Some geotechnical aspects of the marls of Corinth Canal

Quelques aspects géotechniques des marnes du canal de Corinthe

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SYNOPSIS: The Corinth Canal is of great importance regarding the navigation in the Mediterranean Sea and the railway and roadway transportation between Peloponnese and the Central Greece. For a better understanding of the mechanical behaviour of the marls, found in abundance in the narrow zone of the Corinth Canal, investigations of laboratory and in situ testing have been carried out including: Drilling of boreholes and sampling; laboratory testing (determination of Atterberg limits, unconfined and triaxial compression tests, residual shear strength characteristics of the different types of marls involved, consolidation tests, etc.); mineralogical analysis by using X-Ray diffraction techniques and electronic microscopy. In this paper after considering the Engineering geological aspects of the area, results of the tests described above are presented and critically discussed, some correlations are given and some comparisons with marls from other areas of Greece are considered.

1 INTRODUCTION

The Corinth Canal, connecting the Corinthian and Saronic gulfs, is of great importance regarding the navigation in the Mediterranean sea and the railway and roadway transportation between Peloponnese (South Greece) and the Central and Northern Greece. It is approximately 6.3 Km long, 21 m wide near the sea level and the depth of the sea is 8±2 m, due to the ebb and flood. The maximum height of the almost vertical slopes is 75 m above the sea level (Fig. 1).

The whole construction of the Canal was completed during the period 1882-1893, whereas the first attempts to cross the Isthmus of Corinth date back to the times of Periander of Corinth (7th century B.C.), one of the Seven Sages of ancient Greece, and of Nero who started the construction in A.D. 67 using 6000 workers.

Fig. 1. A view of the slopes of Corinth Canal

2 GEOLOGICAL CONDITIONS

The broader area of Isthmus of Corinth belongs to the Sub-Pelagonian geotectonic zone of Greece which includes the following main formations:

- Limestones, sandstones and basic igneous rocks of Palaeozoic age.
- Limestones, radiolarites, shales and ophiolites of Mesozoic age.
- Lacustrine and marine deposits of Plio-Pleistocene age, consisting of alternations of marls, sandstones, conglomerates and marly limestones.
- Volcanic rocks (dacites).
- Fluviatile and marine sandstones, as well as conglomerates and porous marly limestones (calcarenites) of Pleistocene age.
- Alluvial deposits (clays, sands and gravels, pebbles, etc.).

In the narrow zone of Corinth Canal only alluvial, pleistocene and plio-pleistocene deposits can be found as illustrated in the geological map of Fig. 2.

The higher slopes are located about the central part of Isthmus and mainly consist of plio-pleistocene marls with interlayers of marly sands and marly limestones. These marls are homogeneous, whitish yellow to light brown coloured in the upper parts of the slopes and become progressively with depth laminated, yellow grey to bluish grey coloured. The central part of Isthmus, were the highest slopes can be found, consists mainly of the latter type of marls which are the primary concern of this paper.

Regarding structural geology, the region suffered an extension phase from middle Pleistocene up to the present time, with the reactivation or the formation of normal faults with an E-W direction. The high seismicity and the manifestation of strong earthquakes, in the broader area, are closely related to this late tectonic evolution.

Along the Corinth Canal, Philippson (1890) reported 23 main faults, whereas Freyberg (1973), in a detailed mapping of the Canal slopes, marked 45 faults which created a series of tectonic grabens and horsts. Finally, the recent main faults were mapped by Sebrier (1977).

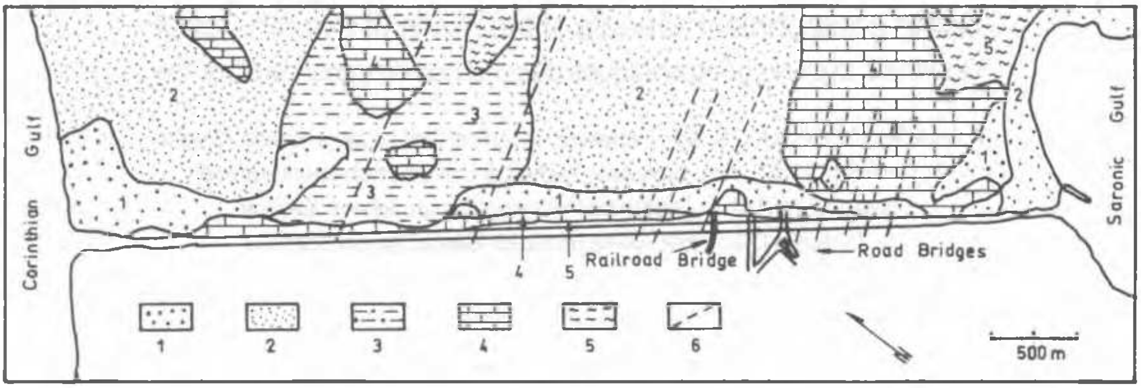

Fig. 2. Geological map of the narrow area of Corinth Canal; 1: Excavated material from the construction of Canal; 2:Alluvial deposits; 3:Clayey sand, Pleistocene; 4: Calcarenite, Pleistocene; 5: Marls Plio-Pleistocene; 6: Fault trace.

It must be noted that the tectonic blocks between abjacent faults are crossed by a series of subvertical joints running parallel to the faults and forming on angle of 30°-40° with the Canal axis. These joints were extended during the strong earthquake of 1981 and caused some problems of instability in the region close to the abutments of the railroad bridge (Christoulas et. al., 1984).

3 GEOTECHNICAL INVESTIGATIONS

A great number of boreholes were carried out to identify the subsurface geology and to obtain samples for laboratory testing. These boreholes were performed during the geotechnical study for the reinforcement of the abutments of the railroad bridge over the Canal and during a main geotechnical investigation program for the deepening and widening of the Canal.

Furthermore, block samples, with dimensions of about 40X40X40 cm, of the bluish grey marls were carefully taken from the toe of the high slopes and 2.5 m above the sea level.

The undisturbed samples from the boreholes were obtained by use of a Denison double core barrel, whereas, the block samples were carefully cut by a saw and then sealed thoroughly with paraffin wax.

The minimum recorded SPT value was 18 (30 cm penetration) at about 10 m depth and the maximum of 50 blows for 8 cm penetration was at depths greater than 26 m.

The water content varies between 18 and 33 % whereas the results of the unconfined compression tests showed values, between 150 and 700 kPa.

4 PHYSICAL AND MECHANICAL PROPERTIES OF MARLS

4.1 Mineralogy

Specimens of yellow grey to bluish grey marls were examined from a mineralogical point of view in order to specify their composition and the type of clay and non-clay minerals.

Using the X-Ray diffraction method and taking into account the chemical analyses carried out, calcite and quartz were identified as the major non-clay constituents with feldspars and pyrite being present in very small quantities. Regarding the clay minerals,these consist mainly of illite, chlorite and illite-montmorillonite. Calcite varies from 73 to 77 %, quartz 13 - 17 %, feldspar 2 - 4 %, pyrite less than 1%, whereas illite ranges between 1.5 and 3%, chlorite 1 - 7 % and illite-montmorilonite less than 1%. From the above analyses it is obvious that the percentage of the clay minerals is very small and varies between 4 and 8.5 %.

On the basis of calcium carbonate content these yellow grey to bluish grey Corinthian marls are classified as limey marls.

4.2 Grain Size Distribution and Atterberg Limits

Grain size distributions were determined using oven-dried samples by both sieve and hydrometer analysis.

Envelopes of particle size curves are shown in Fig. 3. As it is illustrated in this figure, the percentage by weight finer than 74 μm ranges from 88 to 100 %, and the clay size fraction (<2 μm) between 13% and 24%. Thus, the silt fraction is very high taking values of about 75%.

It is clearly noticeable that the clay

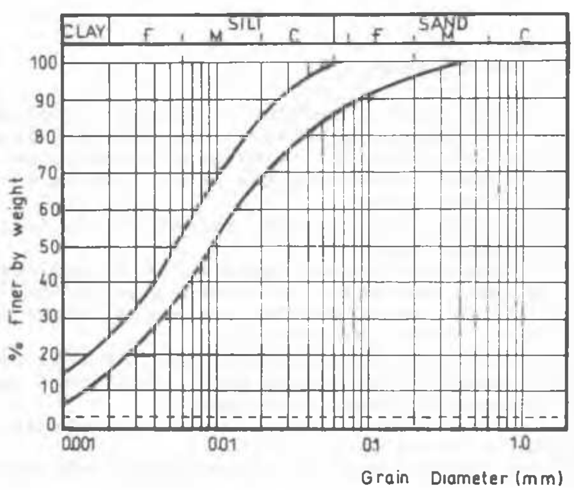

Fig. 3. Envelopes of grain size distribution of Corinthian marls

fraction, as determined by grain size analysis, is much higher than the "true" clay mineral content. This is due to the presence of micritic, material of calcite and quartz in the fraction of these marls which is finer than 2 μm, and this, as it will be shown later, has a great effect on the values of the residual shear strength of the marls considered.

This phenomenon has also been noted in some other limey marls of Greece (Tsiambaos, 1988). On the contrary, clayey marls of Greece may present an aggregation ratio (ratio of clay minerals to clay-sized content) greater than 1, especially when the clay minerals content is greater than about 30%. Davis (1967) and Dumbleton (1967) have also shown that the less weathered marls, which may appear to have as little as 10% of clay-sized particles as measured in the sedimentation test, may in fact contain up to 80% clay particles.

Liquid and plastic limits were determined from oven-dried samples passing U.S. Standard sieve No 40. In Fig. 4 index properties of yellow grey

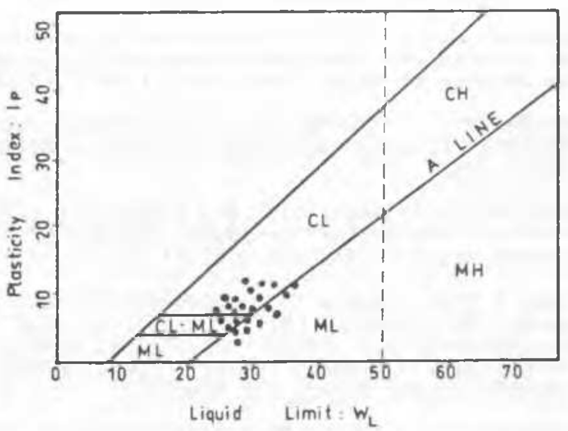

Fig. 4. Plasticity chart for Corinthian marls

to bluish grey marls are plotted on a plasticity chart. As it is shown, the liquid limit of these marls varies between 25 and 37 an the plasticity index from 3 to 12. Therefore, these marls are classified according to the Unified Soil Classification System (USCS) as clays of low plasticity (CL) or silts of low compressibility (ML, Cl - ML).

Activity, as defined by Skempton (1953), is the ratio of plasticity index to percentage of the clay-sized fraction (<2 μm). This parameter cannot be applied to the Corinthian marls since the clay sized fraction is higher than the true clay mineral content. Thus the "Activity" of the samples of the marls examined, takes a value of about o.30 (inactive) when clay-sized content is taken into account, whereas values of 0.90 (normal to active) are found when the true clay mineral is used.

4.3 Shear Strength Properties

A series of tests on the bluish grey marls of Corinth Canal were carried out in the triaxial apparatus. Consolidated undrained compression tests mainly on 3 in long by 1 1/2 in diameter specimens were conducted.

Cell pressures up to 3.5 MPa were used and a back pressure was applied in all tests to ensure full saturation of the specimens. In all cases strain rates were calculated to be slow enough to achieve 95% equalization of pore pressure at failure.

Figure 5 shows the failure envelope obtained from the triaxial consolidated undrained tests. The failure envelope shows a considerable curvature at the low and high stress levels.

The failure envelope is quite well defined with a slope varying from 40° close to the origin to about 30° at a cell pressure greater than 2 MPa.

It is of interest to consider more closely the main reason for the curvature of the failure envelope. It may be associated with the increasing breakdown of the cemented interparticle bonds of the marl under the increasing shear stress which causes a remarkable fall in the frictional resistance of the marly material. The presence of the carbonates (calcium carbonate) is responsible for the existence of these bonds, ordinarily acting as a cementing agent of the particles of marls.

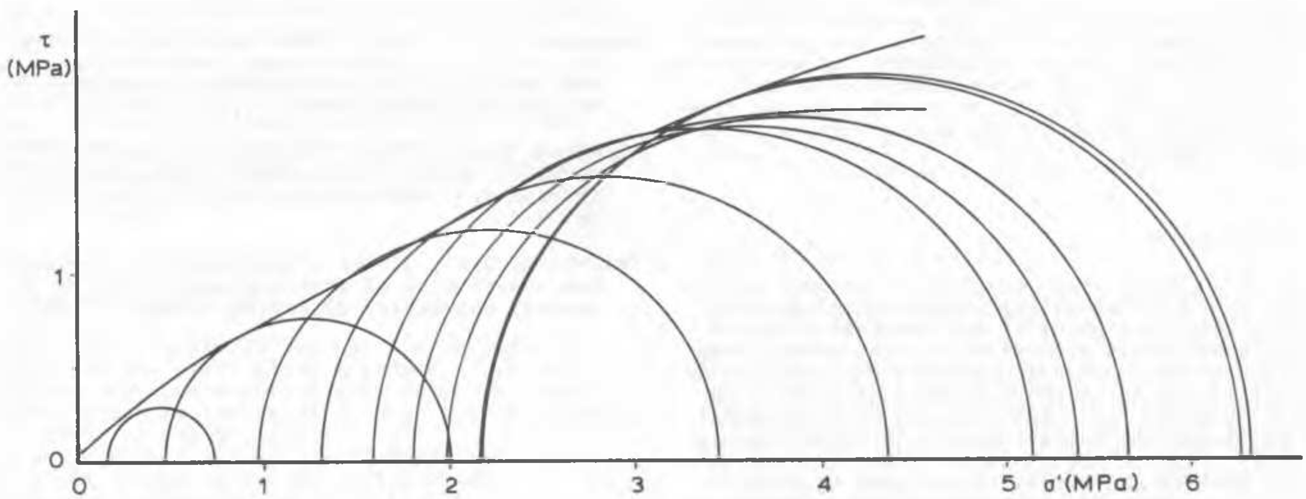

Fig. 5. Effective stress failure envelope obtained from consolidated undrained triaxial tests

4.4 Residual Shear Strength

Figure 6 shows the variation of the residual angle of friction with effective normal stress for three samples of yellow grey to bluish grey marls, as obtained by using the ring shear apparatus (Bromhead, 1979). The specimens were in general remoulded at water contents very close to their plastic limits so that extrusion of the sample material from the groove of the apparatus was avoided. The strain rate was slow anough to achieve full pore water pressure dissipation at all stages of shearing (drained test).

It can be seen from this figure that the resi-

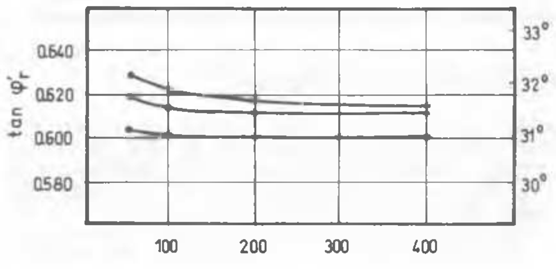

Fig. 6. Residual angle of friction of marls

dual angle of friction varies between 31° and 32°. These values of residual angle of friction can be considered as sufficiently high, but they are in very good agreement with the relationships between clay fraction and plasticity index suggested by Lupini et. al. (1981) and Skempton (1985).

However, it must be emphasized that the above relationships are closely obeyed only if one takes into account the "true" clay minerals content and not the clay fraction determined by sedimentation analysis.

These values of residual angle of friction are in accordance with the values obtained by testing a series of Iraklion (Crete) limey marls with about the same calcite content (>65%). On the contrary, other Iraklion marls with a lower calcite content exhibit values of residual angles of fricrion of the order of 24°-26° mainly depending on the calcite percentage (Tsiambaos, 1988), whereas clayey marls from other parts of Greece have shown much lower values, in the range of 14°-16°.

The residual angles of friction, for all samples show little variation with the values of normal stress in the low stress range (<15C kPa), but generally and for all practical purposes they can be considered as independent of the value of normal stress.

5 CONCLUSIONS

Corinthian marls which constitute the main geological formation along the Corinth Canal exhibit some interesting physical and mechanical properties. These marls are mainly classified as limey marls with high calcium carbonate contents and very low values of "true" clay minarals (<9%). On the contrary, clay-sized contents as determined by sedimentation tests showed much higher values (23-24%), due to the presence of micritic material of calcite and quartz. This fact, together with the presence of cemented interparticle bonds seems to be responsible for the high values of both the effective shear strength parameters and the residual angle of friction.

The curvature of the failure envelope can be related to the gradual breakdown of the cementation bonds of the marly material.

Further research is needed concerning the more accurate determination of the failure envelope, using more elaborate testing techniques, stress paths and initial stress conditions.

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