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Äspö Hard Rock Laboratory

Experience from design and construction

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March 1999

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Abstract

The design and construction work for the Äspö Hard Rock Laboratory has given valuable experience to the people planning and designing the deep repository. The layout has been adapted to planning requirements as well as geology and construction methods. Conventional drill and blast technique has been compared to full face drilling with a tunnel boring machine, TBM. The co-operation between construction workers and scientists has been tested under real conditions. The construction work has also included design, manufacturing and installation of lift, ventilation and groundwater drainage systems. Together with the experience from the operation of the facility in the coming years this will give a god base for the coming work with design and construction for the deep repository.

This report gives an overview of experience from the design and construction work. For the first part of the tunnelling and installation work a "Construction Methodology Report" (PR 25-94-09) was presented in November 1993. The report covers the planning and design phases as well as the second part of the tunnelling work including the TBM drilled part.

Figure 0-1 Tunnel entrance at Simpevarp.

Sammanfattning

Arbetet med konstruktion och byggande av Äspölaboratoriet har givit värdefulla erfarenheter inför byggandet av ett djupförvar. Anläggningsutformningen har fått anpassas till gällande planbestämmelser såväl som till geologi och byggmetoder. Konventionell sprängteknik har kunnat jämföras med resultat från fullortsborrning med en TBM (tunnelborrningsmaskin). Samarbetet mellan byggare och forskare har provats under realistiska förhållanden. Byggarbetena har också omfattad konstruktion, tillverkning och installation av system för t ex personhiss, ventilation och grundvattendränage. Tillsammans med erfarenheter från driften under kommande år så kommer detta att utgöra en bra bas för konstruktion och byggande av ett djupförvar.

Rapporten ger en överblick över erfarenheterna från konstruktion och byggande. För den första delen av tunnel och installationsarbetena har en rapport (Construction Methodology Report PR 25-94-09) redovisats i november 1993. Denna rapport täcker projekt- och konstruktions skedena så väl som den andra delen av tunnelarbetena inklusive den TBM borrade delen.

Contents

Summary and conclusions

The objective of excavating the Äspö Hard Rock Laboratory was to provide the scientists with a facility for various experiments. The excavation of tunnels was a part of the first experiment involving the evaluation of the preinvestigation tests. The actual construction work was also a test of the construction methods to be used in parallel with the scientists' collection of data from the rock and the groundwater.

The very saline water creates a lot of problems for the construction equipment as well as the permanent installations. This implies high demands on daily maintenance on e.g. drilling rigs. The choice of materials and coatings for the installations has to be made carefully to withstand the corrosive environment.

The general experience from the blasting works was that it is most important for the achievement of a smooth and little damaged tunnel periphery is to have straight and carefully directed blasting holes. The experience was that computerised drilling rigs were not yet fully developed. A skilled driller, drilling manually, aided by a computerised directing device achieved the best drilling results.

An electric loader improved the working environment considerably for the workers and researchers. The trucks were also a part in the ensuring of a good working environment. The trucks were equipped with a particle trap (scrubber) and a catalytic converter. They were run on "city diesel", a cleaner diesel than ordinary "tunnel diesel".

The experience from TBM tunnelling was that the vertical curve from the assembly cavern to the declined part of the tunnel created problems at the beginning with some damages to the first and last deck of the back up rig. The first part of the horizontal curve presented also a problem due to the fact that in this part the tunnel described both a horizontal and vertical curve. After this part a horizontal curve of 230 m was performed. Problems with cutters followed in the first 200-300 m of the tunnel and totally 90 cutters were exchanged.

Due to the decline of the tunnel it was difficult to pump water in front of the TBM head until start up of the boring. This caused problems with transport of the muck when starting up after shorter or longer breaks. The inclination of the conveyor belt caused by the declination of the tunnel made the saturated muck go in the wrong direction. One night, the drainage system failed for 6 hours on night in the final part of the TBM tunnel. In this part the tunnel is sloping slightly upwards and the end part of the back up rig was flooded. There were no major damages to the equipment and the boring could continue in the following shift.

1 Introduction

1.1 General

The design and construction work for the Äspö Hard Rock Laboratory has given valuable experience to the people planning and designing the Deep Repository. The layout has been adapted to planning requirements as well as geology and construction methods. Conventional drill and blast technique has been compared to full-face boring with a tunnel boring machine, TBM. The co-operation between construction workers and scientists has been tested under real conditions. The work has included design, manufacturing and installation of lift, ventilation and groundwater drainage systems. Together with the experience from the operation of the facility in the coming years this will give a good basis for the coming work with design and construction for the deep repository.

This report gives an overview of experience from the design and construction work. For the first part of the tunnelling and installation work a "Construction Methodology Report" (PR 25-94-09) was presented in November 1993. The report covers the planning and design phases as well as the second part of the tunnelling work including the TBM drilled part.

Figure 1-1 A view of the Äspö Hard Rock Laboratory and surroundings.

The design and construction of the Äspö Hard Rock Laboratory has comprised several parts and stages. An overview of the plant layout is shown in Figure 1-2. A tunnel ramp was excavated from the Simpevarp peninsula 1.5 km out under the island Äspö. The descent to the tunnel is situated in the vicinity of the Oskarshamn nuclear power plant. The tunnel reaches the island Äspö at a depth of 200 m and then continues in a hexagonal spiral down to a depth of 340 m below the sea level. The tunnelling of this first construction part was entirely done by means of conventional drill and blast methods. For the second part of the spiral (from -340 to -450 m level), full-face boring with a tunnel boring machine, TBM, has been tested. Also the first part of the second spiral follows the hexagonal shape and was done by drilling and blasting. The tunnel then goes down to the -450 m level close to the shafts and continues horizontally westward to an experimental rock volume.

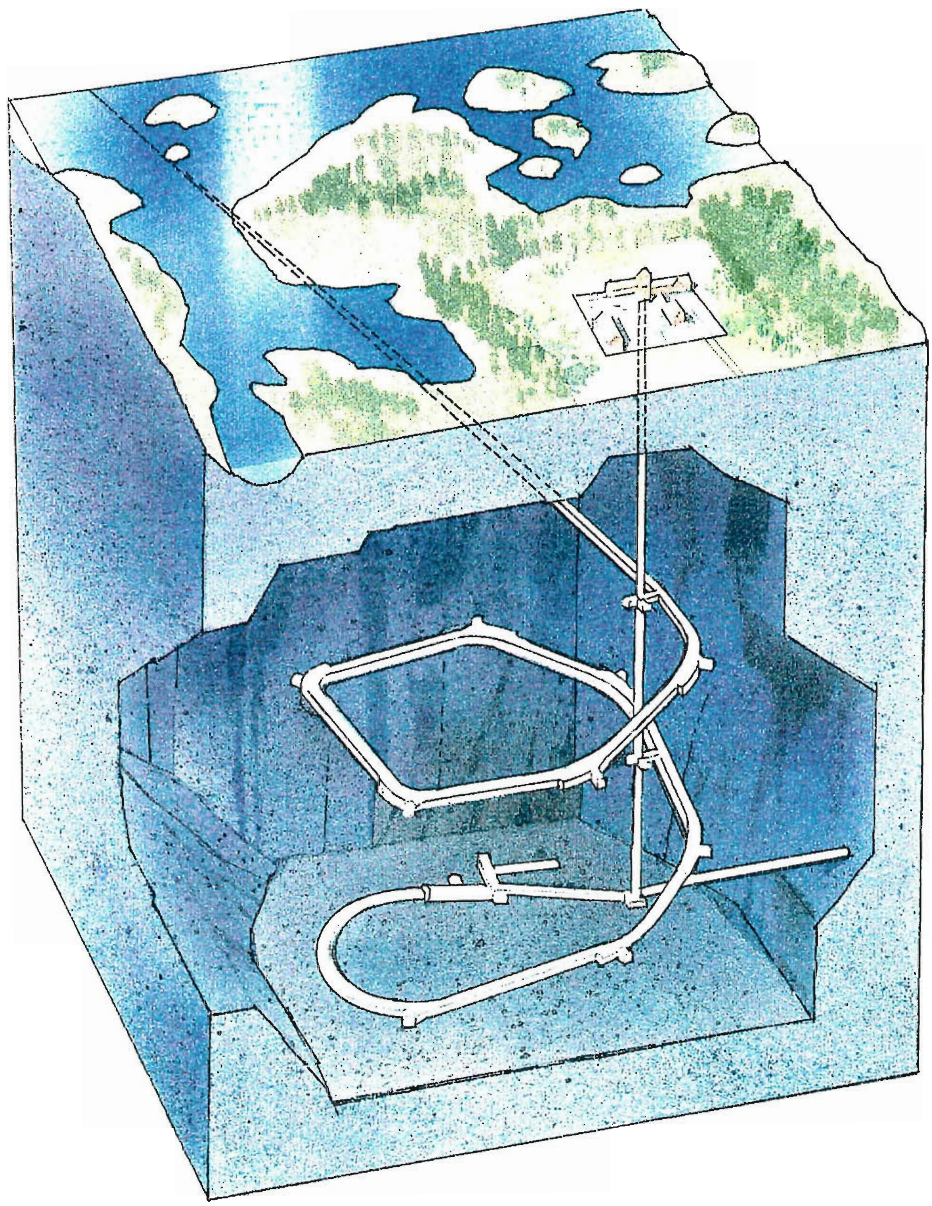


Figure 1-2 Overview of the plant layout.

Figure 1-3 Overview of the research village.

Three shafts have been built for communication and supplies to the experimental levels. Two shafts (diameter 1.5 m) are for ventilation, and one shaft (diameter 3.8 m) is for the lift. The shafts are excavated by raise-boring technique.

Office and storage buildings have been built on the Äspö Island as well as buildings for ventilation equipment and machinery for the lift. Together, these buildings comprise the "Äspö Research Village", which is designed to look like other small villages in the surrounding archipelago. The ventilation system for the underground facilities is installed in one of the buildings on the ground level at Äspö. The system is designed to supply up to 20 m^3 of fresh air per second to the tunnels and caverns. The lift is designed to take 20 persons or 2000 kg and will operate at a maximum speed of 5 m/s.

1.2 Planning and design

Design work was initiated in the spring of 1989 and the construction work was scheduled to commence in May 1990, and the facility would be ready for operation by the summer of 1993. The construction work actually began in the autumn of 1990 and in the summer of 1995 the construction work and installation work on the underground facility was ready for final inspection. The contract work was done in two stages. The first construction phase dealt with the access tunnel and the first spiral rotation up to section 2/600. The second construction phase dealt with the second spiral rotation.

Vattenfall Engineering AB performed the design work. A Design Manager was leading the work mainly with resources from Vattenfall Energisystem AB and Vattenfall Hydropower AB.

The practical handling of a design such as this, places importance on guiding parameters, tunnel dimensions, inclinations, curve radiuses and such, being specified before the detailed design can be started. However, the design must be flexible enough to allow for adjustments to be made, as knowledge increases about the rock once the excavation of the tunnels has begun. In this project furthermore a close co-operation with scientists for the planning of experiments also implied flexibility in the design and construction work.

The facility design was discussed and adjusted during all stages of the project. Different declinations and various designs of the spiral have been suggested and the major steps in the general design were:

- Tunnel entrance at Äspö. A final depth of -480 m reached by four spiral rotations with a radius of 135 m.

- A final depth of -485 m, with a possibility of continuing down to -700 m.

- Portaling at the Simpevarp Peninsula with two spiral rotations with a radius of 150 m.

The design that was chosen had the portaling at the Simpevarp Peninsula, two spiral turns and a final depth of -450 m. The design was decided on in 1989 and had several advantages:

- It was not necessary to build a new large access road, as the existing forest road leading to Äspö was sufficient.

- Äspö's environment need not be disturbed with transports and deposits of excavated rock.

- The site of the Äspö Village could be made smaller.

- A regional fracture zone, NE-1, could be studied in the access tunnel.

- Existing facilities at Simpevarp could be used, such as those for electricity and water.

The final design of the underground facility was decided on during the autumn of 1994. This mainly had to do with the decision on full face-boring of the last part down to full depth with a TBM.

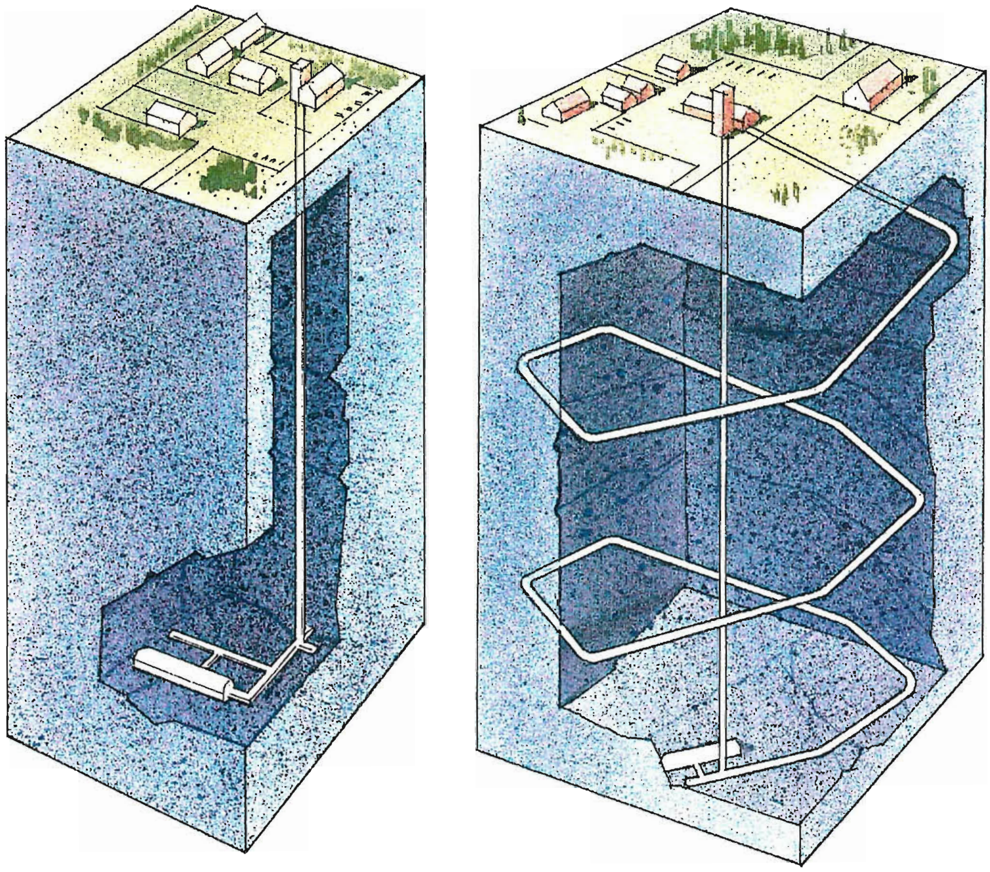


Figure 1-4 *Different layouts discussed in the early planning*

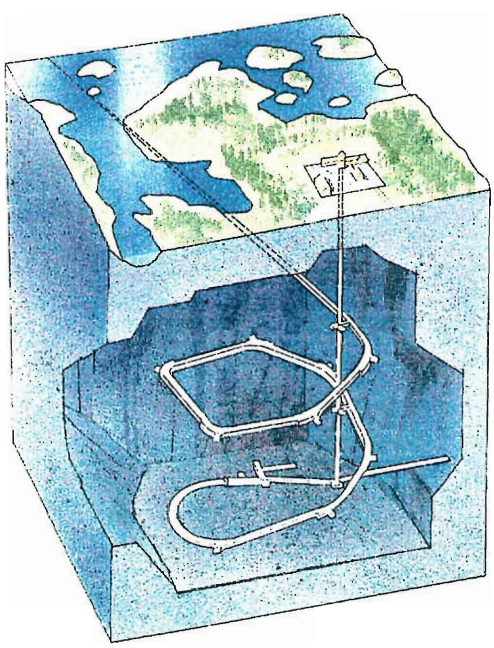


Figure 1-5 *Final layout of the Äspö Hard Rock Laboratory after the tunnel entrance had been moved to the Simpevarp area.*

1.3 Construction period and contracts

SKB's application for a license to construct the Äspö Hard Rock Laboratory was approved in 1990 and the work began. The construction work was completed in the summer of 1995. The main activities and steps of construction work were:

- The access tunnel and the first turn of the spiral to the -340 m level were completed in the summer of 1993. The first part of the shafts down to the -220 m level was also completed then.

- The tunnelling from the -340 m level down to the cavern for assembly of the TBM began in November 1993 and was finalised in March 1994. The rock cavern was excavated in April and the assembly of the TBM began in May.

- The TBM drilling commenced on June 14, 1994 and was completed on September 16. Totally 409 m of tunnel was excavated in 3 months time by the TBM.

- The final phase was excavation of various areas at the -450/-460 m level and raise boring of the shafts up to the -340 m level. All rock excavation work was completed in the beginning of 1995.

- Final installations for the groundwater drainage system and for the lift in the shaft were performed during the spring and summer 1995.

- The construction work for the Äspö Research Village was completed in May 1994. Final inspection was carried out in the beginning of June and the research staff moved in at the beginning of August 1994.

SIAB AB performed the first part of the tunnelling work. This contract included all rock excavation and installations in the tunnel down to the -340 m level. It also included rock excavation for the buildings at Äspö as well as the raise boring of shafts from -220 m to the ground level.

Skanska Sydöst AB built the Äspö Research Village. The contract included all construction and installation work for the village. ABB Fläkt Öst AB supplied the ventilation system for the underground facilities and ABB Industrial Systems AB supplied the lift.

The second part of the tunnelling work was performed by Skanska Stockholm AB. This contract included the TBM tunnelling and the remaining rock excavations, raiseboring and installations down to full depth, -460 m. The raiseboring of shafts was performed by Skanska Raise Boring Team an independent operating division within Skanska, who acted as a subcontractor to SIAB AB in the first phase and to Skanska Stockholm AB in the second phase of the tunnelling work.

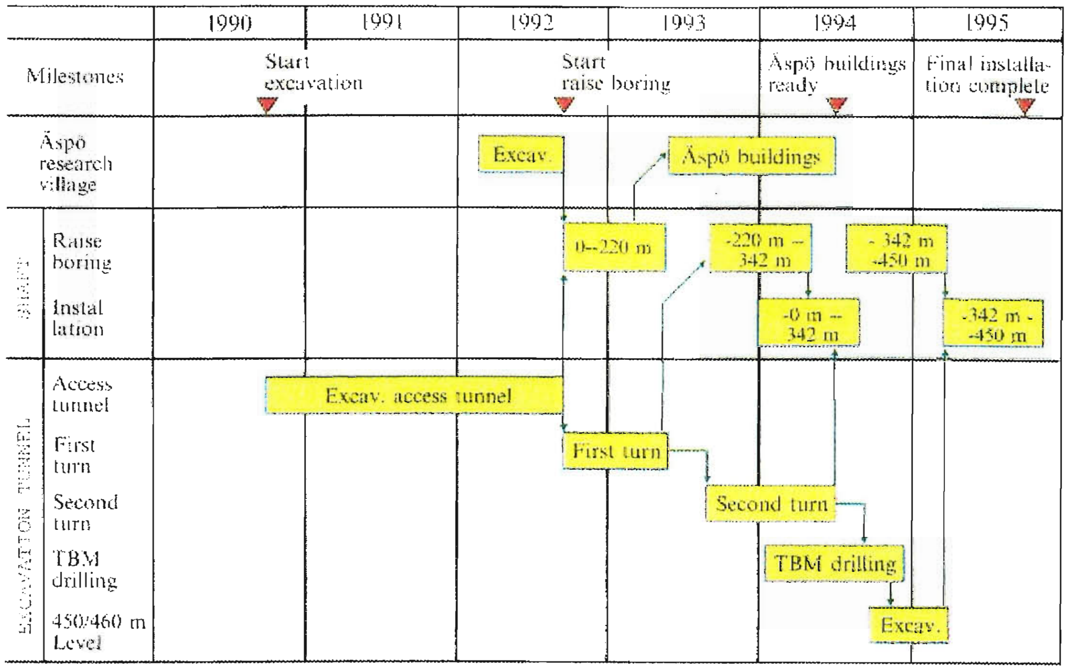


Figure 1-6 Construction time schedule (as built)

1.4 Construction costs

The total cost for design and construction of the Äspö Hard Rock Laboratory has been 295 MSEK. The cost can be split into the following main areas.

Project management, design work and construction management	32 MSEK
Tunnels and shafts (incl. grouting and reinforcement)	122 MSEK
Other underground construction work	50 MSEK
Äspö village	24 MSEK
Ventilation system	18 MSEK
Lift system	19 MSEK
Water and electrical systems	30 MSEK

1.5 General data

Total length of the tunnel	3600 m
Depth of communication shafts	450 m
Excavated rock volume	130.000 m^3
Groundwater inflow	2.100 l/min
Capacity of the ventilation system	20 m^3/s
Capacity of the lift	20 pers/2 tonnes (max speed 5 m/s)

2 General design work

2.1 Tunnel design

The decision on tunnel dimensions was decided based on the profiles of various vehicles to be allowed at a maximum of 3.5 m in height and 3.0 m in width. The height is required to allow SKB's chemical mobile laboratory to be towed down the tunnel.

The section chosen in construction stage 1 was 25 m^2 and 5 m wide. The width was diminished to 4.8 m in construction stage 2. There are no stands for installations in this part of the tunnel. In curves and in passing places, the tunnel has been widened to a total of 8 meters, having a cross sectional area of 42 m^2.

In the TBM tunnel, with a diameter of 5.0 m, the vehicle profile just manages to snugly fit in. This means that a fully loaded vehicle will be extremely difficult to drive down the tunnel. An increase in the margins of the vehicle profile should therefore be considered in future.

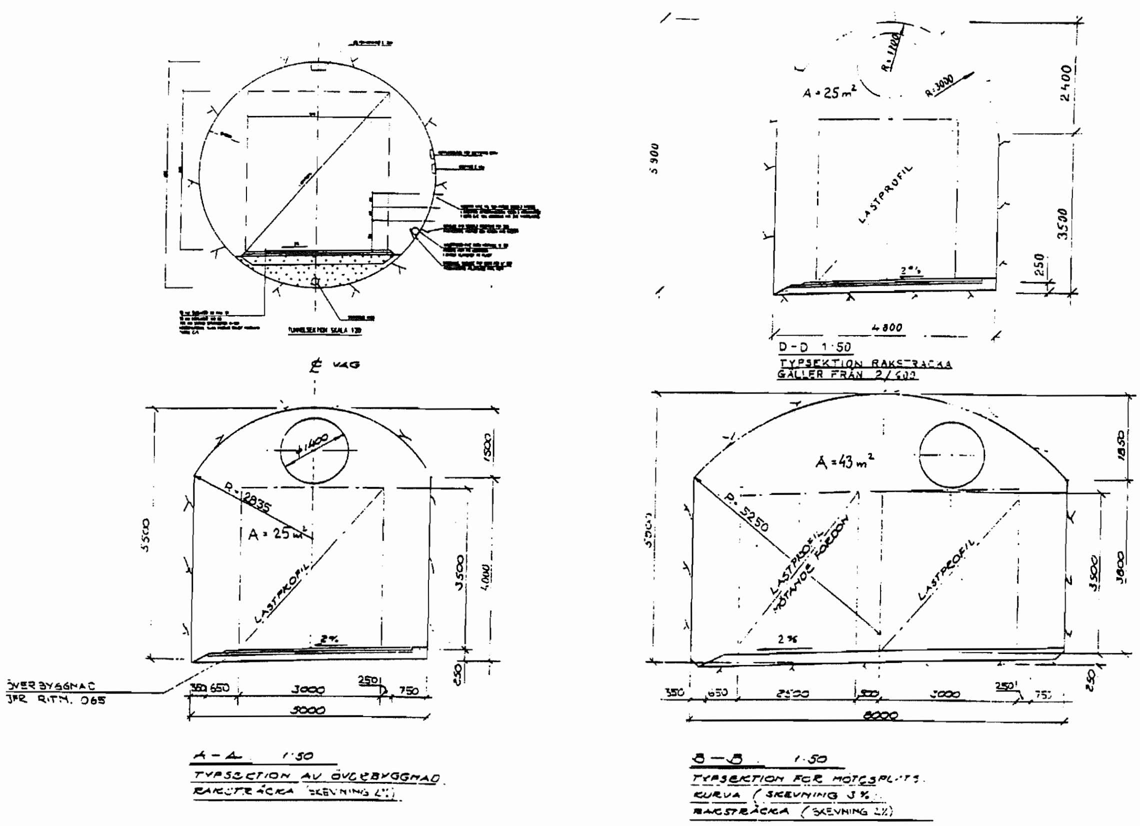


Figure 2-1 Tunnel cross sections.

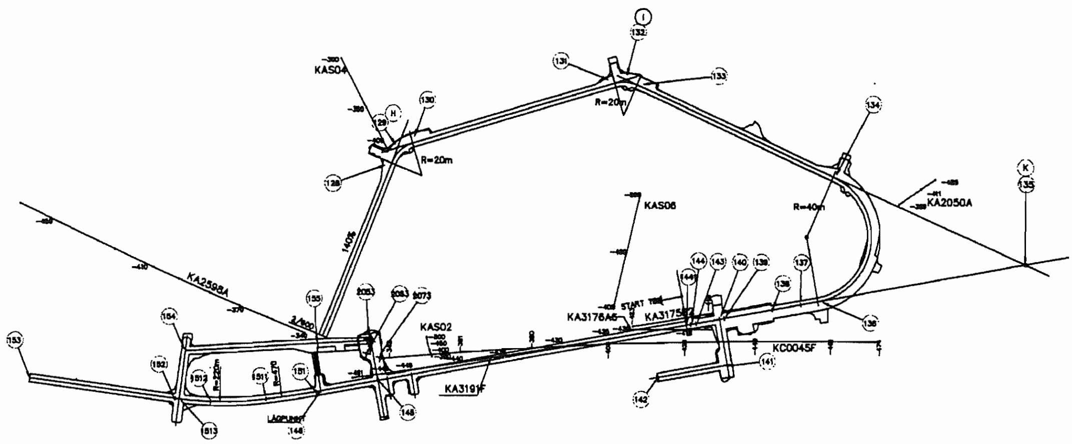


Figure 2-2 The second turn of the spiral.

Curve radiuses in the conventionally blasted tunnel are normally 20 m, except in the longer curves, at the entrance and just ahead of the TBM assembly shop, where the radius is 40 m. The chosen radiuses work well, and do not cause problems for the drivers.

The tunnel is used for heavyweight transports. Lift shafts are used for light-weight transportation and for transporting people into the tunnel. The inclination in the tunnel was chosen to be 140‰, levelling out to 100‰ in curves and passing places. The choice of 100‰ enables a vehicle to start with less trouble than in a steeper rise. The inclination in the spiral's second turn was chosen to be 140‰, also in the curves. This seems to work well, and there has been no experience of problems regarding the 140‰ inclination in the curves.

Turning niches have been provided for at the beginning of each curve. Originally they were planned for use when excavating the tunnel, but they were also meant to be used for investigation borings. Originally the turning niches were located at the end of each curve, but they were moved to the beginning of the curves on request from the contractor.

Passing places in the access tunnel are located 150 meters apart from each other. In the spiral tunnel, passing places are placed at the exact end of each curve. The reason for the location of areas at the end of a curve was that vehicles driving down the tunnel should not have to reverse when encountering a vehicle on a straight section. The chosen locations work well.

2.2 Groundwater

The statutes on water-rights restrict the amount of water pumped out from the underground facility to 50 l/s, or 180 m^3/h. Furthermore, the water may not be let out in the vicinity of Äspö, but has to be led out to the sea close to the outlet of cooling water from the Oskarshamn nuclear power station. High standards have been imposed on the measuring of water leakage. Scientists have decided on locations in the facility where sealing dams and gauging equipment equipped with a Thomson overflow had to be installed. The procedure has worked well.

Figure 2-3 Slurry basin at the outlet.

During the planning of the design it was decided that an extra volume equivalent to water leakage during 12 hours, would be blasted out from the lowest levels. That particular volume was chosen in order to guarantee that a reasonable amount of time for maintenance was allowed for in the case of an operational shutdown in the pump system. As a matter of fact the staff has a minimum of 17 hours at their disposal to resolve a possible operational shutdown in the pump system, if the water flows with the normal amount of 35 l/s. This gives almost 50% more time for solving the problem than the originally 12 hours planned for at 50 l/s. In fact, even having 17 hours at ones disposal requires that spare parts are available and a well planned organisation for repairs, on condition that the shutdown depends on a damage.

2.3 Rock reinforcements and grouting

The locations of discontinuities were identified by drilling done from the ground level, and from information gained when constructing the tunnel. The crossing of the regional discontinuity NE-1 has been discussed in detail in several SKB reports, and it is therefore not discussed in this report. The passage of the access tunnel through NE-1 was both time-consuming and difficult, mainly due to the multitude of restrictions concerning grouting. Therefore, the requirement was made that the second round of the spiral should not pass by, or be affected by, NE-1.

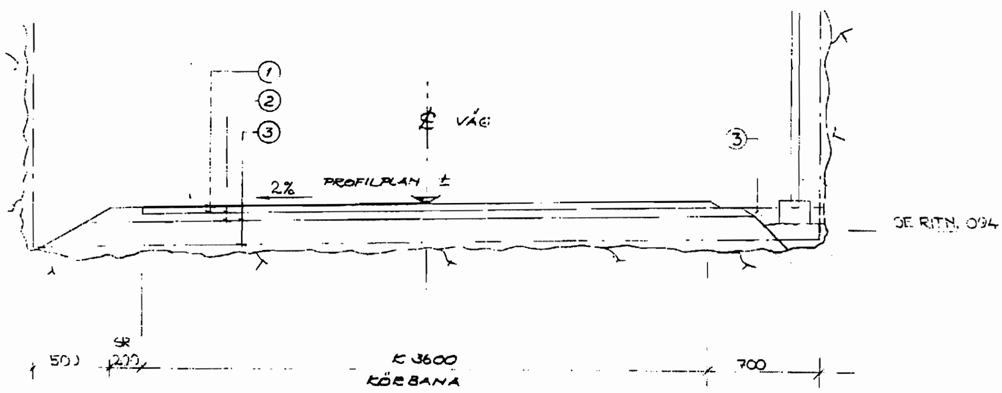
Conditions for reinforcing the tunnels were to use as little shotcrete as possible, and to avoid grouting. The contractor did operational reinforcements in the tunnel after consultations with SKB.

2.4 Road superstructure

Construction drawings show 'regular' sections of the tunnel and road superstructures. The road superstructure in the conventionally blasted tunnel has turned out to be insufficient. When subjected to large amounts of flowing water the 150 mm thick subbase was not be able to control all the water, and the road surface was forced upwards and broken into pieces.

During the construction 50 mm hot mix base course gravel was supposed to be used as road surface, and then afterwards the road would be topped with 50 mm fine bituminous asphalt (12 mm maximum particle size). However, the hot mix base course gravel could not withstand the heavy traffic, so the road had to be paved with the surface course during the construction phase. The allowed axle load is now 150 kN.

The 2 % banking of the road was chosen at an early stage, a larger banking can be perceived as uncomfortable when driving in the tunnel. In the access tunnel, banking to the left was chosen, placing the ditch on the left-hand side. The stands for installations were placed to the right. In the first turn of the spiral tunnel banking to the right was chosen, placing the ditch in the inside of the curves. In the second turn of the spiral tunnel banking to the left was chosen despite the curves are turning to the right, and the ditch was placed in the outside of the curves. The ”incorrect” banking in the curves in the second turn of the spiral have not been experienced as uncomfortable.



POS.	BENÄMNING	MATERIAL	MM
①	SLITLAGER	80 MAB 12 t	50
②	BÄRLAGER	100 BS	50
③	FÖRSTÄRKN. LAGER	MAKADAM	150

TYPSEKTION AV ÖVERBYGGNAD 1:20

ÖVERGÅNG BOMBERING TILL SKEVNING VÄNSTER SEKT. 0/000 – 0/020
TRANSPORTTUNNEL SKEVNING VÄNSTER SEKT. 0/020 – 1/550
ÖVERGÅNG SKEVNING VÄNSTER TILL HÖGER SEKT. 1/550 – 1/580
SPIRALTUNNEL SKEVNING HÖGER SEKT. 1/580 – 1/640
ÖVERGÅNG SKEVNING HÖGER TILL VÄNSTER SEKT 1/640 – 1/672
SKEVNING VÄNSTER SEKT. 1/672 –

Figure 2-4 Cross section of the road superstructure.

2.5 Communication shafts

Various designs of the communication shafts were evaluated during the planning period. It was then proposed that a blasted shaft with slip-formed concrete walls for the lift and the ventilation shafts would be chosen. A raise bored alternative was also studied having a lift shaft with a diameter of 3.8 m and two ventilation shafts with a diameter of 1.5 m each. The raise-boring alternative was at first not considered to be the best alternative due to the high costs. However raise boring was chosen due to the advantages of the low risk of personal injuries involved in such boring compared to drilling and blasting.

2.6 Ventilation system

The rock facility's ventilation system has been purchased as a functional contract. The final quality of the product is completely dependent on the possibilities of defining the functional criteria. This is especially important as the purchaser is supplying certain installed components in the system. The experience from the detailing of the invitation to tender is discussed below.

Defining the facility's environmental data is one of the most vital parts of the facility's functional description. Design temperatures should naturally be specified, but just as important is the inclusion of the design humidity of the outdoor air, the specification of the rock walls dampness, and the amount of free-flowing water drops present in the supply and exhaust air ducts. This information was not accurately specified in the present contract basis.

Even if the contract had specified the above-mentioned parameters, it is doubtful whether it would have been possible to clarify the areas of responsibility for all the involved parties. Instead, the pre-grouting should be planned so carefully that clear construction solutions could be specified even in the invitation to tender. This way of working would apply to all parts of the system where the purchaser is responsible for the design of certain components to be included in the system.

If a fire occurs in the underground facility, the ventilation system will automatically switch to the operational mode for fire ventilation. This function will enable the lift shaft to be pressurised in order to ensure a smoke-free area from which the facility can be evacuated via the lift. At the same time, the amount of supply air in the transport tunnel is increased, to ease the evacuation of smoke via the increased ventilation.

It is very difficult to obtain shafts that are dry enough so as not to allow any major dampness to establish itself in the ventilated air. This is especially apparent in the shaft area between the ground level and the landing area at level -220 m, where grouting was performed in the big pilot hole for the raise boring. On the other levels grouting was performed in smaller holes positioned around the periphery.

In order to solve the problems with water leaking in, a plastic lining has been installed in the upper part of the supply air shaft, and a droplet separator is installed in the exhaust air duct at Äspö Village. The lining has worked well, but we have not yet gained actual experience of what kind of servicing these components will need in the long run. A major disadvantage is certainly that of an increase in the risk of fires occurring in the facility due to these installations, although it is difficult to imagine a fire in which the plastic lining would play a role. Additional heating has later been installed to avoid freezing in the shaft.

The name of the droplet separator indicates that it will only be able to handle the problem of free-flowing water drops in the exhaust air duct. The problem of water condensing and flowing on the floor in the ventilation building has been eliminated since commissioning.

It seems apparent that the ventilation system should be designed to withstand the dampening of the air in the supply and exhaust air ducts. Despite the choice of design for the channel system, all non-replaceable components in the system should be given a corrosion-resistance level adhering in quality to the Swedish environmental class M4A, as the possibility of dampening never can be totally ruled out.

Selective requirements should be made. They should, among others, be based on an analysis of maintenance costs and consequences of a breakdown.

2.7 The passenger lift

The lift system has also been purchased as a functional contract. The possibilities of specifying the functional criteria are therefore entirely decisive for the quality of the final delivered product. Specifying the correct environmental data in the functional description is especially important in view of corrosion problems and capsule classifications of electrical equipment.

The supplier should verify that the delivered product meets the requirements stated in the contract by running a programme of tests. The test programme should be specified in the contract.

The design of the lift building has been decisive when choosing at which point of the compass the lift door should be placed. But this has meant that the design of the landing area did not turn out to be optimal. In future projects, the use of double-doors on the lift cage should be considered.

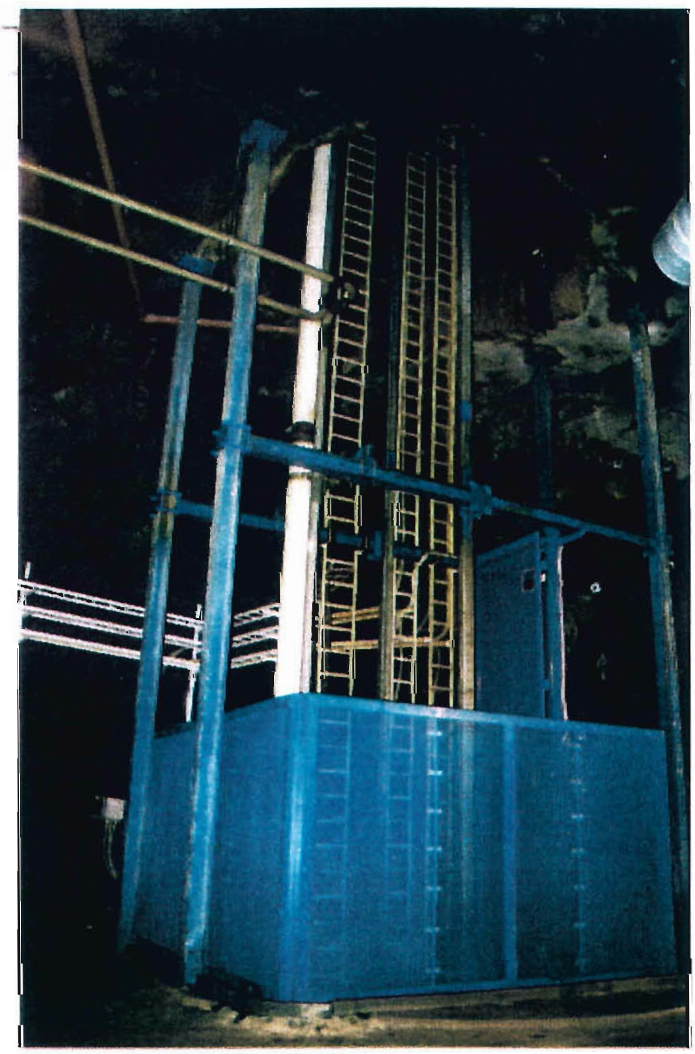


Figure 2-5 Shaft for passenger lift at level –340 m.

3 Construction work

3.1 Tunnelling by drilling and blasting

The cross sectional area of the conventional drilled and blasted tunnel is 25 m^2 and the total length is 3200 m from the tunnel entrance. Various programs for tunnel blasting were tested. Two types of drilling rigs have been in use; automatic and manual. The first one was a newly developed, computerised drilling rig. The rig type was the latest technology available and the accuracy would allow use of longer feeders (18 ft instead of 16 ft). It proved to be possible but difficult to drill semi-manually and manually and still these modes came out to be the two most commonly used. The second type of drilling rig was a more conventional type of a 3-booms rig with 16-ft feeders. This manually operated rig was equipped with a computerised directing device, Bever Control. From this the researchers also could receive information on drilling parameters such as pressure, drill rotation pressure, penetration rate etc. This type of manual rig also proved to be more suitable for probe drilling and other types of drilling.

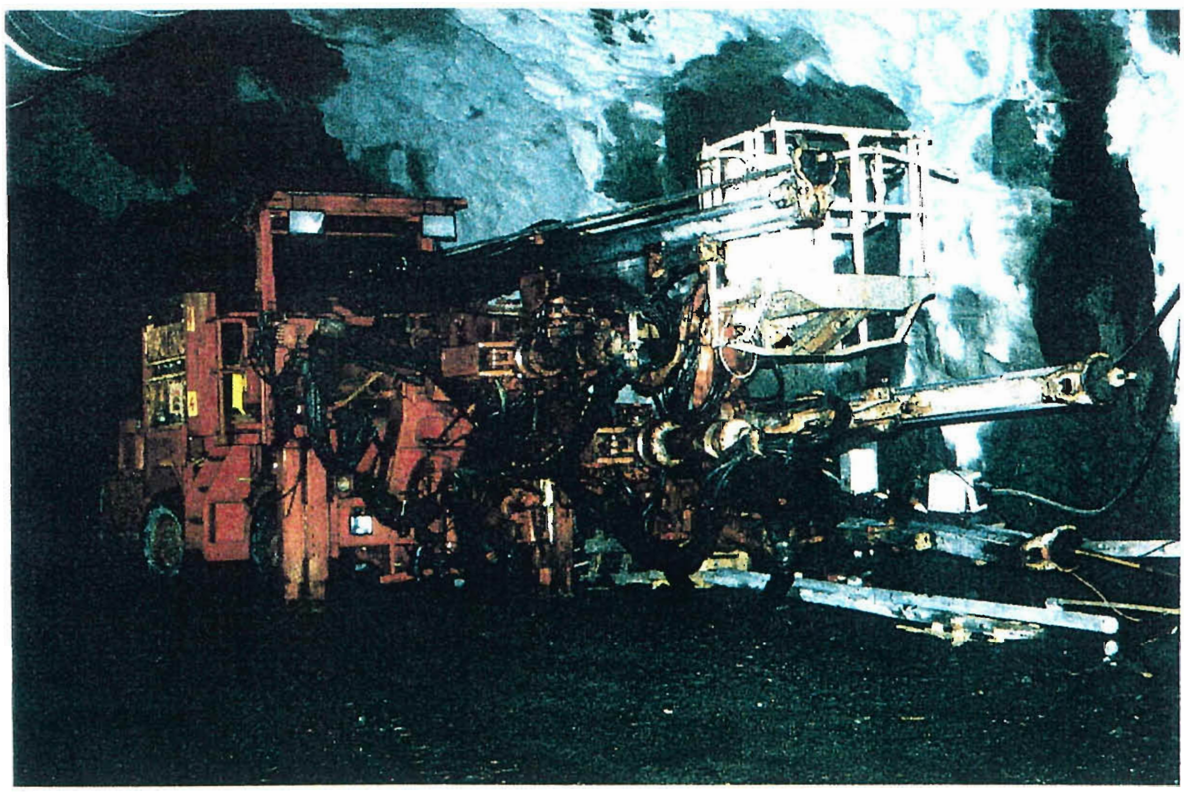


Figure 3-1 Drilling rig used by SIAB.

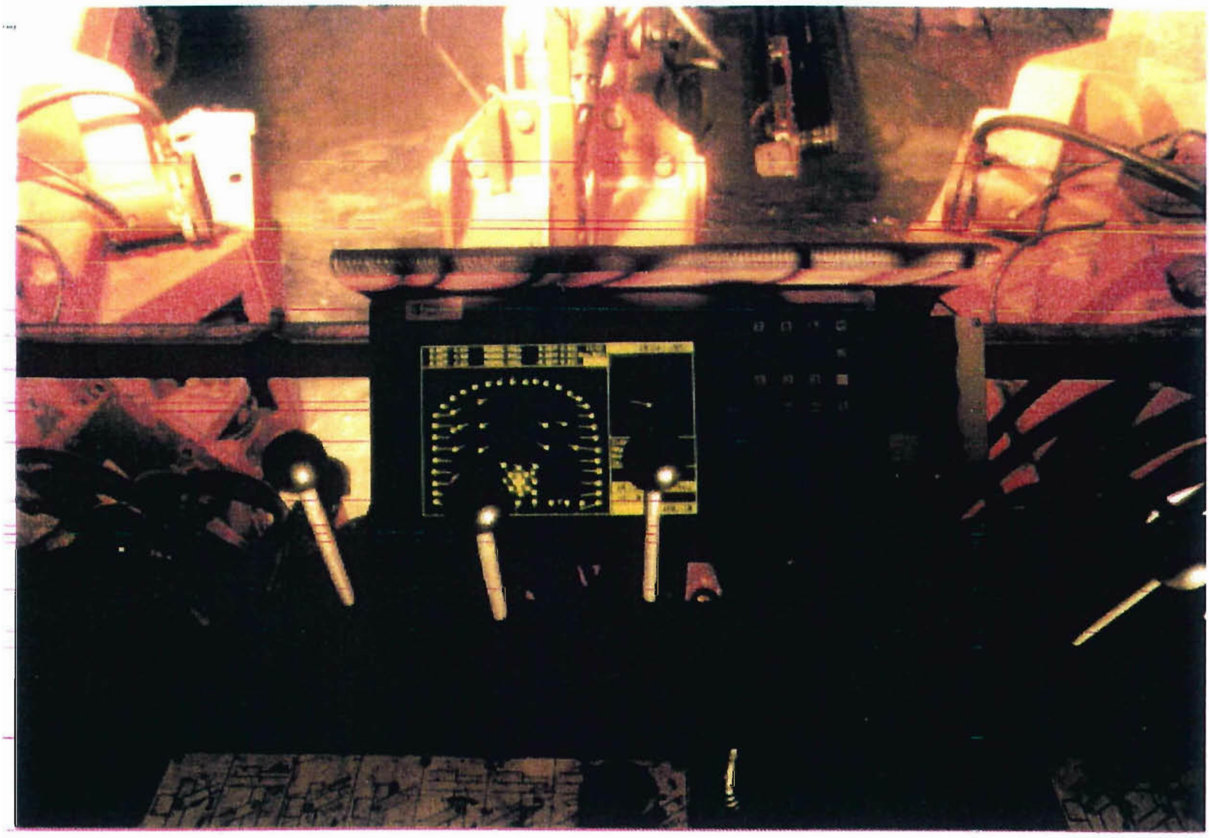


Figure 3-2 Computerised direction device, Bever Control.

A limitation of the damage zone in the remaining rock of only 0.3 m in the contour and 0.6 m in the floor when blasting full face was tested at the beginning. The limitation of the damage zone in the walls did not create any problem. However, keeping the floor damage as low as 0.6 m proved to be difficult at a reasonable cost using available explosives. After a blasting damage investigation had been made, the contractor and purchaser agreed on a blasting configuration reasonable for both parties. It caused a damage zone (theoretical) of less than 0.5 m in the contour and less than 1.5 m in the floor when using Nitro Nobel Dynamex and Gurit. Only explosives in cartridges were allowed due to electric currents in the ground (up to 12 volts).

Mucking out was done by an electric Load Haul Dump (LHD) which loads the muck onto trucks that carry their load to a dump on the ground level. Electric loaders had earlier been used in mines but not in tunnels since they are less mobile compared to diesels. The electric loader type was chosen mainly due to environmental reasons. It was a typical mine-LHD, a Toro 500E, extremely low and compact. The bucket has a volume of 7 m^3 (approximately 18 000 kg of blasted rock).

Figure 3-3 Loading onto a truck.

3.2 Rock reinforcement and grouting

The rock reinforcement used at the Äspö Hard Rock Laboratory includes the normal range of methods used in Swedish tunnelling. Rock bolts, shotcrete with or without steel fibres, cement and polyurethane grouting and shotcreted concrete arches. Netting of the tunnel ceiling and walls rather than shotcreting was favoured at the beginning. The reason was that researchers wanted to be able to revisit spots of interest at a later stage and still be able to observe the rock surface. A few metres of the tunnel were covered by net at the beginning of the project but most of it had to be taken down. The rock conditions were rarely suitable for the application of nets. The span between not having to make any rock reinforcements and having to shotcrete it was very small. The few times nets were put up, they soon became filled with falling rock, thus becoming a hazard for people passing underneath.

Grouting methods were the main interest in the testing of tunnelling methods. The requirements from the researchers stated that the grouting materials must have a limited impact on the ground water chemistry and the spreading of grout in the rock mass must be limited. On the other hand there were requirements on limitation of a total inflow to the tunnel and limited need for grouting after blasting. A grouting program was issued based on these general requirements. Grouting was also needed for the tunnel stability in some areas especially the fractured discontinuity NE-1. The final decision on how and when grouting had to be done, was made when the holes drilled in the tunnel face had a greater flow than a previously set limit.

In general the maximum volume of grout per hole was limited to 600 l in rock class I and II (good quality rock) and to 1500 l in rock class III and IV (poor rock). The allowed types of grout were cement with bentonite and calcium chloride, a thin "start-up grout" consisting of cement and bentonite, and certain chemical grouts, e.g. polyurethane (Taccs). The final placing of grouting holes and their lengths was decided depending on the situation. Documentation of geology, hydrogeology and of the grouting activities was done very carefully during the whole process of grouting. The only grout found suitable when grouting in wide fractures as well as in clay, against a high groundwater pressure and with strict limitations on the spreading of the grout was cement (w/c-ratio 1.0) with addition of bentonite (2%) and salt (8-15% $CaCl_2$). The injection pressure was limited to 20 bars over the hydrostatic pressure.

For the grouting of the TBM tunnel a special program was issued. The weak zones of the rock in this part of the tunnel were dominated by wide single fractures. The maximum volume was limited to 3000 l per hole and 10000 l in each fan. For the final part of the TBM tunnel, grouting was avoided in order not to disturb the future test area.

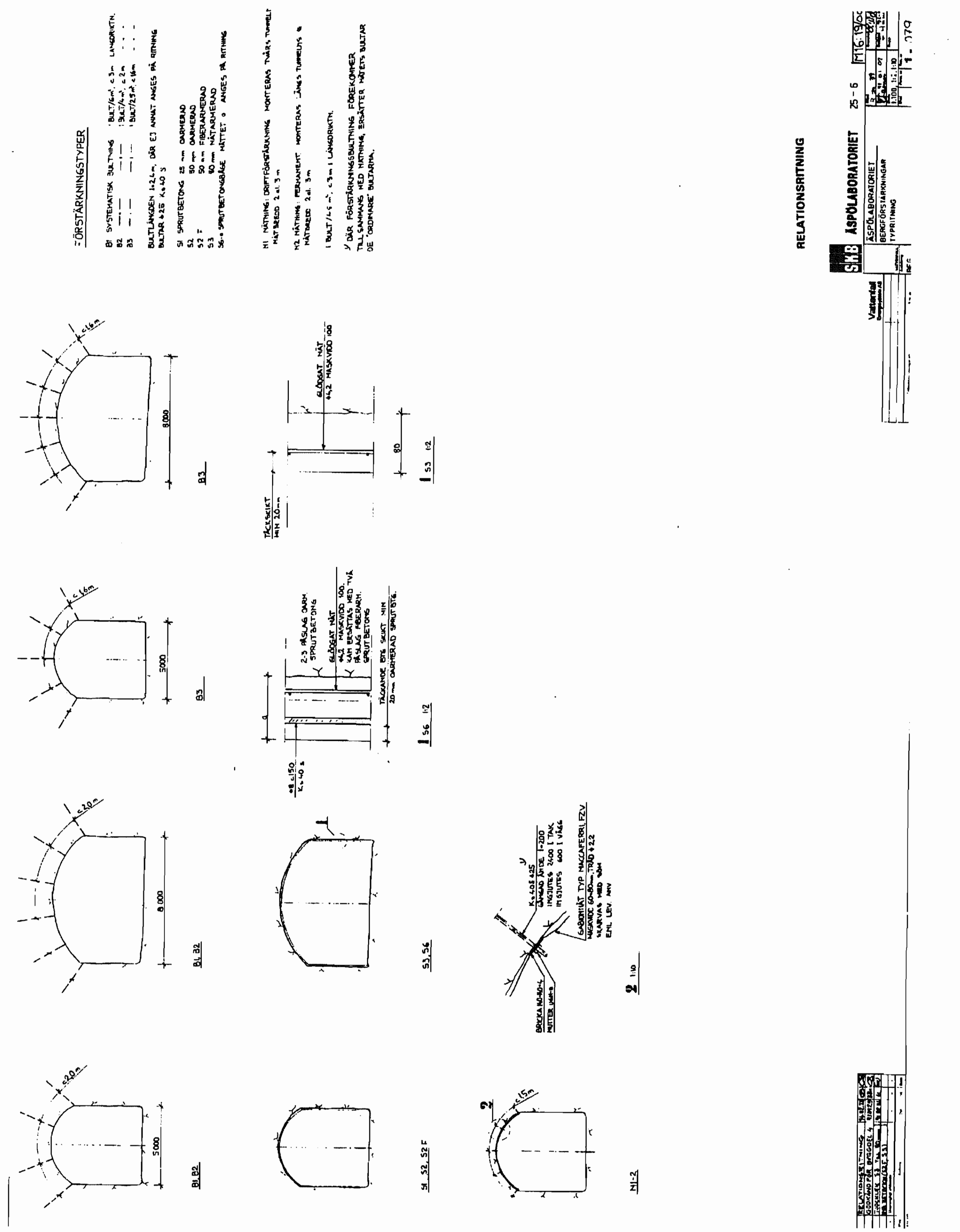


Figure 3-4 Rock reinforcement. Standard drawing.

3.3 Tunnelling with a tunnel boring machine, TBM

The TBM tunnel has a diameter of 5 m and the length 409 m.

The first layout for the second phase of construction was based on a tunnel spiral with a radius of 150 m, making a full turn from the position of the shafts on level -340 m down to the -450 m level. It was also realised that if the TBM failed to maintain the curve radius it could come in contact with the extremely complex and highly water-bearing discontinuity, NE-1. The tunnel earlier intersected this discontinuity and it was clear that another contact should be avoided due to the extent of grouting that was needed for a safe passage of the NE-1.

In conjunction with the evaluation of tenders for the second phase, alternative layouts were studied in order to explore possible ways to minimise the risk. The tender from the contractor Skanska included a proposal to start the TBM tunnel half way down at a point in the western region of the spiral and go with a moderate horizontal radius (250 m) down to the final level. In this way the NE-1 could be avoided and the direction of the TBM tunnel became more or less perpendicular to some minor but very water-bearing discontinuities. By using this layout, the TBM could be tested for the first time at this depth in the bedrock at realistic conditions for a deep repository without the hazard of a contact with a major water-bearing discontinuity.

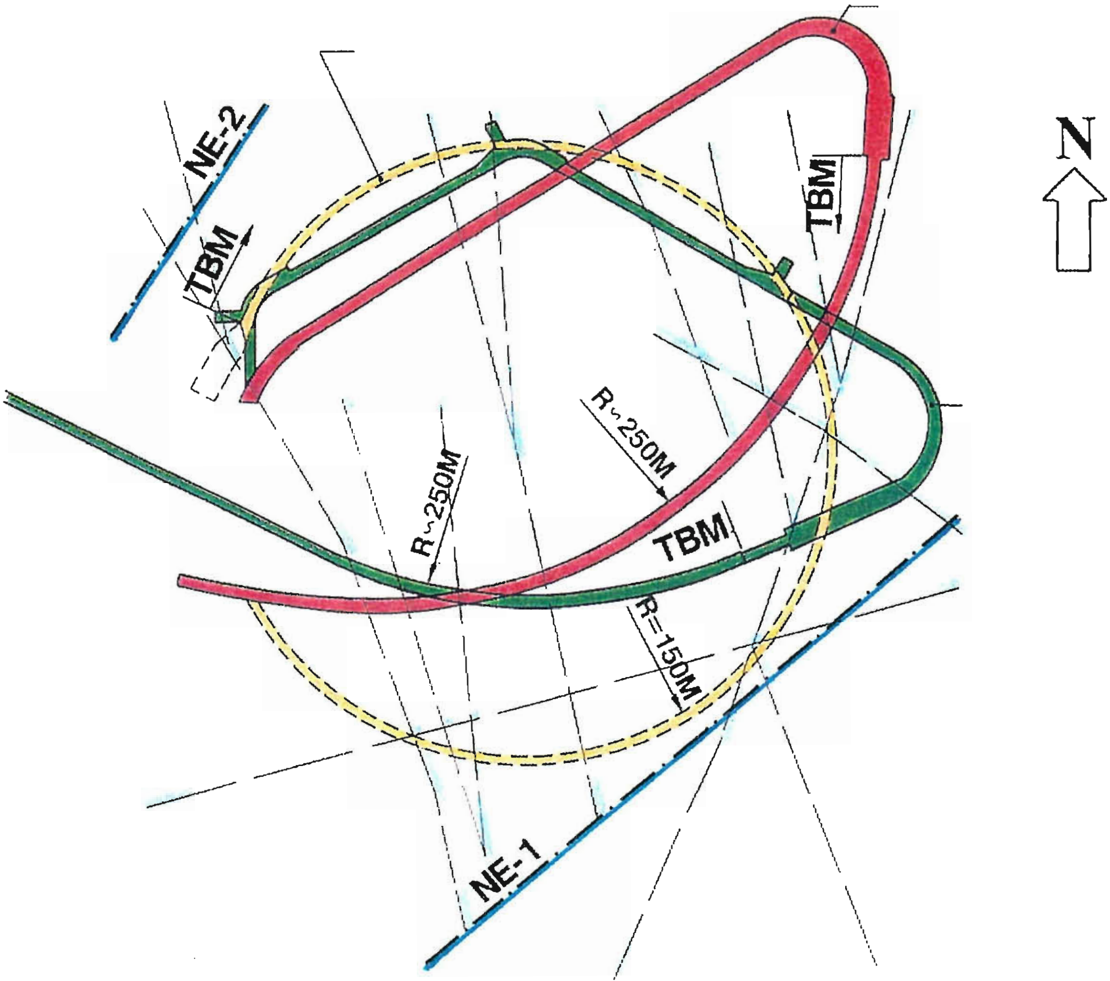


Figure 3-5 Alternative layouts for the TBM tunnelling.

During the summer of 1994 the TBM-tunnelling was carried out successfully. A TBM type Jarva Mk15 manufactured by Robbins Europe equipped with a 5 m diameter drilling head was used. One reason for the choice of this type of TBM was the horizontal conveyor belt for transport of muck from the boring head to the end of the back up rig. An inclined conveyor belt can create problems when the TBM is drilling in a descent and the muck is saturated with water. To adapt the machine to the requirements and conditions for the boring at Äspö it was equipped with some special functions as:

- Two drilling machines, COP 1238, for drilling of holes for probes and grouting.
- Passings in the boring-head for drilling of holes in the tunnel face.
- Electrical frequency changer for stepless variable speed.
- Logging programs for TBM and probe drilling.
- Short back up rig with only six decks.
- A spare diesel generator with capacity for ground water drainage pumps.
- Operators cabin designed as a rescue chamber.

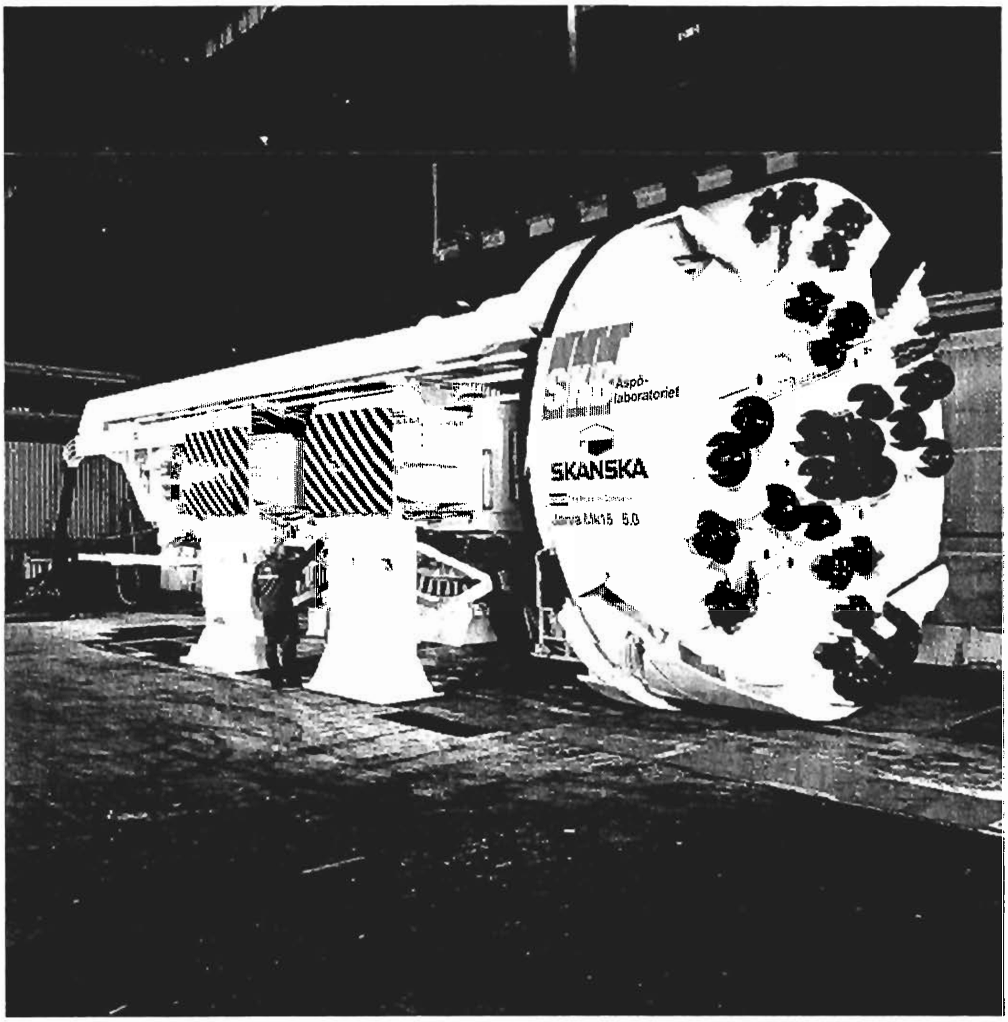


Figure 3-6 TBM before delivery to the site.

The option to drill probe holes through the boring head and the logging program was requested by SKB. Boreholes for grouting and hydrotests were performed successfully from the TBM, by the two drilling rigs. The peripheral holes were drilled as a shield around the TBM-head. Holes have also been drilled through the TBM-head in 8 given positions (when it was stopped). Before start up of the TBM, a 200 m long pre-investigation hole was drilled along the tunnel line. The results from this hole were used for planning of the grouting works. Totally 56% of the TBM tunnel was grouted. When probe drilling, the inflow in a single hole was up to 120 l/min.

The TBM was first assembled at the manufacturer's workshop and after a functional testing it was disassembled and sent to the site. The final assembly was done in a rock cavern situated at the -420 m level. The transport was carried out in as large pieces as possible. The largest part was the "main body", weight 50 tonnes, and the "centre section", weight 30 tonnes. For the transport down through the tunnel a low built trailer with hydraulic steering on all wheels was used. The back up rig was mainly assembled at the site. The transport down the tunnel was done stepwise with one deck at a time. For the assembly work a 50 tonnes overhead crane was established in the assembly cavern.

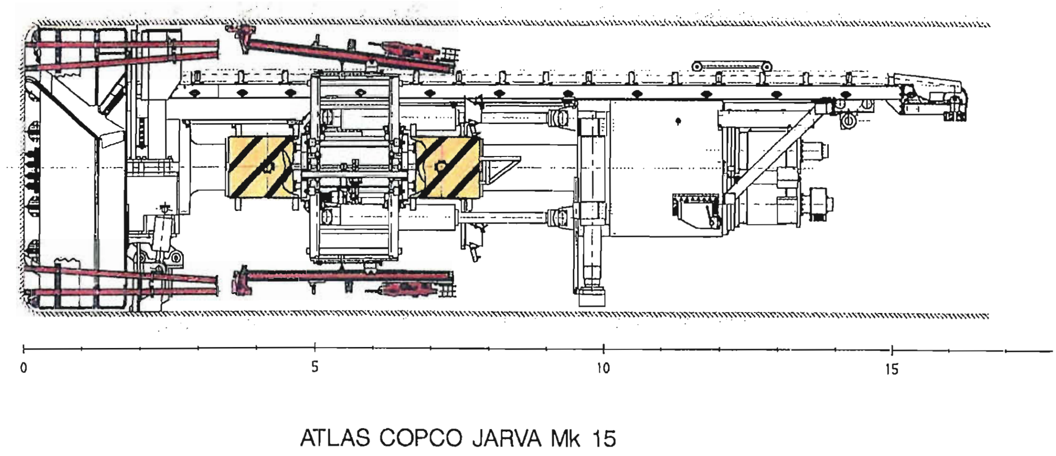


Figure 3-7 Section through the TBM.

Figure 3-8 The 50 metric ton "main body" on a trailer at site.

A well functioning ground water drainage system was a basic requirement for a safe performance of the TBM tunnelling. To ensure supply of electricity a separate back up cable was installed. The total inflow to the tunnel before the TBM start up was approximately 2000 l/min. Two separate pumping systems were installed for a total capacity of 4000 l/min.

During the TBM tunnelling no reinforcement of the rock was needed. The first 200 m of the tunnel were bored downwards with a declination of 14.5%. The mucking out was done with a Toro 500 E, which carried the muck from the end of the conveyor belt at the back up rig to the assembly cavern. From this point ordinary trucks carried the muck up to the ground level.

Some data from the TBM boring:

- Average capacity, 1.36 m/h (effective boring time).
- Highest capacity, 2.5 m/h (effective boring time).
- Average weekly production, 32 m.
- Best day, 14.7 m.
- Best week, 48.7 m.
- The utilisation degree approximately 30%.

Due to the relatively short length of the TBM tunnel (409 m) the experience and data should be compared to a start up period in a "normal" TBM project.

3.4 Raise-boring of shafts

Raise boring of the three shafts for lift, ventilation and other installations was mainly chosen in order to minimise the hazards during the construction period (compared to conventional raise drilling and blasting). Raise boring produces a perfectly cylindrical shaft without any major disturbances to the surrounding rock. The relatively smooth walls with low flow resistance makes them suitable as ventilation ducts. The diameter of he shaft for the lift is 3.8 m and the two ventilation shafts are 1.5 m each.

The first part of raise boring was performed from the ground level to the –220 m level. The raise-boring rig was placed at the bottom of the excavated pit for the lift building at Äspö. For the large shaft a pilot hole of 360 mm was drilled in order to fulfil high requirements on limitation of deviations. However, the deviation was slightly larger than acceptable and reaming of the lower part, from the -220 m level up to -170 m, was done with a 4.1 m reamer-head. For the other two raise boring steps, which only were 100 m long each, the pilot holes were within the limits and the 3.8 m reamer was used all the way. The demands for the ventilation shafts were not so high and a smaller machine and pilot hole were used.

In the first part, down to the -220 m level, pre-grouting was performed in the pilot holes. Limitations similar to those for grouting in the tunnel were imposed also in this work. The results were unsatisfactory and an extensive grouting work was needed after reaming of the shafts. The pre-grouting from -220 m down to -450 m was therefore performed in drilled holes peripherally around the positions for the shafts. This method gave a satisfying result and no grouting work was needed after the reaming. For the upper part above the -220 m level, installations have been made in order to collect the groundwater inflow and leading it to the drainage system.

Figure 3-9 The Raise Boring Machine in the blasted pit for the lift building at the Äspö Research Village.

3.5 Installations

The equipment for the lift and the ventilation system are installed in a building at Äspö Research Village. The machinery and data based control system for the lift is installed below the ground level. The machinery, with a provisional platform fixed to a wire, was used for installation works in the shaft for the lift. Horizontal beams are fixed into the cylindrical walls in the shaft. Vertical guidings for the lift cage are fixed to the beams. Pipes and cable trays in this shaft are fixed to the beams and the installation work was carried out using the same provisional platform.

The ground water drainage system is designed to collect the inflow in various areas and leading it to sumps at the levels -110 m, -220 m, -340 m and -460 m. A sump collecting the water from the portaling is placed just inside the tunnel entrance. A requirement in the licensing for the construction was that the drainage water will be pumped into the see at the vicinity of the outlet of cooling water from the Oskarshamn nuclear power plant on the Simpevarp peninsula. The pipe for drainage water is therefore installed in the access tunnel from the Simpevarp peninsula to the -220 m level. From this level downward the pipe is installed in the lift shaft. At the –460 m level the tunnel system is designed to accommodate a large volume of water if the drainage pumps fail. This gives a margin of at least 17 hours for repair work before the pumps have to be started again, if all pumps are stopped. A stop of the pumps in one of the sumps at lower levels will subsequently give a longer time for repair work.

The installations in the tunnels and shafts will in the coming years give valuable experience of the corrosion resistance of different materials. The environment in the tunnel is extremely corrosive with its high humidity and high content of chlorides in the groundwater. Various qualities of stainless steel as well as galvanised and coated carbon steel have been used. So far ordinary stainless steel (not acid resistant) seems to be sufficient. Carbon steel without protective coating corrodes very quickly if it is exposed to water. Wood and plastic materials have been used when possible depending on mechanical strength and fire protection aspects. Aluminium dissolves very quickly due to corrosion.

3.6 Experiences

The very saline water creates a lot of problems for the construction equipment as well as the permanent installations. This implies high demands on daily maintenance on e.g. drilling rigs. The choice of materials and coatings for the installations has to be made carefully to withstand the corrosive environment.

The general experience from blasting was that it is most important for the achievement of a smooth and little damaged tunnel periphery to have straight and carefully directed blasting holes. The experience was that computerised drilling rigs were not fully developed yet. A skilled driller achieved the best drilling results when drilling manually, aided by a computerised directing device.

An electric loader considerably improved the working environment for the workers and researchers. The trucks were also a part in the ensuring of a good working environment. The trucks were equipped with a particle trap (scrubber) and a catalytic converter. They were run on "city diesel", a cleaner diesel oil than the normally used "tunnel diesel".

The experience from the TBM tunnelling was that the vertical curve from the assembly cavern to the declined part of the tunnel created problems at the beginning with some damages to the first and last deck of the back up rig. The first part of the horizontal curve presented also a problem due to the fact that in this part the tunnel described both a horizontal and a vertical curve. After this part, a horizontal curve of 230 m was performed. Problems with cutters followed in the first 200-300 m of the tunnel and totally 90 cutters were exchanged.

Due to the decline of the tunnel it was difficult to pump water in front of the TBM head until start up of the boring. This caused problems with transport of the muck when starting after shorter or longer breaks. The inclination of the conveyor belt caused by the declination of the tunnel made the saturated muck go in the wrong direction. One night, the drainage system failed for 6 hours in the final part of the TBM tunnel. In this part the tunnel is sloping slightly upwards and the end part of the back up rig was flooded. There were no major damages to the equipment and the boring could continue in the following shift.

4 Detailed design work

4.1 General

For the second construction stage, the CAD technique was used when compiling excavation plans. Even if the various plans have no connection to each other, the use of the CAD technique did save a considerable amount of work, e.g. when calculating co-ordinates and measuring-lengths. The work has been simplified, done faster and at a lower cost than traditional drawing by hand and man-made calculations of co-ordinates. The CAD technique can also be an advantage when compiling information from other technical disciplines and from basic material such as maps and geological data. Although, the design of the Äspö Hard Rock Laboratory did not take all advantages of the CAD technique, it should be utilised when designing the Deep Repository.

Compiled plans were drawn up in order to show all the installations to be made nearby the sumps 2 and 3, and they proved to be very useful in the various construction stages. It made things easier to have all the installations shown on one single plan, not the least for the sub-contractors that had to do the detailed work and were not familiar with the entire installations of the facility. Similar compiled plans would have come in handy for all the sumps, and for the landing areas and other areas where a lot of installations were to be done. The same plans could also be of use for the operational phase of the facility. In view of this, the Äspö Hard Rock Laboratory's operational management later ordered the drawing of compiled plans showing the installations at the -340, -450, and -460 m levels.

4.2 Facility design

4.2.1 The TBM assembly cavern

The allowed declination in the TBM assembly cavern was changed during the design phase from the maximum of 40‰, to the 20‰ that was finally decided on. Because of the drainage, a lesser declination should not be chosen, even if the contractor would have preferred a totally horizontal assembly cavern. The launch hole for the TBM borings, at -420 m, was blasted flatter than it was designed. So, on the advice of the contractor, the declination of the TBM tunnel was increased to 145‰ down to the -450 m level. By doing so, the lowest point of the TBM tunnel would reach just below the level of -450 m. As in other sections of the tunnel, this steep part does not seem to pose a problem for accessibility.

The walls of the TBM launch tunnel must have counterstays for the pressure plates of the TBM. The contractor designed the counterstays, and normally they would be cast in concrete. But in this case, the rock was in a good enough shape for the contractor to use a cautious blasting in order to create the counterstays. Consequently no costly concrete casting was needed.

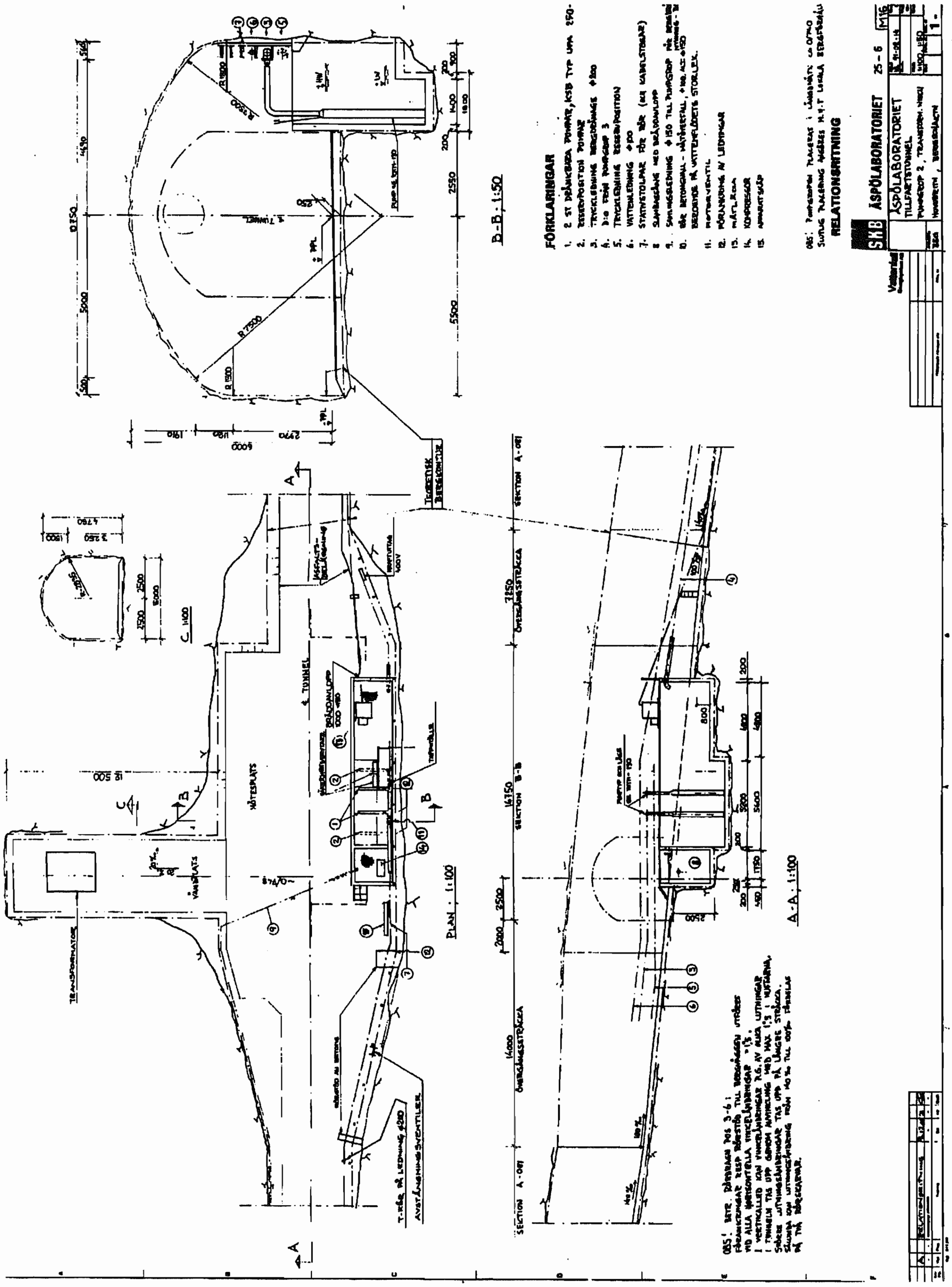


Figure 4-1 Compiled plan from pump sump 2.

4.2.2 Drill holes and discontinuities

During the first construction stage, a probe hole was destroyed when the tunnel passage eliminated it. Therefore SKB decided that all holes drilled in the vicinity of the tunnel, niches and shafts, should be shown on the plans. It is essential to have this information on the plans, and specifications on how the measurements of the various holes were done, to be able to make a layout where the excavations can be put sufficiently far away from them.

Apart from the location of the holes, it is also important to gain as much information as possible on the location of important discontinuities, so that the design of the facility can be adjusted accordingly.

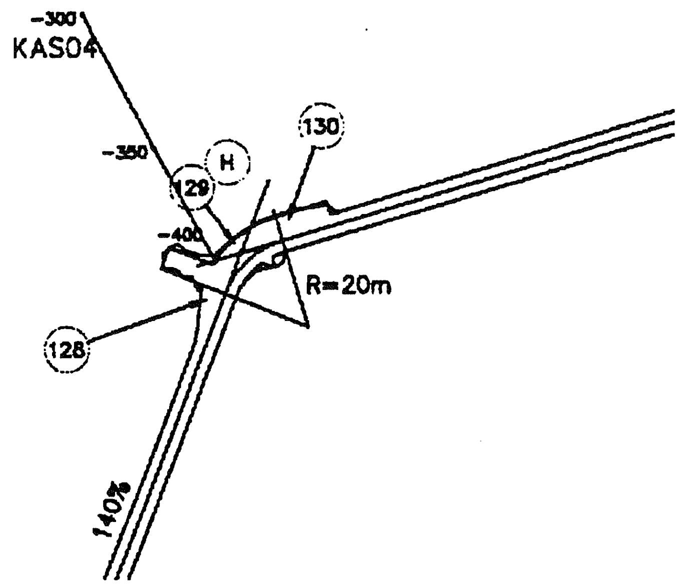


Figure 4-2 Part of drawing showing the location of exploration hole nearby the tunnel.

4.2.3 Transformer niches

The transformers have been built-in in containers, and then put in position. Although they fit into the niches, it would have been better if the niches had been wider and higher for the sake of accessibility and maintenance.

4.2.4 Fireproof walls

Originally it was planned to cast the fireproof wall located between the spiral tunnel and the landing areas but the contractor wanted to avoid any structures involving casting, so several different solutions were studied. A steel structure was considered impossible to use because of the corrosive environment, and a brick-built wall would not be able to withstand the pressure of the fire ventilation system. The solution was to cast a concrete frame, secure it to the rock, and brick up the rest of the wall with lightweight clinker blocks. This solution works very well, and it would be easy to open it up for passage if one wants to.

The casting of the frame prevented any passing by as long as the mould was in position. A prefabricated beam would have been better to use, and, as the casting of the beam was more difficult to carry out than the contractor had foreseen, perhaps a cast wall had been both easier and cheaper to build.

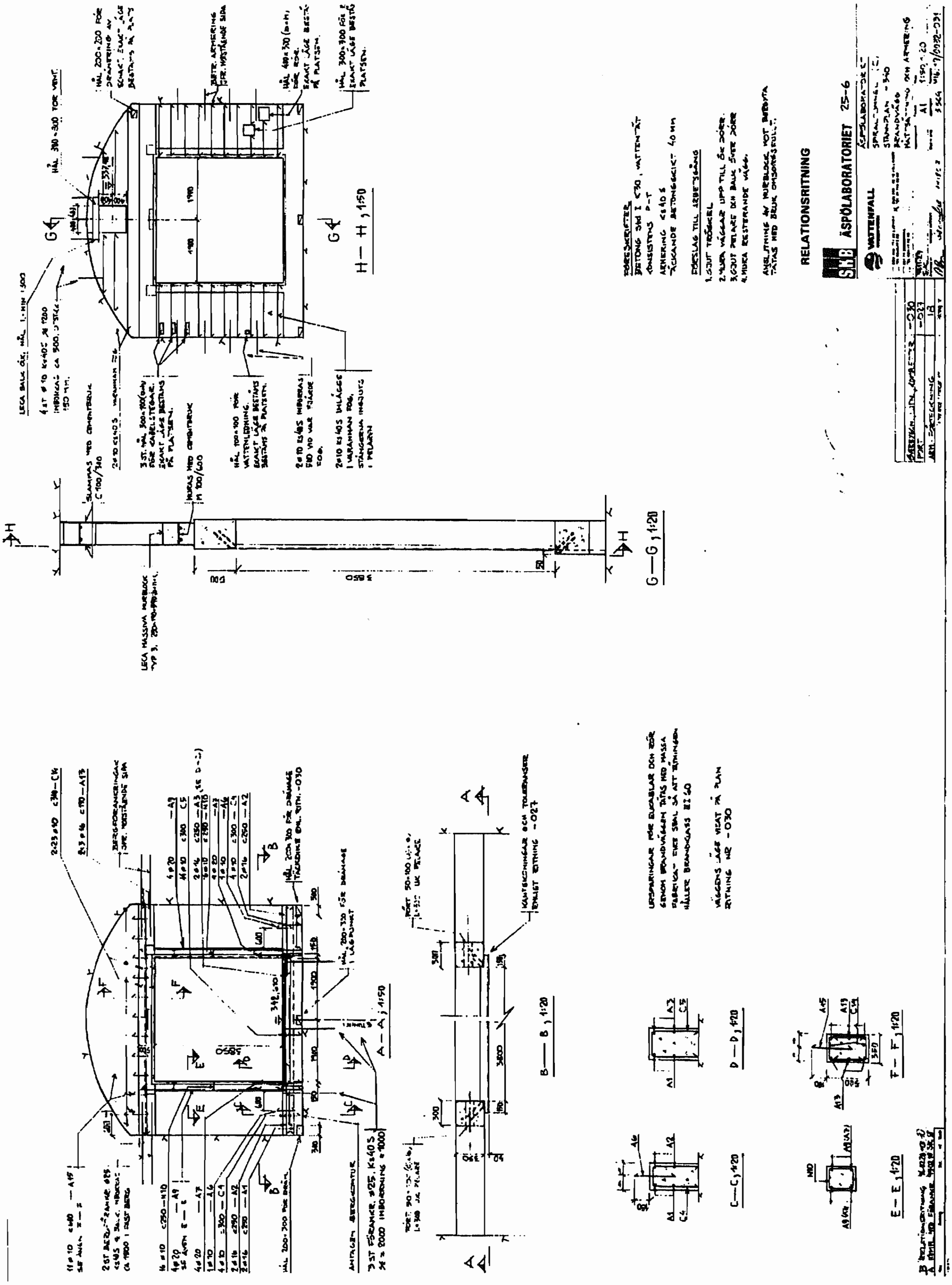


Figure 4-3 The fire proof wall at the lift's landing area at level –340 m.

4.3 The rock work design

4.3.1 Rock reinforcement

Construction drawings of rock reinforcements, with sprayed concrete and bolts, were made for the invitation to tender. The plans were only used to prescribe the reinforcement of the roof in the lift's landing area.

The spans are relatively small. Calculations for the permanent rock reinforcements, with bolts and sprayed concrete, were done for the roof in the landing area at the -220 m level. The same calculations were then used for the landing areas at greater depths.

4.3.2 Bolts

All in all, more than 500 expandable roof bolts of the Coated Super Swellex type were used in the Äspö Hard Rock Laboratory. The exact amount, and their locations, is accounted for in "Overview of documentation of tunnel, niches and core boreholes", progress report HRL-96-19. The bolts, of both Swellex and ribbed bar type, have been surveyed by geologists, and have been approved as components in the permanent reinforcements. However, the exact durability of Coated Super Swellex bolts can not be assessed. The construction drawings prescribe ribbed bar bolts. Although there is a lot of experience on how ribbed bar bolts react in a corrosive environment, long-term experience of how Swellex bolts react in such an environment is lacking. In a proposal for a surveillance programme, plans are made on how to maintain a high level of control. The results from such controls should be systematically compiled in order to gain a better basis for decisions when choosing bolts for the Deep Repository.

4.3.3 Wire netting and sprayed concrete

The scientists initially demanded that no sprayed concrete should be used in the Äspö Hard Rock Laboratory facility, and that all reinforcements should be made with the use of bolts and wire netting instead. However, when the excavations started, the personnel on site pointed out the safety risks involved in wire netting. If wire netting is used as rock reinforcement near the tunnel face, the wire netting could be damaged by the blasting rounds and pieces of rock could fall down. So it was decided to allow the rock reinforcements to be done in a conventional way, involving sprayed concrete instead of wire netting.

Spalling rock was initially only identified adjacent to the level -340 m, and there the rock surface has been covered with wire netting. The reinforcement has worked well, but the wire netting should be kept under close surveillance in order to gain further knowledge of their durability, especially in regard to corrosion. The documentation will be useful when planning the Deep Repository. Later spalling rock has been identified at lower levels.

Rock reinforcements, bolts, sprayed concrete and wire netting, must be checked and controlled every now and then. In connection to the final inspection of the underground facility, a proposal for a control programme was compiled.

4.3.4 Reinforcing the lift shaft

A reinforcement of the lift shaft's connection to the floor of the landing area has been done, by placing a cast concrete ring around the shaft. The ring was given a circular outline, although a cheaper quadrangular outlining could have been used without making the construction inferior. A quadrangular outline would also have eased the installation of the safety crate surrounding the lift shaft. The moulded console at the lift entrance is a good construction, compared to having used steel beams, which would need to be under constant surveillance and repair due to the corrosive environment. The moulding of the concrete console was eased considerably by making use of the horizontal beams for the lift as a support for the mould.

The plans place the upper edge of the concrete ring on the level of the landing area. The purpose was that the asphalt in the landing area should connect to the level of the concrete. But this was not done, so the asphalt is about 5 cm below the upper edge of the concrete ring. The difference in levels means that there is a risk of stumbling.

4.3.5 Grouting in the tunnel

Initially the grouting works were subject to numerous restrictions concerning choice of materials, spreading and volumes used. A number of different grouting concepts were tested, but most of the results were unsatisfactory. Later on, however, the restrictions were eased, and satisfactory grouting results followed shortly.

There was a certain suspicion that it would be difficult to grout at great depths, due to the high pressures, but the grouting works actually went quite well.

Grouting will have to be done in various water-bearing discontinuities surrounding the Deep Repository, partly to make the working environment acceptable, partly in order to keep the pumping costs at a reasonable low level, and partly to maintain a degree of stability. Experience from the construction of the Äspö Hard Rock Laboratory, shows that it may be difficult to control the grouting in order to achieve the required results. Therefore the SKB is developing the grouting technology using the valuable data gathered from the construction of the Äspö Hard Rock Laboratory.

As always, the rule proves correct that pre-grouting is cheaper and more efficient than post-grouting.

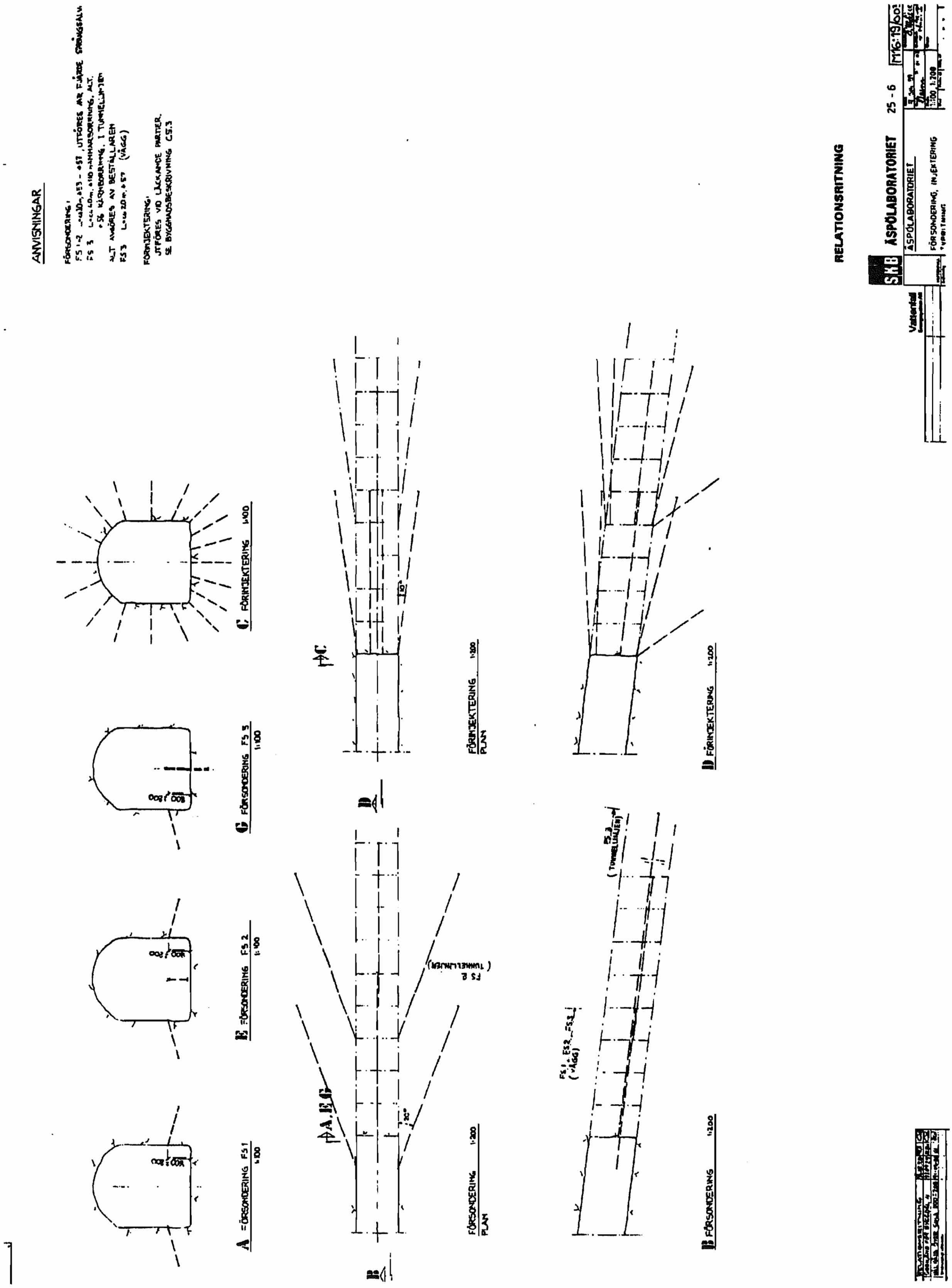


Figure 4-4 *Grouting of the drilled and blasted tunnel. Standard drawing.*

4.3.6 Grouting in shafts

No plans were made beforehand for the work done in the raise-bored shafts, apart from specifying their central co-ordinates. The contractor both suggested, and carried out, pre-grouting in the shafts. In the upper level, running from the Äspö Village down to the -220 m level, the shafts were pre-grouted via the pilot hole, and the results were not satisfying. A number of post-groutings were then carried out via the shafts, but the leakage is still too large. In the following stages, between the levels -220 m - -340 m, and -340 m - -450 m, pre-groutings were carried out via several drilled holes outside the shaft's periphery, and thereafter the shafts were raise-bored. This gave very good results.

4.4 Design of the drainage system

4.4.1 The tunnel

Leaking water is collected in, and led through, ditches and superstructure to the nearest sealing dam. The road's superstructure has a subbase consisting of a 150 mm thick layer of macadam, and this barrier allows the water to pass through it. When the plans were drawn up, the blast-damaged zone in the floor, together with the subbase, were judged to be pervious enough to take care of the water. This has turned out to be the case during normal operational circumstances, which involve a moderate amount of leakage. However, when the pump sumps overflow and water uncontrolled flows down the tunnel, the water pressure from below causes the asphalt surface to crack up. Therefore, the superstructure should be made thicker.

Finer fractions should be avoided in superstructures and niches. Instead one should use a matter where the finer fractions are washed away. In a flooding the finer fractions are transported downwards and plugging up the sealing dams, pipes and sumps.

The TBM tunnel has no room for ditches, so all water must run through the superstructure. Therefore a heavy grade of macadam, 16-64 mm, was prescribed as superstructure. One cannot compact macadam, so the upper layer of the superstructure should consist of rubble stone, size 0-100 mm, so the asphalt surfacing machine can drive on the superstructure without getting stuck.

4.4.2 Flooding of the sumps

Installing an inter-locking device on the pumps can reduce the problems occurring during flooding, so those pumps subjected to flooding further down the tunnel cease to operate. This would keep the level of water running down the tunnel at its normal level. Should a sump for some reason be flooded anyway, the surplus water should not be able to flow uncontrollably down the tunnel. Instead, the spillway should be connected to the collecting pipe system for groundwater leakage downstream of the sump. By doing so, one has prevented the increase of any water flowing in the tunnel if the pump system should break down.

4.4.3 Groundwater measurement

Leaking groundwater is led to the nearest sump. In order to measure the leakage of groundwater section-by-section, 17 sealing dams are constructed. They cut through the leakage flow of the water both at the bottom of the tunnel, and in the ditches. The first dam, placed in section 0/680, and designed according to instructions from the geohydrologists, did not work well. It has been modified later by welding a round bar to it in order to lead the water from the road surface into the ditches.

An alternative design involving an open trench covered by a grating was used on other dams. This design makes inspections, cleaning and maintenance easier to do, and water running down the road can also easily be collected in the trenches. The design is based on the assumption that the cleaning of the trench is to be done with an excavator. The cleaning is actually done with the help of a suction vehicle, so the trench can be made narrower than the ones constructed. A narrower trench also enables the grating to have a shorter span, and so the grating can be made of less stable material at a cheaper price. Under the sealing dams an especially careful blasting has been carried out. Then grouting was done down to approximately 1.6 m in the rock. The contact surface between the concrete and the rock was also contact grouted.

The modified sealing dams work very well. The water on the surface of the road and in the superstructure is taken care of as planned. The groutings under the sealing dams have also worked well.

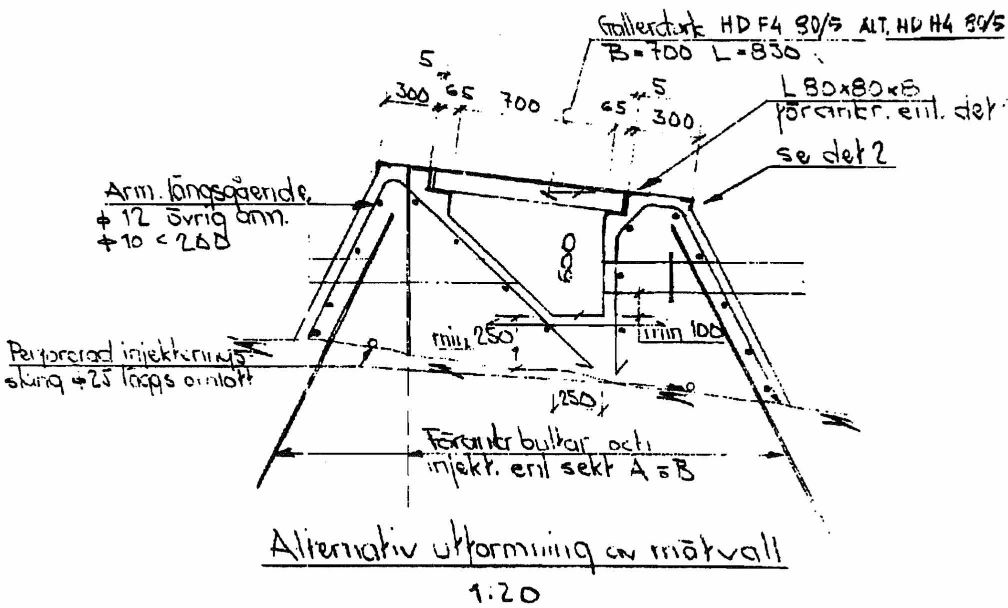


Figure 4-5 Cross-section of modified sealing dam.

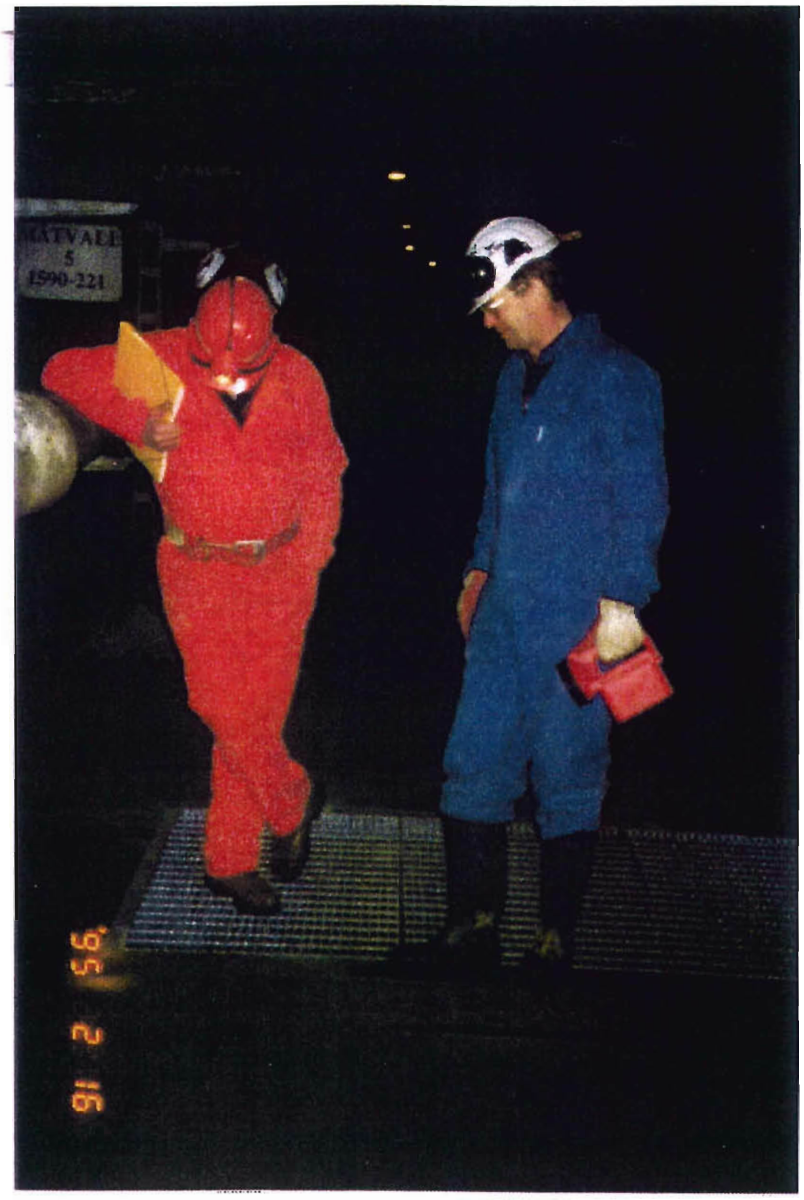


Figure 4-6 Grating on top of a sealing dam.

Filtering wells adjacent to the sealing dams have to rise above the level of the road so that they are not clogged up with sludge in case of a flooding.

A collecting dam in section 1/033 was constructed during the excavation of the tunnel in order to retain the water from the discontinuity NE-3 on the tunnel face. The immersed pump of a standard design that was put there during the construction phase has been left there afterwards. This decreases the cost of pumping up the water. The alternative would be to let the water flow freely down to the sump PG3 to be pumped up. It would be advisable to place collecting dams downstream any larger leakage spots, partly to decrease the amount of water on the tunnel face during the blasting of the tunnel, and partly to decrease the cost of pumping during the operational phase. The latest is especially important if the downstream pump sump is located at a long distance from the problem area.

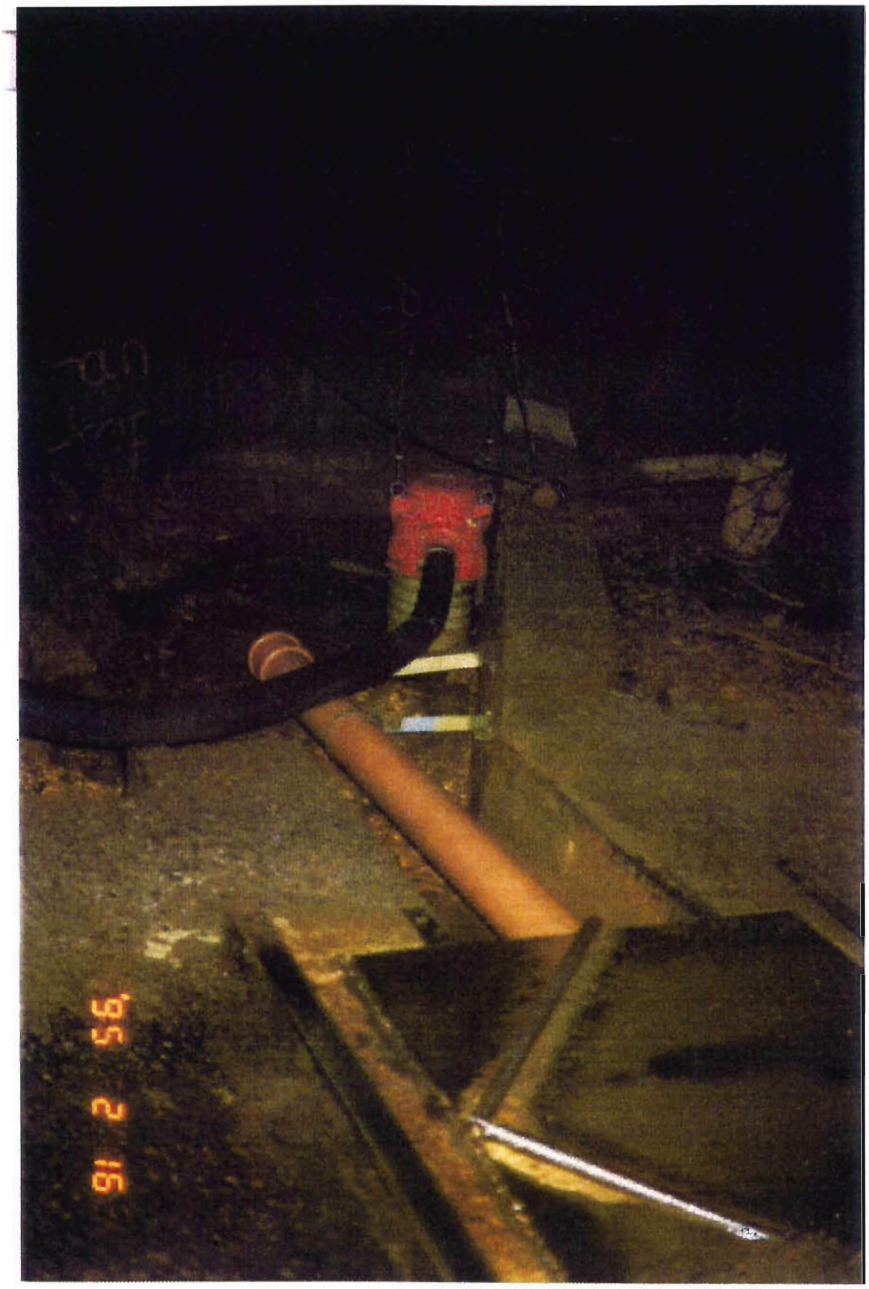


Figure 4-7 Collecting dam and pump at section 1/033.

Gauging equipments are placed adjacent to all sealing dams and sumps in order to measure the inflow of water in the different tunnel-sections, shafts and other areas. The water level in the gauging equipment is depending on the flow. A pressure indicator installed in the gauging equipment measures water levels, but the water level can also be measured against an adjustable stainless steel ruler with grades in millimetres. The gauging equipment has been equipped with exchangeable measuring weirs to enable accurate measuring at different flows. This simple solution works very well.

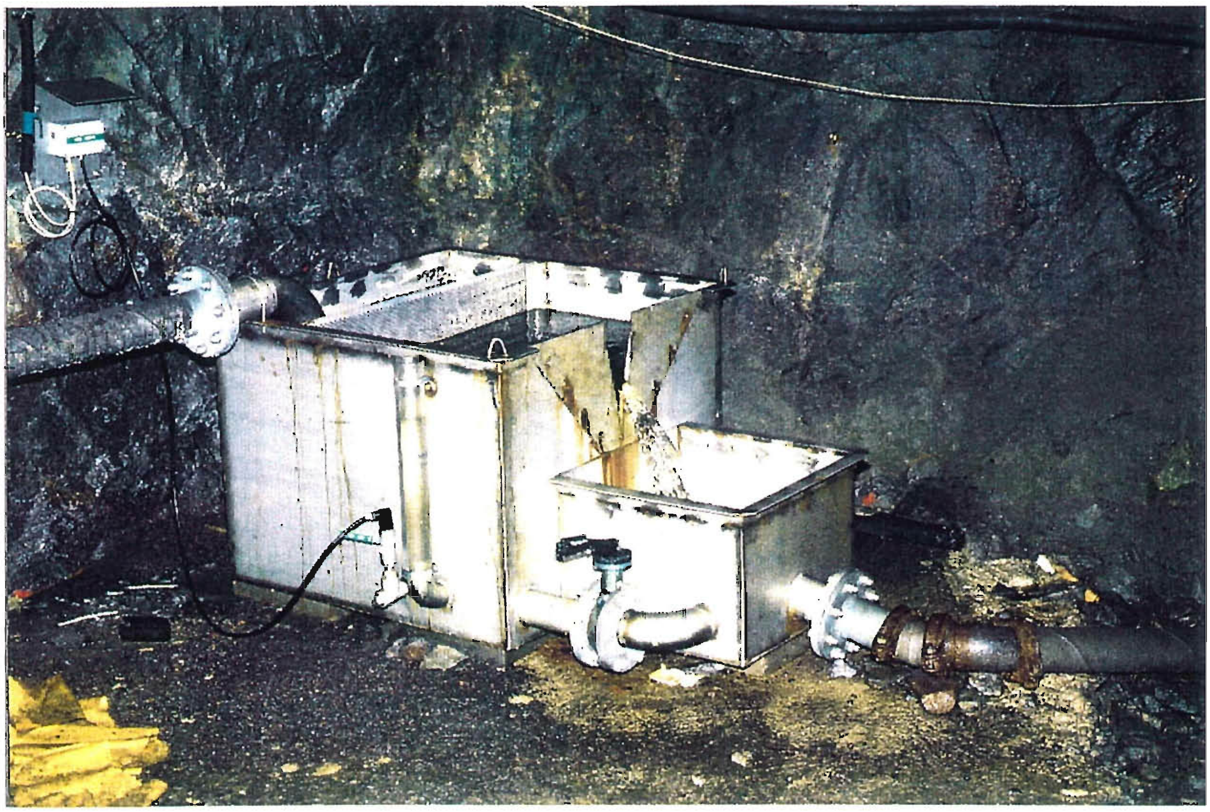


Figure 4-8 Measuring weir and gauging equipment.

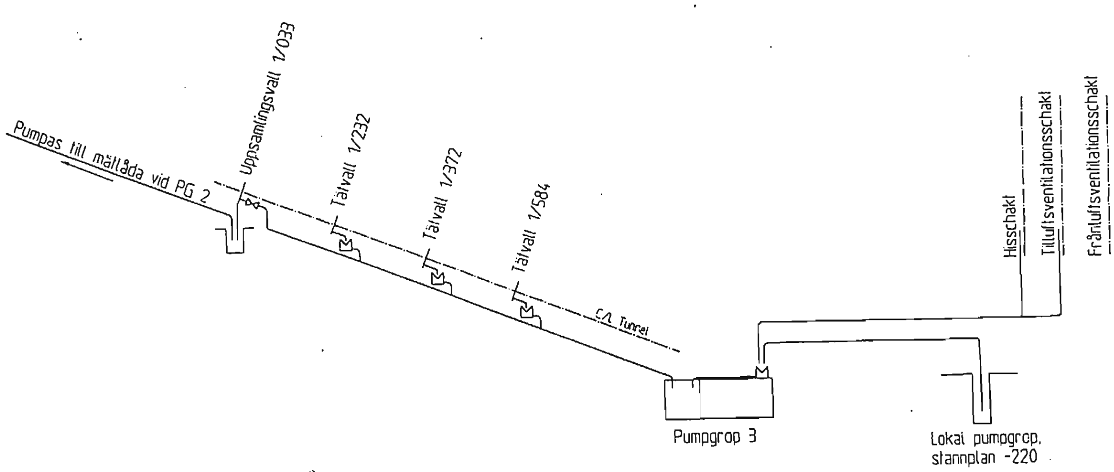


Figure 4-9 Part of the drainage water system and measuring weirs.

4.4.4 Collection of groundwater inflow

In the access tunnel, down to section 1/660, the collective piping for collecting the water from the meters is placed on the lowest bracket of the rack on the right-hand side of the tunnel. Between the sections 1/770 and 3/190 the collective piping is placed on concrete tiles on the right hand side of the road. There is no point to set up a rack just to place the collective piping on it, as the concrete tiles keep the piping in place and also makes it easy to change damaged parts if necessary.

In the TBM tunnel, between sections 3/190 and 3/410, the collective piping lies on brackets fixed on the wall on the right hand side. An alternative solution would have been to place the piping on the superstructure, but then there is always a risk of breaking the pipes by the axle pressure of the traffic. In addition, inspections and repairs would be more difficult to carry out if the piping had been buried in the superstructure.

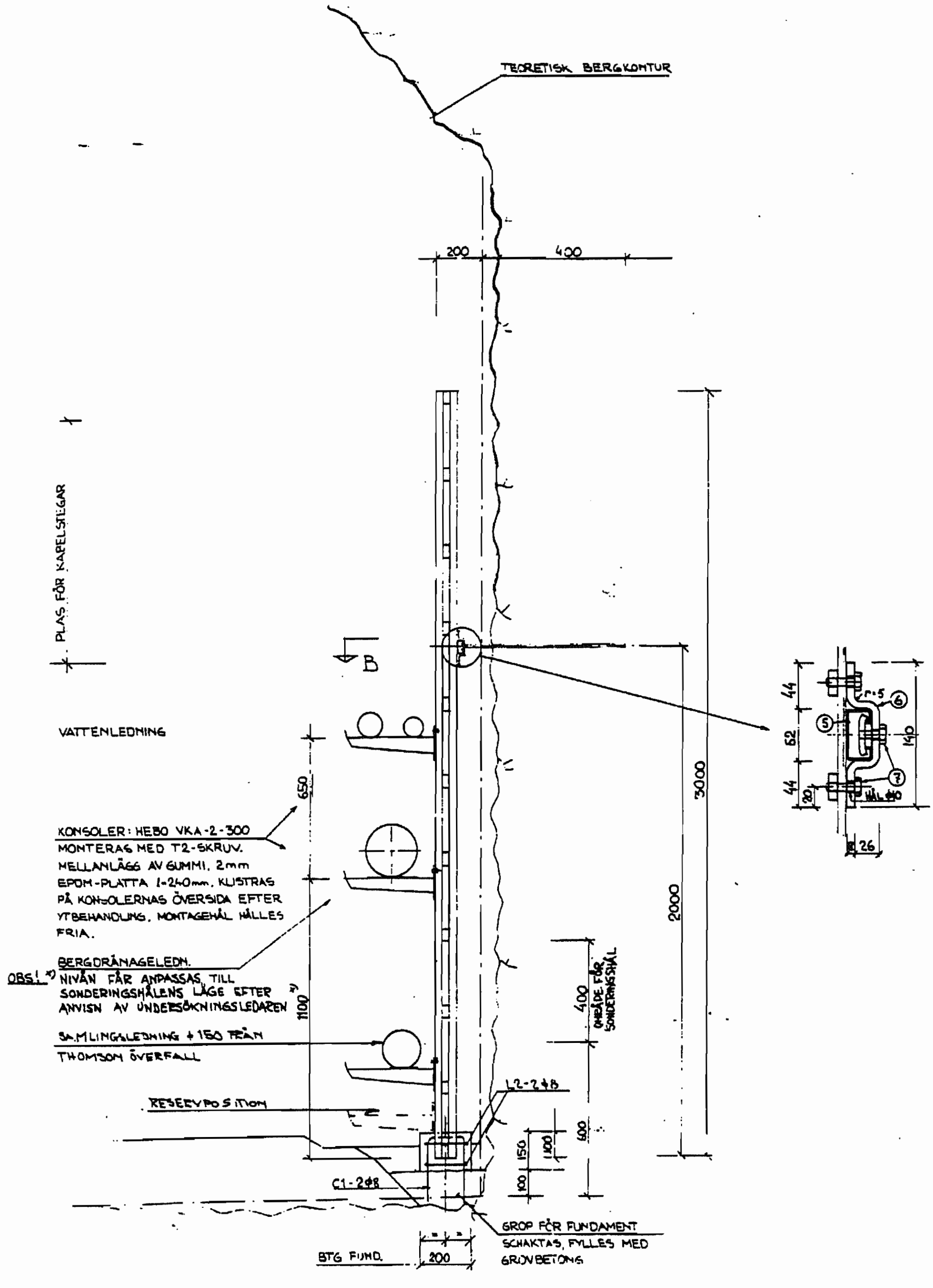


Figure 4-10 Rack for pipes and cables in the upper part of the access tunnel.

Figure 4-11 Collection of water in the lift shaft.

Water leaking into the lift shaft is collected in stainless steel drains below local leakage spots. A drain is placed close to the roof in every landing area, and the water is led from the drains via the collective piping into the meters. The drains were designed by the contractor and the system works well, apart from occasional troubles with the sealing between drains and rock walls not being sufficient.

Water leaking into the supply air shaft located between the ground level and the -220 m level is kept separated from the supply air by the use of a plastic tube hanging inside the shaft. The water is collected in a drain and then led through the collective piping from the lift shaft to a meter. This design works well. Water leaking into the supply air shaft below the -220 m level, and water leaking into the exhaust air shaft, is collected in containers placed beneath each shaft at level -450 m, and then led through the collective piping to a meter. Free-flowing water in the shafts does mean that there is a risk of the air being dampened, and that free-flowing water drops are spread via the air ducts.

4.4.5 The pump system

At the beginning of 1991 solutions for a rock drainage system were examined, focusing mainly on alternatives involving submersible pumps. Dry mounted pumps were not judged to be made of sufficiently high quality material. The best quality that such pumps are made of is acidproof steel, and they would not be able to withstand the highly corrosive environment in the underground facility. Dry mounted pumps also need to have a higher degree of slurry separation.

The chosen system design gives some 110 to 120 m head between each sump. One sump is placed in the middle of the access tunnel and additional ones are placed in every landing area. From the lowest located sump, PG5 at level -460 m, water is pumped to the nearest sump above, which is PG4 at level -340 m. And from that level the water is pumped on upwards passing through each sump. The drainage water pumped from one sump to another is let into the pump chamber so as not to disturb the course in the system of slurry separation. During the construction phase, and in the case of flooding, mud has unfortunately sedimented around the pumps causing overheating. This has in turn resulted in pump stops and flooding of the lower parts.

Decreasing the number of sumps had been technically possible, but the examination of alternative system designs focused on the chosen system solution as it costs less both to install and operate.

In each sump two pumps have been installed. The exception is PG3, which has three pumps. The amount of water flowing into PG3, now and then forces two pumps to operate at the same time so that the sump will not be flooded. One of the pumps in each sump is an emergency pump that can easily be taken into operation if the regular pumps break down.

In PG2 the contractor had installed two temporary pumps of the "Mörck" make. SKB later bought these and had them renovated and permanently installed. All other pumps are of the "Flygt" make. It would be easier to operate and maintain the pumps if they all are of the same make, and, of course, servicing them with spares would also be easier. For this reason the "Mörck" pumps later were replaced by pumps of the same make and model as the others.

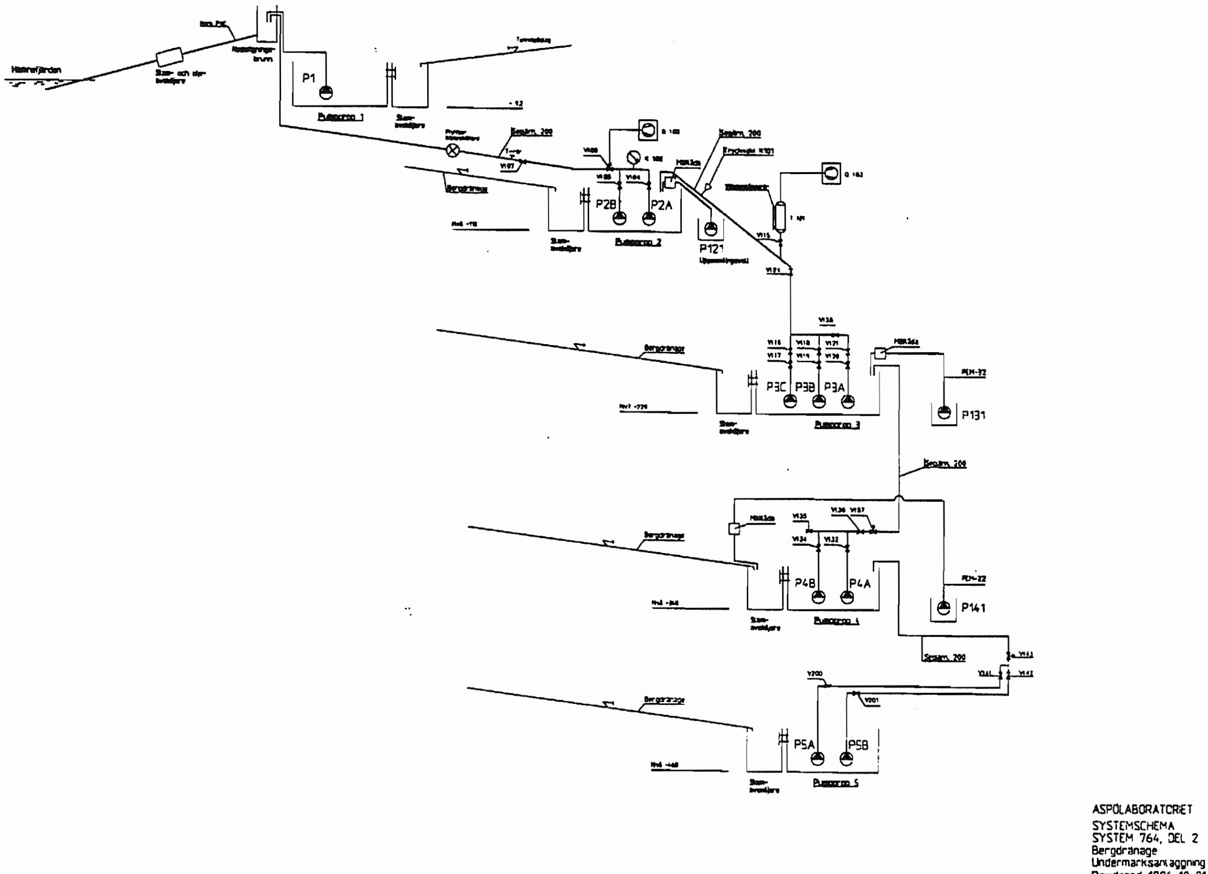


Figure 4-12   System design of the drainage pump system.

The drainage water between levels -460 m and -220 m is led into pipes in the lift shaft. From level -220 m and up to the ground level, the drainage pipes rest on brackets on the stand in the access tunnel. The pipes are easily installed, and they are easily reached for inspections and maintenance. On the other hand there is a risk of damage due to collision from a vehicle.

Rockers operate the gate valves at the sumps PG2-PG5. When the pump started in PG5 pressure percussions were initiated. This was because the gate valve was installed some 50 m away from the pump. The pipe between the pump and the valve was emptied every time the pump was shut down. Later this problem was eliminated by installation of clack valves at the pumps.

The nodular-iron pipes of the VRS type brand work well, as long as they are mounted according to the manufacturer's instructions. This means that the pipes have to be pulled apart, pretensioned, in order to minimise length-going movements occurring during the operational phase, and insulation of all pipefittings to prevent corrosion damage on the clamping rings. To safeguard against a certain degree of wrong installation, the pipes should also be fixed at certain distances along the line. In this way, any length-going movements that might occur can not be transmitted further down the line. At points where the pipe changes direction, it is also important to have them fixed to minimise any movements occurring. Pipe fixations made of concrete must be firmly attached to the rock so that the pipes are stable at all times.

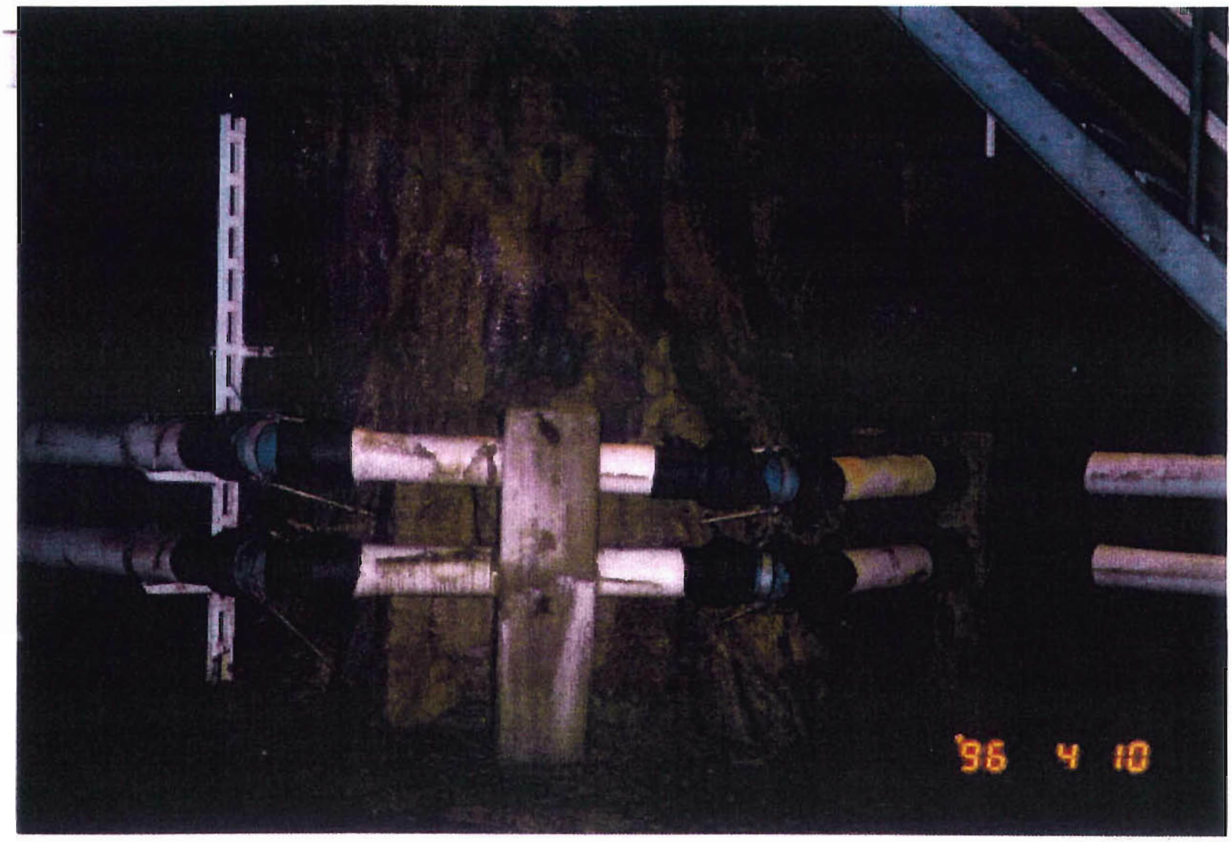


Figure 4-13 Pipe fixations at PG5.

Standard drawings are not always sufficient enough in detail to enable a stable and correct fixation of the pipes, so in order to avoid misconstructions, all anchor points for the pipes must be shown in detail on the plans.

Installations in the drainage system, such as safety switches, apparatus cabinets and pressure tanks, have protected by pent-roofs to avoid water dripping on the equipment. The pent-roofs should not be made too small. The pent-roofs should at least reach 0.5 m outside the equipment it is covering, as long as it does not interfere with the traffic and other activities.

A problem discussed a lot during the design phase was the one of the risk of pressure percussions. The solution of using a pressure tank to minimise pressure percussions works well, but it is important to make sure that the air is refilled regularly. The air in a pressure tank is dispersed rather quickly, and the refilling is done by hand.

The installed alternative solution, using a pneumatic or electrical valve, has up until now worked just as well. The valves operate automatically and need less surveillance than pressure tanks. Using valves involves the requirement of a delayed operational start up of the pumps following a power failure, so that the backwards-rushing water does not cause the pump to rotate backwards when started up again. The operational function of pressure percussions, pressure tanks, pneumatic valves and electrical valves, has to be further studied so that a suitable system solution can be chosen for the Deep Repository.

Figure 4-14 Pent-roofs and pressure tank at PG3.

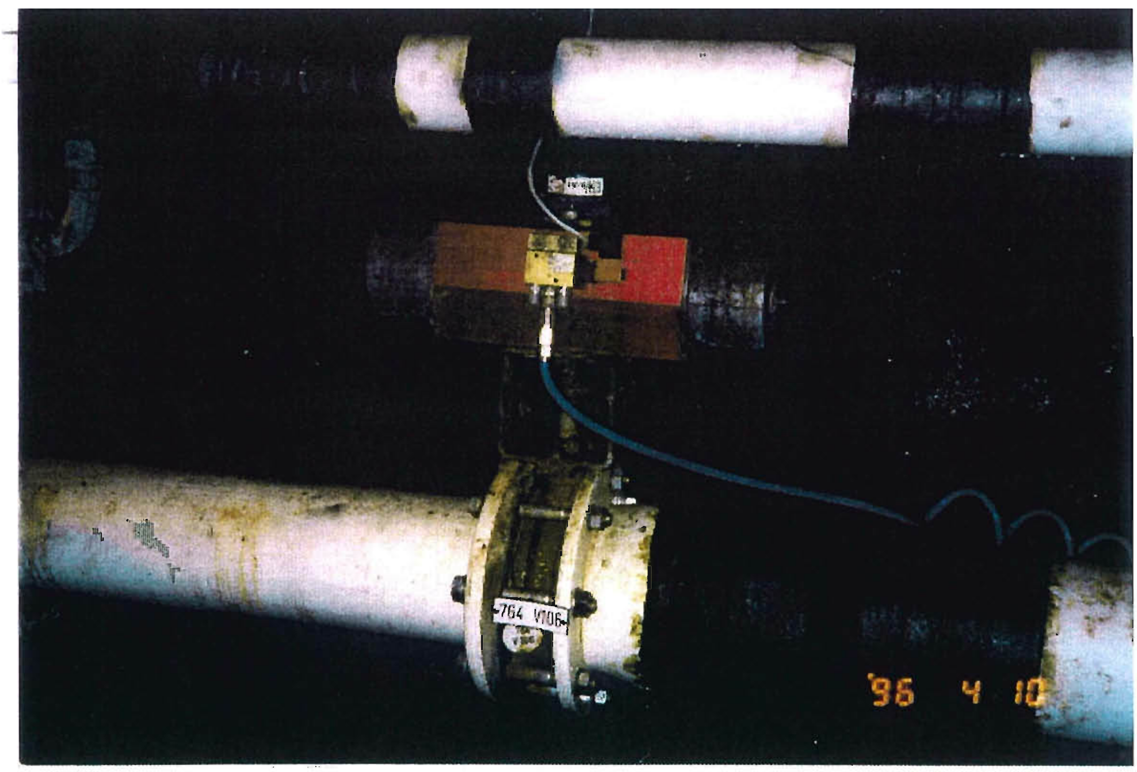


Figure 4-15 Electrical valve at PG2

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The above mentioned pressure tanks require the use of a compressor, as do pneumatic valves. The environment in the underground facility causes the aluminium parts on a compressor to dissolve very quickly due to corrosion. In order to avoid such corrosion damage, stainless steel hoods, equipped with heating, have been placed over the compressors. To make the maintenance easier to carry out, the hoods should be furnished with openings. Doors have later been installed in PG3's hood. Corrosion-resistant compressors have not been seen as an economically sound alternative.

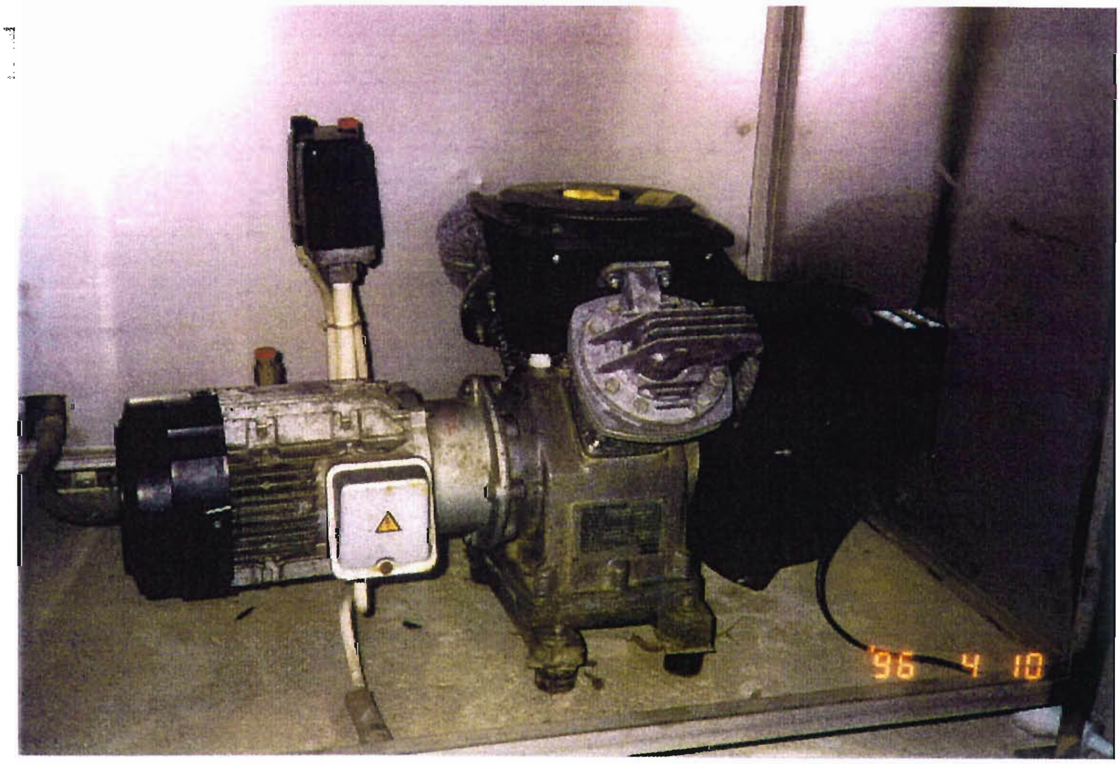


Figure 4-16 Compressor protected by a stainless steel hood.

4.4.6 Sumps

The operational experience has already shown that the slurry basins in the sumps are too small. The actual sump volume should also have been made larger, resulting in a reduced number of pump start-ups and shutdowns.

The sumps have been designed with an extra depression in the pump chamber to allow for the greater part of the sump to be emptied. This has, however, proved unsuitable as mud, which has not been settled in the slurry separator, easily settles around the pumps. This causes the pumps to become overheated and release of the motor protector. In order to prevent overheating the mud in the pump chambers must be cleaned up regularly. A better solution would be to put the pumps on a small elevation in the pump chambers instead. On the other hand, this would require a larger total volume of the sump. One alternative is to use pumps that stir up the sediment each time they are started up.

The operational staff considers PG3 to be a better alternative to PG4 as PG3 is easier to service than PG4. The lighting at PG4 is of a poorer quality, so perhaps better lighting would appease the staff and help to improve the situation.

Safety switches should be placed near the pumps, but not nearby the sump located at the bottom level as safety devices need to be placed high up to avoid them being damaged in a flooding.

4.5 Water supply system

Taps for cold water in the underground facility have been equipped with pressure reducing valves and safety valves in order to limit the water pressure to a maximum of 0.5 MPa, (5 kg/cm^2). At the pipe system's lowest point the inner pressure is restricted to 2.8 MPa, (28 kg/cm^2).

Initially it was planned to install taps for cold water at intervals of about 100 m in the access tunnel, and at intervals of 150 m in the spiral from level -220 m and downwards. In order to lower the costs, the number of taps in the access tunnel was reduced, and there are no taps at all in the spiral except for at the landing areas. Skipping the taps in the spiral has given rise to certain complications. The difference in levels between the landing areas is about 100 m. If a water hose is pulled upwards from a landing area, the water pressure becomes insufficient fairly quickly in the nozzle of the hose. And the water pressure in the hose becomes too high, with a risk of bursting the hose, when it is pulled downwards the spiral from a landing area.

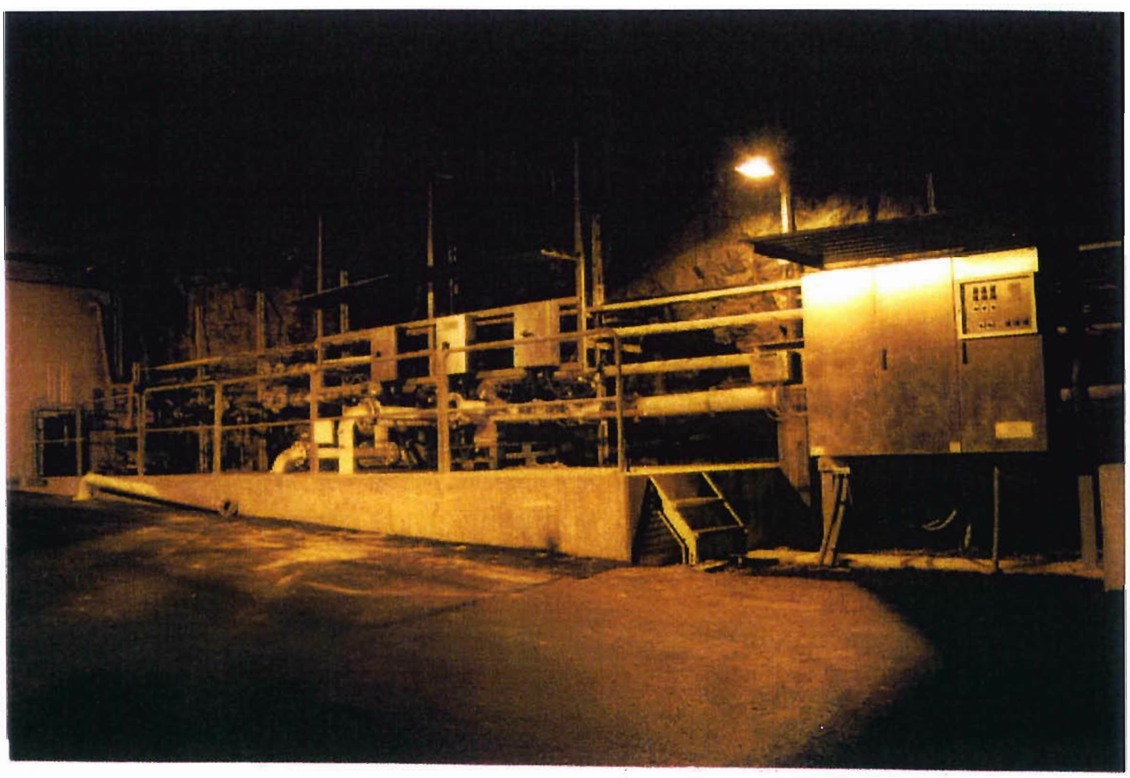
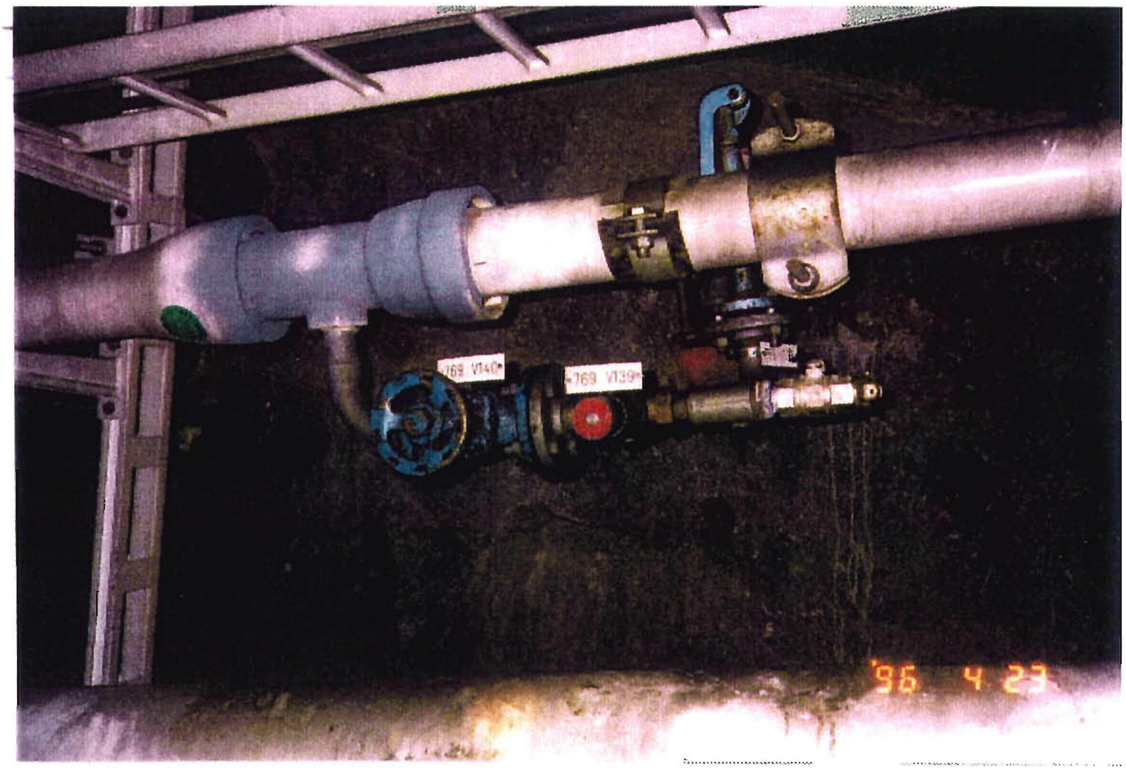


Figure 4-17 Pump sump PG3.



Figur 4-18 Tap for water in the access tunnel.

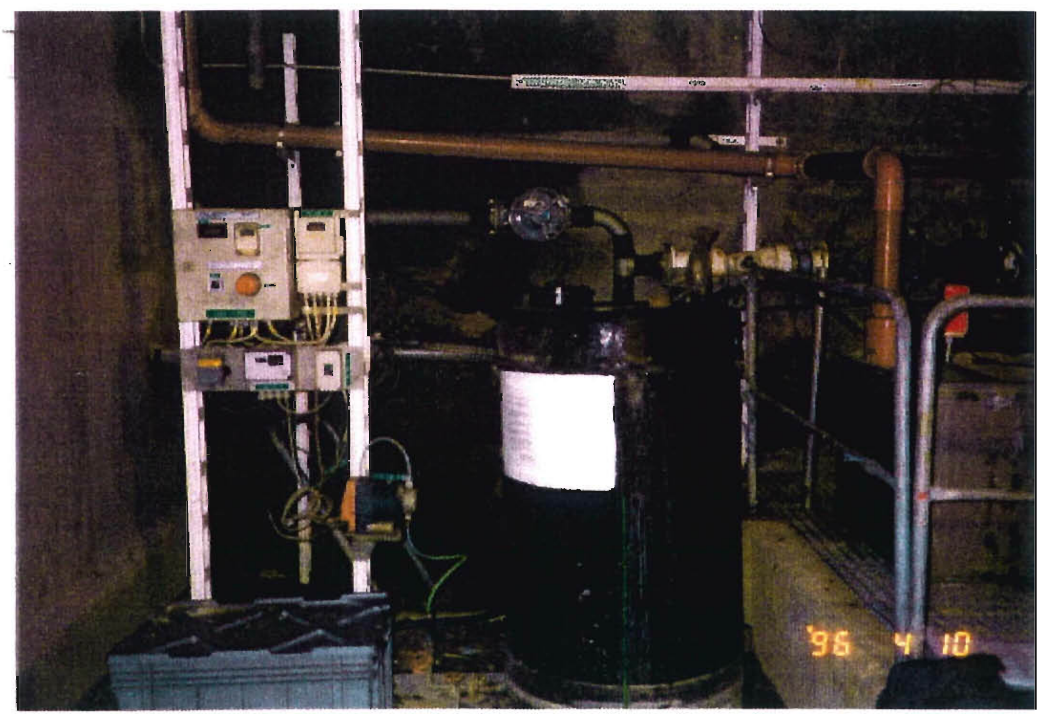


Figure 4-19 Uranine dosage equipment.

All the tap water that is tapped in the underground facility from level -220 m and downwards, receives an additive of uranine in order to mark the water for identification. The equipment used for the uranine dosage is located adjacent PG3 at level -220 m, and it works well.

During the construction phase the uranine dosage equipment was placed at the entrance to the access tunnel. All the water tapped in the underground facility was marked with uranine, but after the removal of the equipment to the landing area at level -220 m, the water tapped from the taps in the access tunnel will no longer receive additives of uranine. The tap water is intended as process water for various works done in the underground facility. However, when drilling the workers usually take water directly from the drilled holes in the rock nearby their workplace.

The tap water used at Äspö Village is led up from level -220 m via the lift shaft to the buildings above. This water is neither pressure reduced nor has an additive of uranine. The pipe is an outwardly galvanised SMS 326 steel pipe with screwthread joints (Swedish standard). The piping hangs in the lift shaft at Äspö Village, and it hangs freely in the shaft with a steering control at each point where the lift guidings are fixed. Initially the plan was to use a VRS nodular-iron pipe, but the chosen steel piping was cheaper and easier to install.

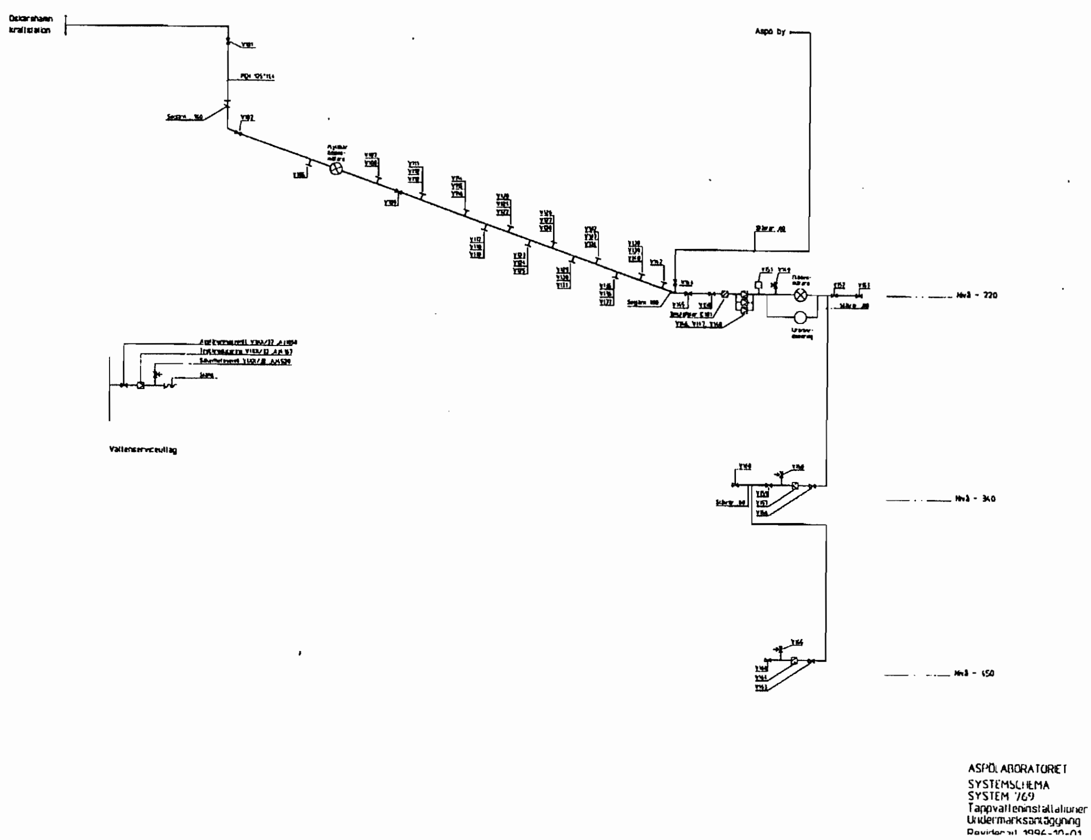


Figure 4-20 System design of the tap water system.

4.6 Corrosion protection

4.6.1 Introduction

A design criterion decided on in the early stages of the planning was that steel components in the Äspö Hard Rock Laboratory would mainly be manufactured in common black iron. Surface treatment would then be chosen taking into account the location of the component, and how often it would need to be replaced. In those cases where stainless steel could be proven to be the economically soundest choice, it would be used. The following choices were thus made:

Environmental classes M2, M3 and M4A mentioned below are according to the Handbook BSK 94 (Boverkets handbok om stålkonstruktioner) from the Swedish Board of Housing, Building and Planning.

Components located at Äspö Village and belonging to the same fire cell classification group, as that of the rock facility, were treated according to the regulations governing environmental class M2. The only exceptions were the components in the exhaust air duct, for which environmental class M3 was chosen.

For the structures in the underground environment, a strategy was chosen whereby those parts that are easy to replace were only treated with hot-dip galvanisation, or were both hot-dip galvanised and then painted if the component in question was manufactured and sold with such treatment as a standard. The cable trays e.g. filled this criterion. Hot-dip galvanisation as an only treatment was also chosen for components expected to be subject to such a high level of wear that any additional surface treatment would be worn off quickly anyway. The other components in the underground environment were surface treated in accordance to environmental class M4A.

The only components that, even from the beginning, were designed in "stainless steel", were the boxes for the measuring weirs. They were made of SS 2333 quality.

While designing, it was noted that the environment would shorten the lifespan of installations only treated by hot-dip galvanisation, such as the hanger rods among others. From level -110 m and downwards, the hanger rods were made of the "stainless steel" qualities SS 2343. Furthermore, certain other components were, due to manufacturing reasons manufactured in the "stainless steel" quality SS 2343 or SS 2347 rather than being treated according to a M4A treatment. These qualities of "stainless steel" are never fully corrosion-resistant in such a chloride rich environment such as the Äspö Hard Rock Laboratory.

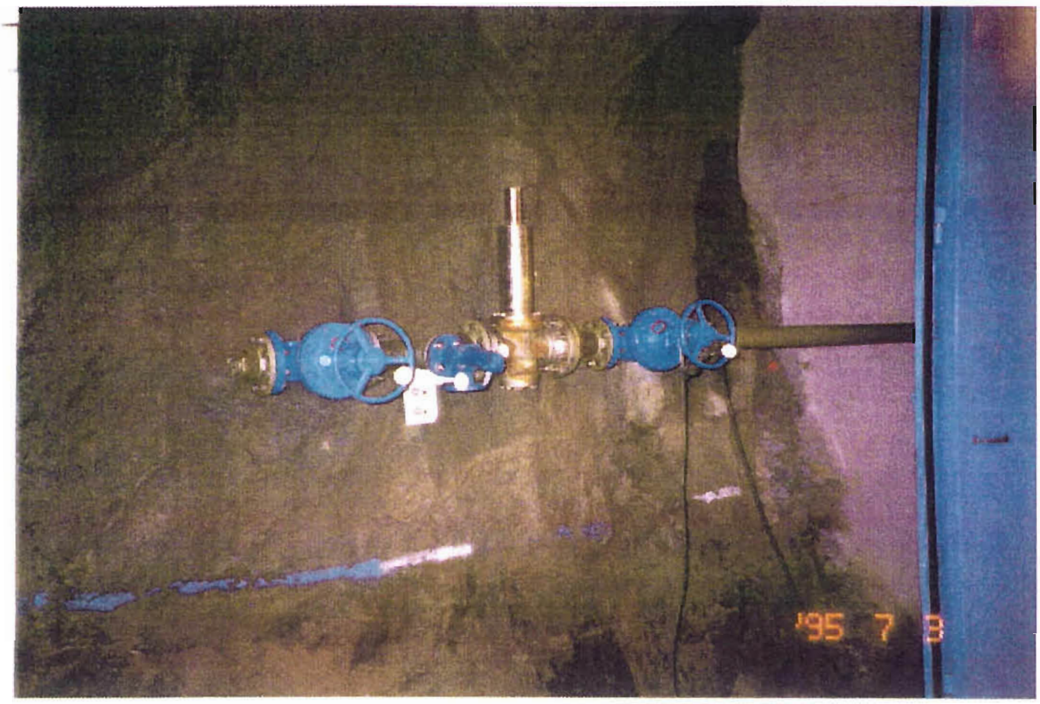


Figure 4-21 Valves painted in accordance to environmental class M4A.

4.6.2 Stainless steel

The choice of the right quality of stainless steel for use in environments, such as the Äspö Hard Rock Laboratory, is a difficult task. Taking into account scientifically made laboratory tests, the choice of such high-quality steels such as SMO steel SS 2378 should be made in order to meet requirements made on corrosion resistance. However, experience has shown that the used qualities do have a high enough level of corrosion resistance to justify the lesser investments that have been made, then would have been possible if SMO qualities had been chosen. This includes the choice of the simplest stainless steel material SS 2333, used for the boxes for measuring weirs. They have not yet been subject to such corrosion damages that their function is at risk. The SS 2333 has now been subjected to seven years of continual exposure to chloride-rich water. These experiences are similar to those gained at the final repository for radioactive operational waste, SFR, although the chloride concentration at SFR is somewhat lower.

In order to gain more practical experience on how various stainless steel qualities behave in an environment such as the Äspö Hard Rock Laboratory, a series of experiments should be arranged, even if they, due to practical reasons, not can be regarded to be of unquestionable scientific quality. Some stainless steel constructions have, after installation, been subject to spraying from welding works, or grinding of carbon steel nearby. Such spray residue can cause spots of corrosion damage on the stainless steel sheet surfaces if not removed. Routines on how to make sure that the stainless steel surfaces are protected from such carbon steel residue should be planned.

Negative effects of mixing stainless steel material with surface treated carbon steel, has only been observed on the entrance doors. The stainless steel rivets applied to the surface treated shielding sheets, have probably had a negative effect on the propagation of corrosion damages around the location of the rivets, although they might not have been the actual cause of the problem.

4.6.3 Paint treatments

The chosen paint system for M4A painting varies subject to whether the construction will remain constantly wet or not. For constructions that will not be constantly wet, hot-dip galvanisation with a follow-up paint treatment has been chosen, whilst constantly wet constructions have only been painted according to recommendations in the Swedish handbook BSK 94.

All the surfaces in the Äspö Hard Rock Laboratory's environment run the risk of being classified as constantly wet because of the risk of condensation. This would usually mean that all anticorrosion paint treatments would be done without an underlay of zinc. On the other hand, there is a great risk of the installations being scratched due to various activities, and this would speak in favour of using a pacifying zinc-layer in the surface treatment. Which criterion that will prove to be the most important can not yet be discussed until further experience has been gained, so the question should therefore continue to be studied throughout the operational phase.

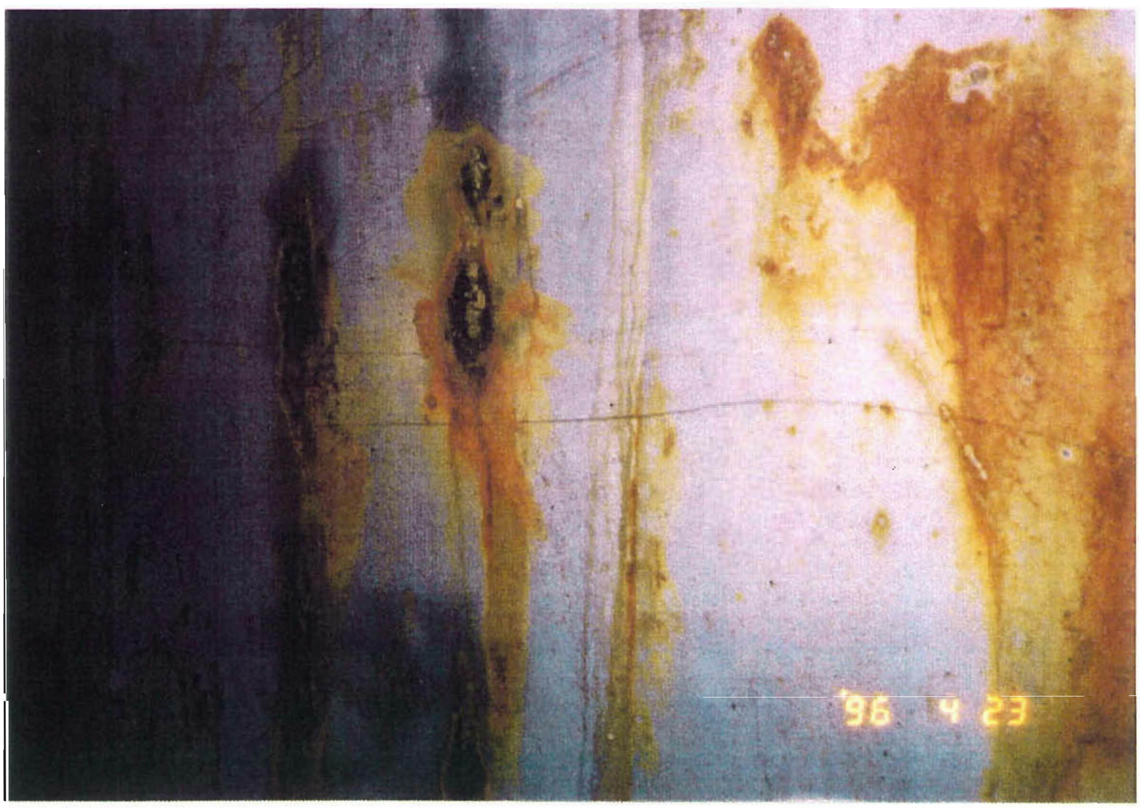


Figure 4-22 Corrosion damages on stainless steel SS 2333.

The surface treatment on the doors was done by painting both the inside and outside according to environmental class M4A. The frame and shielding sheets were painted one by one before being mounted, but the holes for the stainless steel POP-rivets were drilled after the surface treatment was completed, and no additional touching up was done. The results are not good. Large rust stains have emerged around almost every single POP-rivet head after having been subjected to only a very short exposure time in the facility. Fortunately, no damage has yet emerged on the door at the portaling. The combination of drilling damages, damages on the surface treatment due to the rivet work, the risk of crevice corrosion in riveted construction, the choice of aluminium-zinc treatment as the priming for painting the shielding sheets, the way the installations were done, and the stainless steel rivets themselves, are factors that all can have affected the result.

Whichever factor one chooses to focus on as the foremost corrosion problem, it should be evaluated in the future if a sealing welding of the shielding sheets against the doorframe could be an alternative. Why this solution not was chosen for the Äspö Hard Rock Laboratory was due to fear of corrosion occurring on the inside of the door, as such a welding job would involve difficulties in securing a totally sealed construction.

Damages occurring during the construction work, and mechanical damages occurring during the operational phase, can not be excluded. Difficult environmental conditions prevail when one wants to gain good results by touching up the paint in an environment such as the one existing in the Äspö Hard Rock Laboratory. The choice of carbon steel or corrosion-resistant steel should therefore be evaluated with extra care, regarding all the details that could be subjected to damaging risks.

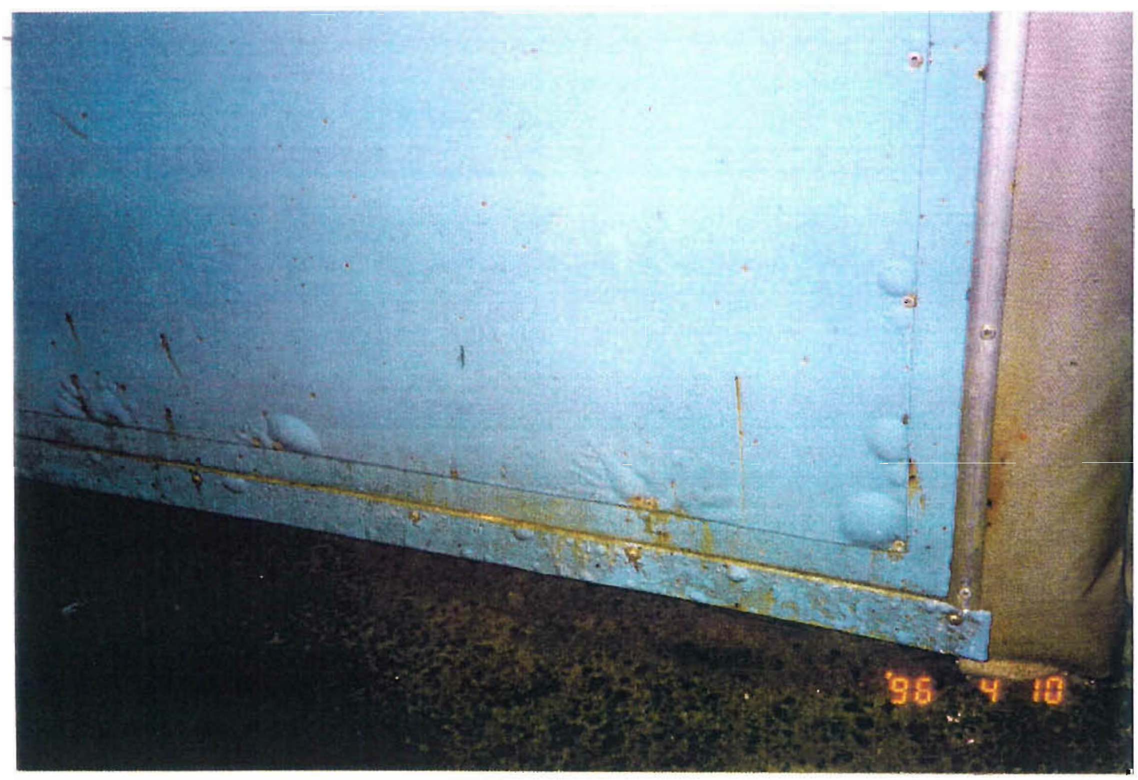


Figure 4-23   Corrosion damages on a door.

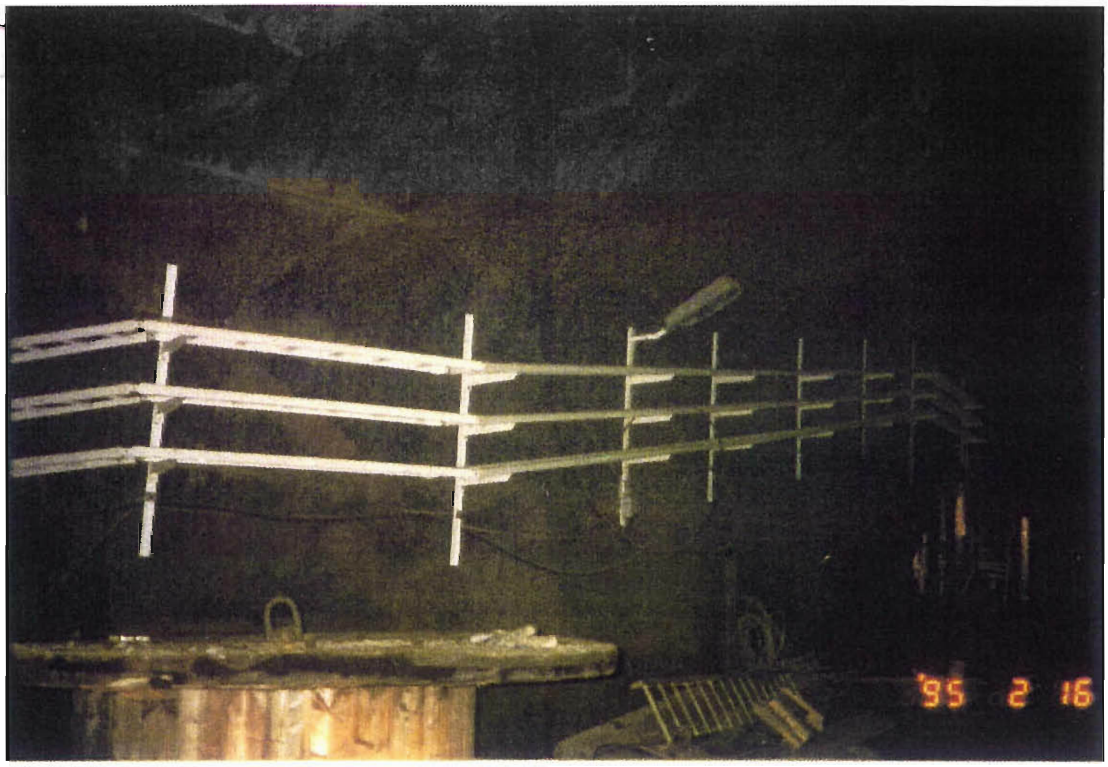


Figure 4-24 Standard painted cable trays and brackets.

Standard painted products; (cable trays, stands etc) have more or less managed well in the Äspö Hard Rock Laboratory's environment. The variation of corrosion damages is natural, as the environment differs greatly at various locations in the underground facility. Furthermore, different makes have been used, which gives a more varying outcome.

Generally speaking, however, standard painting is not enough, and gives rise to extensive maintenance problems. In the future, M4A painting should be considered as an alternative.

For threaded construction details, and where hot-dip galvanisation will not suffice as corrosion protection, complementary paint treatment should only be used as an exception. Finishing treatments done on the spot, as is often the case, always gives a poorer result than painting done in a workshop, and sometimes the screws have to be pulled tighter, which further endangers the quality. Instead, corrosion-resistant steel should be used.

4.6.4 Tectyl treatment

Tectyl was only planned to be used as corrosion protection of the inside of the welding area in the lift's guides, but during the installation Tectyl gradually became accepted as extra protection for the hot-dip galvanised bolt joints in the lift shaft.

However, our experience of this treatment shows that Tectyl corrosion protection should be used only in exceptional cases. The possibility of touching up conventionally painted surfaces close to those treated with Tectyl has become impossible, as the Tectyl has rubbed off on the wrong place. In addition, the corrosion-resistant substances in the Tectyl are highly volatile and need to be frequently touched up.

4.6.5 Other surface treatments

Hot-dip galvanisation as an only protection for carbon steel has been done according to the Swedish standard SS 3583 and its thickness classification groups, class A and C. Class C is a thicker one and puts requirements on the siliceous content of the steel, and so limits the use of class C components.

Our experience is that class A components will not retain their quality for long in the environment of the Äspö Hard Rock Laboratory without having to be subjected to additional surface treatment. The fact that the environmental conditions vary in different places in the facility is proved by the fact that certain components had fared more badly than others. Another reason for the difference in effects is probably because of the big difference in the thickness of applied zinc layers. At the moment, we have no proof of corrosion damages on class C components, but these components were installed at a relatively late stage in the process, so we would not have expected to note any corrosion damages yet. We have registered that certain local damages to the zinc layer in the form of split patches have occurred. This occurs mainly on the lift guides.

The VRS pipes used for pumping out the drainage water have been insulated with concrete on the inside, and have been equipped with thermoplastic insulation as corrosion protection on the outside. The pipes have been subjected to mechanical damages and as a result they have corrosion damages, but otherwise the surface treatments have hitherto withstood the Äspö Hard Rock Laboratory's environment. As yet, we have not evaluated how the touching up of the corrosion protection on the mechanically damaged parts has been doing.

It has not been evaluated how the concrete insulation works. However, nothing points to the concrete on the inside not behaving as it should. The concrete also gives some protection against wear caused by particles in the drainage water.

The joints are a major corrosion problem as they have no protection whatsoever against the environment. This is especially true of the pipe joints equipped with clamping rings whose function could be endangered even in the case of a very mild corrosion damage. The manufacturer recommends the joints to be wrapped up in sealing insulating tape, which would stop the oxygen from getting in and thereby stop the corrosion process.

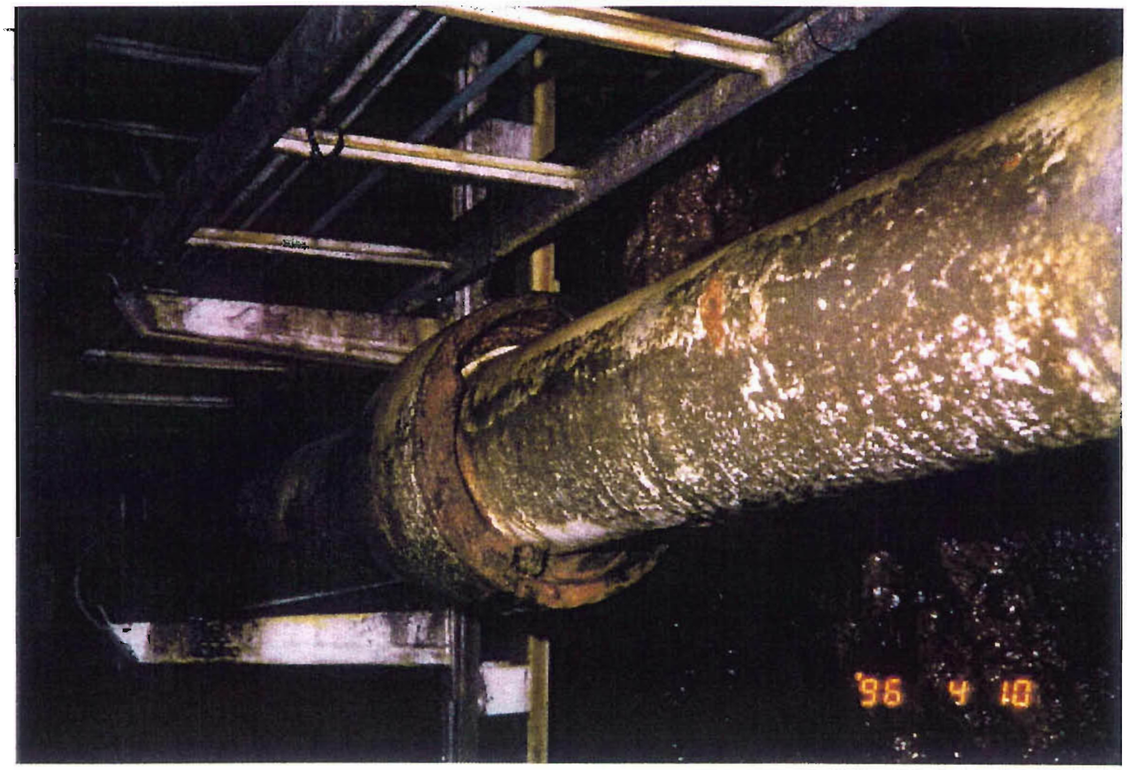


Figure 4-25 Corrosion damaged joint on a VRS-pipe.

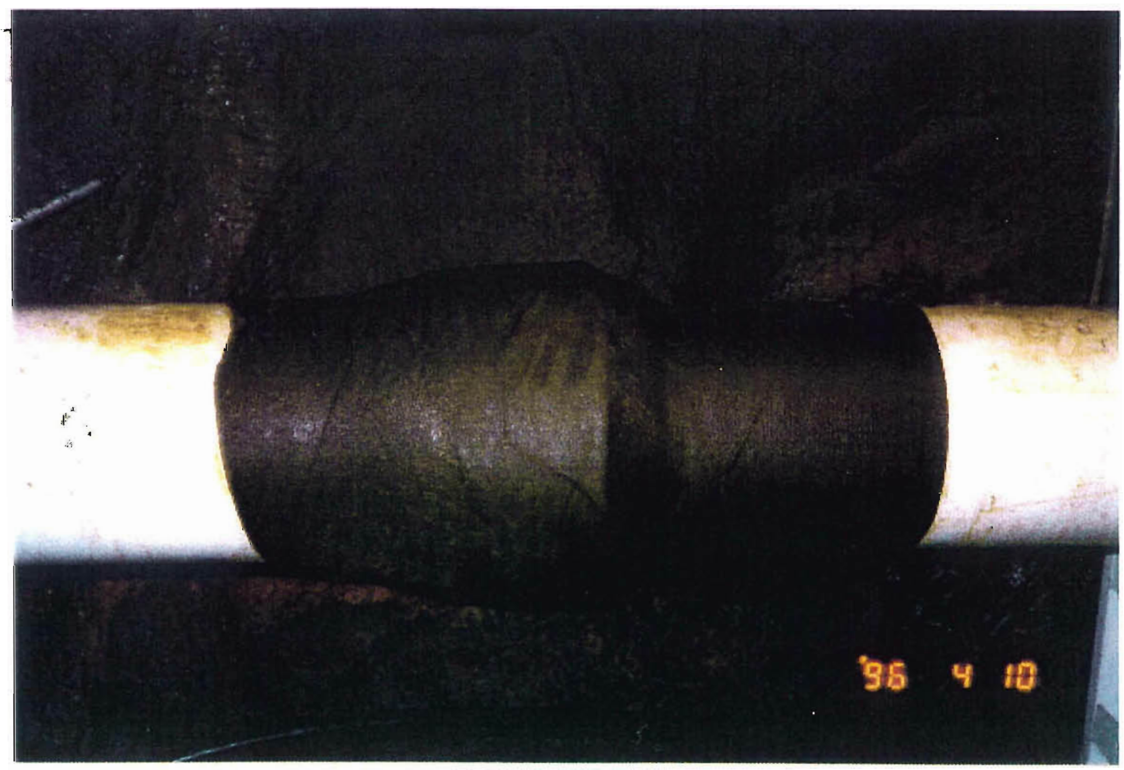


Figure 4-26A wrapped joint of a VRS-pipe.

4.6.6 Choosing other materials rather than steel

In order to keep the risks of fire as low as possible, one has preferred to use steel as the main construction material in the Äspö Hard Rock Laboratory, but other materials could be used. The greatest fire hazard are the electrical equipment, (transformers, cables and apparatus boxes), and the vehicles that are unavoidable features in the facility. There are no rules limiting the fire-load density, so a slight increase in the use of combustible materials could possibly be accepted.

In the present facility there already is a variation of chosen material. The stands for some apparatus boxes have been made of impregnated wood; plastic pipes have been used in the least pressurised drainage system, to name but a few choices. From a technical point of view these test materials have worked well.

The corrosion problems that occur due to the use of steel structures in an environment such as the Äspö Hard Rock Laboratory are so great that the possible use of other materials than steel should be thoroughly evaluated in view of future projects.

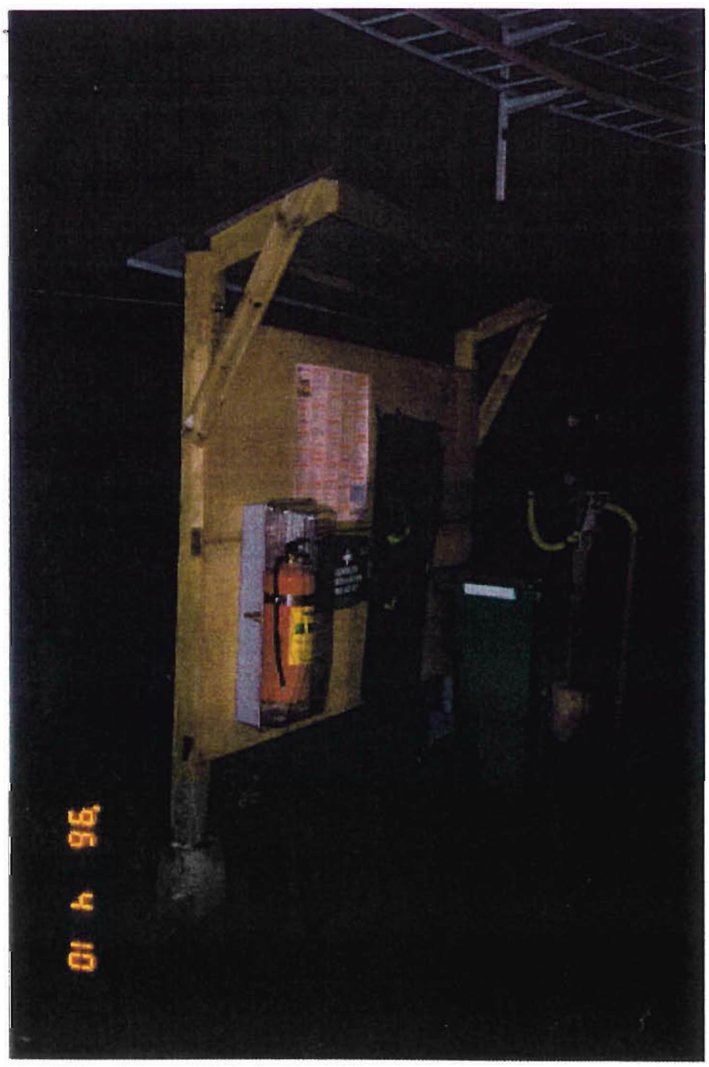


Figure 4-27 Stand of impregnated wood.

4.6.7 Test series

There are difficulties to select corrosion-resistant treatments. As a result, several different solutions have been tested in Äspö Hard Rock Laboratory. This enables us to view the whole facility as a test series of solutions, and to draw conclusions as to which of the solutions is the most cost effective, or to see which treatments done on various components are the most corrosion-resistant after a certain number of years.

As the environment varies from place to place in the facility it will not be possible to draw any far-reaching conclusions from such full-scale tests. As a supplement to these full-scale tests, simpler test series should be run. Test components could be installed at various places in the tunnel system subject to radically different environments. While such tests can not be done in accordance to a high level of scientific accuracy, they would probably gives us more valuable information than would the full-scale tests on their own. All forms of corrosion-resistant steel should be included in the study, such as hot-dip galvanised steel, painted steel, and combinations of galvanised and painted steel. The Swedish Corrosion Institute report No 1993:8 “Guidelines for testing of anti-rust painting by field exposure”, should be adhered to as far as possible. Documentation of the course of events can be done through ocular inspections at intervals of e.g. three months.

4.7 The electric power system

4.7.1 Electric power and sub-stations

The system analysis called for power being supplied from two different locations. The power supplied to the tunnel comes from OKG’s distribution plant, while the power for Äspö Village comes from the regional grid. The supplied voltage for the Äspö Village is 10 kV. In the event of a drop in voltage, one can switch to reserve supplies at the sub-station at Äspö Village. However, parallel switching of the two mains must never occur. The sub-station at Äspö Village is equipped with two transformers with a level of 1600 kVA each, after a system analysis had been done.

Experiences gained until now show that it is important to thoroughly analyse the need for power supplies in each separate part of the system, so that an under dimensioning of the power supplies does not occur.

The sub-stations are placed in separate niches adjacent to the landing areas. Some of the sub-stations have been equipped with an extra pent-roof to protect it from water dripping from above. The pent-roof should have a big enough overhang.

- The transformer capacity should be dimensioned to suit the supplied short-circuit power.
- The sub-stations should be big enough to make it easy to replace the transformers.
- The transformers should be cleaned at least once a year, considering the environment.

4.7.2 Lighting

Electrical light fittings are placed at every 20 meters in the tunnel, and are installed along the rock wall at a height of ca 3.5 - 4 meters and placed in a 45° angle towards the road. In the TBM tunnel the light fittings are installed in the middle of the tunnel roof instead. The light should allow for reading. The source of light should be a high pressure sodium vapour lamp with an effect of 150 W. The capsule classification should be that of IP54 (5 =dust protection, 4 =protection against water sprinkling from above.). The lights are switched on and off at the door at the portaling.

The capsule classification of the light fittings that have been installed is IP65 (6 =dust-proof, 5 =protection against water jets.) Even though the capsule classification chosen is an improvement, there have still been problems with water getting into light fittings through the cable-screw joints.

The lights have been switched on day and night during the whole construction phase, and this is probably just as well, as unheated light fittings allow water to be retained inside.

4.7.2 The alarm system

If a component that is part of the electric system ceases to function, the alarm system is activated. At Äspö Village, the malfunction is registered in the reception as either an A or a B alarm and written out in clear describing which transmitter has been activated by the alarm. At the same time, an indicator is shown on a viewing screen at the control room of CLAB, the central interim storage facility for spent nuclear fuel.

In the case of a fire or a burglary alarm, the alarm goes off at both Äspö Village and CLAB. The alarm is also directly transmitted to the SOS Emergency Service Centre in Växjö.

A lot of discussions took place with the supplier regarding the responsibility for the working order of the delivered products, and the guarantee obligation for the various components. It would therefore be better to clearly state in the purchasing documents which general rules should be applied for the engineering work, delivery and installations of the electric and electronic equipment.

4.7.4 Classification of various electrical materials

The classification for electrical material has been restricted to, at the lowest, grade IP54 (5 =dust protection, 4 =protection against water sprinkling from above.).

Although the chosen capsule classification is supposed to withstand sprinkling of water, the protection has not been sufficient. In order to improve the protection against dripping water, it has therefore been necessary to equip some of the installations with separate pent-roofs to prevent water from leaking into the various apparatuses and components. And, as the environmental conditions vary greatly from one place to another in the underground facility, each installation has had to be analysed separately.

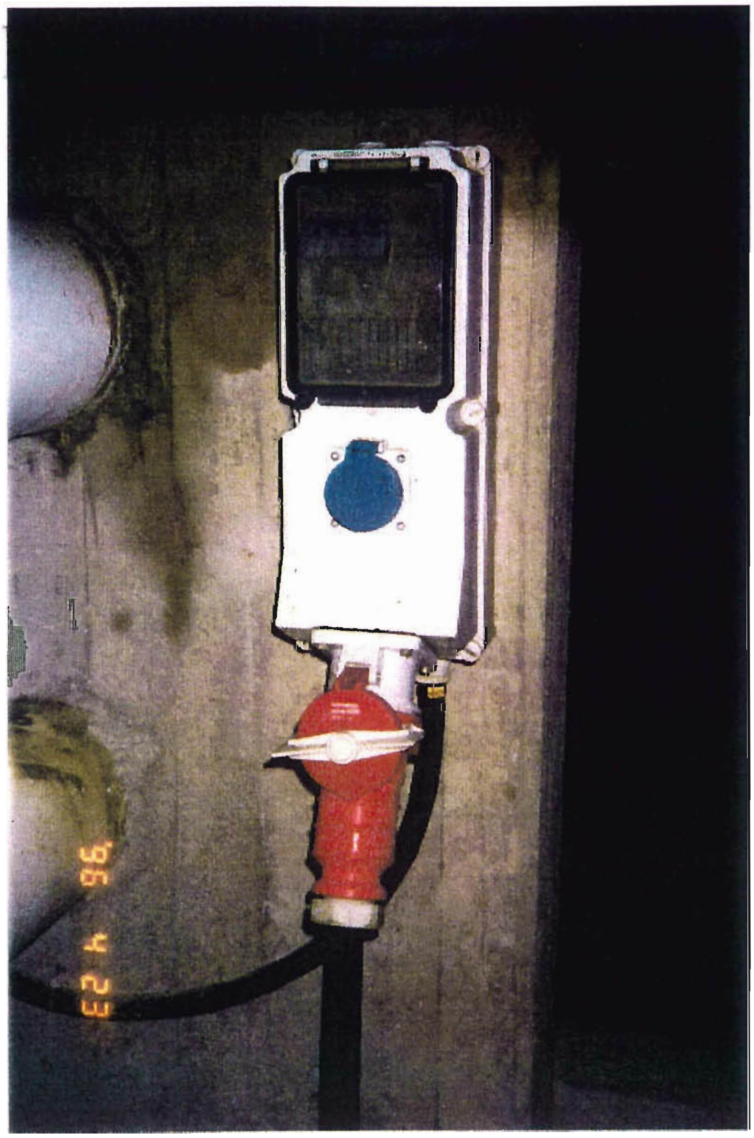


Figure 4-28 Socket with fuse.

4.8 Fire protection

4.8.1 Introduction

A fire occurring in a rock facility such as the Äspö Hard Rock Laboratory is envisioned as something of a nightmare. So ever since the plans were first initiated, they have been constantly reviewed with the help of the rescue services. The grouping of the fire cells, the design of the ventilation and lift facilities, the choice of materials for the facility components, the staff's emergency equipment, and the fire alarm system, have been regarded as essential issues.

There are no standard regulations to be applied to a facility such as the Äspö Hard Rock Laboratory regarding fire prevention and protection. So it is of the outmost importance that a continuing dialogue is held with the rescue services in order to gain a final approval of the operation of the facility from the authorities.

Co-ordinating the radio communication system with the needs of the operational organisation and the needs of the rescue services, is one of the most important issues to be regarded in order to ease the work of the smoke helmeted firemen, and at the same time enabling the alarm signals to reach to and from the staff in the tunnel. With regard to this, a close collaboration is essential.

Some important issues remain to be answered, and a continuing collaboration is necessary, as in the development of the final fire alarm system, the staff's emergency equipment, the fire-extinguishing equipment, and routines needed in order to educate the staff on security matters.

4.8.2 The planning

The underground facility is divided into three separate fire cells consisting of the access tunnel, the landing areas including the lift shaft and the experimental area. The three groups are connected to each other via six fireproof doors. The fire classification of the doors is that of grade EI 30 according to the Building Regulations 94 from the Swedish Board of Housing, Building and Planning.

The fire cells are supplied with air from the joint supply air shaft. On the exhaust air side, two of the fire cells are connected to the exhaust air shaft, while the access tunnel can be evacuated via the tunnel.

Experience shows that the fire cells are difficult to maintain even under normal operation. The fireproof doors that are most frequently used should perhaps be equipped with some kind of automatic control device, so that they always are closed after a vehicle has passed through. This relates mainly to the fireproof door in the TBM tunnel.

All the fireproof doors are equipped with indicators that will sound an error signal if the door is kept open for too long. The study and maintenance of the indicator functions are a matter of importance from a safety aspect.

The experience of the operation of the ventilation system shows that the chosen operational modes should be re-examined, especially with regard to the access tunnel. Here, the ventilation flux is increased automatically in the case of fire to almost the double amount, and this causes the staff situated above the fire to be evacuated up the access tunnel with at least the same speed as the smoke. It would probably be better if the ventilation flux could be shut off altogether until the staff has been evacuated, and then turned on again by hand to a position of intensified ventilation to assist the evacuation of smoke. Full-scale tests have been done to examine how the air flows depending on the how the ventilation system is adjusted.

4.8.3 Choice of materials

One of the basic criteria considered during the design phase was that of choosing materials in order to minimise the fire-load densities. Wood and plastic materials would only be used as exceptions, instead steel and concrete were the prioritised construction materials. The cable insulation is now the largest, single, permanent fire hazard in the entire facility. There is approximately 18 tons of PVC in the tunnel system. The below mentioned experiences should be viewed through the above-mentioned perspective.

When deciding on the design criteria, it should be clearly stated whether the criteria is to be seen as a guiding principle or as an absolute requirement, otherwise all kinds of deviations will flourish in the facility.

A low level of fire-load density will always be the ultimate aim when constructing an underground facility such as the Äspö Hard Rock Laboratory. However, a large amount of cables have to be installed in order to enable a smooth operation of such a facility.

These facts should be taken into account when deciding on design criteria for the fire-load density in future facilities. A marginal increase in the already large risk factor that the cable insulation stands for could be allowed without greatly endangering the balance. If plastic or wood could be used for stands and similar installations, many corrosion problems could be avoided. A study should be made of where to draw the line, to aid the construction of the Deep Repository.

4.8.4 Vehicles

The greatest potential fire hazard in the Äspö Hard Rock Laboratory is, without doubt, the presence of the vehicles. During the whole construction phase only diesel-powered vehicles were allowed. No vehicles caught fire, but three different incidents, involving uncontrolled vehicle movements, could have caused a fire. Since the operational phase was started up, petrol-powered service vehicles have been used, and the risk of a fire occurring has thus been greatly increased.

Experience shows that a change in practical and economical conditions soon effects the level of fire-load density in a facility. It is therefore important to have a flexible fire-fighting system. It is of outmost importance that every single vehicle driving down the tunnel system should be equipped with a mobile fire extinguisher. Instructions on how to used the fire extinguishing equipment together with regular maintenance of the equipment are important prerequisites in order to keep the risks of full-scale vehicle fires at a low level.

4.8.5 Detection and alarm system

The installation of a complete fire alarm system in a facility such as the Äspö Hard Rock Laboratory, is a rare commitment. Mines are rarely equipped with such fire alarm systems, although SFR was equipped with a complete system based on optical detectors. However, our experience shows that a different system than the one used in SFR must be adopted for the Äspö Hard Rock Laboratory in order to gain a system that will keep the level of false alarms occurring at a minimum.

Thus, a system based on highly sensitive detectors connected to a sampling pipe system has emerged as the system solution best suited for the job. There are no reference facilities equipped with such a system solution, although mine at LKAB in Kiruna has been equipped with a fire alarm system operating in an environment resembling the one at the Äspö Hard Rock Laboratory. Evaluating that particular system, and taking into account experiences gained from discussions with suppliers, gives us reason to believe that a system solution based on detectors is the most reasonable way to construct a well-functioning fire alarm system.

As such equipment, due to the design, reacts to the environment in highly individual ways, a permanent installation has to be proceeded by a test installation. Our experience of such tests is discussed below.

Experience gained from tests done over a long period of time, shows that sampling equipment encapsulated in regular apparatus boxes probably will do well in the Äspö Hard Rock Laboratory's environment as far as corrosion risks and everyday contamination are concerned. The sampling equipment needs regular service.

Tests done on the equipment by simulating fires, or in other ways 'disturbing' the equipment, have shown that the unchecked use of vehicles in the rock facility causes a major problem. Some of the available measuring range has to be considered as hazardous due to exhaust gases causing false alarms. On the other hand, there is also a risk that this fire alarm system will not be able to react to smouldering fires with a slight build-up of smoke.

Other tests have shown that the rock facility's environment is so complex that a future extension of the fire alarm system should be done step-by-step. This strategy would enable operational experiences to be taken into account, before any decisions are taken for a complete extension.

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