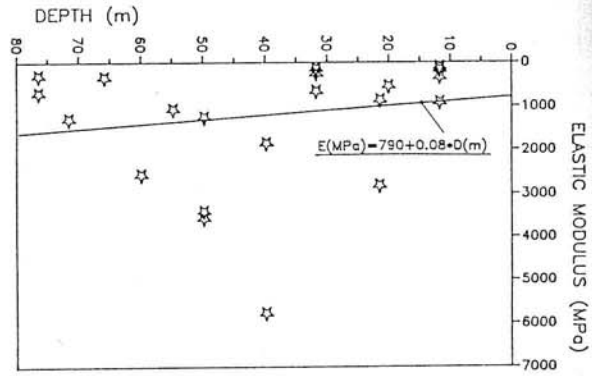

Fig.13 - Elastic modulus versus depth.

The "Creep pressure" which characterizes the beginning of a plastic phase, showed values generally within the 2-3.5 MPa range with maximum values of approximately 5 MPa. The limit pressure, calculated using a graphic extrapolation procedure (Van Wambecke and D'Emricourt, 1971 Fig.10), was obtained reliably for those tests where a complete pressiometric curve was developed. These values fall within 7.5 to 9 MPa, while for the tests where the plastic phase was not reached the limit pressure was much higher than the maximum pressure values applied during the test (6 MPa approx.).

7 STRENGTH

The shear strength of the "Argille Scagliose" was calculated by carrying out consolidated anisotropically drained direct shear tests (DS CKoD).

The tests were carried out using a test sample with a square cross section

(4-6 cm) and a height of 2 cm, reaching shear deformations in the order of 30 mm where residual strength values were obtained.

Fig. 14 gives the test points of the tests carried out in the σ-τ diagram, together with the linear regression curves.

The strength parameters obtained are as follows:

- peak strength
  $c_p = 0.02 - 0.12$ MPa
  $\phi_p = 18^\circ - 29^\circ$
- residual strength
  $c_r = 0.02 - 0.07$ MPa
  $\phi_r = 7^\circ - 21^\circ$

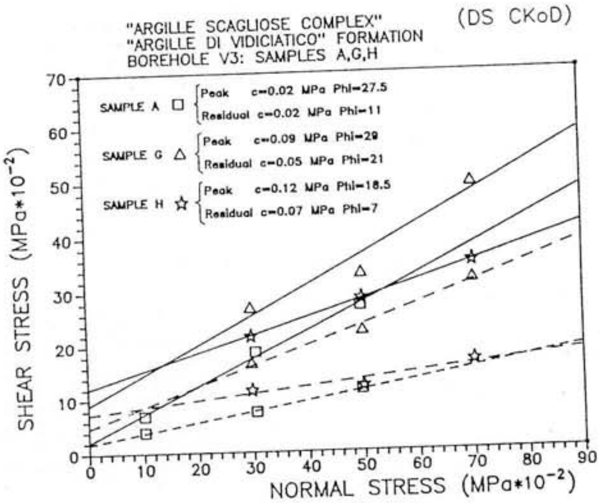

Fig.14 - σ-τ diagram: peak and residual strength envelopes.

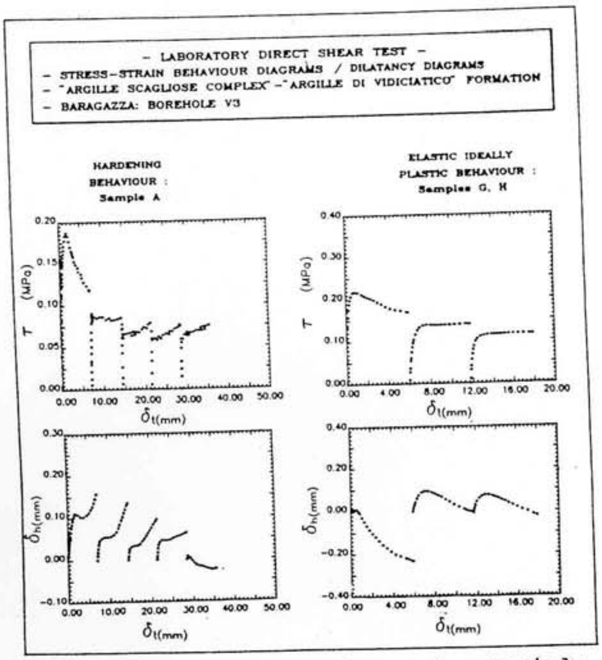

Fig.15 - Typical behaviour of materials

Two main types of shear behaviour were identified (Fig.15) according to the respective type of facies (clayey or marl):

- in the first case (clayey facies), after the initial peak strength (elastic-brittle behaviour) a marked hardening was detected (hardening behaviour);
- in the second case (marl facies), the highest deformation phase exhibited an elastic type behaviour that was perfectly plastic.

8 SWELLING

In order to determine the swelling properties of "Argille Scagliose", 9 No. oedometric consolidation tests were carried out with a controlled load and the swelling prevented. The swelling pressure was measured (swelling pressure test).

The tests were carried out by applying a force corresponding to a vertical load on the test piece equal to 25 KPa approx. and introducing water into the cell to simulate normal conditions under the water table. The tendency to swell was contrasted by progressive increase of the vertical load. The results of these tests gave maximum swelling pressure values of between 50 and 150 KPa with a peak of 580 KPa approx.

One of the main factors influencing the swelling potential of clays in the presence of water is given by the nature and quantity of clayey minerals. The triangular diagram in Fig. 16 shows the swelling properties on the basis of mineral content only. It can be seen that all 18 samples analysed fall within field A of the diagram, defined as being of high potential swelling. This confirms the results of the swelling tests.

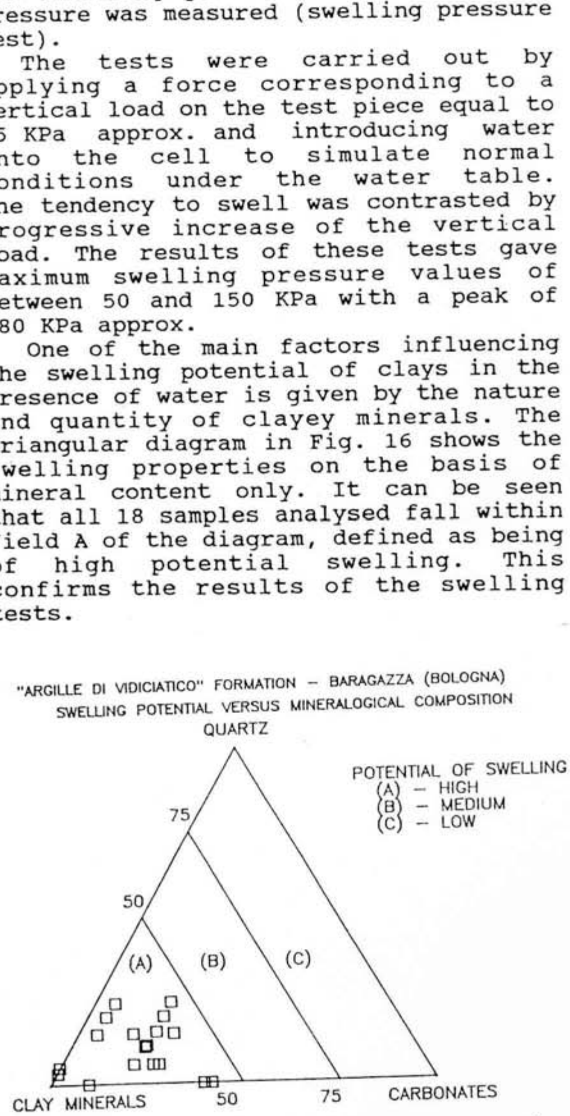

Fig.16 - Swelling potential versus mineralogical composition.

9 MINERALOGICAL AND PETROGRAPHICAL FEATURES

X-ray diffractometric and infra-red spectrophotometric analyses were carried out to determine the mineralogical and petrographical properties of "Argille Scagliose".

Particular attention was paid, in the diffractometric analyses, to detecting and identifying the minerals of the clays that have a strong influence on the mechanical behaviour (swelling in particular) of these materials. The most common minerals in the clays are illite (25-50% approx.) and illite-smectite (mixed strata) (25-50% approx.); chlorite and kaolinite are of lesser importance (5-25% approx.).

The main components of the clays were recognized by means of the spectrophotometric analyses and these were phyllosilicates, carbonates and quartz. These percentage incidence was also determined.

10 STATISTICAL ANALYSIS OF THE PROPERTIES OF "ARGILLE SCAGLIOSE"

Due to the extreme variation in the geotechnical data relating to the "Argille Scagliose" of the Northern Apennines it is very important, in the opinion of the authors, to analyse the data statistically in order to find those ranges of variation in which the data is most frequently found. A considerable amount of informations was collected from the existing literature (c.f. bibliography); the locations of these data are reported on Fig.1.

For purposes of comparison, the processing of this data was the same as that first described.

From the granulometric point of view the data collected showed less scattering than that previously analysed (Fig.17); the most prevalent fractions were the silty and clayey fractions.

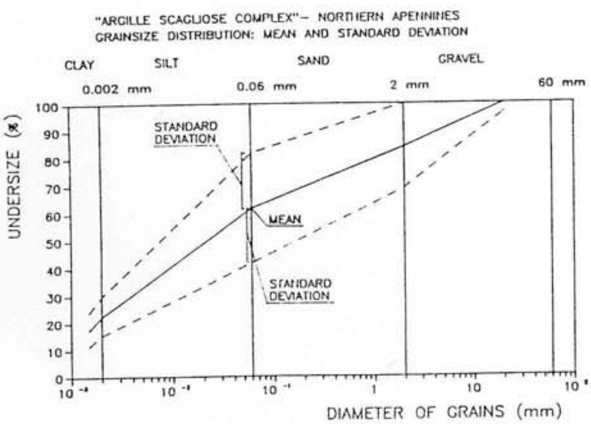

Fig.17 - Grain size distribution range.

On the other hand, the Casagrande plasticity diagram showed that most of the samples could be classified as low and medium plasticity inorganic clays and rarely as high plasticity clays (Fig.18).

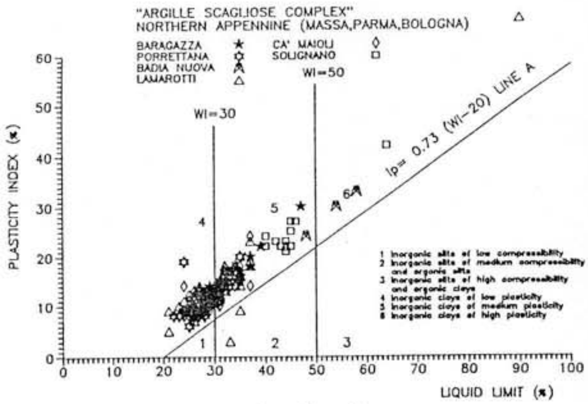

Fig.18 - Casagrande Chart.

The CaCO3 content show a very scattered distribution with a slight increase with increase in depth (Fig. 19); the materials are classified as marl-clays.

The deformation properties of the material were ascertained by carrying out dilatometric and pressiometric tests. Extreme scattering of the data was observed, closely connected with the percentage of stone-like bodies contained in the material. Deformability clearly increases with depth (Fig.20) and the elastic modulus showed values that fall mainly withn the 1000-3500 MPa range.

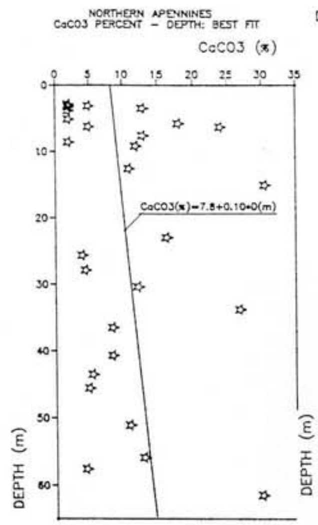

Fig.19 - Statistical percentage of CaCO3 versus depth.

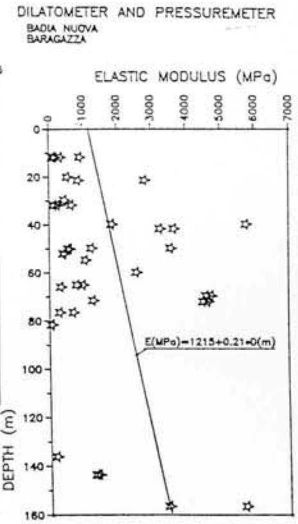

Fig.20 - Elastic modulus versus depth

The strength properties were calculated from data contained in the literature: "Argille Scagliose" of the Central and Southern Apennines (D'Elia et al, 1984; Picarelli, 1986; Pellegrino, 1986; D'Elia and Tancredi, 1979; Allevato et al, 1980; Dente et al, 1980; Manfredini et al, 1981; Cancelli et al, 1981; Bertini et al, 1986; Cotecchia et al, 1986).

The results of the analysis showed that peak strength values in terms of effective stresses (consolidated drained direct shear tests (CD) and consolidated undrained with pore pressure measurements triaxial tests (CUDPP)) vary within the following ranges (Fig.21):

$C_p = 0\text{-}0.08$ MPa
$\phi_p = 14^\circ\text{-}27^\circ$

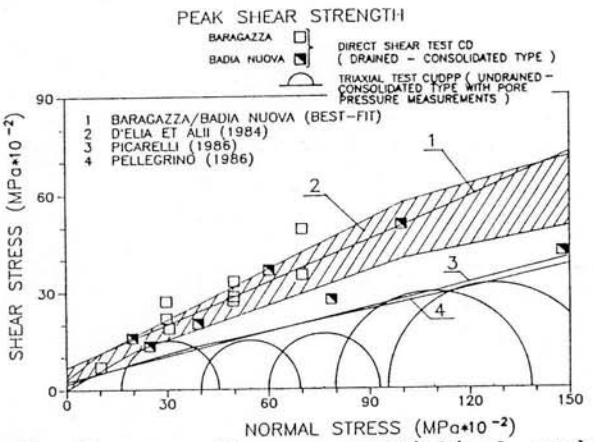

Fig.21 - σ-τ diagram: statistical peak strength envelopes.

The following was obtained for residual strength (consolidated drained direct shear tests (CD)) (Fig.22):

$C_r = 0\text{-}0.1$ MPa
$\phi_r = 9^\circ\text{-}17^\circ$

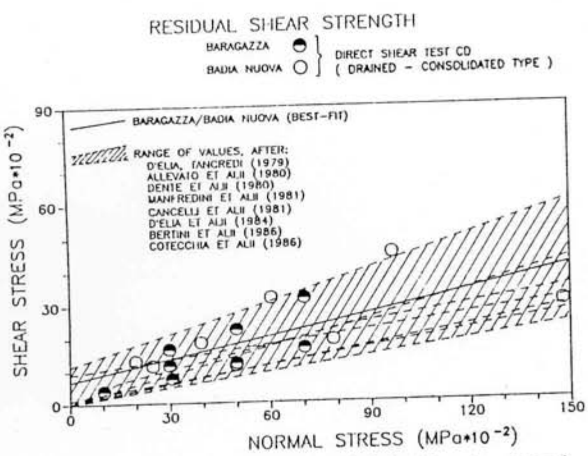

Fig.22 - σ-τ diagram: statistical residual strength envelopes.

For swelling properties, Fig.23 gives, in the triangular diagram, the percentage values of the main mineral phases of the "Argille Scagliose" in the S.Donato tunnel (Barla et al, 1988); the high swelling potential of these lithotypes, which fall in field A of the triangular diagram, is confirmed.

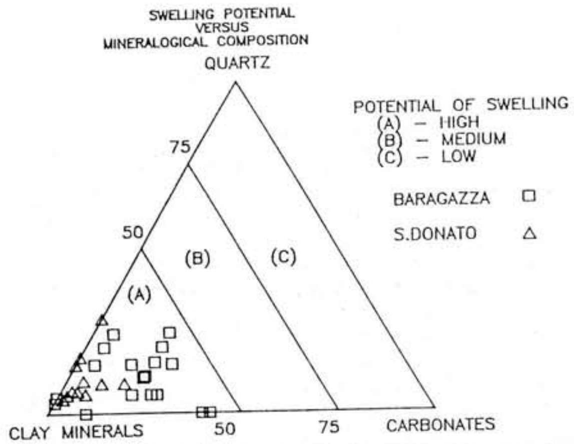

Fig.23 - Statistical distribution of the swelling potential versus mineralogical composition.

Figure 24 gives the percentage deformation values as a function of vertically applied forces. The swelling parameter (k) can be determined from this. The parameter corresponds to the swelling deformation developed with the application of a vertical force of 0.1 MPa and in the case in question is between 5% and 9%.

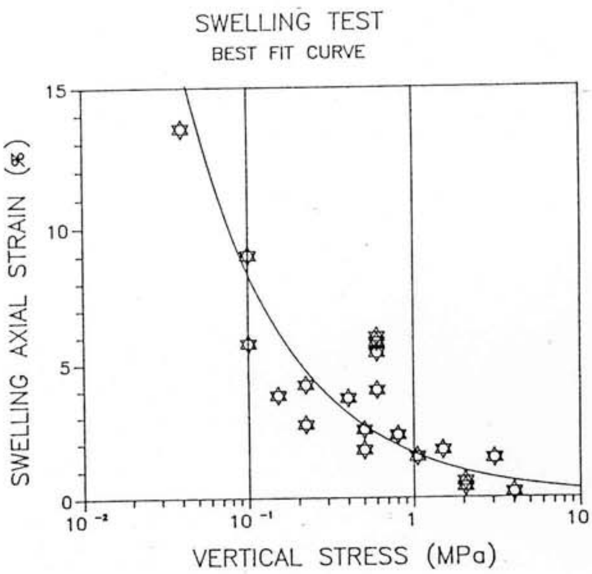

Fig.24 - Swelling test.

11 CONCLUSIONS

The study that was carried out represent a useful contribute to knowledge of the geotechnical features of the "Argille Scagliose", marl-clay materials belonging tectonic-stratigraphic allochthonous units known as the "Ligurid Units".

Outcrops of the "Argille Scagliose" are to be found throughout the Italian Apennines but the study in this paper relates to those belonging to the Northern Apennines, where three important tunnels are to be built. The structure of the "Argille Scagliose" is very complex due to the high level of tectonization and lithological heterogeneity. The latter causes considerable variation in granulometric data.

According to BS 5930, the "Argille Scagliose" are classified as mudstone.

Plasticity properties show that the fine fraction belongs to low and medium plasticity clays. On the basis of mineral composition the "Argille Scagliose" possess swelling potential properties.

The degree of mono-dimensional swelling as ascertained by the swelling tests is in the 5% to 10% range.

The strength properties show the presence of two different facies with different degrees of litification and different mechanical behaviour.

In general, the strength and the deformability properties show wide variation due to the highly heterogeneous nature of the materials. Residual strength values show a high level of decay with respect to the peak values.

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