Tunnelling in Soft Ground

Tunnels dans les Sols Mous

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The Specialty Session No. 1 was organized and prepared by Dr. H. Breth, the Organizer and Mr. O. Moretto, the Co-Organizer until immediately before the Conference. But, due to unavoidable reasons, both Dr. Breth and Mr. Moretto became unable to attend the Conference. The Organizing Committee appointed Dr. S. Ibukiyama (Japan) as the chairman of the Specialty Session No. 1 and Mr. M. Londez (France) as the vice-chairman. The Session was presided by the Chairman and Vice-Chairman on behalf of the Organizer and Co-Organizer. The session program was prepared by the Chairman based on the Organizer's program, as follows

1. Opening Address: Prepared by the Organizer and read by Dr. H. Sommer on behalf of the Organizer

2. Presentation of Selected Papers

Surface Settlements due to Shield Tunnelling in Rome	M. Ottaviani
Tunnelling in Soft Ground with the New Austrian Tunnelling Method	J. Golser
Tunnels in Granular Soil: Washington and Baltimore Case Histories	B. Shmidt
The Principle and Field Experiences of a Slurry Mole Method for Tunnelling in the Soft Ground	G. Miki

3. Floor Discussion

4. Closing Address: Chairman

The Chairman made a brief review on the presented papers before the floor discussion. In the closing address, the chairman stressed the need for the further research, including environmental and contractual aspects.

(T. Konda :Session Secretary)

The tunnelling in soft ground in urban area has gained in point with the increasing traffic problems. This was doubtless a reason why this theme was thoroughly dealt with at the 7th International Conference (1969) in Mexico and at the 5th Panamerican Congress (1975) in Buenos Aires. PECK [1] gave in his State-of-the-Art report in Mexico a comprehensive review on the problems in shallow soft ground tunnelling. He came to the following conclusion: "In a mixed heading, conditions may lead to greater surface settlements than would occur if the heading were being constructed in any one of the individual materials. One of the most urgent needs for the advancement of the art of tunneling is further detailed information about settlements associated with a variety of soil conditions and methods of tunneling. Because of the dependence of loss of ground on construction details, there seems little likelihood that theoretical investigations will prove fruitful except for some of the simplest of materials such as plastic clays. Full-scale field observations remain of outstanding urgency."

CORDING et al [2] in his general report analysed thoroughly the type and source of lost ground in the different soil conditions, and recommended the average slope of the settlement trough as a parameter for evaluating damage to structures.

Following the suggestions of these conferences, three topics were chosen for discussion in this Specialty Session:

1) Correlation between construction methods and deformation of soil and earth pressure

2) Measurements of settlement and earth pressure

3) Methods of Calculation

Compared with current interest in the tunnelling in soft ground, just a few papers were proposed to submit. Among these, only seven papers are concerned with the matters for discussion, six of them dealing with shield tunnelling. Only one paper reporting on the so-called New Austrian Tunnelling Method let us know a recent line of development and way of thought.

1 SHIELD TUNNELLING METHOD

1.1 Heterogeneous Soils

Since shield tunnelling method was firstly used in London for tunnelling below the Thames 150 years ago, there has been a remarkable technical improvement. However it remains the same from principle. The tunnelling procedure was developed from hand shield to fully mechanized shield, in which detail of shield is finally determined by soil and groundwater conditions.

SCHMIDT [3] presents problems associated with shield Tunnelling in a mixed granular soils with little cohesion, and introduces a concept of soil tensile strength for assessing stability of tunnel against roof and face fall-out. Based on this concept, he shows how the behaviour of such soils in tunnelling may be predicted in advance with the aid of two case histories. This paper delivers an interesting matter for discussion of experiences gained in cohesionless soils. Ther arises particularly the question in how far the behaviour of mixed layers of water-bearing sands and silts located below the groundwater level can be predicted from laboratory test results and theoretical considerations as well as the construction procedures can be chosen after these considerations or whether we should employ also in the future the tunnelling technique so flexible that it may be provided for all eventual cases; In addition to dewatering mechanical or hydrostatic support of tunnel face, compressed air, method of vacuum drainage , grouting , and ground freezing are to be mentioned.

MIKI et al [4] in their paper show how the tunnel face can be supported by slurry mole method. With fluid pressure from slurry, the soils at tunnel face are kept stable, and so the loosening of ground is reduced to a minimum. They describe the percolation properties of the slurry fluids which have to posses in order to fulfil their supporting task, and present briefly three case records with data on surface settlement along the tunnel axis. It would be interesting to learn how the settlement trough in the tunnel cross-section has formed , so that results obtained by the mud-shield method can be compared with those obtained by other methods. Perhaps, the authors could give some additional information about it during their report. The temporary support system with slurry fluid from bentonite, clay or loam has also been used in Mexico, Great Britain, and Germany, and seems to be a useful mean for stabilising the tunnel face, even if the groundwater level is high and the soils are to be hardly injected by grouts or chemicals.

As another way for reinforcement of soils near an advancing tunnel heading, the ground freezing method seems to become recently more important. This method presents an interesting solution, when the effect of grouting on sealing and reinforcement appears to be questionable due to soil conditions. As an example, a subway tunnel constructed in Stuttgart is described [5] . The subsoil consists of keuper marl, an irregular series of saturated silts and silt-stones which are rapidly transformed into a slurry-like medium during excavation, and are consequently washed out. With 40-m long pipes drilled for supplying freezing fluid, an arch-shaped frozen body was previously provided at tunnel crown as shown in Fig. 1, and under this hood a tunnel tube having 8 to 11-m diameter could be excavated without a shield. To safeguard the tunnel mined in this way a 25-cm thick shotcrete liner was placed on the excavated, frozen tunnel wall. The maximum surface settlement due to tunnel excavation was on the order of 10 mm, and a settlement of 15 mm was added to this due to additional drainage measures. The frozen body hinders leakage of groundwater into the tunnel, and so the tunnel face could be kept stable. In like manner twin tunnels with a diameter of 7 m are being driven in Frankfurt just few meters below the Main River. The ground is composed of stiff plastic clay with irregularly interbedded, water-bearing sands and limestone bands which should be drained for tunnelling.

Tunnel excavation under protection of frozen crown or frozen ring appears to be promising, if in saturated fine sands, silts, and clays, particularly in heterogeneous soils, method of vacuum drainage or grouting can not guarantee the stability of tunnel face. The use of ground freezing method for tunnelling has become possible, after with the aid of the drilling technique available, the pipe for freezing fluid can be installed in the desired direction of target and so, construction of frozen body in a statically required dimension can be guaranteed.

1.2 Cohesive Soils

The conditions given for tunnelling in cohesive soils, compared with those in the cohesionless soils, are more favourable for the stability of tunnel face as well as for the prediction of settlements.

ITO et al [6] show in their paper how the external pressures acting on tunnel lining can be computed by using the integral equation method. The analytical results are compared with the experimental values obtained from model tests and in-situ measurements.

NIWA et al [7] describe various types of segments, and introduce newly developed reinforced concrete segments with which tunnels excavated by means of shield and compressed air are supported. According to the full-scale loading tests these new segments equipped by pin and mortise result in more favourable distribution of ring stress and smaller deflection of lining. The conditions for this are also rapid closure of the tunnel ring and grouting into the tailpiece void as the tunnelling machine advances. The authors stated that the erection of new-type segments had required less time than the other kinds of segments.

The settlement of ground surface depends mainly on the depth and size of tunnel, and naturally also on the deformation behaviour of soils. Furthermore, it is largely influenced by the excavation process at the tunnel face, the duration of ring closure, and grouting behind the ring. There are two papers dealing particularly with the deformation behaviour of clays for shield tunnelling.

PALMER et al [8] present field measurements in a 2,16-m diameter tunnel constructed in a soft to firm clay. They give observed data on surface settlement and soil deformation as well as total pressure on the lining and deformation of the lining. It is noted that about 70 % of the soil deformation occurred after the tailpiece of the tunnel boring machine had passed. These finings correspond with the experiences gained in Frankfurt clay.

OTTAVIANI et al [9] report on a subway tunnel in Rome. Two parallel tunnels with a diameter of 5,5m are driven in clay one after the completion of the other using a mechanized tunnel shield, and surface settlements are measured in 9 tunnel sections. The measured values are compared with results of finite element analysis. The computed settlements are about 10 - 20 % greater than the observed values. It was noted that this fact was for the reason that the presence of the tunnel lining and grouting into the voids had not been considered for the finite element analysis.

2 NEW AUSTRIAN TUNNELLING METHOD

In Austria a new tunnelling method, known as New Austrian Tunnelling Method (NATM), was developed in the fifties. In contrast with construction procedures previously mentioned, the soils are considered in this method no longer simply as loading, but are also mobilized to carry loading for a limited duration. In opposition to the shield tunnelling a support system is provided in cooperation with the soils, shotcrete lining, and rock bolts in which the final tunnel lining can be accomplished. The application of this method is conditioned by nature of soil which is at least for a while stable enough or which can be made stable by additional measures such as grouting or ground freezing.

GOLSER et al [10] describe procedure and substantial characteristics of NATM, and compare settlements observed in a subway in Munich with results of the finite element analysis. The NATM is distinguished by a minimum employment of machines and large flexibility to excavation and erection of lining. By means of several excavations stages and erection of shotcrete lining a circular ring can be formed, and under this protection the tunnel can be sealed, and then the inner concrete ring is lined.

In 1970, experimental twin tunnels were excavated simultaneously in stiff-plastic, fissured clays in Frankfurt at a depth of 6 m below structures by means of the NATM. Under the same soil conditions twin tunnels with the same size and depth were driven one by one by a shield. Consequently, there was an opportunity for comparing both tunnelling methods with regard to the settlements and earth pressure acting on the tunnel walls. An extensive field instrumentation program was carried out, and ground displacements were measured not only along the tunnel axis, but in tunnel section (Fig. 2) as well [11], [12], [13]. From these observations it can be concluded as follows: In both cases the settlement occurred with time can be divided into 3 stages; A primary settlement occurs until soils begin to loosen over the tunnel crown. It is succeeded by a main settlement, once the soils start to settle at the crown more rapidly than at the ground surface. It is associated with loosening of soils above the tunnel crown. The remaining settlement may be comprised in a subsequent settlement.

In case of shield-driven tunnel the primary settlement is small, conditioned by the art of support system at the tunnel face and by the shield resistance to bending. As shown in Fig. 3 the main settlement occurred after the shield had passed; about 6 m high zone was disturbed, and loosened. Immediately above the tunnel crown a main settlement of 30 mm and a subsequent settlement of 10 mm were recorded. The surface settlement over the centerline of the tunnel was 30 mm altogether. It implies that the soils settle uniformly over the loosened zone. The main settlement can be reduced by rapid and complete closure of ring space by grouting.

In case of tunnel mined by NATM the main portion of settlement occurred before the tunnel had been excavated until the measuring point. It is associated with a corresponding loosening of soils. Like in shield-driven tunnel, this disturbance extends to a limited height above the tunnel crown. The soils overlying this zone do not develop the surface settlement. The height of loosened zone corresponds to about the tunnel diameter, i. e. about 6 m. The loosening of soils and the main settlement are stopped, when the ring is closed. Then, the subsequent settlement occurs due to the compressibility of shotcrete ring. This portion to the total settlement is small. Both primary and main settlement are dependent on the procedure of excavation, while the subsequent settlement is **not** dependent on it. The latter can be controlled to a limit by the thickness of shotcrete lining and reinforcement with wire mashes installed within it. According to the observations in Frankfurt clay the deformation develops in the loosened zone with a constant velocity. Thus, the main settlement depends on the rate of tunnel advancing and the length of excavation. Consequently, the main settlement can be reduced by short length of excavation step, rapid closure of the ring, and use of rapid-hardening shotcrete.

The NATM, compared with the shield tunnelling, offers considerable advantages. In the traffic system of urban area, twin tunnels by a shield are usually driven one after another. After completion of the first tunnel excavation the shield is turned, and the second tunnel is driven in return. Therefore, the settlement troughs caused by excavations of first and second tunnel are superimposed. This superposition results in a "see-saw" movement to which structures react more seriously than in the case of twin tunnels driven simultaneously by the NATM. The settlement trough is flatter in latter case and induces less damage to structures. In contrast with shield tunnelling, the excavation procedure can be adopted to soil conditions surrounding the tunnel face, in particular, if plastic clays like in Frankfurt are interbedded irregularly with bands of hard limestone. In the meantime this method has been improved with further construction of two tunnels located over one another and a large metro station in Frankfurt. This metro station was constructed by means of tunnels driven side by side as well as one above. Figs. 4 and 5 show the layout, the succession of the tunnels driven, and the surface settlements occurred. In combinations of grouting and ground freezing, the NATM can be employed in difficult and heterogeneous soil conditions. Thus, this method is an equivalent alternative to shield tunnelling.

With the third topic it should be discussed how far it is possible from present sight to predict the settlement occurred due to tunnelling and which methods of calculation are available. Because of obvious influences of excavation method, detail of shield as well as soil conditions altering not seldom in short distance, there seems to be little hope for application of the calculation methods to cohesionless and heterogeneous soils, except for the plastic clays. Investigations performed by OTTAVIANI et al [9] for shield-driven tunnel in Rome and by GOLSER et al [10] for a Munich subway excavated by NATM show satisfactory agreement of experimental and analytical values. We also have obtained an efficient agreement of computed and observed values for the experimental tunnels constructed in Frankfurt by the NATM. The deformation characteristic of Frankfurt clay obtained from undrained triaxial tests was used, under assumption of non-linear stress-strain behaviour, for the finite element analysis. WANNINGER [14] illustrates with Fig. 6 that anchors installed at the tunnel crown and sides have little influence on the surface settlement trough, but seem to be of most significance for the stability of tunnel and for forming and arching in the ground.

Messrs.GOLSER, MIKI, OTTAVIANI and SCHMIDT will now present the papers submitted by them to this Session. I hope their presentations lead to an active discussion. I would like to propose the following two themes for discussion:

1) Influence of construction procedures and measures for safeguarding on the magnitude of settlement and deformation

2) Usefulness of finite element analysis for predicting the effect of constructional measures on the stability of tunnel and nearby structures

In particular, the question should be discussed in how far in a special case the stress-strain relationship of soils can be determined with an accuracy which is a condition for the application of finite element analysis to be able to give a recommendation, or whether this analysis is rather to be understood in order to make general statement about the influence of constructional measures depending on the deformation characteristics of soils and on geometric boundary conditions, whithin the scope of parameter studies.

The four papers and discussions presented to this Session will be published in seperate Proceedings which will be distributed upon request by Deutsche Gesellschaft für Erd- und Grundbau e. V., 4300 Essen, Kronprinzenstrasse 35a, F. R. G.

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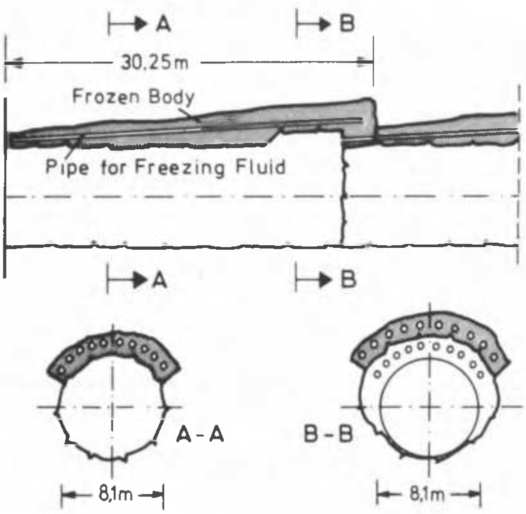

Fig. 1 Ground Freezing in Metro Stuttgart

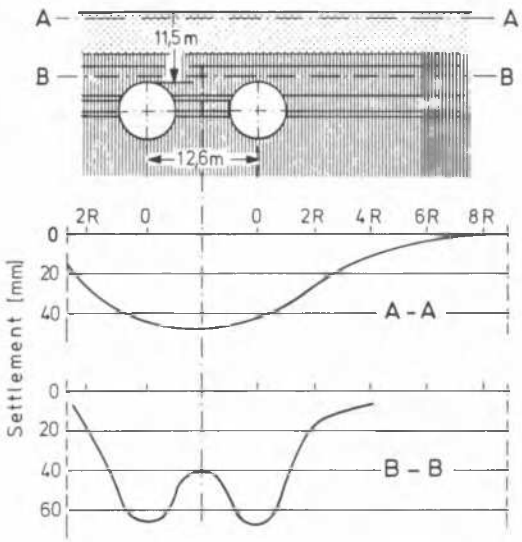

Fig. 2 Settlements at ground surface and tunnel crown

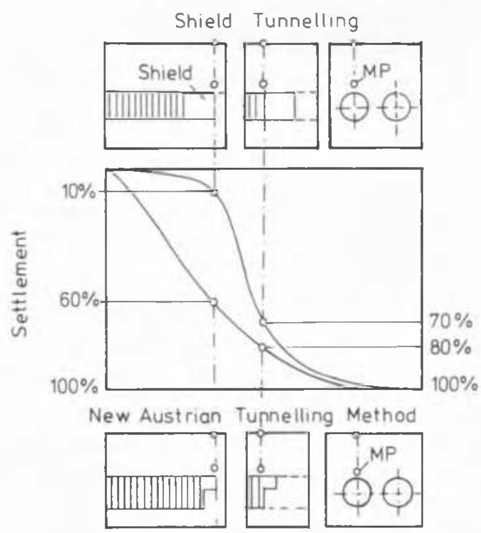

Fig. 3 Settlement at tunnel crown due to Shield Tunnelling and NATM

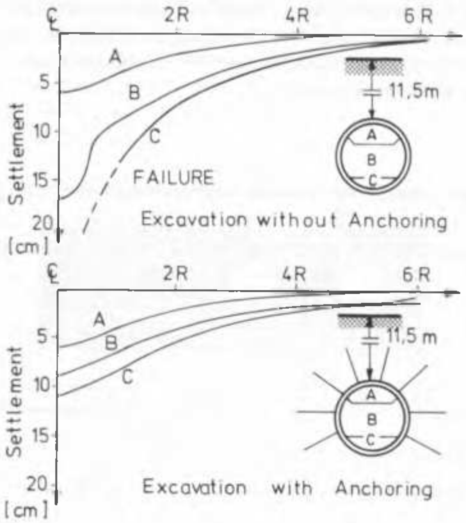

Fig. 4 Settlement trough in a Metro Frankfurt constructed by NATM

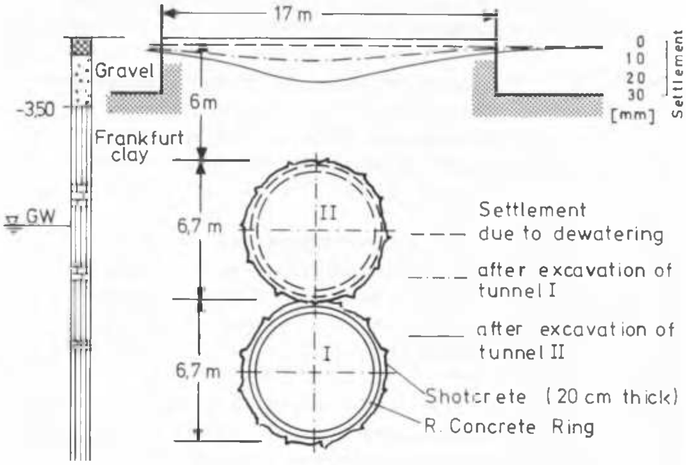

Fig. 6 Settlement at tunnel crown for different stages of excavation

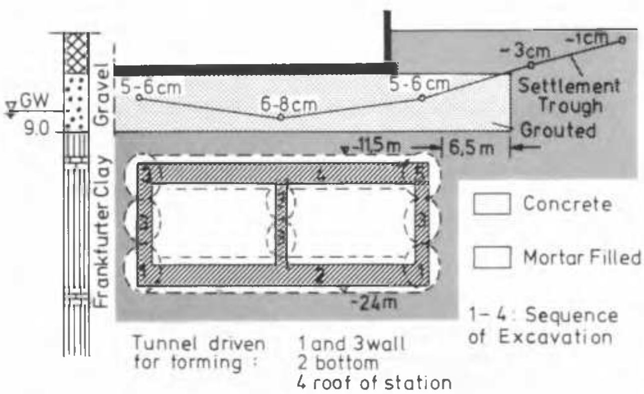

Fig. 5 Settlement trough in a Metro Station Frankfurt