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Creative use of the underground in Oslo, the capital city of Norway

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ABSTRACT: Although Oslo is relatively small (500,000 inhabitants) and fairly spacious, and having variable rock quality, the city has utilized its underground to a large extent. A constant development in design and construction methods, together with the ever increasing focus on environmental aspects, and the soaring cost of land, have made underground solutions increasingly favourable. A great variety of underground tunnels and caverns have been constructed in Oslo: 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. The paper presents an overview of these and describes a few of these interesting projects.

1. INTRODUCTION

Norwegians have long experience in developing underground facilities. They started mining ores and minerals a thousand years ago, and continued with railway tunnels in the late 1800s. Oslo started using the underground in the 1920s with tunnel construction for the mass transit tram. A reduction in excavation cost, and a marked increase in the excavation and tunnelling capacities have gradually taken place during the last 50 years. This development has been important in the increased use of the underground.

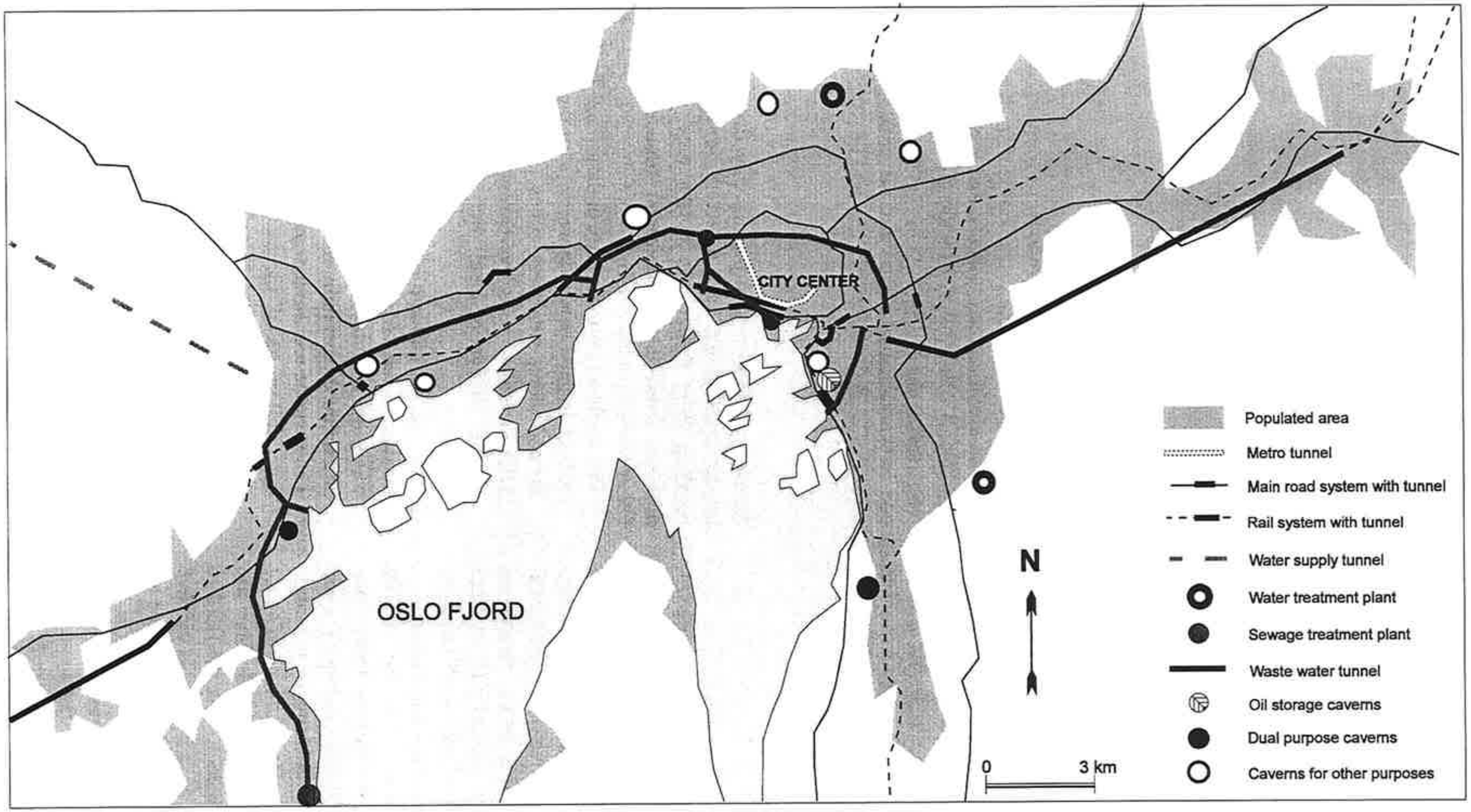
Surrounded by hills and forests, the city of Oslo is located at the end of the 40 km long Oslo fjord. Although a city with only 500,000 inhabitants, Oslo has experienced the common problems of urbanization, such as traffic jams, pollution, and lack of space for building purposes. From the late 1970s there has been a trend among city planners to link the fjord to the city and its inhabitants. As a means to achieve this, the underground is used to make the surface areas available and attractive. Further, the use of underground space has played an important role in improving the water quality of the Oslo fjord.

The built up areas in the central part of Oslo consist mainly of 4 to 5 storey buildings from the second half of the 19th century. Many of these are founded on Quarternary marine clay deposits. One major challenge has been to avoid damage of these building from settlements in the clay caused by drainage from the underground tunnelling work. Other challenges have been:

- The shallow depth of many underground facilities in Oslo located below depressions in the bedrock, formed along weakness zones (faults). This results in limited rock overburden, which requires careful excavation and well planned stability measures.
- The risk for damage of buildings and structures located in the vicinity of tunnel blasting works. Thorough planning of the blast with weak charges and reduced blast pulls are often necessary.
- The variable rocks mass conditions which require strict follow up of the excavation and the rock supporting works.

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



UNDERGROUND FACILITIES NOT SHOWN: More than 35 km of fresh water tunnels
Approx. 25 km of waste water tunnels
Several air-raid shelters in rock

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

(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. Many underground excavations in Oslo therefore require strict prevention of ground water leakage.

The variable geology in the Oslo area has been a challenge to geologists and engineers. Although there is an abundance of rock of excellent quality for tunnelling, the differing rocks with variable jointing result in 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.

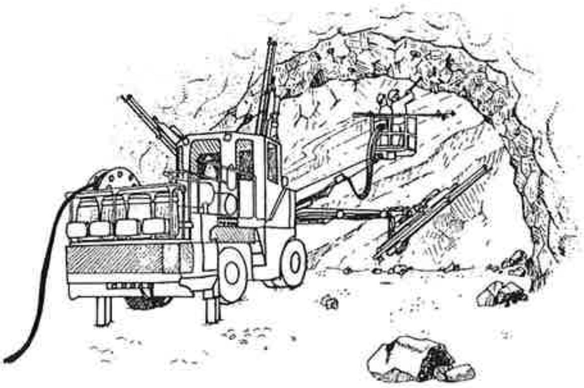


Fig. 2 Installation of rock bolts. From [2]

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).

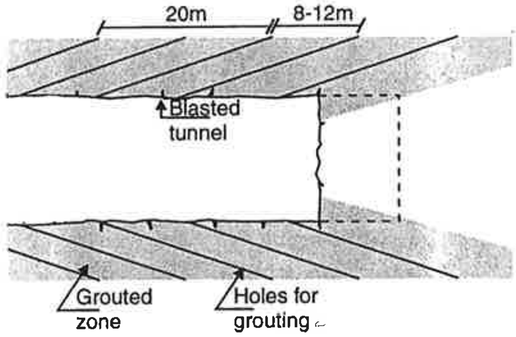


Fig. 3 Scheme for pregrouting. From [1]

To maintain a constant ground water table, strict control of ground water leakage into underground excavations are required. Permanent waterproofing is taken care of by pre-grouting the rock mass surrounding the openings, or in situ cast concrete lining. In road tunnels, various types of element cladding are in use.

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 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 m^2 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, incorporating an underground station. An extension of this tunnel and station is now in the planning stage.

The rapid railway line southeast of Oslo to improve the link to Sweden is under construction. Dimensioned for 200 km/h it involves several tunnels. There are also plans for a new railway line to Hönefoss, west of Oslo to shorten the distance to Bergen by 60 km. A large part of the 45 km long new line will consist of tunnels.

4.2.1 The Romeriksporten tunnel.

The 14 km long Romeriksporten tunnel is under construction. Finished in 1998, it forms part of the rail link to the new Gardermoen airport north of Oslo, designed for a train speed of 200 km/h. This double tracked, 105 m^2 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.

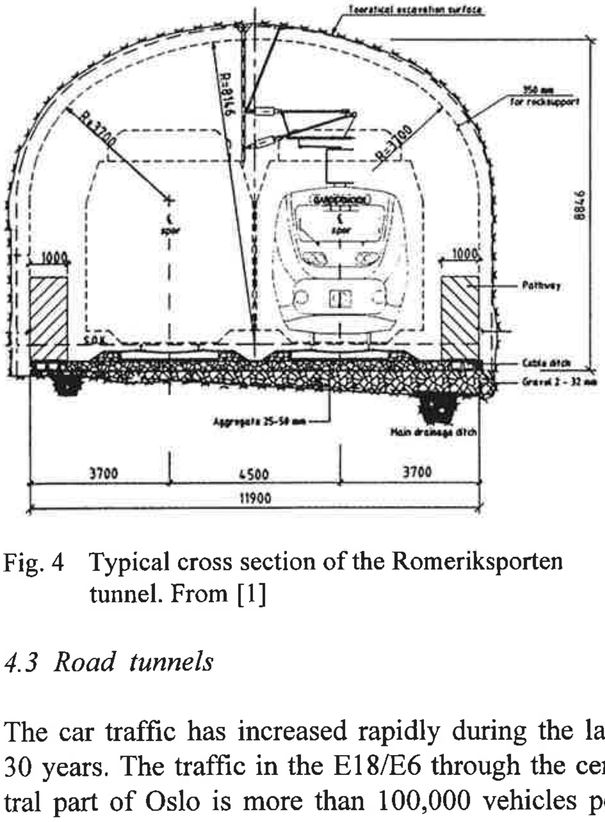


Fig. 4 Typical cross section of the Romeriksporten tunnel. From [1]

4.3 Road tunnels

The car traffic has increased rapidly during the last 30 years. The traffic in the E18/E6 through the central part of Oslo is more than 100,000 vehicles per 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 in Section 4.3.1.
- The Granfoss tunnel completed 1992, consisting of two 2.3 km long tunnels.
- 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 more than 10 km of road tunnels; and approximately the same amount is found in the nearest communities around Oslo. Road tolls have made it possible to finance new road systems, resulting in a big increase in traffic capacity the last years.

4.3.1 The Oslo Tunnel

This tunnel is part of the main E18 route through Oslo and was constructed from 1987 to 1990. The tunnel was located mostly in rock to avoid open excavation in large built up sections in the centre of Oslo, which would have resulted in enhanced traffic problems, access difficulties to downtown buildings as well as possible settlements of the same. Ramps made as bedrock tunnels and cut and cover tunnels give connection to the inner ring road system.

The tunnels are 1.5 km long in rock and 270 m as cut and cover tunnel. Each of the twin tunnels has 3 lanes with cross sections varying from 88 m^2 to 153 m^2. 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 m^3 to 600 m^3.

The maximum road gradient in the tunnels is 50 $^{o}/_{oo}$ with the lowest point 47 metres below sea level. In this location, where erosion along a fault zone in the surface above had developed a deep depression filled with marine clay, the rock cover is only 4.8 m. Here, the rock is highly fractured along 6 to 13 metres of the tunnels. In the northern tunnel a 25 m^2 pilot tunnel was first driven through the zone and later enlarged to full cross section. The rock was successively supported with bolts 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.

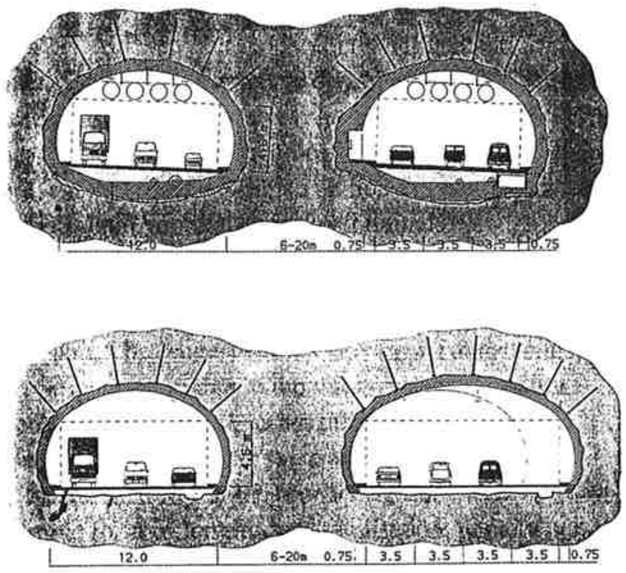


Fig. 5 Cross sections of the Oslo Tunnel. From [1]
Watertight lining (top) with sealed concrete lining around the whole cross section.
Drained lining (bottom). The concrete lining is drained and the base is not concreted.

The cost of the Oslo Tunnel was USD 81 mill., i.e. USD 53,500 per metre, excluding installations. Experience from the construction of this tunnel 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 forest 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. More than 35 km of fresh water tunnels have been constructed, with cross sections between 5 and 10 m^2.

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

5.1.1 The Oset water treatment plant.

The plant was commissioned in 1971. It has a design capacity of 6 m^3/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 m^2.

The rocks consist of syenite intersected by joints and weakness zones. To reduce the amount of rock support and limit construction problems, the various caverns were located at a favourable angle to the dis-

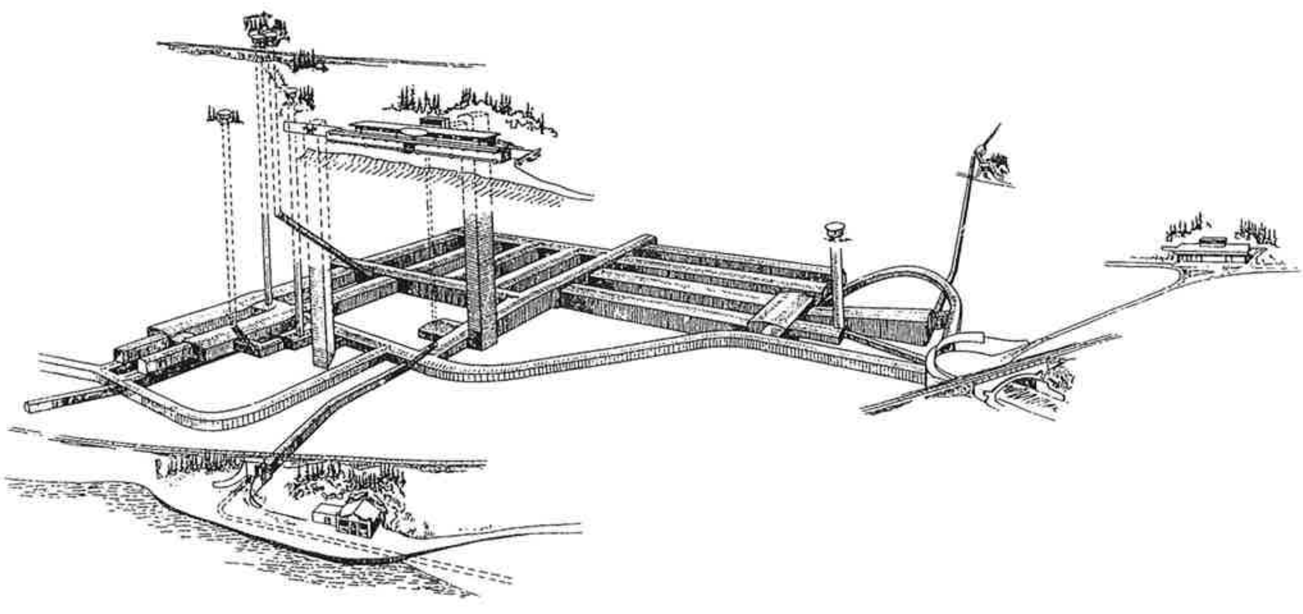


Fig. 6 Layout of the Oset water treatment plant. From [1]

continuites. 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 m^2. 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 m^2 and 10 m^2 tunnels leading to the treatment plant.
The following quantities can be mentioned: excavated rock volume 400,000 m^3, formwork 150,000 m^2, concrete 50,000 m^3

5.1.2 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 m^3/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 m^3 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 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. The plant would have occupied vast areas of land if located on the surface, producing fumes and smells not acceptable to the public. Today, the sewage system consists of more than 55 km of tunnels.

5.2.1 VEAS - the western Oslo fjord sewerage scheme.

The scheme is located on the western side of the fjord and handles sewage from 315,000 people in this region 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.

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 to this plant consist of 42 km with 40 inlets, including a 23 km

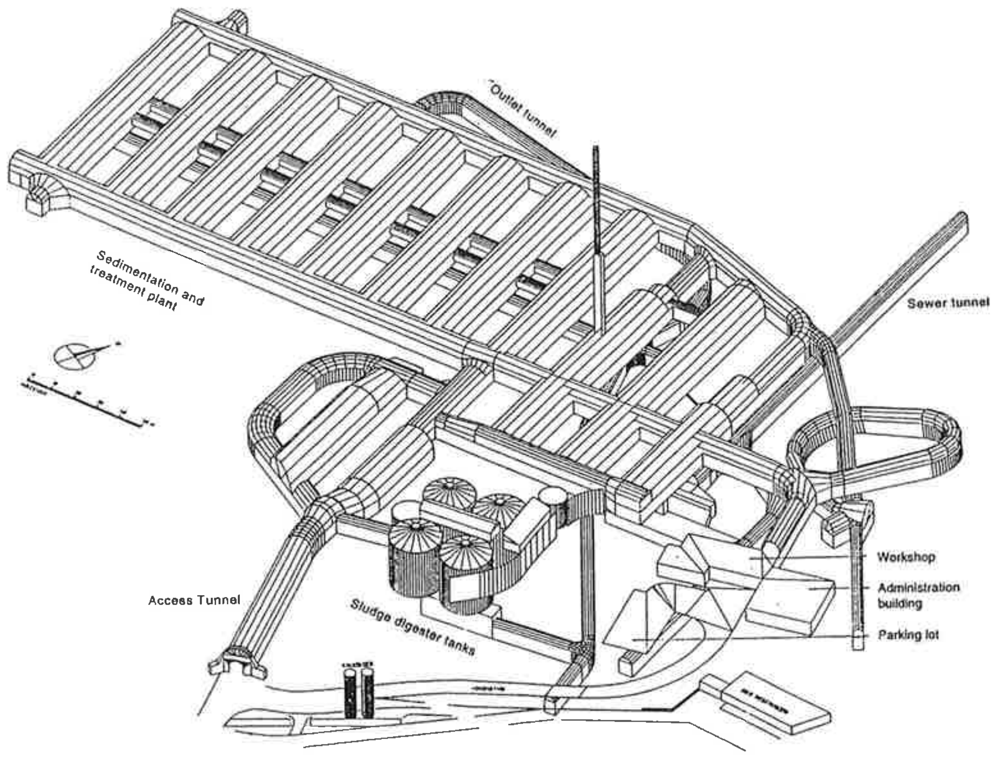


Fig. 7 Layout of the VEAS waste water treatment plant. From [1]

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 m^3/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 seal the tunnel in sections where thick clay deposits were in the vicinity above the tunnel 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 caverns of the underground plant have a volume of 400,000 m^3. 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 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 m^3 of open rock excavation.

6. DUAL PURPOSE UNDERGROUND FACILITIES

The Civil Defense Authorities has provided 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 m^3.

6.1 Holmlia sports hall & swimming pool

This is a typical facility of a dual purpose facility located in rock. It is authorized as a defence air-raid shelter for 7,000 persons. Located only 250 m from Holmlia 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 53,000m^3 and the total floor area 7,550 m^2.

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 m^2 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.).

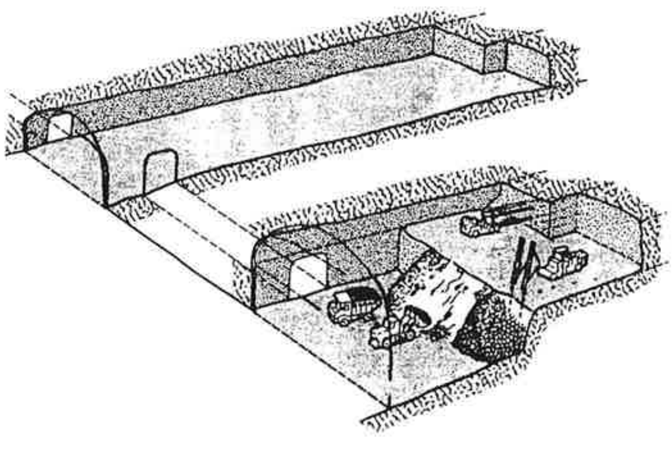


Fig. 8 Principle for excavating the rock caverns. From [3]

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.

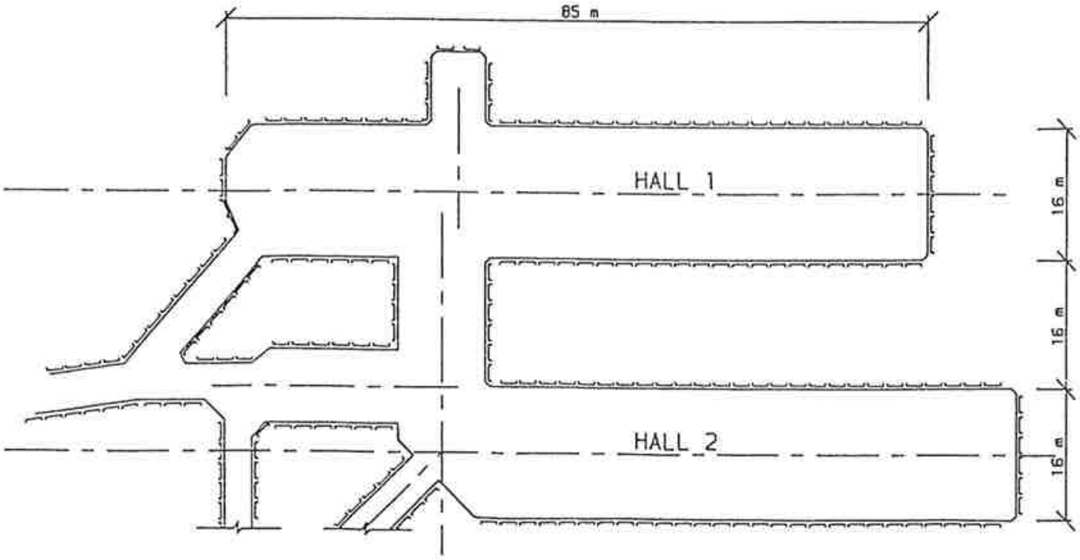


Fig. 9 Layout of the rock caverns for housing the central archives. From [4]

7. ROCK CAVERNS FOR VARIOUS PURPOSES

7.1 Storage for petroleum products

Oslo also has huge rock caverns for strategic storage of petroleum products. The actual volume of these caverns is not released, but at the eastern harbour there are more than 4 km of tunnels and caverns for petroleum storage and distribution.

7.2 Food storage

It has become increasingly popular to refrigerated and other types of food storage 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 m^3. 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 m^3 was opened in 1965. All kinds of goods are stored in these caverns, which have temperatures from freezing to temperate.

7.3 Underground air traffic control centre

This centre, located inside a granite formation in the vicinity southwest of Oslo, was constructed 1989 to 1992. The main rock cavern has a span of 22 m.

7.4 Underground caverns for electric transformers

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.

7.5 Underground excavations for Public Record Office

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 m^2 storage area in which are installed 100 km of shelves. Extension of the archives with additional caverns will start in the near future.

7.6 Other underground openings

There are several types of other 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.

8. CONCLUSION

The utilizing of the underground by tunnels and caverns in the Oslo area is mainly connected to traffic solutions, water supply and discharge, storage, protection, and installations. It is roughly estimated that all together 180 km of tunnels and additionally a volume of 1,500,000 m^3 in caverns have been excavated in the Oslo area. The many reasons for this great activity are mainly connected to one or more of the following:

- to develop infrastructure;
- to protect against enemies;
- to shelter from climate;
- to protect the environment;
- to save land;
- to save money.

The exploitation of the underground is still in its 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

[1] Hope J., Finborud B., Fredriksen U. and Överland O. eds. (1995): Norwegian urban tunnelling. Publ. no. 10, Norwegian Rock and Soil Association, 86 pp.

[2] Hafsaas G. (1994): Handbook in rock bolting (in Norwegian). Statens Vegvesen, Veglaboratoriet, 113 pp.

[3] Martin D. (1983): Norwegian underground sports halls double as air raid shelters. Tunnels & Tunnelling, November 1983, 3 pp.

[4] Urdahl O.T. (1993): Archives in rock caverns. In Publ. no. 9, Norwegian Rock and Soil Association, 4 pp.