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Ground water control in sensitive areas, the Arlanda project and other projects

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ABSTRACT: Tunnelling in hard granite rocks in Sweden has given experiences and effective routines how to prevent induced settlements due to construction in sensitive areas. Geology background is the key to success and the engineering geology is the most important discipline to be used for planners and clients before and during tunnelling, especially in built-up areas. The water leakage from cross-zones is described, but the influence from small quantities of leaking groundwater has been proven to be equally important for the long time effect from tunnelling. Some difficult projects are reported and technology in connection with basic geological knowledge can be the solution for reducing project costs. The GIM-system is presented which lead the tunnellers in to the "cyber underworld".

1 INTRODUCTION

The Svehofennian ridge, formed 1.800-1.900 million years ago, is the major bedrock in Scandinavia (Sweden and Finland). The oldest rocks from this era are those that settled in a water bearing environment namely schists and sandstones in combination with volcanic rocks. Magmas of different ages have intruded these fine crystalline rocks and the granites have subsequently crystallised in a deep environment over a long period of time. During the cooling off period the bedrock was shaped and fissures were active during several different periods of geological activity and many larger zones of movement have occurred, caused by existing stresses in the rock masses.

The granites in this area normally show major irregularities in the fissure configuration and most of the rock surfaces are extremely cracked up. In recent years (10.000 years), the ice age scraped clean the bedrock surfaces and shaped the landscape as we can see it today. Depressions in the surface strata are filled with loose materials such as clay, gravel and sand.

The famous eskers, which have been our lifeline and survival, are the best evidence from this period of geological activity.

How to best use this environment in the construction of systems of tunnels and other underground excavations and to establish a better way of living on the surface has been a major challenge to engineers over the past 100 years.

This paper will point out the need of respect for and the need of knowledge about the groundwater protection when tunnelling, specially in sensitive built-up areas (cities and airports).

New factors which today are more and more taken into consideration during excavation are the small cracks and fissures and the minor water seepages. To achieve a competent sealing and undisturbed ground situation one has to respect the geological processes before any start-up of underground constructions.

The "rock water" which Nature during thousands of years has filled up in the cracks can not be restored by man in reasonable time at acceptable costs.

The preinvestigation of the rockmass before excavation is essential to find the less cracked rock block where to design the underground structures. A full documentation is needed not only for the construction in question but also for extension which normally will take place in the future. In built-up areas the underground is today used at a larger and larger scale, which means that new projects will affect the already existing ones. Groundwater monitoring is the key to a successful development of the underground.

Some interesting tasks during the tunnelling in Sweden during the last 20 years will be described in the following.

2 THE STOCKHOLM SUBWAY SYSTEM

During the period 1950-60, the subway system in Stockholm was excavated with over 50 km of tunnels in hard rock. Blasting operations in built-up areas have been handled with care and vibration controls and adjusted drilling and charging have been developed. No major damages have occurred.

One secondary effect from the tunnels has been shown several years after completion of the tunnels.

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Groundwater lowering due to small leakages have had (and still have) negative effects in some parts on surface construction such as buildings and street foundations.

Due to groundwater lowering the clay areas are compressed and the basement concrete floors are sinking and streets are damaged which results in breakage of water pipes, sewage pipes and electrical installations in the above ground. The repair can be arranged but as leakages of groundwater continue, the repairs are repeated at regular intervals. The major problems have been the damages to the buildings' foundations of wooden piles, which have been proven to become rotten as the air comes in contact with the upper parts of the wooden piles. The costs to repile the buildings have been extremely big in some areas of Stockholm and the municipality has been the responsible part.

The developed zones of weaker grounds are normally the major water ways which early were known by water-well drillers. Tunnellers learned to try to avoid the zones as the influence from the zones in costs and extra time when passing with the zones were much greater than in "normal" ground.

If no action is taken to stop the water flow, the weaker zones and the tunnel is to blame for the drainage of groundwater and the upcoming settlements. Groundwater stability is a question of outlet and inlet of water. As we are covering large areas with asphalt and concrete, the catchment area is affected and this means that you have to be extra careful when tunnelling not to increase the dischargement of the groundwater magazine. The cross-zones are often the bottom of wide stretched clay filled deposit areas – large areas which will be affected by an uncontrolled dischargement of groundwater beneath the clay.

When the construction of the subway system was made, knowledge of the groundwater protection was learned the hard way. Several buildings and large street areas were to be repaired and paid for.

3 NEW TUNNELS IN SENSITIVE AREAS

In the late 1980's and now in the 1990's, we are more aware of the size of damages which can occur if planners and contractors do not respect the geological landscape. Steps to be taken for a good geoplanning of underground constructions such as tunnels and large rock storages are today well known and often included in preliminary studies and also included in the quality assurance programs for a project.

The lessons learnt from earlier blasting of tunnels made us introducing the TBM tunnels in Stockholm in the late 80's. The Saltsjö project, a 7 km sewage water transmission tunnel was built as a 3,5 m diameter TBM tunnel. Pregrouting and tight water control and level of 5 litres/100 meters and minutes were incorporated in the tender documents to safeguard the sensitive area above the tunnel alignment. Techniques for continuous pregrouting were developed and after some start-up problems, most of the tunnel length was grouted. Costs for grouting etc. can be calculated at 20-30% of tunnel construction costs, which compared to costs for groundwater lowering and the damaging effects described earlier were acceptable.

Tunnel techniques chosen with respect to geological surroundings including clay areas, are today an accepted procedure.

After the Saltsjö tunnel, we designed the Snake project which is located in the city centre of Stockholm. It was constructed during 1991-1993 and has been reported earlier at the Tunnelling '94 Conference in London.

3.1 *What can go wrong in spite of big efforts to minimise the risks?*

Our technique to design tunnels with respect to known geological environment can be mistreated if not sufficient preinvestigations are done. This has happened in the South of Sweden, to the Hallandsås tunnel project, an 8 km twin tube tunnel project designed for TBM. The importance of interpretation of geological documentation when machine design is chosen here strongly affected the construction and development of the project. Due to the open hard rock TBM design, the rockmass played an important part in the catastrophical result in performance.

After difficult times for more than one year, the contractor and the machinery were discharged from the project and blasting operations had to take over. The geological situation has thus proven to be too tough even for conventional methods. Unfortunately, the clients or contractors had no experience with a double shielded machine (and still does not). We have to wait and follow up the project when completed, maybe at the end of next year.

Water in rocks which are weathered and cracked has played a trick again to both planners and clients. As we earlier learnt from tunnelling in built-up areas, the water control is the key to the success of tunnel projects.

4 ARLANDABANAN, AN EXAMPLE OF PLANNING AND CONTROL

The newest project planned and excavated is the Arlandabanan project, a quick link from the city centre to the airport of Stockholm. Drilling and blasting operations are completed in September 1997.

The groundwater control by pregrouting and measurements in observation holes has been continuously done for the whole of the rock tunnel, 10 km. Mapping and preinvestigation and calculations have been extensively executed.

In the late 1980's, preliminary studies were done how to develop a fast link to the city centre from the airport. The alternative with an underground solution was early accepted as the most suitable one. The investigation and earlier knowledge from other surface constructions were taken into consideration and a pre-

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liminary tunnel alignment was placed. An extensive investigation along the line took place with rock quality tests and coredrilling at expected rock surface low points etc.

Groundwater modelling due to clay deposits beneath the landing strips took place and a conception design model was created upon which the tender discussion was based. A new technique for Sweden called BOT, Build-Operate-Transfer, was chosen and given to NCC-Siab-Vattenfall and Molev/Ahlström. After the procedure for permissions (environment etc.) the project started late 1995. Rock excavation of about 800.000 m^3 is now completed and the final installation of the station etc. will be completed (including rolling stock) in mid 1999.

The maximum allowed water drainage is 5 litres/100 m tunnel and minute, which is achieved by using continuous pregrouting with microcement 800 and some additives (flow + acc.). Drillholes of 20 m length are drilled with a diameter of 64 mm around the whole tunnel section, bottom holes are important.

Tunnel sections with splitted areas are pregrouted with holes 48 mm in diameter and the "umbrellas" are covering each other with 5 m. Grouting pressure is in the beginning of the cycle very high (40-60 bar) during the first 10 min, to open up the rock mass fissures to make it available for grout. Grouting is stopped after 350 litres of grout have passed into the rock in order to reduce the risk for uplift on above structures. Drillholes for groundwater measurement have been drilled along the two existing landing strips as they are located on clay area or filled-up areas. These holes are controlled and water levels are measured regularly according to a program designed together with measurement in the tunnels. Total water leakage is controlled in all tunnels and documented.

4.1. *Subsidence of landing strips etc.*

A groundwater control program was designed and a daily or weekly measurement took place.

Small quantities of leaking groundwater was almost not allowed according to modelling work done of the catchment area. Blasting of tunnels were designed mostly with respect to vibration control, which resulted in a smooth rock surface with a minimum extension of geological fissures etc. due to gas volume from the explosives.

Pregrouting, rockbolting and the controlled blasting leads to a tunnel with very little rock damage due to excavation techniques. Geological documentation and modelling in 3-D was introduced for the first time in full force. All follow-up and recalculation were done with full geological information. Groundwater leakages were taken care of directly at the face and no lowering of levels could be measured in the observation wells.

The program includes a control for a longer period even when the project is completed.

5 WATER IN FISSURE AREAS

The crystalline solid rock of granite can in principle be considered watertight, i.e. there is no water circulation of practical importance along the joints between different crystals. Water circulation is localised at zones of crushing and cracking in the bedrock. Consequently, it is such failures of bedrock solidity which cause water problems in connection with work for underground installations. Failures in the rock-mass consist mainly of deeply penetrating systems of fissures which were developed in connection with tectonic action in Precambrian or later times. Often the cracks have been filled or sealed up by minerals (quartz and calcite) or dykes (diabase). In some cases, they are filled up with clay from altered dykes. Due to tension and stress connected to previous covering of ice, temperature stresses and frost breaking, the rock surface has often been cracked more than the deeper parts, which now has been documented by several deep rock projects around Scandinavia.

Isolated zones of fissures and cracks occur with a frequency connected with the tectonic situation in different areas. In long tunnels one has observed distances between such zones as large as 100 meters and in these parts the rock was quite dry. The water carrying in zones varies considerably, sometimes catastrophical inflows through fissure zones or openwide cracks occur and water flows of 500 litres/minute are often documented. Normally a regular of 100-200 litres/minute can be accounted for in most underground projects. The procedure to handle this case is well proven by contractors – cement grouting – pregrouting is often recommended.

Several years of experience from drainage pumping of both tunnels and caverns shows that the rest of the Precambrian bedrock is moderately water carrying even if the work is done at the shore or below the sea.

The new value for acceptable water inflow in a cavern of about 100.000 m^3 is stated as 10-20 m^3/day. Within good bedrock, the quantity of inflow after sealing off the main water carrying fissures and cracks is generally less than this value.

As a comparison it can be stated that measurements within tunnel sections of more than 100 km in granite, gneises, diorite and gabbro have resulted in a mean value of 60 litres/minute and kilometre of tunnel. Considering what have been pointed out earlier and the risk of groundwater lowering, it can be said that even with such a low value of inflow it often exceeds the quantities conveyed to the ground through precipitation.

Within granite-gnejs bedrocks the total width of the fine cracks over a 10 meter tunnel section generally amounts to 1.5-5.0 mm. The frequency of cracks as well as their width vary tremendously. It is striking that so many cracks show a width of less than 0.3 mm.

Measurements in a tunnel show that even through thin cracks (0.01-0.3 mm) there is an inflow large enough to drain sensitive soils above the tunnel.

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Experiences from the rockstore projects for petroleum products etc. show that by storing heated petroleum products, steam, hotwater etc., the rock is heated, which result in a certain "self sealing" at a temperature of 50°C when the rock will expand about 5 mm within a distance of 10 meter.

It is not possible to seal off the fine cracks only with a cement grout, more mobile materials have therefore been in use which, with pregrouting, also close the fine fissures (microcement and chemical solutions).

In order to obtain full secure water filling of the cracks in the bedrock surrounding a cavern, infiltration of water through long boreholes has, for example, been applied with good results. Water curtain galleries are normally used before blasting of the caverns, especially to "screen off" different products in caverns close by. For the compensation of water losses in surface soils through the pumping drainage in tunnels, water has been infiltrated in the soil. This is, however, a very complicated matter because of the soil conditions resulting from the former inland ice. Generally it can be said from experience that many closely located infiltration wells are necessary in order to safely retain a groundwater level from lowering.

6 THE GIM-SYSTEM (GEOLOGICAL INFORMATION MODELLING)

Many years of underground project works have shown the need of more distinct documentation of irregularities in the bedrock. We have during the last 5 years developed a system which makes it possible to have a full 3-D vision around the installation.

The work process together with groundwater modelling gives us a base to follow-up and adjust the tunnel progress, especially where the groundwater levels are to be protected and documented. Mapping (engineering geology) is necessary not only for the project in question but for most of all future expansions or new projects in the nearby bedrock.

The risk of damages caused by the sinking of the groundwater levels as a consequence of the constructions of tunnels and caverns occurs in areas with special geological conditions. Water in rock, accumulated in the cracks during thousands of years cannot, if disturbed, be completely restored by man within a reasonable time and at a reasonable cost.

7 CONCLUSIONS

7.1 *How to prevent settlement cases at enormous costs?*

The tunnelling society has a responsibility for future generations to plan and design the project based on geological know-how. The occurred tunnel problems, which have happened at many different projects, are often due to late arrivals of the geologist or better called the engineering geologist.

With the knowledge of the geological background and technical experiences the following is to be recommended.

1. Planning based on engineering geology and environmental respect is a must for a successful underground development.
2. If not possible to avoid cross-zones etc. pregrouting should be included as a normal procedure.
3. Lining should be considered more often to secure a minimum of influence to the "groundwater landscape".
4. Preinvestigation must include a risk analysis and documentation of the present situation of the constructions above the tunnel or installation.
5. Groundwater documentation and follow-ups must be done before, during and after the project.
6. As an extraordinary step, preparation for water infiltration must be carried out.
7. Laws and regulations must be developed to safeguard property owners and the future expansion of underground constructions.
8. New tunnels etc. must be planned with respect to existing installations, especially the question "how many more leakages can be accepted?" must be answered.

This presentation of some current cases and how we can solve the groundwater protection in built-up areas is concluded with a well known statement:

"The Art is not to overmaster nature by means of new technologies, but with a deeper knowledge of geology – to adapt the engineering to nature."

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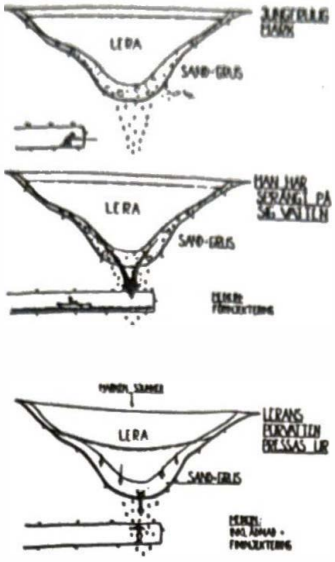
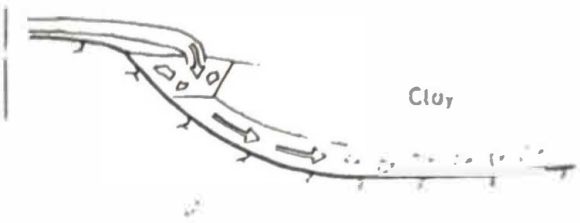
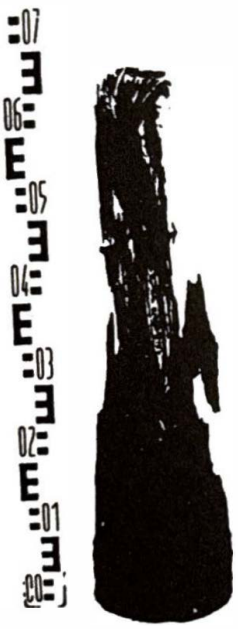


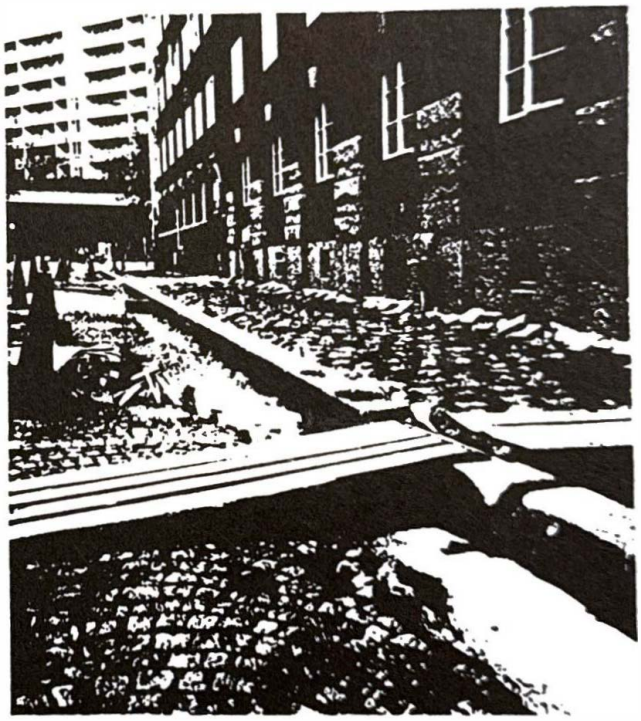
Tunnelling in geological sensitive environment. Results in groundwater lowering and settlements of clay areas.



The principle of infiltration to protect clay areas from loss of groundwater pressure.



Wooden pile affected from no groundwater protection due to tunnels below.



Street under reconstruction after long-time groundwater lowering due to tunnels beneath the sensitive area (Stockholm).

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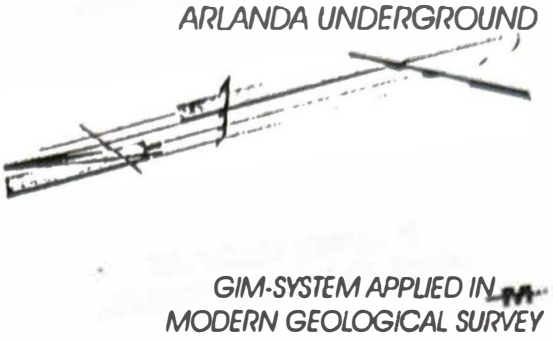
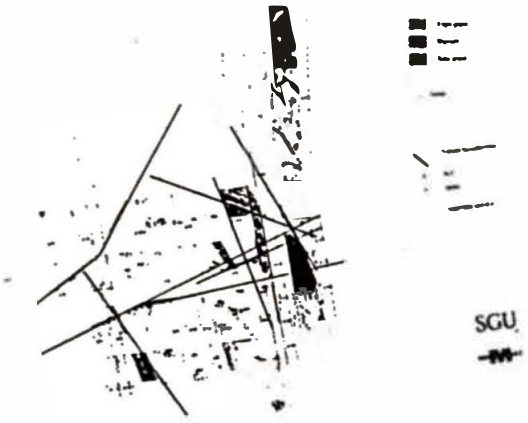
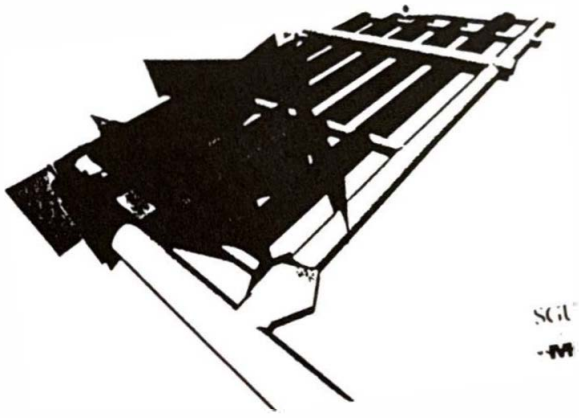
Groundwater observation holes along a tunnel project (the Arlanda project).



GIM-system at the Arlanda project Stockholm. Rock discontinuities described in 3D before rock excavation.



Geological documentation at the Käppala project, a sewage treatment plant outside Stockholm.



Geological Information Modelling, GIM, at the Käppala project (3D).