

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Regional Settlements caused by a Subway Tunnel in Oslo

Tassements régionaux provoqués par le percement d'un tunnel à Oslo

by GUNNAR HOLMSEN, dr. phil., State geologist, Geological Survey of Norway, Josefinegt. 34, Oslo, Norway

Summary

In May 1912 work was commenced on a tunnel for taking several suburban railways into the centre of Oslo. Ground borings were first made along its course in order to investigate the position of the surface of solid rock underneath the clays. The length of the tunnel is 1,960 metres of which 500 metres were built in open cut, while the remaining 1,460 metres are in tunnel in solid rock.

The tunneling caused an unexpected regional settlement of clay deposits near the tunnel resulting in considerable damage to buildings in the neighbourhood. An extensive lawsuit ensued, necessitating the investigations which form the basis of the present paper.

Geology

The rocks underlying Oslo are folded Ordovician sediments striking approximately NE-SW. The tunnel cuts the layers at a right-angle.

The sedimentary rock series is built up of shales, calcareous shales and limestones, very slightly metamorphosed by the surrounding igneous rocks. The series is fairly regularly folded, and partly cut by shear zones along which small dislocations have probably taken place. The rock is cut by dykes of various types; most common are diabasic dykes striking NNW, which cut the rock at an angle of abt. 70° and are thus sub-parallel to the tunnel.

Over the area of the present city the ice movement was approximately N-S, scouring the rocks at an acute angle to the strike of the layers. The ice eroded the pliable shales more deeply than the resistant limestones, which remained as ridges. Even the igneous dykes have left their mark on the relief in the form of ridges, at least where they attain some width, as they will then form cross-cutting ridges.

Consequently the present-day surface of the solid rock is irregular. A number of elongated rock basins or canyons have been scooped out along the shale layers. As the entire area was submerged during the melting of the ice in the latest glacial period, these rock basins have been filled with marine deposits,

Sommaire

Le percement d'un tunnel destiné à relier des lignes de banlieue au centre d'Oslo fut entrepris en mai 1912. L'on procéda préalablement à des forages le long du tracé afin de reconnaître la position du substratum rocheux au-dessous de l'argile. La longueur totale de l'ouvrage projeté était de 1960 m; dont 500 m à ciel ouvert, tandis que le restant était un tunnel creusé dans le roc solide.

Les travaux de construction provoquèrent un tassement régional inattendu dans les couches d'argile avoisinant le tunnel, ce qui causa des dommages considérables aux bâtiments des alentours. Un long procès s'ensuivit, lequel nécessita les investigations sur lesquelles est fondé le présent travail.

mainly clay, and could appropriately be called clay-filled "channels". If the clay was removed they would appear as minor elongated lakes. The original surface, however, has been levelled and partly hidden by settlement, and the city has been laid out regardless of the position of the rock and soft clay (Fig. 1).

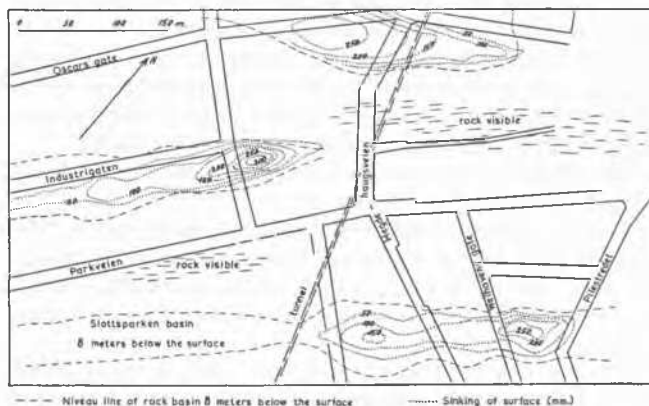


Fig. 1 Map of Some Channels along the Line of Tunnel
Plan de quelques sillons épigénétiques le long du tracé du tunnel

The Character of the Clays

The top stratum of such a channel consists of a rather hard crust of clay attaining, in general, a depth of several metres. Downwards it gradually merges into soft clay. Stony moraine frequently constitutes the bottom layer and may contain strata of clayey sand and gravel or, more rarely, pervious sands.

At an early stage of the tunnel work (June 1915) the strata of a channel were sampled right down to the bottom, 18 metres below the surface.

A number of mechanical analyses of clay samples from Oslo proved that the content of fine clay (smaller than 0.002 mm) is usually between 40% and 50%, gradually increasing towards the sandy bottom of the channel. The softest clay with only about 2–3 t/m² shear strength occurs just below the hard and dry top-stratum. The clay here often contains 29–32% of water by weight, thus approaching the liquid limit, which for fat clay is approximately 33% and for lean clay 29%. This means that the clay in general is highly sensitive, or, at places where the salt is leached out, even “quick”.

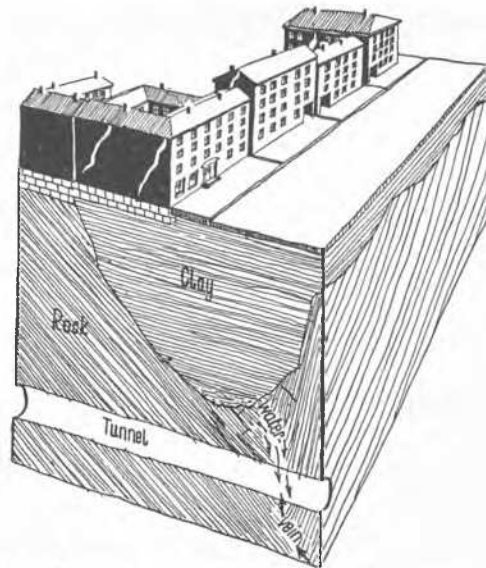


Fig. 2 Section Through Clay Channel
Coupe transversale d'un sillon épigénétique rempli d'argile

Settlements

Damage to buildings resulting from overloading of the ground is a common phenomenon in Oslo. Heavy, poorly founded houses may show severe settlements which may take place during a long interval of time if the houses are founded on soft clay. Cracks are commonly observed in old houses built on the treacherous ground of a channel. The systematic damage along the clay deposits under which the tunnel was built surpassed anything of the kind previously seen in Oslo.

Cutting of the Water Veins and Subsequent Ground Settlements

Water veins in solid rock were cut during blasting, and a considerable amount of water was emptied into the tunnel. The veins occurred in connection with fissures and shear zones.

On 5th September 1912 the tunnel cut a vein connected by a shear zone with the Slottsparken channel. 8–10 days later the first cracks appeared in houses along the channel. In the course of a month, settlements were observed in a number of buildings, even at a distance of 260 metres from the tunnel. Somewhat later, in the middle of November, the tunnel cut and caught another vein which passed beneath the deepest part of the same channel. On an average the two veins emptied 70 m³ of water a day into the tunnel until the leakage was stopped in August 1914. The flow of water, abundant immediately after the cutting of the vein, gradually subsided.

Cases of damage increased in number as more veins were cut by the advancing tunnel. More than a hundred houses were more or less distorted and in 1914 work on the tunnel was temporarily suspended because of the resulting settlements.

The damage to the houses first appeared in the plastering and later the walls cracked. Doors and windows were twisted and had to be adjusted, floors undulated, and walls went out of true. The cracks were commonly known as those wide enough for mice to enter, the rat-sized ones, and those enabling the cat to pursue the intruders.—A few dangerously leaning houses had to be pulled down.

Buildings founded partly on solid rock, partly on clay proved to be more exposed to damage than others. This deplorable type of foundation was common along the edge of channels where solid rock rises steeply to the surface, as shown in Fig. 2.

The damage was not, however, confined to houses. In the spring of 1913 after the snow had gone it was evident that streets crossing the channels had subsided in several places. Further, water and gas pipes near the tunnel were broken or otherwise damaged more extensively than usual.

The settlements attained a maximum over the deepest parts of the channels. During the 1913–1916 period it amounted locally to 350 mm. The rate decreased during this period, but the process was still not finished in 1916.

As mentioned above the leakages in the tunnel beneath the Slottsparken channel were not stopped until August 1914. This was effected by means of a tight wall of concrete with iron drain pipes through which the water could escape while the concrete hardened. Finally, concrete was pressed into the drain pipes in order to stop the leakage completely. In June 1916, however, it was observed that some water still seeped into the tunnel at the edge of the concrete walls.

The Causes of the Damage

At the time when the damage appeared, geotechnical experience was not sufficiently developed to reveal their cause. The theories proffered for the explanation of the settlements

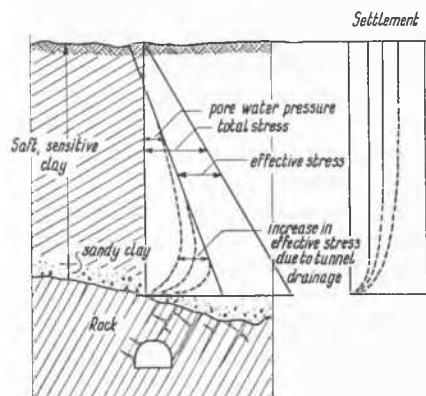


Fig. 3 Stress Conditions During Tunnel Drainage
Contraintes au cours du drainage du tunnel

were multifarious and, seen against the background of present knowledge, somewhat beside the point.

Since then, *Terzaghi's* treatise on the relations between effective stress, total stress and pore-water pressure offers a satisfactory explanation of the phenomena. Fig. 3 will give an idea of the variations of total and effective stress in depth before the advance of the tunnel and during the reduction of pore-water pressure brought about by the tunnel. In view of the fact that the clay deposits may attain a depth of 15 metres, and, further, considering that the increase of effective stress in the clay above the solid rock increased by approximately 12 t/m², it appears obvious that drainage at such a scale will result in considerable settlements. Also, the sandy and hydrous quality of the soil resting on rock explains the settlements at a great distance from the tunnel.

The above theory is confirmed by the investigations carried out to localise the ground-water level in the clay-filled rock-

basins. Ground-water pipes were laid, though unfortunately long after the influx of water into the tunnel had become constant. Besides, some of them were immersed in clay, where very little circulation took place. However, during the last period of tunnel blasting, 1926–1927, the ground-water level in one place was seen to sink 6 metres from December 1926 to February 1927, during which time several water veins were cut by the tunnel.

Compensation

The ruling of the Supreme Court in the case between A/S Holmenkollbanen and owners of damaged houses was pronounced in 1931. It stated the Holmenkollbanen tunnel to be one of several causes of the damage to the buildings concerned, wherefore A/S Holmenkollbanen had to pay a compensation of about 2½ mill. N.kr.