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DIFFICULTIES OF TUNNELLING IN PLIOCENE CLAYS

PERCEMENT DES TUNNELS DANS LA CONSTRUCTION DE DIGUES

J. ROSSMAN, D. Sc., Director
R. and D. Hydraulic Engineering, Warsaw, Poland

Synopsis.

Large scale experimental works gave full information on the difficulties of tunneling in pliocene clays. The greatest was the pressure of ground water included in inclosures and fissures of the clay. The best way to overcome the difficulties was by introducing the compressed air method, but the simultaneous attempts to lower air pressure by ground pressure on the tunnel lining did not present great problems.

Introduction.

This problem exists for the planners of subways in modern cities: should the subway be constructed in deep galleries or in shallow tunnels near the ground surface. The space under the ground surface in the cities is occupied by different utilities and underground works. This is the reason that some of the subway planners prefer the deep tunnel solution. But in such cases the geologists and soil mechanic experts have to answer to the question if the deep ground strata are suitable for tunnelling. In some circumstances the borings and laboratory tests cannot be sufficient and only large scale experiment can give the right indication.

The character of subsoil and the first tunnelling works.

From 1951 to 1957 years some introducing and experimental works have been executed for subway in the capital of Poland. The geological characteristics of Warsaw subsoil are known from different publications. Numerous borings have been executed to control the possessed data. According to the published materials it could be shortly repeated that the fundamental ground bedding is constituted by pliocene formation underlying the alluvial strata of different thickness. The pliocene formation is composed chiefly of clays and silts. The preliminary results of geological estimation suggested that the pliocen strata are good and adequate for tunnelling like London and Leningrad clays. But the observations during works gave a real answer which differed from preliminary estimation. The pliocene strata show considerable glacio-tectonic perturbations, traces of erosion and many fissures and inclusions. The execution of 17 shafts of 18 feet inner

diameter and from 45 to 190 feet deep gave real picture of ground conditions. The shafts have been executed with great difficulties and by different methods: sinking shaft, mining, ground freezing, compressed air caissons. Even some trials of electro-petrification have been used. The execution of working tunnels of small diameter in different places started. The main question for the designing engineers was to find such localizations of the underground stations where the clay strata could be at most adequate for underground works. Extensive program of borings was performed and detailed geological studies have been executed. By the end of 1953 a tunnelling shield of 18 feet diameter was put into operation and the execution of a junction chamber about 100 feet under ground level was started. But in this time a restriction of works was decided and through the next three years only the mentioned shield driven tunnel and the junction chamber have been continued. It was decided to do the works only as an experimental basis to clarify all problems of tunnelling in the pliocene clay grounds.

The tunnel was dug using a shield guided with a downward inclination of 0,033 and passing through quaternary sands to tertiary clays. The shield had a diameter of 18 feet. The first part of the 0,7 mile long tunnel was executed by applying ground dewatering by means of pumping from wells. For the next part of tunnel the compressed air was used to help working in partially dewatered grounds. Some difficulties caused by compressed air escaping through the dewatering wells have been observed. The shield entered into the clay strata and was very exactly introduced into the junction chamber. The tunnelling in clays have been

performed using compressed air. The execution of the junction chamber 180 feet long was wholly done by using compressed air. The chamber was situated about 100 feet under the ground level and about 15 feet under the top of clay strata. The mentioned works have been accomplished in 1957. The general plan of the Warsaw subway was changed in the meantime and general solution of applying the shallow tunnels was adopted.

The main problems of tunnelling in pliocene clays.

The above mentioned works explained the problems and difficulties of tunnelling in pliocene strata. It was stated clearly that the stiff pliocene clays do not constitute firm and uniform bodies, but that they have a number of inclusions and fissures filled with ground water. Now the constructors of tunnels could present questions as follows:

- what can be the ground water pressure in the sandy and silty inclusions? It was namely obvious that the introduction of compressed air was the best method of tunnelling in these conditions. But the question arose whether the height of ground water pressure was low enough to be overcome by compressed air pressure. A second question was rising: whether the ground water pressure could be lowered in such a manner that the working people in tunnel could support the compressed air pressure. The nominal height of water pressure in some places reached 6 at. /55 psi/. Also a consequent question have to be posed:
- what will be the pressure of the pliocene clay on the tunnel lining i.e. during the driving operation on the temporary supports and later on the permanent tunnel lining.

The observations in working tunnels of small diameter showed that in some places the clay was swelling in a characteristic manner. It can be mentioned that the pliocene clays have following properties:

$$w_1 = 70-75\% , w_p = 28\% , w = 22-23\%$$

$$\rho_u = \text{about } 10^0 , C_u = 20 \text{ psi.}$$

The swelling of clay caused some damages in two surrounding buildings. In the same time great forces acting on the temporary tunnel lining were stated. But it was found later that the use of compressed air was of great help in preventing swelling and excessive pressure of soil. The construction engineers had of course many other problems and observations e.g. the quantity of compressed air required for different tunnelling conditions, the ground level deformation caused by underground operations and by dewatering works of large scale etc.

At it was stated above, the junction chamber was situated in clay strata, but the strata had water bearing inclusions and

fissures. Two ground water levels existed in the ground. The first was in the sands of quaternary formation. The first water level was lowered about 18 feet by pumping from 12 wells. The second existed in the tertiary pliocene strata only in the sand inclusions which of course were not easy to find by borings. One deep well of 150 feet have been in one of the inclusions. The ground water there was pumped in small quantity. The engineers have been satisfied at that moment by the results and hoped that the ground water lowering would help them in working. The pressure of compressed air was hold during the driving operation as an effective method of preventing the swelling of clay and as a safety means against possible ground water inflows. The height of the pressure was about 18,5 psi, which did not correspond to the height of water pressure. No coincidence between the situation of the first ground water level and the height of compressed air pressure was stated. An interesting accident gave information. The tertiary water pumping from time to time was stopped. The tertiary ground water level rose quickly. It occurred that the tunnelling works entered in such a moment into the sandy and silty inclusion and it was absolutely necessary to rise the air pressure to the total height of ground water pressure /fig.1/

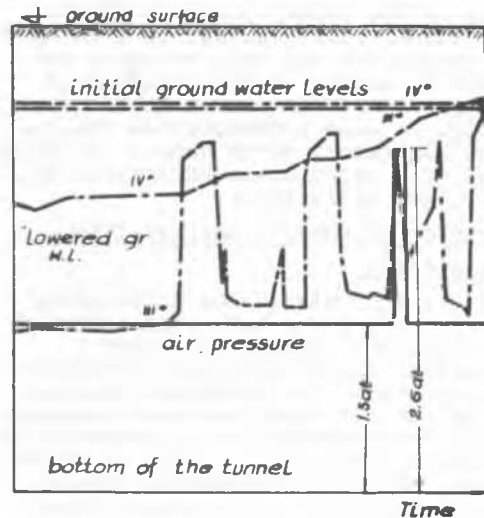


Fig.1. Air pressure and ground water levels during driving operation in 1955.

It could be stated that the lowering of the upper water level had over the tunnelling operation in the pliocene clays no influence. It should be necessary to find all possible water bearing grounds inclosures and to lower there the water ground pressure. This was however not possible. The next conclusion should be that by working in

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such conditions it is necessary to take into account the necessity of working under pressure of total height resulting from geological conditions up to the first ground water level.

The behavior of pliocene clays under compressed air was not only practically observed but also tested. An unconfined compression test apparatus was used to examine the strength of samples within compressed air zone and some clay samples were tested outside these zone. The samples have been compressed: immediately after 24, 48, 72, 480 and 720 hours. It was also controlled whether the clay samples could suck the water by a wick and what will be the result. 98 samples have been tested. It was found that the samples of clay in the zone of compressed air have kept better their properties when the samples in normal pressure. The suction of water by samples from a height of about 10 inches caused a loss of strength of clay sample of 20% in 720 hours. It was further stated that the water content of clay samples in zone of compressed air which have not been protected by parafin coating has slightly increased. In the same time similar samples in normal conditions have hardened and could not be compressed by the apparatus.

The execution of the junction chamber have been done by using two tunnelling methods: the so called German method and the so called Hungarian method introduced in Budapest subway which is a variant of the first method. The excavation was held for months under compressed air without the permanent lining and no changes in the clay side walls have been stated.

The ground pressure on tunnel lining in pliocene clays.

Studies and experiments to find the forces of ground pressure on tunnel lining were performed.

Different methods of measurements have been used for the shield driven tunnel and for a branch tunnel of the junction chamber. The shield driven tunnel had lining of cast iron tubbings. The measurements of stresses have been executed by the method of "discharching" the tubbing ribs. Strain gauges have been stuck on the ribs. Afterwards the tubbing ribs have been cut causing local discharching.

A large program of tests proved that not the ground pressure is dangerous and decisive for the tubbings, but the efforts during the driving operation. It was also practically confirmed by construction and deformation control of experimental branch tunnel of 18 feet diameter with concrete lining that thin 15-in. lining is better than the thick one /30 in./ This was a confirmation of the fact found by Terzaghi in Chicago subway construction. It was a very important fact.

For the designing engineers of underground structures the problem of great importance is to have an indication what is the ratio of horizontal to vertical pressure on tunnel and chamber lining. The first cautious advices were that it should be taken into account as a value about 0,6 - 0,4. The observation on the experimental works indicated that the number 1,0 could be closer to the reality.

Conclusions.

The execution of underground works and large scale experiments proved as obvious that the tunnelling operations in pliocene clays which are not uniform and monolithic need such working method which allows to overcome the existing and possible water pressures. The compressed air method is the most suitable and efficient, but technical operations to lower the height the water pressure i.e. air pressure proved as difficult and inefficient. The depth of tunnels should be chosen according to the possibilities of working in compressed air. On the contrary the ground pressure on the tunnel lining present even in difficult conditions not as great problem as the execution techniques. The advances of the world tunnelling methods have lately proved this in other conditions, that the lining can be thinner and simpler than it was usually accepted.