Settlement above Air-Pressure Constructed Tunnels in Soft Soils

Tassement au dessus des Tunnels Construits sous Pression de l'Air dans Sol Tendre

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SYNOPSIS

Surface settlement occurs always above tunnels constructed in soft soils. The tunnels below the water table in soft soils usually are constructed under air pressure. One part of the settlement occours during the construction time and the other only after the removal of the air pressure. The settlement associated with removal of the air pressure will be more significant if the relation of the air pressure to the soil pressure is higher.

INTRODUCTION

In soft soils the tunnels usually are constructed under air pressure.

The determination of extent and area of surface settlement has always been a concern of designers, especially with tunnels below built in urban areas. The methods known in the technical literature assume a linear arrangement of the tunnel and determine the settlement along its cross section.

However, in case of station construction, the spatial pattern of the settlement is also important. If this is known, then there is a possibility to organize the sequence of construction in such a way that the settlement of the buildings on the surface should be optimal, i.e. nearly equal.

The compressed air is used during tunnelling below the water table to eliminate or reduce the water inflow to the tunnel. The compressed air effects not only to keep off the water inflow to the tunnel, but acts as a support on the excavated surface and the tunnel lining too.

THE MAIN PROBLEMS OF THE SURFACE SETTLEMENT

The following four problems should be solved when determining surface settlement:

/i/ The maximum settlement
/ii/ the extent of the settlement profile
/iii/ the shape of the settlement trough
/iiii/ the relation of settlement to time

The methods dealing with the first three of the above mentioned problems can be catagorised into two groups, one of them is solving the problems by the methods of the classical solution of the elastic half plane [3,4] . The displacement on the upper boundary is equal to the surface settlement. The results of these solutions are well known but because of the difficulties from mathematical point of wiew they are not widespred in the tunnelling practice. The various simplifications are far from the real situations. The solutions of this type by the finite element method are depending from the soil parameters taken into account. [2]

The methods of the other group are operating on practical, empirical datas and theoretical considerations in connection with that. These methods are using empirical parameter for unfilled voids around the tunnels, for the displacement zone, for loss of ground entering through the face etc. [7] The introduced empirical coefficients are mostly usefull only for tunnels constructed in similar soil conditions. For characterising the shape of the settlement profile mostly is using the Gauss function. A lot of research work gives some correction factor to this function. One of the discussed theme is the distance of the infection point from the central axis [1]. In connection with the settlement timetable partly reological computation, partly reological computation, partly practical observations are used.

ANALYSIS OF MEASURED SURFACE SETTLEMENTS DURING THE CONSTRUCTION OF THE BUDAPEST METRO LINE

The surface settlements are divided into two categories, i.e. settlement above running tunnels and settlement above deep level stations.

It is interesting to note the special transitional feature of settlement above the different structures /ventilating tunnels, connecting tunnels/ and above running tunnels intersect, or are built close to each other.

Surface settlement above the running tunnels of the Budapest Metro.

The outer diameter of the running tunnel is 5,5 m. On the East-West underground line /appr.30 m below the surface/ the settlement was 25 to 45 mm. The 45 mm settlement occured where the roof on some parts broke down.
The average settlement can be taken as 30 mm caused mainly by the slow tunnelling speed /2,5 m /day/, due to unfavourable soil conditions, the relatively slow setting time of cement-sand grouting mixture.
Basically, the major factors minimizing settlement are higher advance speed, a suitable technology of tunnel construction, and the complete fill out of the veids around the tunnel lining with a fast setting material. At later stages of the construction, and at the first section of the Nort-South line, the excavated silt was used for grouting mixed with bentonite, cement, waterglass and water. The injected material sets generally in 20 minutes.

The settlement was significantly smaller mainly in those sections where the tunnelling speed had been higher /5 m /day/ and where the up-to-date grouting technology had been used. In these sections the average settlement during the construction under air was not greater than 15 ÷ 20.
According to experience the settlement trough develops during the tunnel driving, after only the depth of the settlement increases.

Surface settlements above deep level stations

Experience has shown that, the settlement above a station is much greater than above running tunnels.The width of the settlement trough is not changing much and one above the other, but the settlement depth is increasing continuosly to the construction sequence.

During the construction of a deep level station not only the rail track and the passenger platforms, but also the electrical substations of railway operation, ventilation tunnels and ventilation machine chambers are constructed.
Thus, a 30-33 m wide and 120 m length underground space was contructed by the interconnected tunnels [5] built side by side.

Significant settlement accored at spots under which construction had been performed at several levels. Thus the settlement was larger than the average over the interchanging point of Deák Square station. The cavities required by various structures were constructed in several operations, drift, pilot tunnels were driven side-by-side and one above the other , which were connected by struttings.

Settlements above stations according to the stages of construction

The surface settlement above station constructions can be divided into 5 stages [6].
The first stage involved the completion of outside pilot tunnels, ventilation tunnels, longitudinal and transversal transport drifts and the bottom beams of the first section. During the second stage the side walls of the t ensioning chamber of the escalators and the bottom beams, during the third stage the drifts for the head beams were completed, the columns were put in place and the head beams were constructed. In the forth stage the arches were built. In the fifth stage the lower arches were completed.

Settlement development in relation to time

The settlement is a function of time. This has a twofold meaning, i.e. the settlement develops according to the stages of construction and continues to increase until the full consolidation. When the shield is just under the measured point the settlement reaches about half of its final value in cohesive soil and twothirds of the final value in granular soil. Consolidation takes place and the final settlement is reached after a certain time and at a given distance from the actual construction point. This means that the settlement goes on after completing the tunnelling work until full consolidation.

<u>Effect of the removal of air pressure</u>

Underground lines in bad soil are constructed mostly by the aid of air pressure.The air pressure not only helps keep away ground water from the construction work, but acts as a temporary support too . After the removal of the air pressure the additional settlement curve is very similar to the consolidation line of foundation structures.

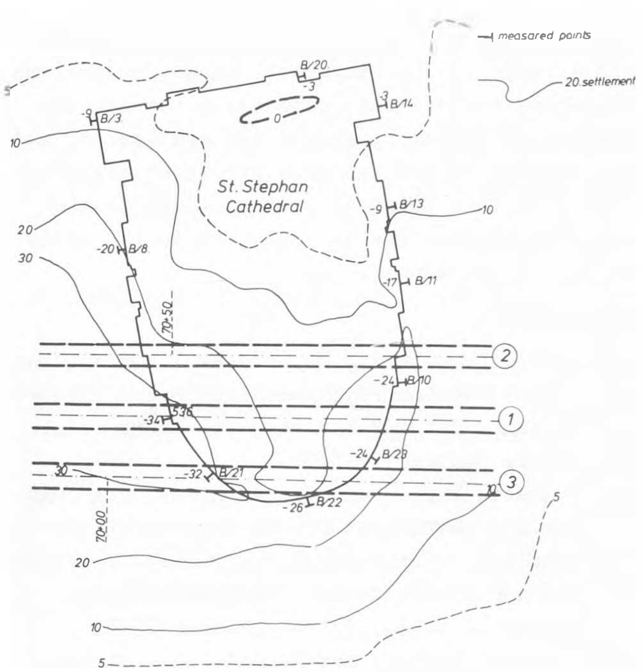

Fig. 1/a. Location of tunnels under the St. Stephan Cathedral

Measurements proved that the effect upon the settlement of the removal of air pressure depends on the relationship between the overburden pressure and air pressure too. The figures 1 a, b, c, show the measured settlement of running tunnels in the North-South line in Budapest below the St. Stephen Cathedral under air pressure and after its removal. Figure 1/a shows the location of the Cathedral above the tunnels in plane. The fig 1/b. shows the cross section above the tunnels. The figure 1/c shows the geotechnical situation, and the

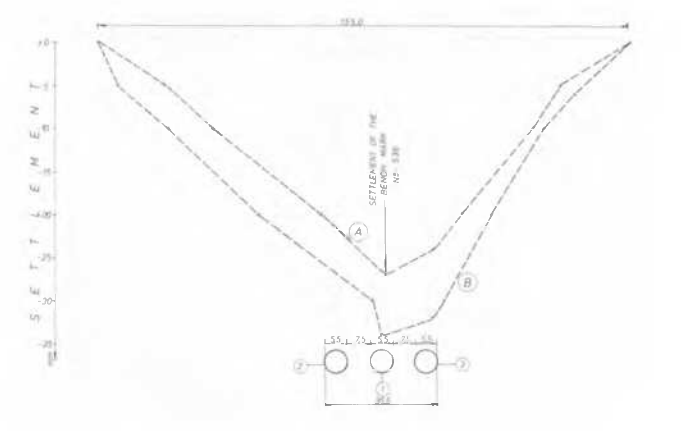

Fig. 1/b. Surface Settlement
1 - 2 - 3 Sequence of tunnel construction. A Settlement after tunnelling
B Settlement after removal of the air pressure.

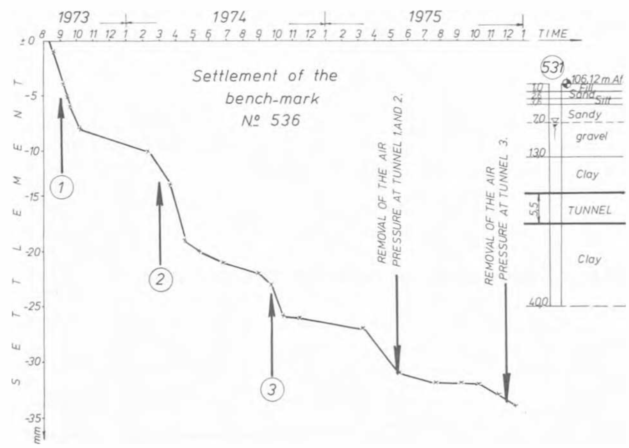

Fig. 1/c.

results of measurements on the bench-mark N^{o}536. It is worthwile to note the influence of the stiffness of the buildings.

The effect of the removal the air pressure was measured on the station construction too. The station is constructed by tunnels built side by side and among the arches there are supporting structures consisting of lower beam, column and upper beam. The measurements were made on the steel columns. Points were marked on the columns in four direction and the distances between the points were measured. By measuring the compression it is possible to estimate the forces acting on the column and thus acting also on the tunnel lining. Measurements were performed on five stations. By the meassurements we

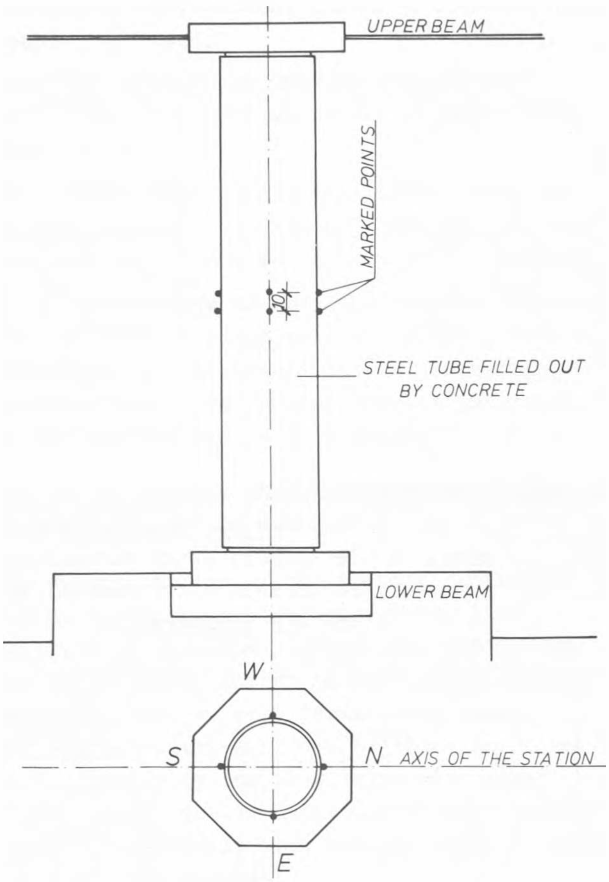

Fig.2. Measured points on the columns

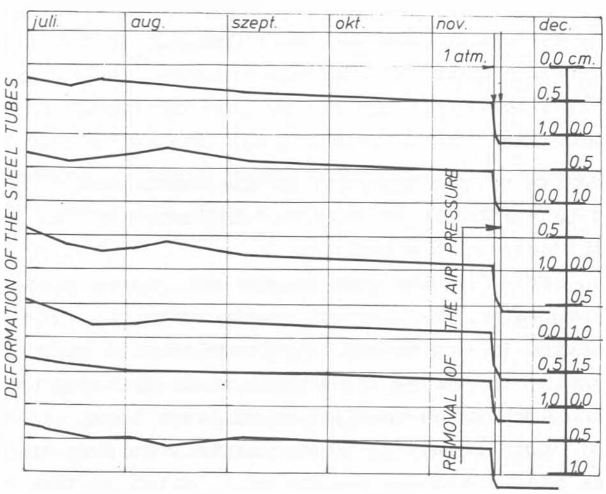

Fig.3. Effect of removal the air pressure on station columns

estimated the effect of the removal of the air pressure Fig. 2,3. The settlement of the foundation of columns was measured too but only by the usual survey method at various points of the station construction and compared with the forces acting on them. The results showed that the columns which settled more than the adjacent ones, had a lesser load.

In a cross section of a station we found that the load acting on the row of column is the highest in the middle of the station and decreasing towards the sides.

The effect of the air pressure as a temporary support acting against soil pressure is very significant in cohesive soils. After its removal the load on the construction increases by the value of the air pressure, and causes additional settlement. The value of the settlement is not only a function of the load acting on the tunnels but depends on the other well known factors too. Therefore is no direct connection between the removal of the air pressure and settlement, but the removal of the air pressure is as significant from this point of view as great is the relation between the air pressure to the loads acting on the tunnel.

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