

Extensive use of the Underground in Oslo is giving a better City

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ABSTRACT: Norwegians have a long tradition in underground work which is clearly exhibited in Oslo. Although a small (500,000 inhabitants) and fairly spacious city, with variable rock quality, the underground is utilised to a large extent. The ever increasing focus on environmental aspects, and the soaring cost of land, have made underground solutions increasingly favourable for all kind of utilisations. Traffic systems for road, metro and railways; collection and conveyance systems together with treatment plants for water supply and sewerage; sport arenas and car parking; energy generation; control systems; oil and food storage. Roughly 180 km of tunnels and additionally 1,500,000 m³ of caverns are located in the Oslo area. The paper describes the ground condition and rock work methods in general and some of these interesting projects in particular.

1. INTRODUCTION

Norwegians started mining ores and minerals a thousand years ago. In the late 1800s the first railway tunnels were excavated. Oslo started using the underground in the 1920s with tunnel construction for the mass transit system. A reduction in excavation cost, and a marked increase in the excavation and tunnelling speed have gradually taken place during the last 50 years. This development has contributed significantly to the increased use of the underground.

The city of Oslo is located at the end of the 40 km long Oslo-fjord between the water and hills and forests. Although a city with only 500,000 inhabitants, Oslo has experienced the common problems of urbanisation, such as traffic jams, pollution, and lack of space for building purposes. As a result of an marked increase in the standard of living, the fjord has become increasingly used as a place for recreation. From the late 1970s there has been a desire among city planners to link the fjord closer to the city and its inhabitants in order to improve the quality of life and the city's aesthetic appearance. As a means to achieve this, a number of new underground projects were started.

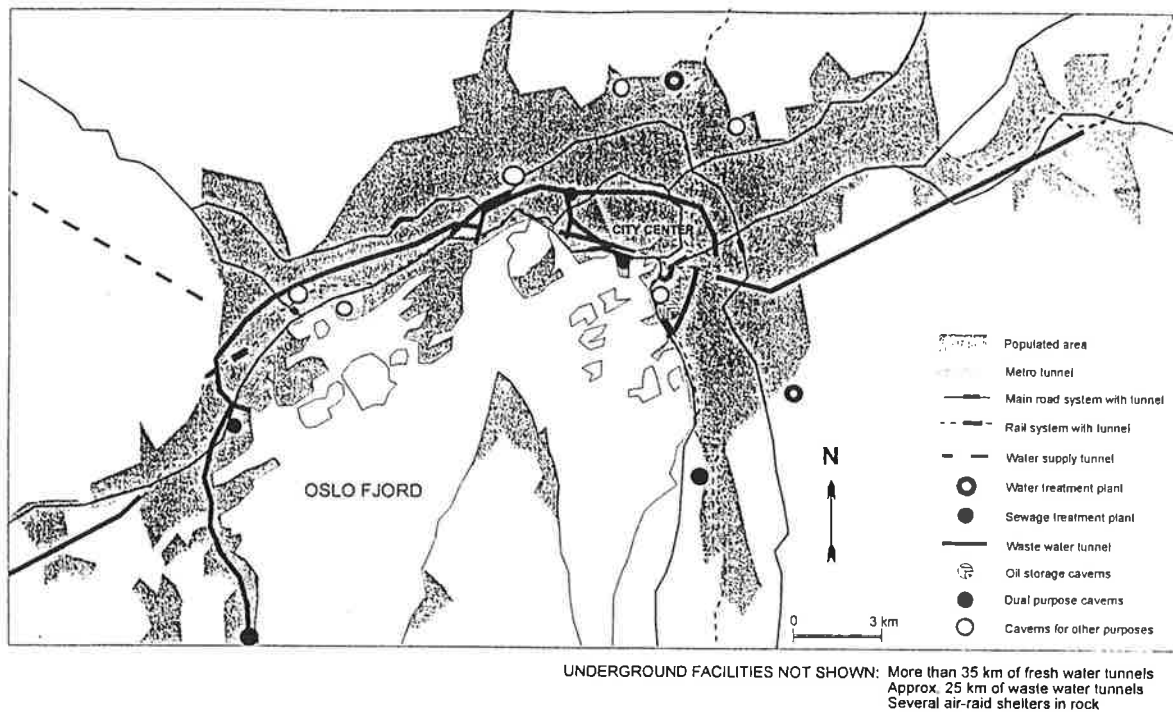


Fig. 1 An overview showing the location of the main underground facilities in Oslo

2. GEOLOGY OF THE OSLO AREA

The geology of the Oslo area is rather complex, with rock types from Precambrium to Permian age (1800 mill. to 250 mill. years old rocks). The area is a classic ground in geological research, consisting of basement rocks (gneisses), sedimentary rocks (shales, limestones, sandstones) and plutonic (granites syenites), lavas (rhomb porphyry, basalt), and dyke rocks (diabase). The Caledonian folding and the Permian and younger block faulting resulted in the formation of the Oslo graben, with the younger rocks occurring between the older basement. In and along the graben there are several faults.

Tunnels and caverns cross these faults in several cases. In Oslo, alum shales are also found, which, when drained, can undergo considerable swelling due to oxidation and a breakdown of diagenetic bonds. Groundwater that leaks through this rock can be extremely aggressive. Therefore many underground projects in Oslo require strict measures against inflow of ground water.

The variable geology of the Oslo area has been a challenge to geologists and engineers. The variable rock mass qualities result in very different stability behaviour and need for reinforcement.

3. ROCK SUPPORT AND EXCAVATION METHODS

In the design of rock support the Q-system is often applied as a useful tool. The most frequently used rock support methods in the Oslo region are the same as are generally used in Norway, i.e. rock bolts and wet mix shotcrete reinforced with steel fibres. These methods allow for great flexibility in support design, and they do not significantly influence the rate of excavation, as is the case with the more rigid method of concrete lining. The result is saving of time, even in poor rock masses.

In general, the sedimentary rocks with sills and dykes, gneisses and granites of the Oslo field need some support, at least rock bolting. Heavier rock support, such as reinforced ribs of shotcrete or in situ cast concrete, are often necessary when traversing fault zones.

Most underground excavations in rock in the Oslo region have been carried out by the drill and blast technique. Some of the sewage tunnels have been excavated by tunnel boring machines (TBM).

To avoid settlement of buildings founded on clay deposits, the ground water table need to be controlled during and after the excavation. As a measure strict control of water leakage into the underground openings is necessary. Permanent solutions are pre-grouting the rock mass surrounding the openings and/or in situ cast concrete lining.

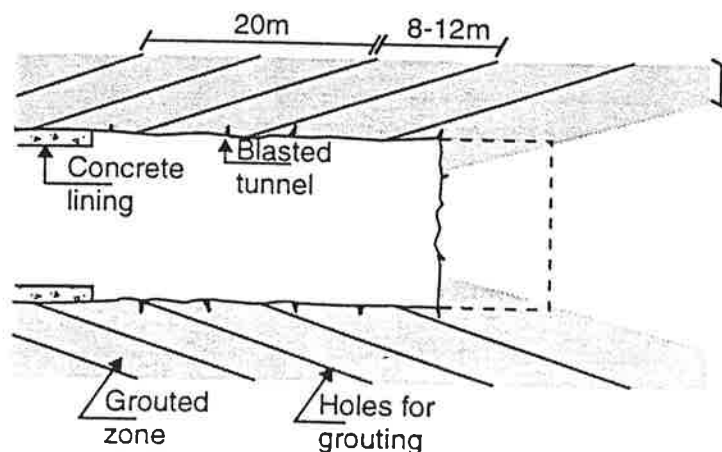


Fig. 2 Scheme for pregrouting. From [1]

In some tunnels inflow of small quantities of water are allowed. To prevent the water from dripping onto the pavement of road tunnels or freezing on the walls or ceiling, various types of element cladding are in use.

The shallow depth of many underground facilities in Oslo especially below depressions in the bedrock, formed along weakness zones (faults) is one major problem. The resulting limited rock overburden requires careful excavation and well planned stability measures. The risk for damage of buildings and structures located in the vicinity of tunnel blasting works requires thorough planning of the blast. Weak charges and reduced blast pulls are often necessary.

4. METRO, RAILWAY, AND ROAD TUNNELS

4.1 Metro tunnels

First stage of the metro line opened in 1928. It included a 2 km long tunnel on which work started in 1912. Extension of the subway by an eastern line opened in 1977 with two main underground stations and a 2 km long tunnel. The western and eastern lines were connected at a new underground station under the centre of the city in 1980.

4.2 Railway tunnels

The 10 km long Lieråsen railway tunnel 20 km west of Oslo is part of the main western line. This 2-track tunnel of 50 m² was constructed 1962 to 1967. The eastern and the western railway stations in Oslo were linked by a 4 km dual track tunnel in 1977, crossing below the centre of the city with connections to the main underground station. A widening of this tunnel and station is now in the planning stage. The rapid railway line south-east of Oslo to improve the link to Sweden is under construction. This line is designed for 200 km/h speed and involves several tunnels. There are also plans for a new railway link to Hønefoss, north west of Oslo in order to shorten the distance to Bergen by 60 km. A large part of this new line will consist of tunnels.

On the rapid rail link to the new Oslo at Airport Gardermoen a 14 km long tunnel called Romeriksporten is now under construction and will be finished in 1998. This double tracked, 105 m² tunnel passes closely under both densely populated and sensitive, recreational areas. Its eastern end is extended by a 500 m long cut and cover tunnel. The geology along the tunnel consists of various gneisses in most of its length, at the western end separated from the sedimentary rocks by a regional fault. The tunnel is excavated by drill and blast in 5 metres long rounds. The planned rock support is bolts and fibre reinforced shotcrete with a very small portion of cast in place concrete lining.

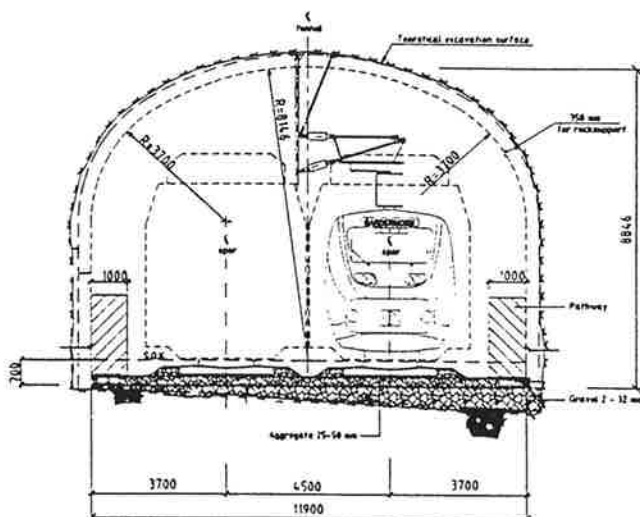


Fig. 3 Typical cross section of the Romeriksporten tunnel. From [1]

4.3 Road tunnels

The car traffic has increased rapidly during the last 30 years. On the E18/E6 passing through the central part of Oslo, more than 100,000 vehicles are passing each day. Over the last 10 to 15 years, extensive construction activities have taken place for the development of highway and road systems in the Oslo region. This development has included several new road tunnels, of which the most important are:

- The 0.7 km long Vålerenga twin tunnels, completed 1988.
- The 1.8 km long Oslo Tunnel, completed 1990. The project is further described below.
- The Granfoss 2.3 km twin tunnels completed 1992.
- The 1.4 km long Ekeberg tunnel, opened 1995.

A new ventilation system including electrostatic filters and use of water for cleaning the air has been developed and installed in the latest tunnels.

The city now has a total of more than 10 km of road tunnels. Approximately the same length of road tunnels is found in the neighbouring communities around Oslo. Road tolls have made it possible to finance a number of new road schemes - the result being a significant increase in capacity.

The Oslo Tunnel

The Oslo Tunnel is part of the main east-west highway route through the city of Oslo called E 18, was constructed from 1987 to 1990. The tunnel alignment is chosen so as to leave as much as possible of the tunnel in rock in order to reduce the length necessary for open excavation. This is due to the large built up sections in the centre of Oslo, where cut and cover operations would have resulted in enhanced traffic problems and conflict with existing buildings.

The twin tunnels have 1.5 km length in rock and 270 m as cut and cover. Each of the twin tunnels has 3 lanes with cross sections varying from 88 m² to 153 m². The rocks along the tunnel route are limestone, clay shale, gneiss, and dolerite dykes. Excavation was by conventional drill and blast technique. The volume in a normal blasting round was from 350 m³ to 600 m³.

The maximum road gradient in the tunnels is 50 ‰ with the lowest point 47 metres below sea level. In this location the rock cover is only about 5 m with highly fractured rock along 10 meters length. The rock here was successively supported with spiling placed ahead of the tunnel face. Fibre reinforced shotcrete was applied shortly after blasting. As the ground conditions in the southern tunnel were expected worse, it was decided to freeze the ground before the tunnel was excavated through the zone.

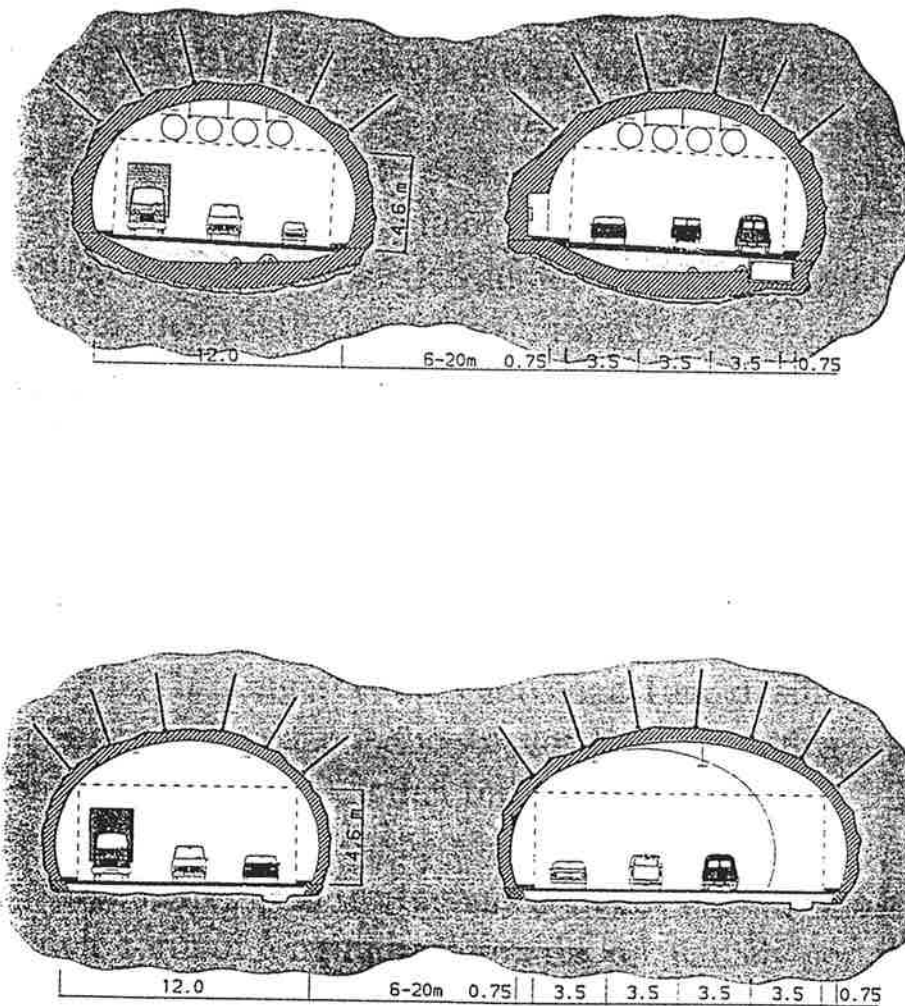


Fig. 4 Cross sections of the Oslo Tunnel. From [1]
 Watertight lining (top) with sealed concrete lining around the whole cross section.
 Drained lining (bottom). The concrete lining is drained and the base is not concreted.

The total cost of the Oslo Tunnel was USD 81 mill., i.e. USD 53,500 per metre, excluding technical installations.

The main lessons from this tunnel project was:

- There was minimum damage to the surroundings from blasting vibrations.
- The water tightness achieved in the tunnels was satisfactory.
- Rock grouting was an effective method to seal the tunnels.
- It was technically feasible and less expensive to seal off tunnels by use of extensive rock grouting as compared to watertight concrete lining.

5. WATER AND SEWERAGE SCHEMES

5.1 Supply of drinking water

Oslo is supplied with drinking water from lakes in the surrounding hilly and forested areas. The water is treated in several plants before being transported to the municipal distribution network. Because of the rugged terrain and suitable rock mass conditions around the city, the water is transferred in rock tunnels. To date more than 35 km of fresh water tunnels have been constructed, with cross sections between 5 and 10 m².

Owing to restrictions on land use, also the plants and reservoirs have been built underground. The two major water treatment plants in Oslo are described below:

The Oset water treatment plant.

The plant was commissioned in 1971. It has a design capacity of 6 m³/s and consists of a network of water basins and channels. A large part of these channels are covered by concrete slabs designed to carry vehicle traffic loads. The total floor area is 30,000 m².

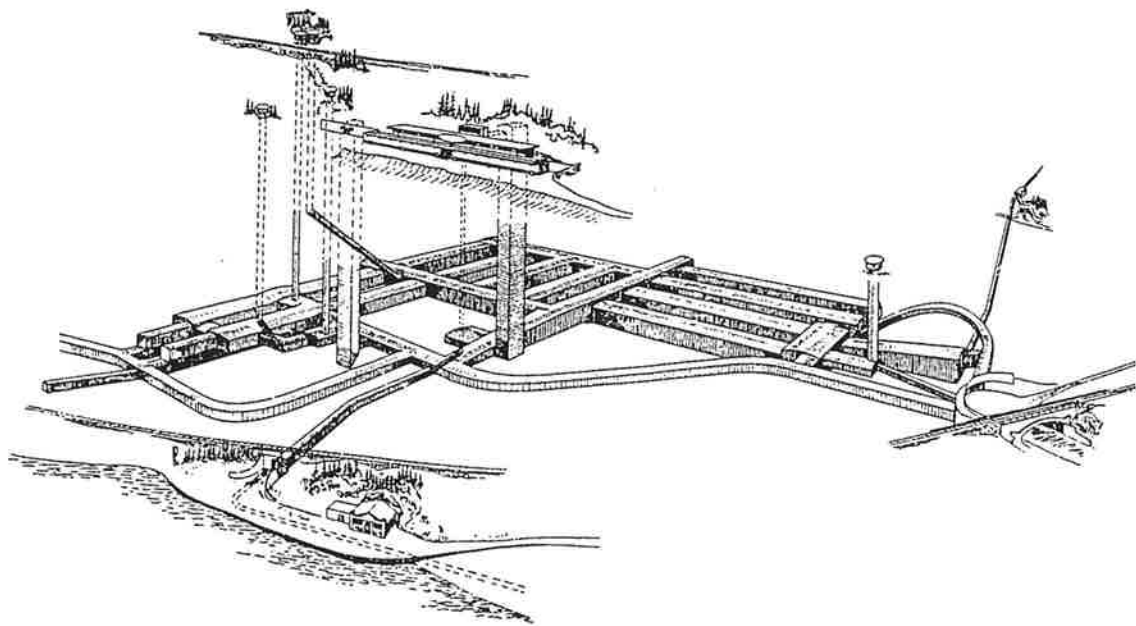


Fig 5 Layout of the Oset water treatment plant. From [1]

The rocks consist of syenite intersected by joints and weakness zones. The alignment of the various caverns were made at a angles versus the discontinuities so as to reduce the amount of rock support and limit construction problems,. The rock support was performed mainly by rock bolts and occasional cast in place concrete lining.

The main caverns have a free span of 13.2 m and a height of 16 m, i.e. a cross section of 200 m². They were excavated in three sections: a top heading 8 m high, and two benches each 4 m high. The water intakes are at depths of 30 m and 12 m with 22 m² and 10 m² tunnels leading to the treatment plant. The size of the scheme can best be described by the executed quantities:

excavated rock volume	400,000 m ³ ,
formwork	150,000 m ² ,
concrete	50,000 m ³

The Skullerud water treatment plant.

This plant is a first step in upgrading the water quality southeast of Oslo. Completed in 1995 with a maximum capacity of 2.3 m³/s, it is designed to satisfy EU rules and standards. The caverns have a maximum span of 12 m. Excavated rock volume is 110,000 m³ including two low level reservoirs, one high level reservoir, caverns for storage tanks, and in addition, access and transport tunnels.

The bedrocks in the area consist of gneiss of fair to good quality for which rock bolts and fibre reinforced shotcrete were applied systematically as roof support. In the walls, only occasional support was applied.

5.2 Waste water plants

In the 1950s and 1960s the water pollution in the Oslo fjord was becoming an increasing problem, due to a combination of densely populated areas and narrow inlet of the inner part of the Oslo fjord inhibiting the exchange of water with the North Sea. To improve the water quality, a sewage transportation tunnel system and an underground sewage treatment plant were constructed during the 1980s. If located on the surface, the plant would have occupied vast areas of land, producing fumes and smells not acceptable to the public. Today, the sewage system consists of more than 55 km of tunnels and a 400.000 m³ cavern area.

The scheme, called VEAS, is located on the western side of the fjord and handles sewage from 315,000 people in addition to commercial and industrial waste water equivalent to approximately 250,000 people. Commissioned 1982, the plant uses a mechanical/chemical process which has been extended to include a fixed film biological removal system.

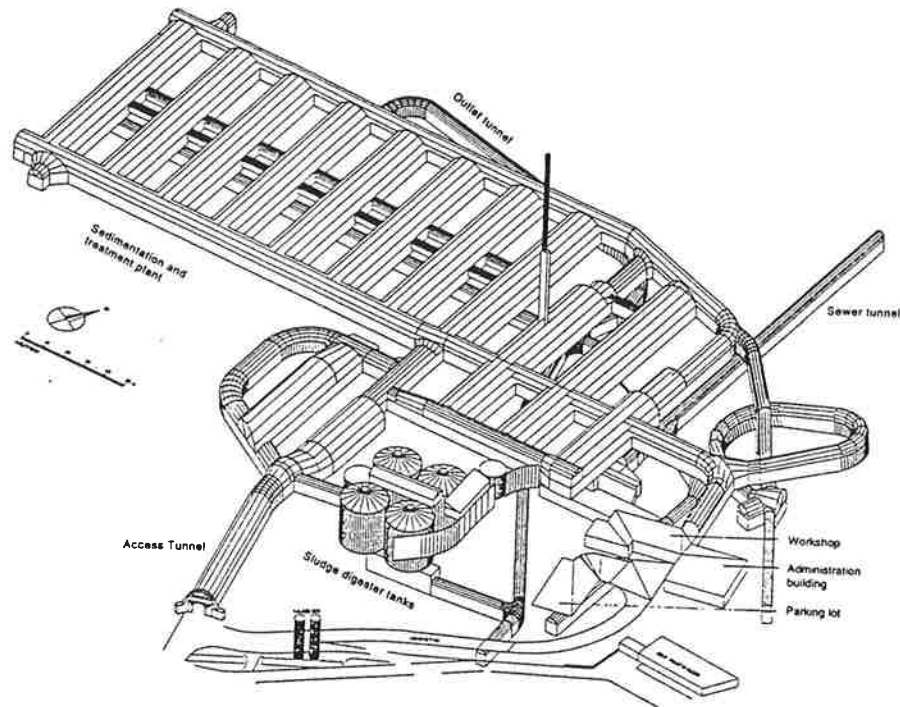


Fig. 6 Layout of the VEAS waste water treatment plant. From [1]

The sewage tunnel system brings water from the centre of Oslo along the west side of the fjord to the treatment plant. The collecting tunnels consist of 42 km with 40 inlets, including a 23 km long tunnel which was excavated by TBM. The tunnel diameter varies from 3 m to 3.5 m. An underground pumping station is located in the city centre with a maximum capacity of $2.4 \text{ m}^3/\text{s}$.

The rocks along the tunnel consist of sedimentary rocks, mainly limestones, shales, cut by several igneous dykes (diabase) with thickness up to 20 m. A comprehensive pre-grouting was performed to avoid settlements of the ground surface. The tunnels are basically unlined with rock support mainly by rock bolts and shotcrete where necessary in low stability areas (7 % of tunnel length). Only 400 m of the 23 km long tunnel had to be lined with cast in place concrete in faulted rocks.

The treatment plant is located in sedimentary rocks of limestones and shales. The maximum span and height of the caverns is 16 m and 20 m, respectively with a distance between them of 12 to 14 m only. Rock support was performed where needed in 50% of roof area, the rest is unsupported. An outfall tunnel was constructed under the fjord with outlet at 90 m depth.

To meet the new requirements to reduced discharge of phosphorous and nitrogen components, the plant was rebuilt 1991 to 1995. Extension in 6 of the 8 caverns was performed, plus 700 m additional tunnel, and surface sludge which included $60,000 \text{ m}^3$ of open rock excavation.

6. DUAL PURPOSE UNDERGROUND FACILITIES

The Civil Defense Authorities has provided air raid shelters for more than 50% of the population in Oslo. Because rock installations give good protection against bomb attack, rock caverns are often used. Many are dual purpose facilities, serving in peacetime as gymnasiums, swimming pools, bowling halls, shooting ranges etc., and can in very short time be converted into wartime civil defence shelters.

Oslo has two such facilities, and the nearest surrounding communities also have a couple of these combined sports and swimming halls. A typical hall has a volume of 35,000 m³.

One of them, Holmlia sports hall & swimming pool, is a typical facility of a dual purpose facility located in rock. It is authorised as a defence air-raid shelter for 7,000 persons. Located only 250 m from a railway station, it is used by schools, sports organizations, and the public. In addition to the swimming pool, gymnasium, running track, and club rooms, it includes trim rooms, sauna, and solarium.

Excavation of the caverns started in 1979 and was completed 18 months later; the structural works and installations took another 24 months. Excavated rock volume is 53,000m³ and the total floor area 7,550 m².

The rocks are gneisses intersected by joints and shears. The roof in the 25 m wide gymnasium was supported by reinforced, concrete beams in direct rock contact. The inverted T-shaped beams spaced 5 m are used as support for precast concrete slabs installed between the beams. The swimming hall has a span of 20 m. Its roof was support by cast in place concrete arch.

Totally, 2000 rock bolts were applied as support in the caverns and tunnels. 1500 m² of the walls are covered with shotcrete. The excavation cost in 1983 was NOK 36 mill. (USD 5.8 mill.) while the total cost was NOK 53.7 mill. (USD 8.7 mill.).

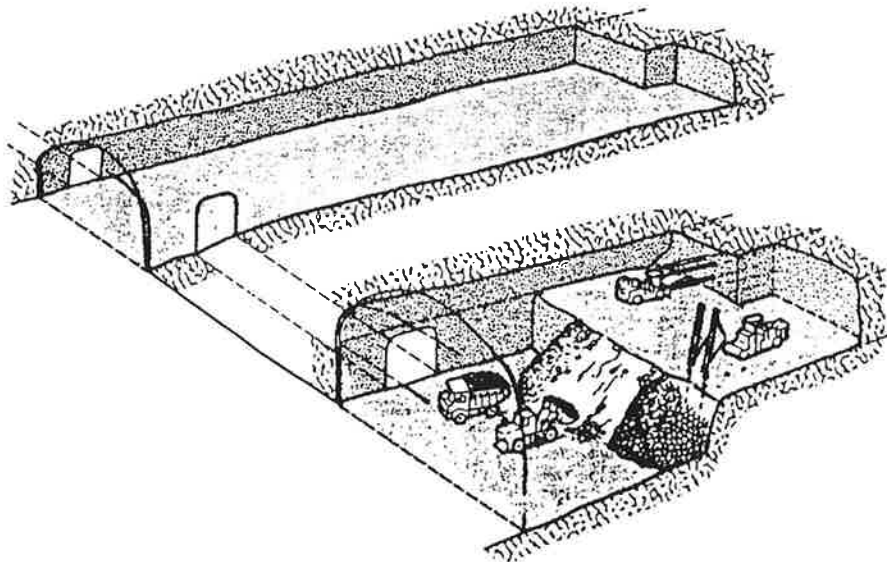


Fig. 7 Principle for excavating the rock caverns. From [3]

Since the opening in 1983 only regular maintenance has been performed on the technical installations. For the building structures the expenses for maintenance has been zero. The energy consumption is far below that of comparable sport halls and swimming pools in surface buildings other places in Oslo, with an annual energy consumption of 1.92 mill. kWh compared to 3.0 mill. kWh.

7. ROCK CAVERNS FOR VARIOUS OTHER PURPOSES

In the Oslo area there are huge rock caverns for storage of petroleum products. The actual volume of these caverns is not released.

It has become increasingly popular to store refrigerated and other types of food underground. Deep freeze stores are built in rock. The volume of a deep freeze facility for storing ice cream, meat and fish in the Oslo area is 160,000 m³.

Old air-raid shelters are also used for different storage purposes. At the dockside in the eastern part of Oslo, a complex of 48 caverns with a total volume of 23,000 m³ was opened in 1965. All kinds of goods are stored in these caverns, which have temperatures from freezing to temperate.

A new air traffic control centre for the Oslo area is located inside a granite formation in the vicinity south-west of Oslo. This centre was constructed 1989 to 1992. The main rock cavern has a span of 22 m.

Electric transformers, operating centres for telecommunications and other technical centres are also commonly placed underground for protection against war and sabotage. The Oslo Energy Board has several transformers and switch-gear in rock caverns, and plans are underway for more.

The National Archive of Norway has since 1978 had its archives placed in underground storage facilities. 4-storied concrete buildings have been erected inside rock caverns, giving 100,000 m² storage area in which are installed 100 km of shelves. Extension of the archives with additional caverns will start in the near future.

There are also several other types of underground openings located in the Oslo area, such as:

- caverns for telecommunication centre
- caverns for heat pump and district heating facilities
- underground openings for civil defence shelters
- underground caverns for car parking.

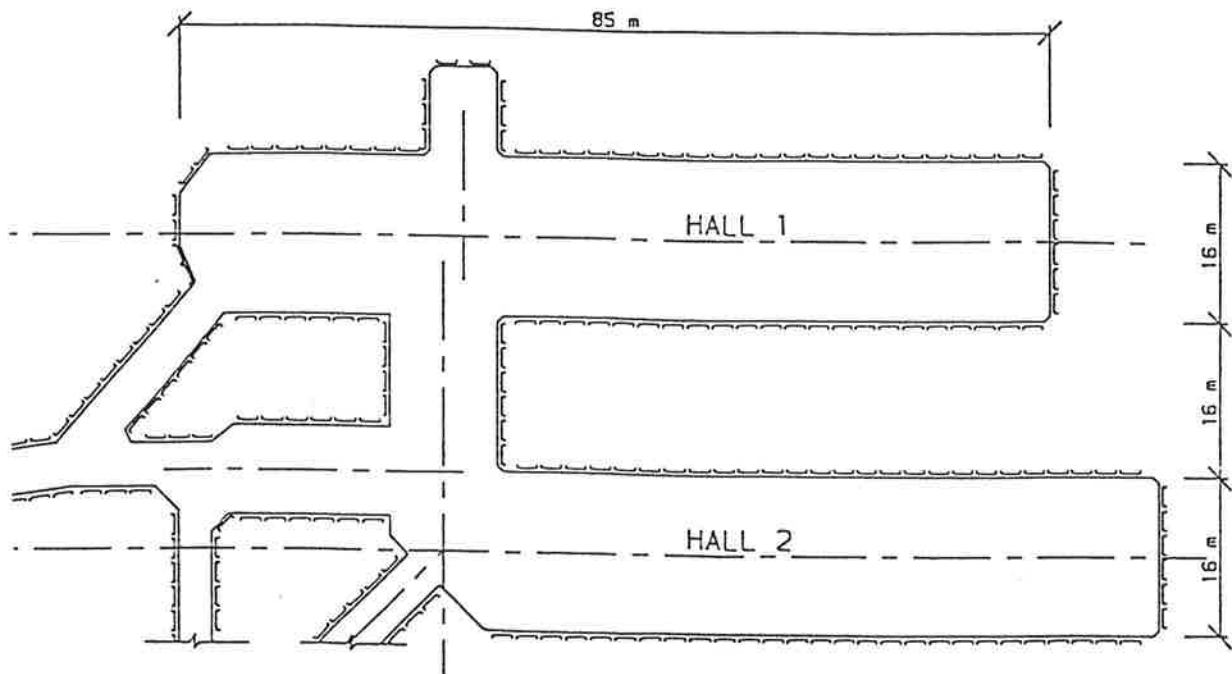


Fig. 8 Layout of the rock caverns for housing the central archives. From [4]

It is roughly estimated that all together 180 km of tunnels and additionally 1,500,000 m³ of caverns are located in the Oslo area. However, the exploitation of the underground is still in its very beginning. To be in front of future development, the planning authorities of the city of Oslo are preparing legislation for regulating underground construction, in the same way as above ground.

As construction techniques continuously improve and an increasing number of activities are attracted to already densely developed areas, a prosperous future can be seen for the underground construction business.

9. REFERENCES

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