Improvement of clay and silt by dewatering with a new anchoring technology

L'amélioration des argiles et des limons par épuisement de la nappe avec une technologie nouvelle d'ancrage

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SYNOPSIS: Recent efforts have been made in an Austrian Coal Mine to develope and practically use a new anchoring technology to improve clayey-silty soils and thus stabilize the tunnel. This new anchoring technology is based on the application of electro-osmosis in connection with perforated metal anchors. Dewatering in highly dense and almost impermeable silty clays is economically only possible when using low voltage electric current.
Dewatering resulted in significant increase of shear strength and stress/strain tests did also show significant improvement of anchoring capacity. As anchors act at the same time as electrodes for the electro-osmotical dewatering, special economic advantages are captured. Because of periodic changes of cathodes and anodes, homogeneous underground improvement is provided.
The duration of operation described is in the range of several hours only.

1. INTRODUCTION

For many years silty and clayey soils have been a problem in tunnel construction, especially when combined with water and thus creating soft ground conditions. Solutions have been found in connection with full-face shield-technologies, assisted by compressed air, slurry supported faces and sometimes with ground water lowering wells. More recently earth-pressure-balance shield systems have been developed. Due to short stand-up time of such soils mostly precast concrete lining in circular shapes have been used even if short distances did not justify high mechanization. An other alternative to stabilize such soft clays is ground freezing, which is consuming high amounts of energy wether based on liquid nitrogen or on calzium-pot ash.

All these methodes have in common, that they are expensive in relation to the main construction work, which they are only assisting. In the course of their professional career the authors made experiences with respective projects described as follows.

In 1972 a subway section of the city of Stuttgart/F.R.Germany has been designed to drive tunnels in silty clays, to be stabilized by circumferential soil freezing. An alternative has been investigated with the help of clay and silt anchors, but has been rejected because of little knowledge at that time, though offering significant economic advantages.

In Eastern Austria a highway tunnel has been under construction in 1976, which created big problems when running into silty clays. Soil samples have been investigated at the site, trying to find out wether the soil characteristics of these very soft conditions can be improved when treated with electro-osmotic dewatering or not. Though the results did confirm the assumptions, the project was under construction and did not allow significant changes of the construction procedure.

Roughly at the same time another highway tunnel in Southern Austria had some soft clay problems, and again the proposed alternative with clay and silt anchors could not be realized because of the projects maturity and the on-going construction procedure.

Both projects have been constructed under conditions requiring changes in the construction procedure, but based on conservative and more expensive solutions.

As a consequence of these experiences a research and developement project has been established in 1985, which resulted into the application of a program supported by the "Research Foundation" of the Austrian Government

In the course of this program extensive investigations in the laboratory and in the field have been executed. This paper deals with the results of these works.

2. BASIC IDEAS

Since about 100 years it is well known from literature, that soils of high density and little permeability are difficult to dewater. Solutions have been found among others with electro-osmotic treatment of these soils by using cathodes and anodes at low voltages. When dewatering such soils, the mechanical properties are improved, which means also improvement of shear strength and stand-up time. For tunnellers that means improvement of tunnelling conditions.

In conventional tunneling, anchoring technologies increased their importance by covering more and more possible geomechanical conditions. A combination of both technologies promised to offer significant advantages, and to open new feasible possibilities in underground construction. To realize the concept of improvement of soil stability, research work has been necessary and has been fulfilled in the course of "the clay and silt anchor research program".

3. TEST-RESULTS IN LABORATORY

Regular electro-osmotic dewatering is well known and acts usually successful in silty soils. One of the aims of the research program was to find out if it is possible to reach homogeneous conditions in the soils investigated.

While in regular tests the soil is only dewatered in the vicinity of the anodic electrode, the soil in the vicinity of the cathodic electrode is enriched with water and thus even more difficult to treat from the point of view of tunnelling.

Therefore it has been important to investigate the possibility of alternating terminals which means, that the direction of electric current was to be switched in course of the test program several times.

By having one electrode for both cathodic and anodic conditions, the soil has been treated in both directions of the current field, and homogenous conditions were reached in the test using specially selected uniform grained clay and silty material, which provides reproducable test-conditions every time.

After some series of dewatering tests the soil material has been suitable for another important test program.

As it was assumed, that as a consequence of the dewatering the shear behaviour of the soil should also be improved, the anchors, first acting as kind of dewatering wells, should also be able to act

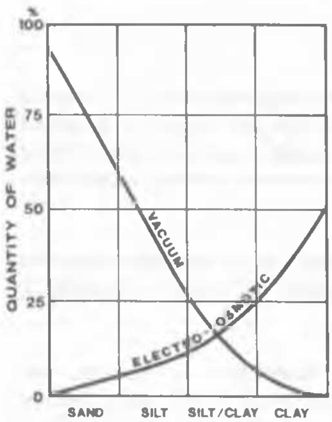

Fig. 1 Relation between dewatering by vacuum and electro-osmotic dewatering (by L.K.Tervinskaia)

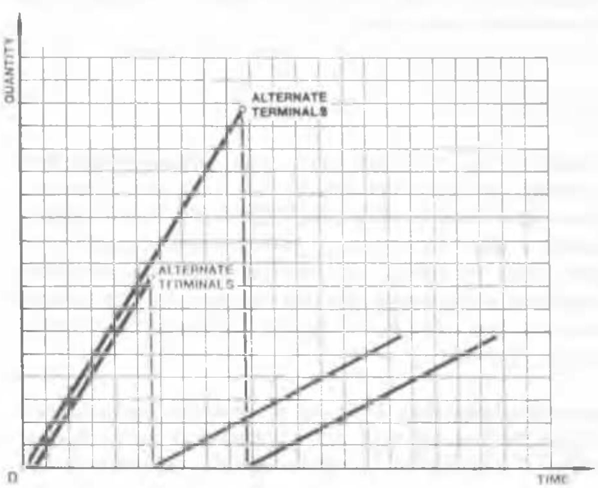

Fig. 2 Electro-osmotic dewatering relationship by alternating the terminals

Fig. 3 Laboratory test arrangement for homogeneous dewatering

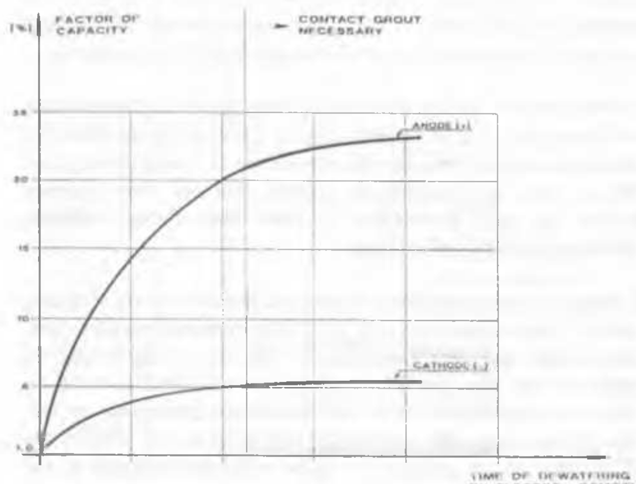

Fig. 4 Results of laboratory tension-tests

as tension bolts. Therefore series of tension tests have been carried out, recording at the same time acting forces and deformations produced. The results of these tests did show much bigger forces and much smaller deviations, than expected.

4. RESULTS IN THE FIELD

After the test program in laboratory has been finished successfully, it was the target of the research work, to prove the applicability of the system developed so far under real underground conditions.

The site has been an Austrian coal mine, in between the cities of Linz and Salzburg. This coal mine is owned by SAKOG-company.

From the geologic point of view in depth of approx. 100 - 180 m the coal seems are embedded in mostly stable clay, but also clay-stone and sand-stone formations. In some areas the clays became very soft, when they got in touch with water. In sections already excavated, this circumstances created real problems for the stability of the tunnel and especially for the continuity of the coal mine production.

The clays in the region of the problem have been investigated with a special developed measurement device with respect to the electro-osmotic characteristics, to find out if they are reacting or not. The water content has been close to liquid limit with high plasticity. After it was found that the required conditions are available, the test field has been selected.

One of the conditions to carry out the tests was the requirement to guarantee uninterrupted operations and production of the mine.

The field itself consisted of 8 anchoring rows, spaced with 0,8 m per row, and a total of 48 anchors. The average lenght of each anchor was 2,50 m with an internal diameter of 2". The placing of the anchors has been done with a special ram.

As anchors have been placed downwards, the water collected in the anchors was to be pumped out by means of special pumping equipment.

With respect to mining respectively tunnelling practice it showed as a result of the application in the tested anchor field, that both the dewatering and the stabilization effects as expected from the laboratory tests, have been confirmed under real field conditions.

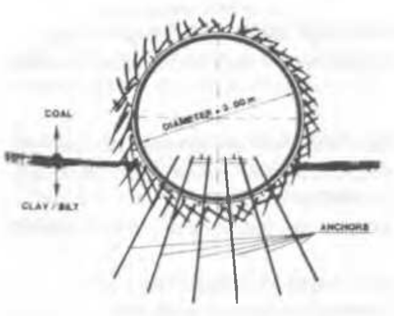

Fig. 5 Test-field, cross-section

The problems in connection with the installations of the necessary equipment (ramming equipment, transformers, pumps, double track recorders and other measurement devices, as well as energy, compressed air) could be solved to the satisfaction of both, the mine, and the research program.

5. SUMMARY AND CONCLUSION

For more than a decade observations have been made and problems have been discovered in more than half a dozen projects when tunnels have been driven through soft and silty clay conditions.

Based on the idea, that highly impermeable soils try to keep the water in their capillar system and produce difficulties when dewatered, electro-osmotis has been found to be a reasonable and

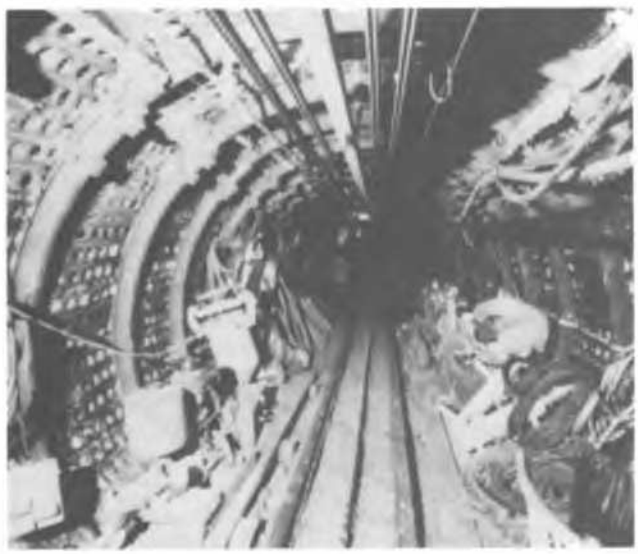

Fig. 6 Coal-mine-test field-area

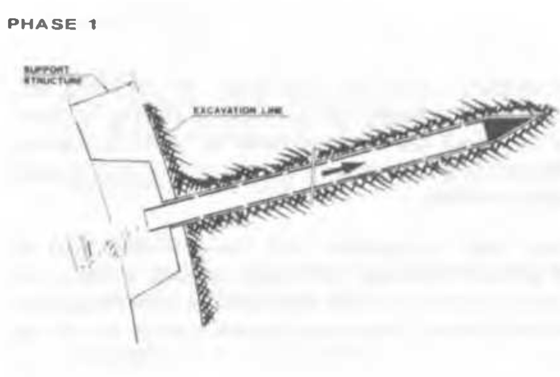

Fig. 7 Placing of Anchor

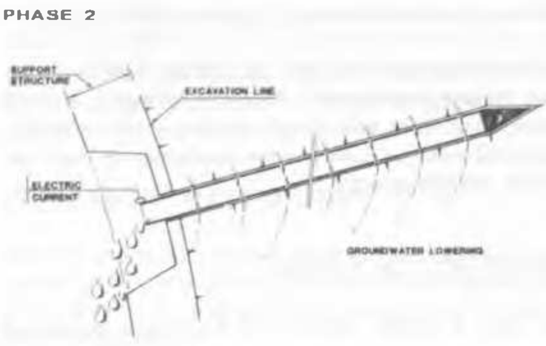

Fig. 8 Electro-osmotic dewatering

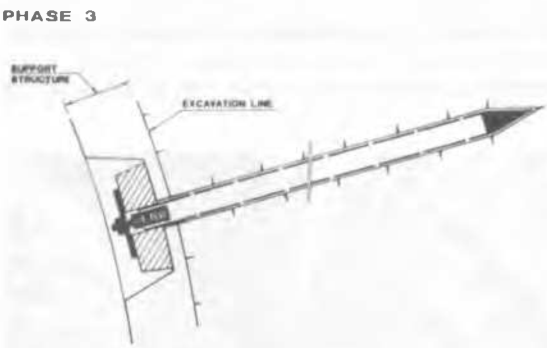

Fig. 9 Installation of Anchor-head

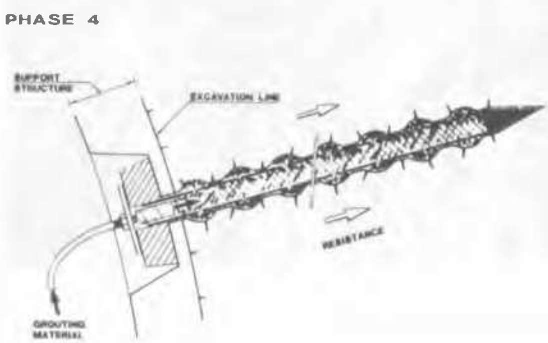

Fig. 10 Contact-Grouting

highly economical method for dewatering. By combining this method with latest knowledge on the effect of anchors, a system has been developed and made available for users in practice. Laboratory and field investigations did lead to proposals to solve such difficult problems.

The system itself is applicable and flexible with respect to different ground conditions and cross sections. Usually the problems starts in the crown and can be solved just by arragement of pre-running almost horizontally placed anchors in the top heading.

According to greater thickness of the respective layer these anchors could be extended also in the side walls. The rate of

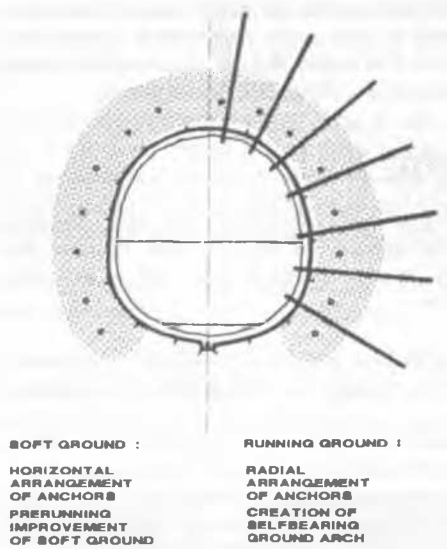

Fig. 11 Cross-section of an example of an application for tunnelling

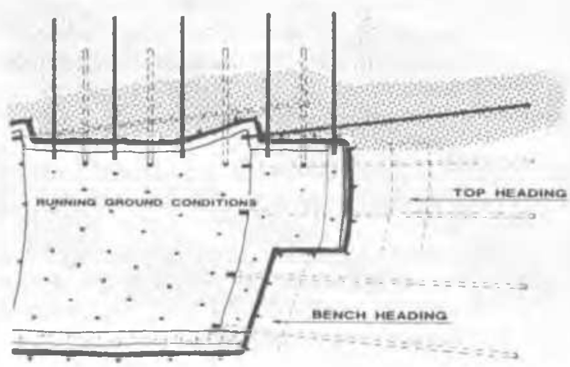

Fig. 12 Longitudinal section CS-anchor arrangement

advance depends on the possible length of the excavation section.

Improvement of the soil usually doesn't last longer than 12 to 24 hours. The amount of electric current is low at also low voltages. If additional support resistance is required after installation of initial lining (e.g. steel arches, wire mesh, shotcrete) due to continuation of deformations, this can be achieved by placing radial anchors, thus creating additional selfbearing arches in the soil.

From the construction point of view the development of a project under such difficult ground conditions should start with soil mechanic investigations, followed by

- first cost estimate, in conjunction with project optimization
- general design to be based on a feasibility study
- offer for works, based on detailed design and
- technical assistance during construction.

It is essential for each of such projects, to use the advantage of

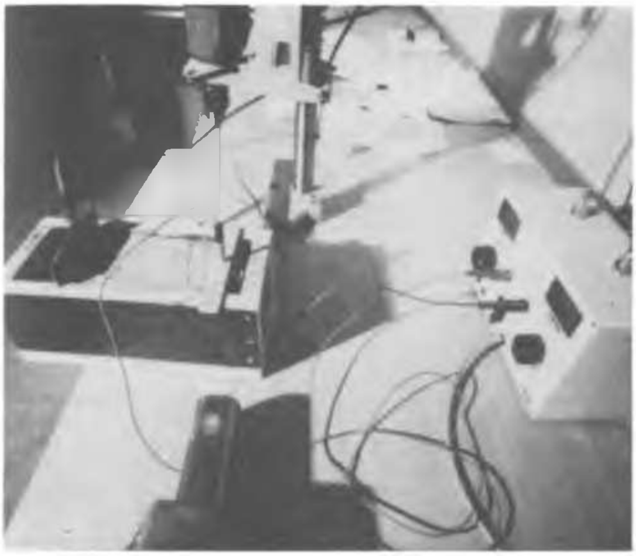

Fig. 13 Testing device for electro-osmotic soil reaction

available experience and a complete set of equipment, consisting of

- CS-anchors with respective placing equipment,
- direct electric current,
- pump units and distributors,
- grouting units,
- compressed air if necessary,
- micro-processor for pump controlling and,
- other recording and controlling units.

6. ACKNOWLEDGEMENT

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