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Norwegian Tunnelling in General

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ABSTRACT

"Norwegian Tunnelling in General" will cover the following subjects :

- Short introduction to the geology of Norway
- Major considerations in rock installations
- Hydropower plants, roads, tunnels, oil and gas storage in rock, drinking water storage, sewage plants, frozen food storage, defence and civil defence projects, including sports arenas and swimming pools, etc.

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1. NORWAY IN BRIEF

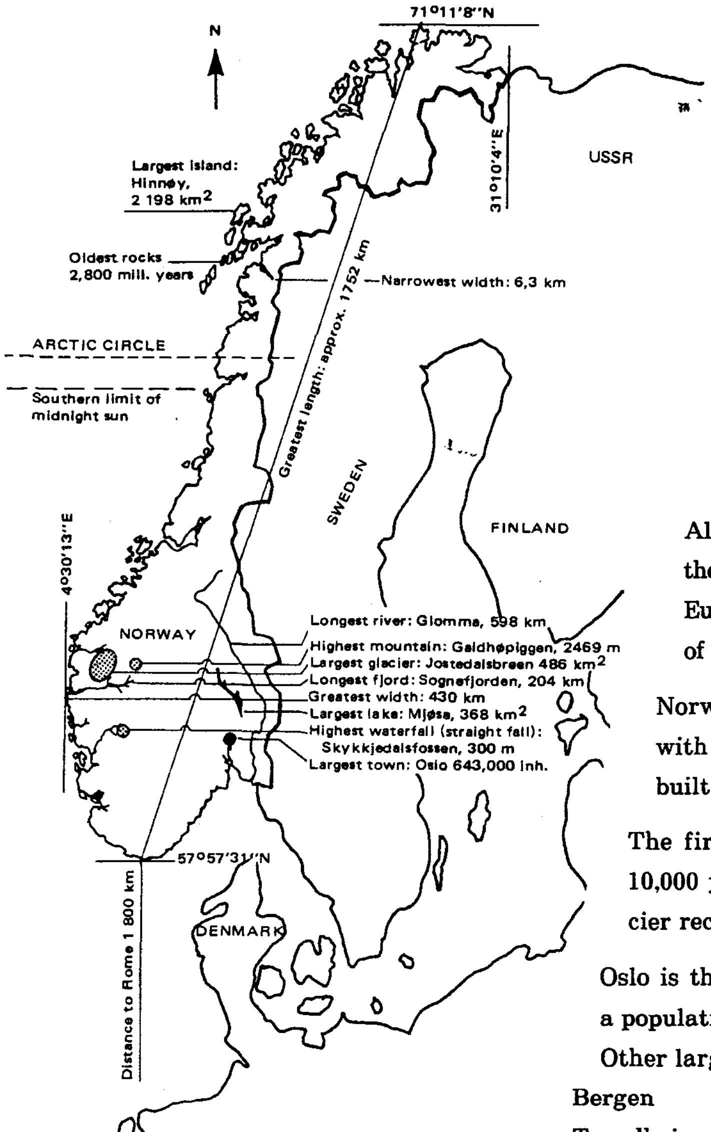


Fig. 1

NORWAY(originally Nordweg, meaning the "northern way")is a part of Scandinavia, the large peninsula in northwest Europe. It borders with Sweden (1619km), Finland (716km) and Russia (196km).

The land area is 324,000㎢(excluding Spitsbergen and Jan Mayen). About 50% of the country is made up of exposed bedrock. A mere 2.8% of the area is cultivated soil, 5% lakes 20% productive forest, while less than 1% is populated. Although Norway is the country with the second lowest population density in Europe, it is the fifth largest in terms of area.

Norway has a population of 4.2 mill. with about 45% living in towns and built-up areas.

The first people came to Norway at least 10,000 years ago when th huge inland glacier receded.

Oslo is the capital and the largest city with a population of 643,000.

Other large towns are :

Bergen	180,000
Trondheim	127,000
Stavanger	90,000
Drammen	57,000
Kristiansand	51,000

The oldest town, Tϕnsberg was founded about 900AD. Hammerfest is the most northerly town in the world.

The coastline(excluding fjords) measures 2,650㎞, including the 50,000 islands the total shoreline is as much as 55,000㎞.

There are great climatic variations in Norway. Thanks to the Gulf Stream and the prevailing westerly winds the country enjoys a more pleasant climate than the location between 58 and 71 degrees north should indicate. The temperature varies little from north to south, but there is a significant contrast between the inland and the coastal regions.

The average temperature is 8 degrees Celsius(46 degrees Fahrenheit) along the west coast and -2 degrees Celsius(28 degrees Fahrenheit) in the northern most parts (Finnmark).

The average annual percipitation is 1,960 ㎜ in Bergen and 740㎜ in Oslo. The lowest recorded temperature is -51 degrees Celsius (-60 degrees Fahrenheit) in Finnmark.

In the arts, sciences and humanities the country has fostered many personalities of international stature, among them Henrik Ibsen, Edvard Grieg, Bjϕrnstjerne Bjϕrnson, Gustav Vigeland, Sam Eyde, Roald Amundsen and Fridtjof Nansen.

The first tourists found their way to Norway at an early date, but it was not until after the First World War that this new industry really gained momentum, leading to the building of a wide network of roads and a host of up-to-date hotels, pensions and mountain lodges. Norway's unique attraction lies in her unpolluted lakes and rivers, clean fresh air, and a wealth of unspoiled scenery that includes tumbling waterfalls, breathtakingly beautiful fjords, and vast expanses of mountain moorland far removed from the bustle of city life. Fascinating too is the vivid contrast between snowcapped mountain peaks and verdant valleys.

In summer, days are long and nights but a fleeting twilight. And for weeks on end in the north, in the Land of the Midnight Sun, the sun never sinks below the horizon.

2. A SHORT INTRODUCTION TO THE GEOLOGICAL HISTORY OF NORWAY

Precambrian

The Norwegian continent is part of the Baltic shield, one of the bigger continental shields in the world. It includes Fenoscandia(Norway, Sweden, Finland) and the western part of Russia.

The dominating rocks originated in medium, and late Precambrian, presently some of the older types of rocks on earth. The Baltic shield is limited by the Caledonian mountain range on the western edge, and by the much younger sedimentary types of rocks on the continental shelf towards the Norwegian Sea and the North Sea. (see Fig. 3.)

Paleozoic

The geology of Norway and Scandinavia is basically a result of folding and metamorphism during the Caledonian orogeny 550～400 mill. years ago, when the sea bottom with sediments from Cambrian-Silurian times was compressed to form this Caledonian mountain range. It is assumed that the range was eroded down to a low hilly scenery over a period of 50 mill. yesrs.

Mesozoic

During this era Scandinavia was most flatland.

There are only very few remnants left from the events during this 160 mill. years long era.

Cenozoic

Tertiary sediments are not found onshore in Norway. The flat Scandinavian landmass only a few meters high is believed to have been uplifted and tilted in connection with faults outside western Norway. This event is responsible for the characteristic highlands in Norway. In the following periods, rivers and later glaciers were eroding their way down to create the valleys we find in Norway today.

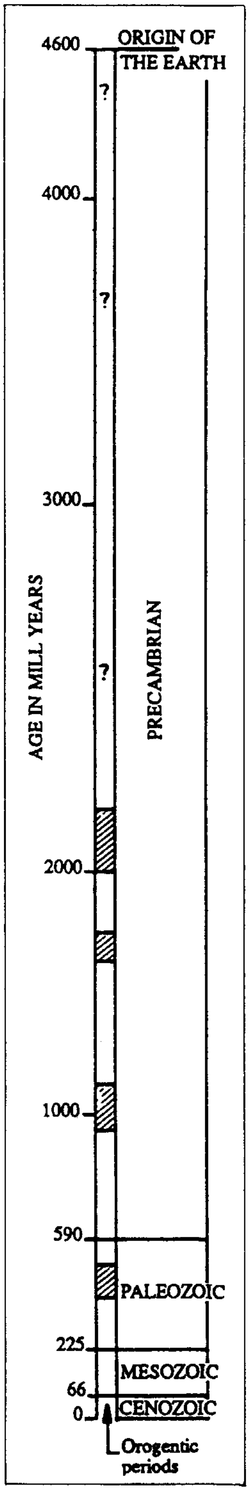


Fig. 2.

The glacier erosion in Quarternary during several ice ages ending some 10,000 years ago has effectively removed the weathered rocks. The rock surface of today is therefore fresh and in many parts uncovered by soils. This feature frequently offers excellent possibilities to study the bedrock conditions from simple surface observations.

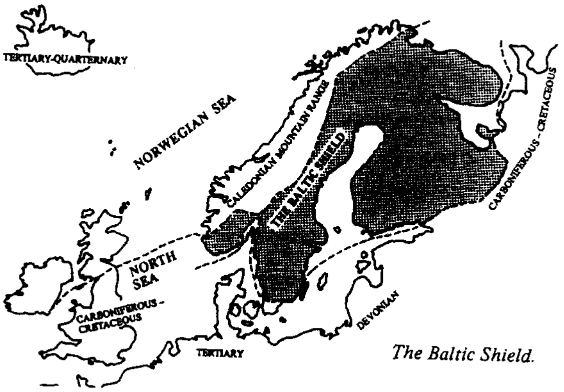


Fig. 3.

3. MODERN METHODS IN ENGINEERING GEOLOGY

3.1 Geological mapping and classification

In the Norwegian Method of tunnelling (NMT), great emphasis is placed on thorough descriptions of geological and geotechnical aspects of the project. The owner and his consultant have as their objective the preparation of tender documents that reflect as closely as possible the likely equipment, tunnelling methods and tunnel support materials for successfully tunnelling through the investigated rock. Since the Norwegian Geotechnical Institute(NGI) has been responsible for the geological mapping and classification of at least one quarter of the 4,500km of civil engineering tunnels constructed in Norway in the last 20 years, some emphasis will be given to the methods developed and used by this consulting group.

Table 3.1 Essential features of the Norwegian Method of Tunnelling(NMT)

1) Areas of usual application:
   Joined rock; harder end of scale
   (σ_c = 3 to 300 MPa)
   Clay bearing zones, stress slabbing
   (Q = 0.001 to 10)
2) Usual methods of excavation:
   Drill and blast, hard rock TBM and excavation in clay zones
3) Temporary support and permanent support may be any of following:
   CCA, S(fr)+RRS+B, B+S(fr),
   B+S, B, S(fr), S, sb, (NONE)
   (see key below)
   * temporary support forms part of permanent support
   * mesh reinforcement not used
   * dry process shotcrete not used
   * steel sets or lattice girders not used; RRS used in clay zones
   * Contractor chooses temporary support
   * Owner/Consultant chooses permanent support
   * final concrete linings are less frequently used, i.e., B+S(fr) is usually the final support
4) Rock mass characterisation for:
   * predicting rock mass quality
   * predicting support needs

  - * updating of both during tunnelling (monitoring in critical cases only)

5) The NMT gives low costs and
  - * rapid advance rates in drill and blast tunnels
  - * improved safety
  - * improved environment

CCA = cast concrete arches,
S(fr) = steel fibre reinforced shotcrete,
RRS = reinforced ribs of shotcrete,
B = systematic bolting, S = shotcrete,
sb = spot bolts, NONE = no support needed.

A key requirement for ensuring consistent mapping quality, good tender documents and good records of actual condtions is a method that describes the rock mass in quantitative rather than just qualitative terms. Although the high level of experience in the Norwegian tunnelling community has allowed "rules-of thumb" and much "previous experience" to dictate a lot of the support estimates, more and more companies are realising the value of a documentation method such as the Q-system for regulating the description of rock mass conditions and support recommendation(Barton, 1980).

The Q-system is an empirical method based on the RQD method of describing drill core (Deere, 1967) and five additional parameters which modify the RQD-value for the number of joint sets, joint roughness and alteration (filling), the amount of water, and various adverse features associated with loosening, high stress, squeezing and swelling. The rock mass classification is associated with support recommendations based originally on 212 case records. (More than 1000 new case records are presently being processed at the Norwegian Geotechnical Institute(NGI).

3.2 Cross-hole tomography

Urban tunnelling through difficult fault zones with low cover, or the approach of a major fault zone mid-way beneath a deep fjord are two typical tunnelling scenarios that call for more information of the rock mass. With good warning well ahead of the face, a tunnel contractor can plan his strategy, mobilise equipment and minimize risk. In other cases he may avoid costly over-reaction and unnecessary delays. Cross-hole seismic tomography(and also tunnel radar) are invaluable aids in this respect.

Borehole reflection seismics and seismic tomography have been performed between boreholes and the seafloor in the case of a sub-sea tunnel, between boreholes and the tunnel face, and between pairs of probing boreholes ahead of the tunnel face. For weak limestone assessments, the geotomography method gives excellent information of heavily jointed and karstified rock masses.

The special probing device fits in boreholes 46㎜ in diameter or larger.

In the case of large caverns where choice of location also exists, improved knowledge of the internal structure of the rock mass can save considerable sums in rock support if a location within higher quality rock can be found.

A perfect example of this was the cross-hole seismic investigations performed for the 61m span Olympic Ice Hockey Cavern at Gjϕvik, Norway, one example of which is shown in Fig. 4.

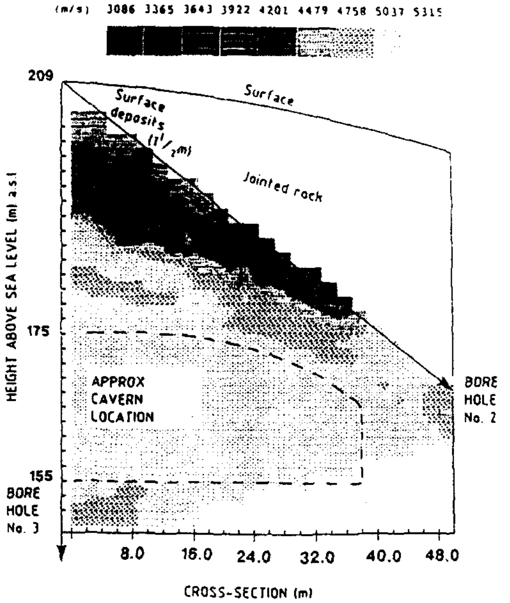


Fig. 4.

4. ROCK INSTALLATIONS. MAJOR CONSIDERATIONS

4.1 General remarks

After blasting and excavating the rock, the result will be a cavern or systems of caverns with characteristic properties.

Weak zones are secured in a proper way, depending on rock quality and the design criteria. The cavern itself will normally be humid and have some leakage through the walls and roof. It will have approximately constant temperature of 6-8 degrees Celsius(Norway).

To make this cavern fit for any kind of modern installations, the inside climate must be controlled.

The main problem will be to control the leak-water and humidity. High humidity often occurs when warm humid outside air is brought into the cool cavern and thus leaving condensed water on the cool rock surface. In winter periods, the opposite can happen when warm, humid air from inside cavern meets cold surfaces, especially in the entrance tunnels.

To solve this problem in rock caverns an inner lining or building inside the cavern is required to keep the leak water away from the inner space or rooms. These rooms must be dehumidified and ventilated(air-conditioning).

Exceptions from this rule will be oil and gas caverns as well as caverns used for storing frozen food.

Fig. 5. The rock cavern.(Holmlia Sport Facility)

Leakwater or condensed water from the rock surface must be drained out of the caverns in a closed drainage system. Due to the fact that water in a rock installation normally will not sink into the ground the drainage system must be aboslute dependable. Possibility for clean up of the drainage system, must be installed.

4.2 Ventilation and humidity

In an underground facility good ventilation is very important. It should be well balanced to the utilization of the facility and have full control of temperature and humidity(relative humidity).

Personnel in an underground facility will normally be more sensitive to the quality of the air, temperature and humidity than in a conventional surface building. Fresh air and good inside climate is therefore essential for physical health and the efficiency of the personnel.

A controlled air condition is also of decisive importance for operation reliability and maintenance cost of the technical equipment and the facility itself.

The only outside factor influencing the underground installation is the condition of the outside air used for ventilation. Therefore it is very easy to maintain constant and controlled climate conditions inside the facility, fairly independent of outside conditions.

However, it is very important that the technical installations are reliable. A breakdown of the dehumidifications system could have disastrous consequences for the installations.

The fresh air quality must be balanced to fit the general use of the facility(command centres, workshops, stores, sports facilities etc.), and should maintain satisfactory hygienic conditions for the personnel. The system should maintain an adequate overperssure relative to the outside atmosphere.

The fresh air quality shall be sufficient to satisfay the conditions above, but should not be oversized, owing to

- installation costs
- operations costs.

To obtain a satisfactory distribution of the outside fresh air, and to be able to control temperature and humidity, the fresh air could be mixed with recirculated air. The recirculated air must be carefylly filtered to avoid the feeling of foul air. Smoking should only be allowed in special smoking areas, where the air can be evacuated to avoid recirculation.

4.3 Humidity Control

The relative humidity in the facility should be 40~50%. This is most comfortable for the personnel, and gives longest lifetime and lowest maintenance costs for the equipment and structures.

The humidity will be carride into the facility by

- fresh air
- respiration from occupants
- evaporation from wet rock surfaces.

The humidity in the fresh air and respiration can easily be calculated and controlled.

To be able to obtain full control of the humidity, an internal building inside the rock cavern will be necessary to protect the installations.

Depending on the use of the facility, the building might be of steel, reinforced concrete or in the most simple cases, just a tent of diffusion proof fabric.

4.4 Emergency Power Supply

Emergency power supply is "a must" in an underground installation. Depending on the operational function, more or less sophisticated systems for the emergency power are available. The main source will normally be a diesel engine and an electric generator. This system has proven to be very dependable. When power failure is considered critical for the operation of the facility, two or more generators will be installed to secure the most vital power supply.

4.5 Fire Prevention

Considerable effort is needed in all stages of planning, design, construction and use to prevent fire in an underground installation. Since the escape possibilities are limited, smoke and fire could be even more hazardous than in above-ground facilities. The choice of non-combustible construction materials is mentioned before. Escape routes and emergency exits must be clearly marked and kept clear of smoke by the ventilation systems.

To discover smoke and/or fire, several systems are used. The detectors will normally activate alarm systems, signal to the control room and activate special fire-ventilation systems, and signal to fire brigade etc.

To extinguish fire, there are also several systems depending on the function of the room. Examples are:

- Automatic dry extinguishing system; Halon and CO_2-gas
- Sprinkler system; Water
- De-luge-system, Water curtains
- Hose reel water. (Handoperated)
- Manual fire extinguishers. (Handoperated)

4.6 Construction of underground facilities

The construction work ranges from blasting and excavating to building constructions including HVAC, sewage, water, electrical and electrotechnical systems etc. Normally, contractors must prequalify for the job. The contractors must prove skill and experience in underground installations.

4.7 Manuals

It is of vital importance that a complete set of manuals for the operation and maintenance is worked out and ready when the user of the facility takes over.

These manuals should be tailor-made for the specific installations, be easy to understand and in native language.

4.8 Maintenance and education of personnel

Maintenance follows a well established system for underground installations. Also, technical employees in the facility must be given adequate education in the operation of all technical as well as electrical and electronical installations and equipment.

A course is normally given by the involved contractors and/or consultants.

4.9 Psycological Impact

Studies made in Norway have shown that only few people react negative to work in an underground space.

Nevertheless large effort is done to compensate "lack of sunshine", view and confinment. Important factors are variation in light intensity and the use of interior and colours. Fig. 6 and 7 show an example. Note the "windows", giving an impression of outdoor light.

A scientific programme concerning these questions is launched in 1992 in connection with the Olympic Ice Stadium in rock at Gjϕvik, Norway.

Fig. 6. Canteen in rock. By variation of light-intensity, "windows", colours and interior the lack of sunshine etc. is compensated.

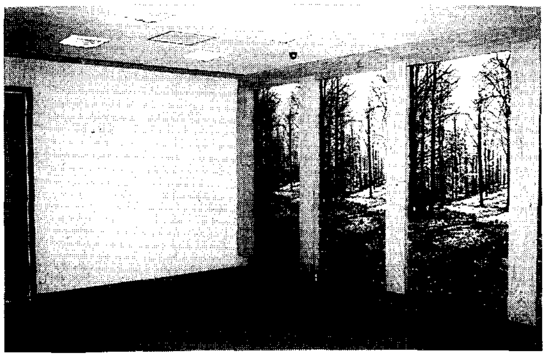
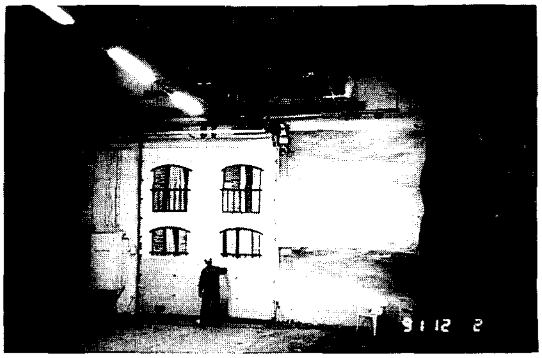


Fig. 7. Water purification plant in Rock. Painting on walls gives the impression of outdoor view.



5. EXAMPLES OF ROCK INSTALLATIONS IN NORWAY

5.1 Underground Hydropower Stations

The partiality for sub-surface powerhouses in Norway has brought 90% of the country's generating capacity underground. Both safety and cost aspects are strong arguments in favour of going underground.

Contributing to this accomplishment is, aside from the generally suitable rock conditions, a forefronting geoengineering discipline. Compact design of powerhouses is achieved through reducing the cavern span by various means, by omitting any facilities that may be superfluous, and by converting excavated space needed for construction such as auxiliary adits to permanent use.

As early as 1916 the first hydropower unit was installed in a rock cavern. The first fullfledged underground hydropower installation, Bjϕrkåsen Power Plant was commissioned in 1923. From about 1950 it became normal procedure to place powerhouses below the surface. Today there are an approximately 200 powerhouses built underground.

Key Figures for the Norwegian Hydropower Tunnelling

99.6% of Norwegian electricity production is based on hydropower.

As of today :

Hydropower tunnels :	approx. 4,000 km
Underground power stations	approx. 200
(World total	approx. 300)

Capacity in operation totalling 26,936MW.

Norwegian tunnelling	1987	1988	1989	1990
Total(1,000m^3)	4,481	3,232	2,918	4,091
Total(km)	116	80	73	110
Hydropower(km)	72	31	31	41
Hydropower(1,000m^3)	1,869	880	813	923

Underground powerhouses of up to 127,000m^3(Sima)

Max. pressure: Static water head of 1,180m.

Power stations of up to 1,240 MW capacity.

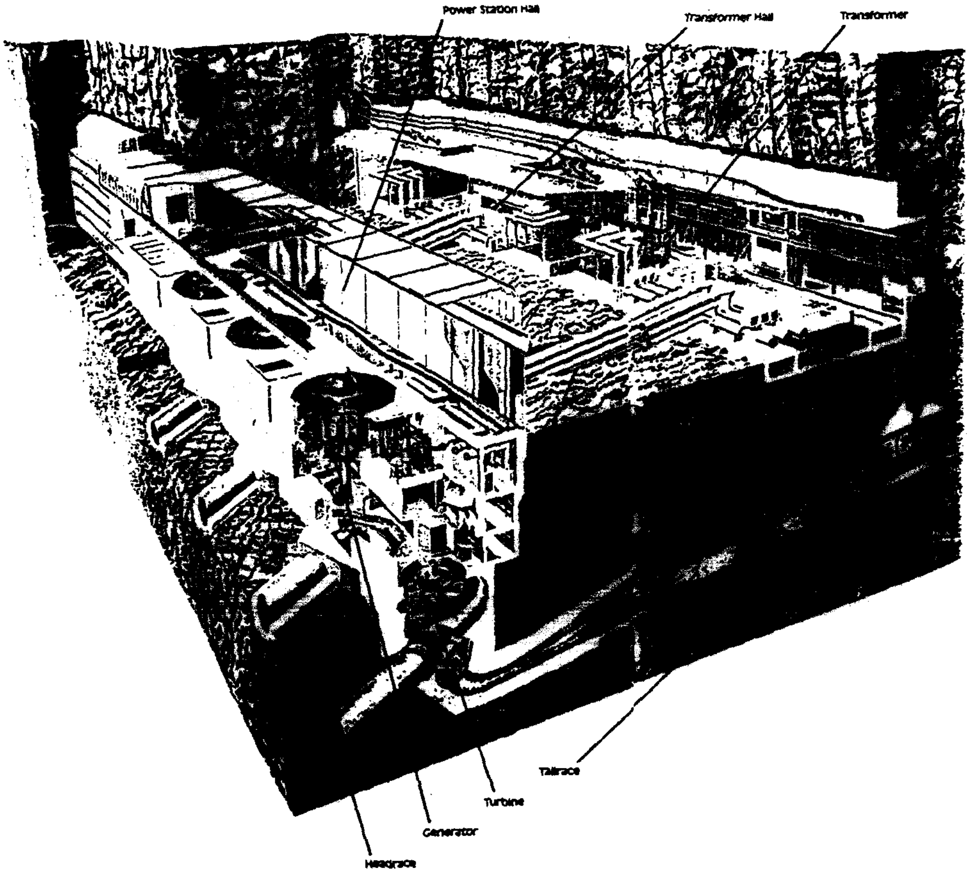
Turbines of up to 350MW capacity.

Fig. 8 shows typical sceneries from an underground power station in Norway.

Specialities in Norwegian hydropower Tunnelling:

- Lake taps. Piercing the bottom of a lake with a tunnel.
  Number more than 500, of which 70 have been made since 1908. The deepest carried out at 120m water depth.
- Unlined tunnels and shafts with up to 1,000m static water head.
- Air cushion surge chambers as replacement of surge shafts for dampening of water oscillations. Chamber volumes of more than 100,000m^3. (Kvilleal: 118,000m^3. Max air pressure 42 atm.)

Fig. 8



5.2 Rock Tunnels

On the Norwegian national and country road network there are now a total of 620 tunnels with a total length of about 450km. To this there are annually added another 30 km at a cost of about 500 million NOK. The majority of these tunnels are short ones built to moderate standards. But standards are gradually being heightened.

Most newer tunnels are rather long. The world's fifth longest tunnel opens to traffic in 1992. There are today a total of 16 tunnels exceeding 3km in length. The seven longest of these are:

1. Rv 17	Svartisen tunnel	Nordland	7610m
2. Rv 13	Høyander tunnel	Sogn og Fjordane	7522m
3. Rv 7	Vallavik tunnel	Hordaland	7511m
4. Rv 625	Fjærland tunnel	Sogn og Fjordane	6381m
5. Rv 803	Tosen tunnel	Nordland	5800m
6. E 76	Haukeli tunnel	Telemark	5688m
7. E 68	Flenja tunnel	Sogn og Fjordane	5024m

A new development is the introduction of sub-sea tunnels and the use of tunnels in urbanized areas. Such urban road tunnels are built to the higher standards required with heavy traffic volumes. In the capital city of Oslo several road tunnels are newly constructed to facilitate the continually increasing traffic demand. In such areas tunnels often represent the only feasible solution in order to avoid disruption of established development.

Even though most road tunnels are built to moderate standards, they do have excellent safety records. Their injury accident rates compare favourably with those of our safest surface routes-the motorways. The safety probems of tunnels are generally associated with their entrance zones.

An interesting aspect of tunnelling in Norway is their construction cost level. Through extensive rationalization and the development of efficient supporting methods, it has been possible to cut costs to 12,000 NOK per linear meter(1 USDollar = NOK 6. 4).

In Norway most tunnels are constructed by conventional methods. A small crew of three to four persons are normally used on two lane tunnels. Usually all work operations are done by this crew, including drilling, blasting and rock supporting. There is a continuous mechanization under way, including the introduction of domestically developed automated drilling rigs using advanced data processing methods.

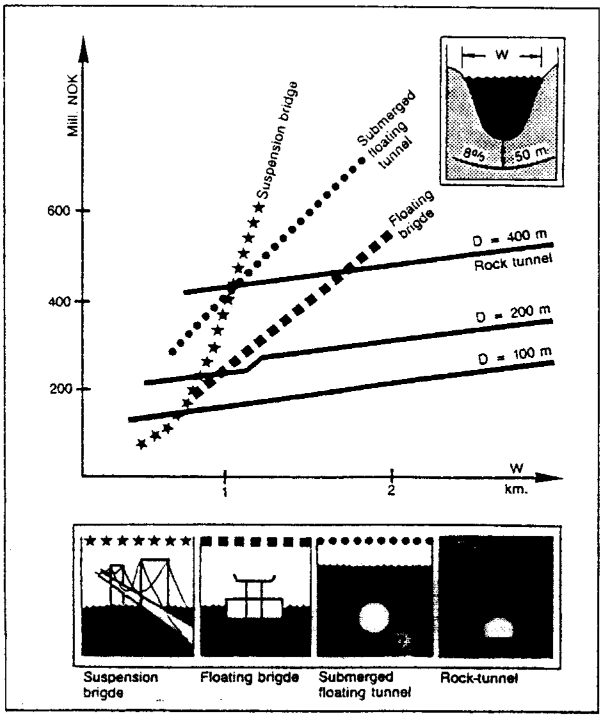
Traditionally bolting is done to prevent rock falls. In bad rock, fiber-reinforced shotcrete or concrete lining is used. To avoid frost or water leakage problems insulated aluminium panels are often used. Experiments are going on to use of other materials, for instance PVC coated polyester fabric. The results are promising.

Drainage to collect seepage water is provided for in subsea tunnels. This is a Norwegian speciality. In cities and urban areas ground water depression is being prevented by a combination of pregrouting and waterproof non-reinforced concrete lining(the Oslo method).

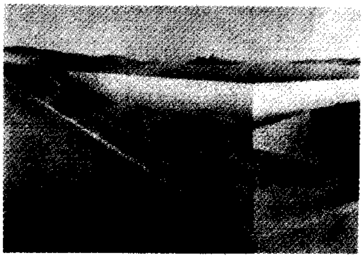
Also tunnel boring machines have been used to build long road tunnels. In the "West coast Capital" of Bergen work has just been concluded on the construction of a 3500 meter twin tube. The working diameter was 7.8 meters, which was subsequently widened to nine meters. The rock encountered was an extremely hard and rarely fractured gneiss (compressive strength at about 2500 kg/㎠). This was the longest tunnel boring operation ever in such a hard and solid type rock. The Bergen project therefore, has contributed in bringing the tunnel boring technology a significant step ahead. The operation was performed by Public Roads Administration personnel. At present about 60% of all tunnel construction is undertaken by personnel from the Public Roads Administration and the rest by various contractors.

Today there are a total of 153 ferry crossings in Norway. The combined length of these various ferry crossings is 2400㎞. It is a high priority task to replace these ferries by bridge connections. Many of the remaining ferry crossings are across fjords and sounds with depths and widths that make it infeasible to build conventional bridges or immersed tunnels. Other alternatives have been assessed, including submerged tubes or "floating tunnels".

However, sub-sea rock tunnels have stirred the greatest interest due to their low costs. The Aalesund tunnels prove that sub-sea rock tunnels can be built within a reasonable cost limit.



The figure shows costs for various technical schemes as a function of fjord width (W) and water depth (D). Sub-sea tunnels are the more cost efficient with wide crossings.



The figure applies to two lane roads. As far as rock tunnels are concerned, three lanes are chosen due to steep grade. They also demand a prudent choice of standard as far as supporting methods and equipment is concerned.

Fig. 9

Fig. 10 Under describes two cases for subsea tunnel

TWO CASES

The deepest and longest sub-sea road tunnel in the world: Aalesund — Vigra

The two Aalesund — Vigra sub-sea tunnels in western Norway are 3.5 km and 4.2 km long.

Their lowest points are approximately 140 m below sea level.

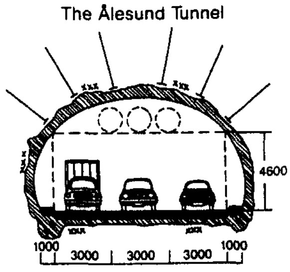
Minimum rock cover is 30 meters.

Accepted seepage is 300 1/100 m/min.

The tunnels are longitudinally ventilated, and equipped with emergency telephones, wireless communication systems and fire extinguishers.

The tunnels were constructed in 21 months from January 1986 untill October 1987. Daily traffic is anticipated to reach approximately 3000 vehicles.

Total costs for these tunnels are approximately NOK 300 mill. (USD 40 mill.)



Typical cross section for the Aalesund Tunnel

Most heavily travelled tunnel in Norway: The Oslo tunnel

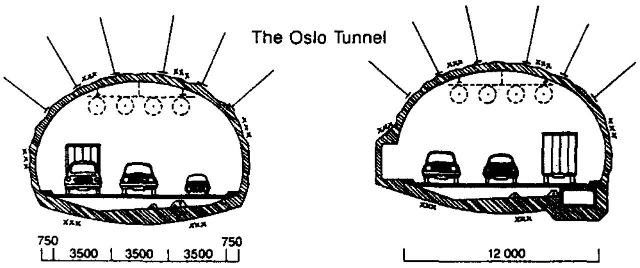
In the central part of Oslo a 2,2 km long twin tunnel at a cost of NOK 1330 mill. (USD 190 mill.) is under construction.

The tunnel consists of two tubes with 3 lanes in each carrying a total of AADT 100 000 vehicles.

Complex interchanges complete the tunnel.

Half of this tunnel is passing through rock (gneiss, shale and limestone) the rest is partly cut-and cover, partly immersed tunnel.

The lowest point is 45 m below sea level.



Typical cross section for the Oslo Tunnel

In the central part of Oslo lowering of the ground water level is not accepted. Therefore the seepages must be less then 2-7 l/min./100 m. This will be accomplished by pre-grouting, concreting, the use of non-reinforced concrete with thickness 30-90 cm, and water infiltration.

The tunnel will be longitudinally ventilated. Furthermore the tunnel will be equipped as is normally the case for a heavily travelled city tunnel.

5.3 Hydrocarbon Storage in Unlined Rock Caverns

In Norway, 8 large-sized unlined cavern storage plants for crude and refined oil products are presently in operation.

The caverns, constructed mostly in good quality hard rocks have spans up to 22m and heights up to 40m. Bolting and shotcrete are the main supporting methods used to increase rock mass stability.

For installations larger than roughly 50,000m^3, Norwegian experience is that unlined rock caverns would be the most cost advantageous alternative. Other advantages are better environmental protection, lower fire-, explosin- and sabotage-hazards, and lesser land requirements.

Storage principle and prerequisites for using the technique In essence, the technique of storing hydrocarbon compounds in unlined rock caverns, applies the pore water pressure of the surrounding rock to contain the oil product inside the cavern. The cavern design must ensure such rock conditions that its cracks, joints and fissures always convey water leaking into the cavern rather than product leaking out of it.

For successful application, four prerequisites must be met:

1. Competent and stable rock conditions which are suitable for construction of large openings.
2. The stored products must be lighter than water.
3. The stored product must be insoluble in water.
4. The rock surface in contact with the stored product must hold a pore water pressure higher than the static pressure exerted by the stored product.

Conventional cavern storage plants are completely closed and sealed by an overburden of water-saturated rock. It is considered a safe method, provided that adequate safety measures are implemented. The main safety provisions are precautions to prevent gas and/or product leakage, i.e. to prevent fires and explosions and to protect the environment in general.

Type of prodcuct stored	Installation	Year Comm.	Dimersion width x height(meter)	Temp. (Cels)	Abs. Pressure (bar)	Rock type
Crude oil	Mongstad, Bergen	1975	22×30	ca. 7	1	Meta - anorthosite and gneiss
Diesel & gasoline	Ekeberg I, Oslo	1969	12×10		0.1	Granite gneiss with diabase dykes
Diesel & gasoline	Ekeberg II, Oslo	1978	15×10	60	1	Granite gneiss with diabase dykes
Diesel & gasoline	Ilsvika, Trondheim	1976	12×15		0.1	Quartzdiorite
Diesel	Namsen	1983	17×30		1	Gneiss
Diesel	Olavsvern	1984	8×8		1	Gneiss
Propane	Rafsnes, Porsgrunn	1977	19×22	9	6.5	Granite

Some Norwegian unlined rock caverns for hydrocarbon storage.

Although all unlined caverns for storage of hydrocarbons work on the same basic principle, their configuration often vary, depending on the product stored.

Caverns for crude oil storage usually have an overpressure varying between 0.5~2.5 bar abs, and utilize fixed water beds. Special heating devices are often installed to provide prossibilites for melting and removing wax and paraffin accumulations.

Caverns for storing of destillates have different configuration depending on product stored, e.g. auto and marine diesel, kerosene, and motor gasoline etc. Their utilization range from commercial storage installations with an extensive circulation of the stock to emergency storage depots with turn-around-times of several years.

Depending on the product type, the caverns might have variable water beds when gasoline or other volatile products are stored, or more commonly fixed water beds for heavy fuel oil and diesel fuel etc.

Storage of (liquified) gases. At present, two gas storage plants are in operation. One 100,000m^3 volume cavern storing propane at 1.9 bars abs. pressure. The plant has been in operation since 1977 with no operational problems reported, and one 60,000m^3 storage plant for butane.

Ballast water caverns are used at export terminals receiving large amounts of ballast water. These caverns have rectangular shape and are used both for equalization of large oil-contaminated ballast water streams prior to treatment and for gravitational separation of oil and water.

Pumping arrangements. Both dry mounted and submerged pumps are used. Submerged pumps, which are suspended from the discharge pipes located in vertical shafts leading into the caverns have had a rapid development and are now extensively used.

Ground Water Control System. Nearly all unlined Norwegian hydrocarbon storage caverns have installed artificial ground water control systems. Such systems are usually implemented before excavation starts, because it may be difficult and time consuming to establish a drawn-down ground water level.

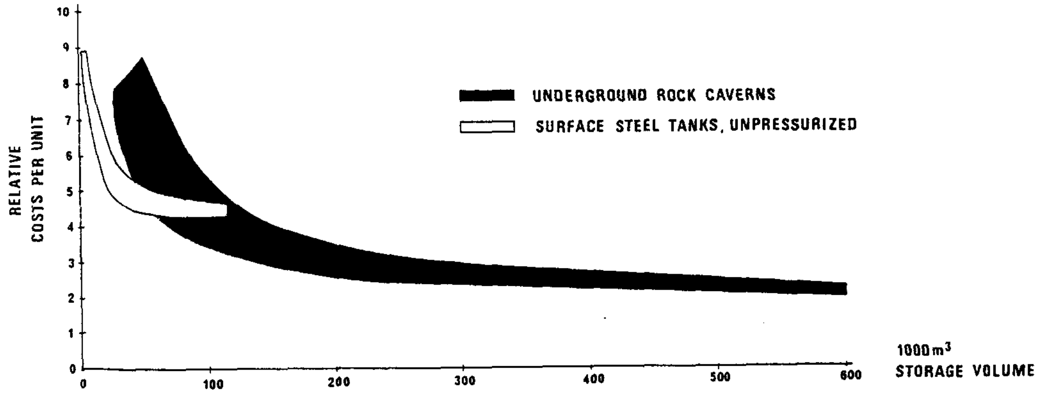


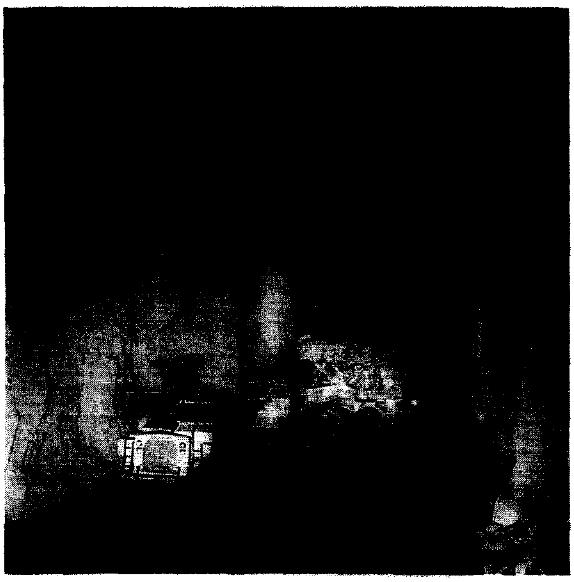
Fig. 11 Relative rock cavern/steel tank costs.

Cost aspects Numerous cost compilations and comparisons of rock storage caverns and alternative solutions, i.e. steel tanks, have been made.

Unlined rock caverns in Norway are considered economically favourable for storage volumes 50,000 mc(300,000 bbl.) and larger.

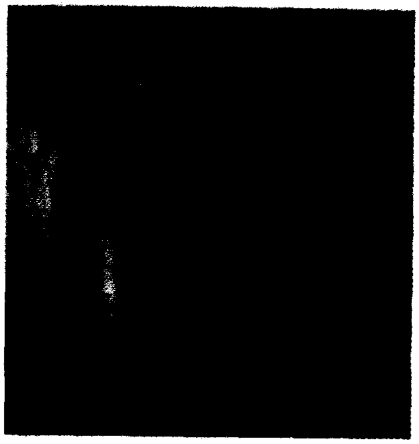
Over the past two to three decades, innovations in rock excavating techniques have increased the economic advantages of rock-caverns when compared to steel tanks. This trend is expected to continue.

Fig. 12, 13 and 14 under are from Norwegian storage plants for oil in unlined rock caverns.



An underground oil storage cavern The caverns with cross section 530 m^2 was excavated in four stages – top heading and three benches (Berdal)

Submerged pumps in an underground oil storage cavern (Berdal)



Gallery and service tunnel for underground oil storage caverns (Berdal)

5.4 Drinking Water Storage in Rock Caverns

During the last 3 decades a number of underground openings have been excavated in the hard bedrock of Norway as replacements for or alternatives to open reservoirs, concrete tanks, or steel tanks for the storage of drinking water. A closed water tank-which is what a rock cavern tank is-has several advantages over traditional open reservoirs. Above all, it is easier to keep pollution under control with a closed tank.

In open reservoirs the drinking water is exposed to the influence of sunlight and pollution from the air. Moreover, open reservoirs are commonly situated in natural or artificial depressions and will therefore tend to collect drainage from the surrounding landscape. If such reservoirs are located close to populated areas, there is a danger that polluted surface water or ground water may be drained into the drinking water.

Today open reservoirs for the storage of drinking water are not normally acceptable to the health authorities in Norway. They have to include closed tanks of some kind and old schemes with open reservoirs often have to be redesigned and reconstructed.

The basic function of a water tank is to act a storage buffer to meet variations in consumption and keep the water head stable. This makes it easier to operate the treatment plant and the pumps at constant capacities and it allows smaller dimensions of the main pipe lines. The water tank also acts as emergency storage in case of fire or failure in the supply system.

Small water tanks are normally single-chamber tanks. For volumes exceeding approximately 10,000m^3, double or even multiple-chamber tanks are often used. This allows one chamber to be emptied for cleaning and maintenance without interrupting the water supply.

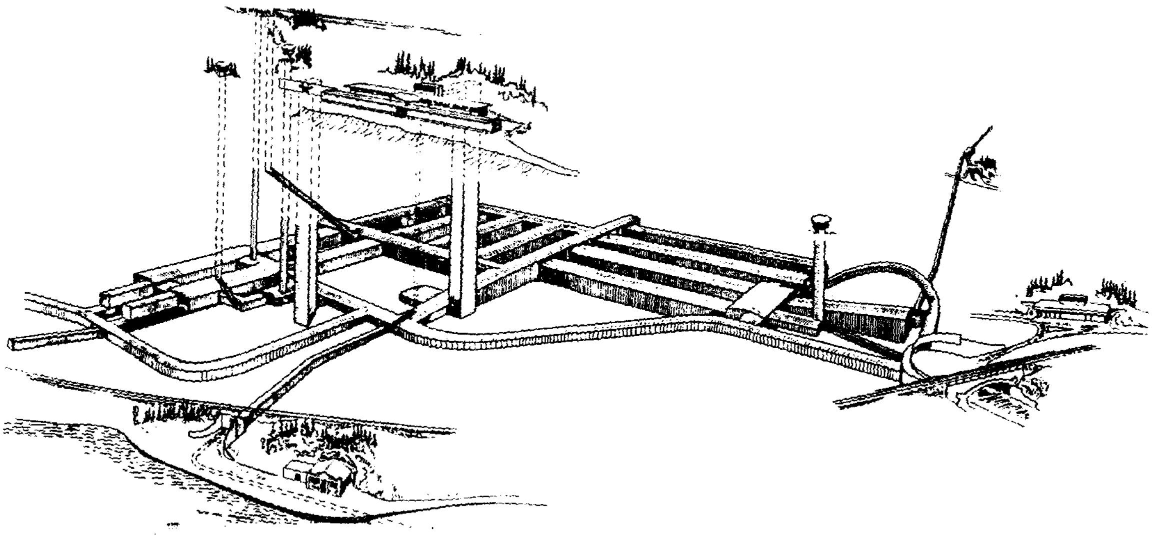
A water tank should be situated at an elevation which gives a suitable water perssure in the consumption area. It is also preferable to locate the tank as close to the consumption area as possible, especially if the capacity of the tank is designed to cover the variations in daily consumption.

Most water tanks in Norway have been freestanding structures made of conventional reinforced concrete or prestressed concrete. When double chambers were necessary, either two separate structures were constructed or two concentric chambers were built in one structure. To minimize the impact of such concrete structures on the environment, they have often been dug partially into the ground or hidden in other ways.

One way of making water tanks invisible, of course, is to put the tank completely underground. And the most economical way of doing this is to use the rock mass as the construction material, i.e., excavating caverns for water in bedrock. A rock cavern tank is normally comprised of an access tunnel and one or more chambers in the form of large, short tunnels; in front of the chamber there is a dam wall.

You will find a large number of such installations throughout the country. One of the larges you will find in the city of Oslo.

Fig. 15 below gives an impression of the tunnel systems.



5.5 Sewage Plants in Rock Caverns

Such installations you will find in many cities throughout the country. The very first and largest, is found in the city of Oslo. This city is situated in the northern end of a very long fjord, the Oslofjord. In the following this plant is descibed briefly.

The Oslofjord has suffered from a steadily increasing pollution load since the introduction and acceptance of the water closet at the turn of the century. As the region grew, waterborne pollution in the densely populated area grew with it, reaching an unacceptable maximum during the seventies. The results of pollution are not only visual; we can all see those on the surface, and on the shoreline, with decaying algaegrowth and slimy beaches. More important is the lack of life in the deeper strata of the fjord. Lack of oxygen makes the smaller feed animals extinct; thus fish, shrimps and prawns also disappear. Water quality control measures have simply been insufficient.

The Oslofjord Waste-water project(Vestfjorden Avløpsselskap) started in 1976. It is the largest of a number of measures that are being put into action to stem and reverse the negative trend in the water quality of the fjord. The project is regional; the city of Oslo is cooperating with the communities of Bærum and Asker on the west side of the fjord. The authority's main task was to design, construct and operate the largest treatment plant yet to be built in this country, together with a long collection tunnel. Construction started in 1977, and the system was put in operation in the spring of 1982-on schedule.

The works will serve some 600,000 people. Apart from domestic flows, they will take sewage from industry and from all kinds of commercial activities. The area served runs from Akerselva(river) in the east to the community of Rφyken in the west. The quantity of sewage to be treated amounts to some 3.0m^3/sec or 100 million m^3/year(66 MGD). Between 200 and 300 tons of phosphorus will be removed(85～90%) each year. That is about 50% of all the phosphorus that is currently discharged into the fjord.

The target laid down by the water research people was; remove as much phosphorus as possible from the wastewater! Phosphorus acts as a nutrient to algae-growth. Algae decompose and utilize oxygen in the process. Oxygen-deficient water makes it impossible for the lower feed organisms to live, and higher organisms such as shrimps and fish disappear. We get a putrefied and lifeless fjord.

The tunnel which collects and transports the wastewater is 40km long and has 48 inlet stations where the sewage from the local discharge-areas is collected. The tunnel is circular, with a diameter of 3.5m; the full-face boring method was used during construction.

All the water gravitates to the main inlet pumpstation at the plant. The tunnel has during dryweather flow, extra room or volume which can be used during wet-weather

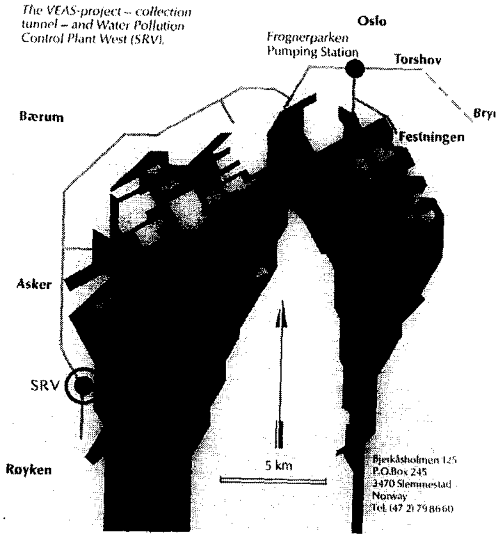


Fig. 16

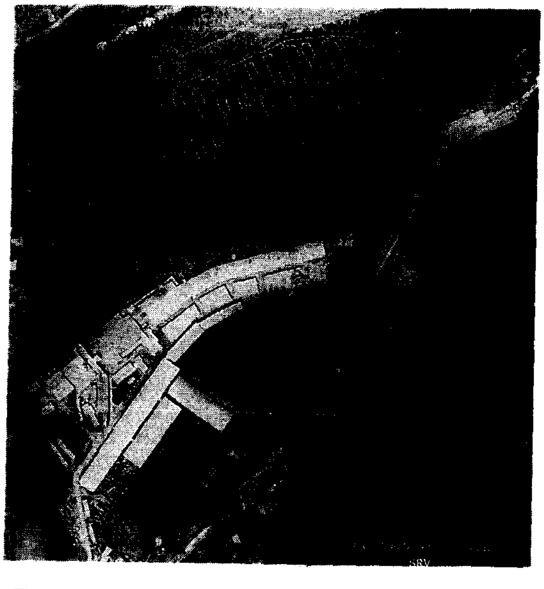


Fig. 17 The Water Pollution Control Plant West(SRV) is situated inside the hill Bjerkås

periods, when flows through the tunnel exceed the treatment-plant capacity. In this way overflows from the local areas are eliminated or reduced, again saving the fjord from pollution. When the tunnel is full and treatment capacity is at its maximum, then excessive flows are led by a controlled overflow(through primary treatment)at Lysaker to discharge through a deep-sea outfall into the fjord.

The treatment plant operation is highly automated and computerized. From 2000 primary instruments scattered throughout the plant, data is collected and processed in the computers; instructions are returned, if necessary to regulate the various processes.

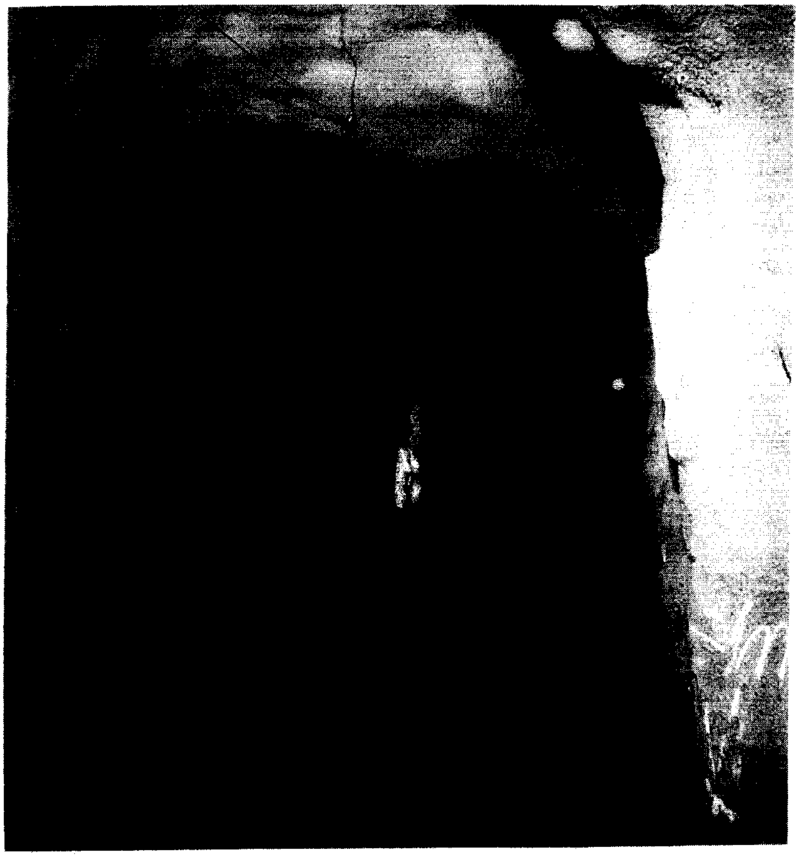


Fig. 18 Full-face boring machine breaking through after 4 years of continuous work.

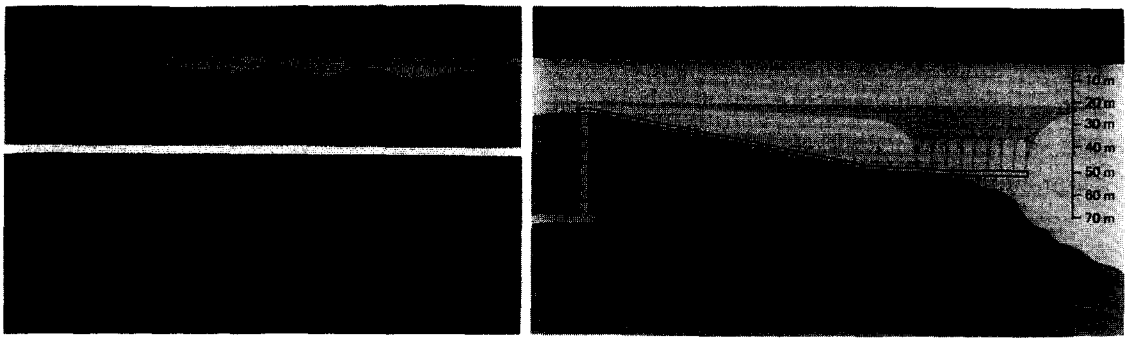


Fig. 19 Discharge system of the treated effluent into the Oslofjord.

The deep sea outfall or effluent-discharge system is arranged in such a way as to prevent residual pollutants reaching the productive toplayers of the fjord during the summer season. This arrangement is almost as important to the fjord as the treatment plant. The more efficiently we treat the wastewater, the more byproducts are separated and accumulated in the plant. These byproducts must be disposed of or recirculated in a safe way. The screenings and the grit from the gritcham-bers are considered as refuse and discharged on dumps. The byproduct from the chemical treatment is called sludge, and is a watery 'soup' of which some 2000m^3 are produced daily. The sludge has to be 'dried up' (or dewatered as we call it) before it can be managed properly. After dewatering (see the schematic flow diagram)the sludge is reduced in volume to some 150~200m^3/day and is utilized or recirculated in two different ways: one half of the dry cake-like product it trucked directly to farmlands growing rye, barley or other grainproducts; the other half is composted by forcing air through the sludge and thereby increasing the temperature to 60℃. This produces an odourless soil-like substance, permitted to be used in parks, on roadbanks, green belts and so on.

5.6 Food Storage in Rock

Throughout history, subsurface stores have been used to keep supplies of food.

In natural caverns and in deep cellars dug out by hand, the temperature was low and even and the air humid, independent of the seasonal variations in climate. Fruit and vegetables were stored for months after harvesting, and wine and cheese matured to perfection.

The modern rock blasting technique has made constructions in rock competetive with conventional building for storage purposes. In the last 30 years, several deep freeze stores in rock have been built in Norway.

Experience of this operation indicates that the running economy for deep freeze stores in rock is better than for comparable conventional stores in terms of power demand, annual energy consumption and maintenance cost.

Consequently, the running economy for a cold store in rock, with temperature closer to the initial rock temperature is far better.

A study has been carried out to examine the energy aspects of deep freeze stores and cold stores in rock in comparison with conventional stores.

In the following, a short summary is given of the conditions for the study and the results derived.

Due to diverse local conditions, the results will be within wide ranges.

In the ideal food store the temperature should be even. The temperature of the surrounding surfaces should be as close to the air temperature as possible and the relative humidity of air as high as possible to prevent evaporation and sublimation from the stored food, causing weight loss and quality reduction.

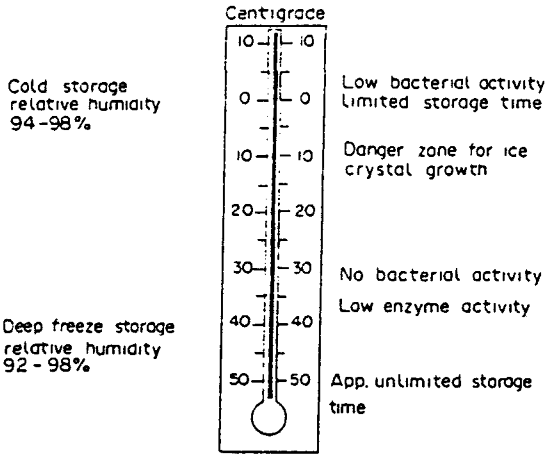


Fig. 20 Ideal climatic conditions for food storage.

Deep freeze storage

In deep freeze storage, the growth of micro-organisms is stopped, oxydation processed and enzyme activities are very much slowed down. At temperatures of -35~-40 degrees Celsius, the storage time is almost unlimited.

In a deep freeze store, an even temperature is very important. Fluctuations in temperature and temperatures above -18 degrees Celsius make the ice crystals in the cells grow and pucture the cell walls, causing serious quality reduction.

Cold Storage

Fresh fruit and some vegetables will be destroyed by deep freezing, and have to be stored at temperatures slightly above the freezing point, the temperature depending on the type of food to be stored.

In cold storage, the growth of micro-organisms and the biological activity are very much slowed down, without really stopping. Storage time will therefore be limited.

An even temperature, however, is very important in a cold store. Sudden leaps in the temperature may trigger the biological processes, for example sprouting of potatoes.

Thorough researches and studies in Norway has brought following conclusions:

Deep freeze storage:

At the given environmental and inside conditions, the maximum power demand for the deep freeze store in rock is 50% of the conventional store. The annual power consumption for the rock store is 75% of the convention store.

Cold Storage

The maximum energy requirement for the rock store is 26% of a conventional store. The annual energy consumption for the rock store is 18% of the conventional store.

These studies show that a food store in rock enable substantial savings in energy demand and energy consumption compared with a conventional store.

The following factors will increase the advantages for the rock installations:

* Lower thermal productivity in rock(for example limestone).
* More extreme outside conditions.
* Higher storage temperatures.

Because of the accumulation in rock, the rock store can handle great peak loads, without adverse temperature rise, for example during harvesting periods.

Breakdown in power supply or in refrigation equipment does not represent any immediate danger to the stored wares. The store can be without cooling for weeks, before damaging high temperatures occur.

Construction of food store in rock is a very profitable and very safe investment.

Throughout Norway you will find a great number of such facilities. Fig. 21 shows one.

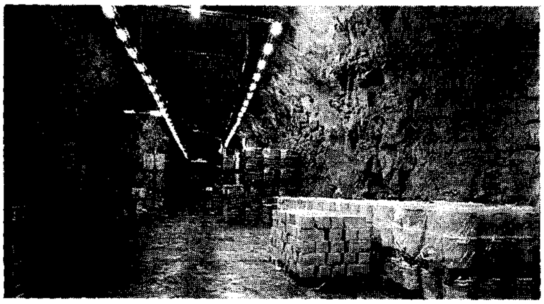


Fig. 21

5.7 Large dual purpose installations in rock

Norway has put large effort in protection of its inhabitants in case of war. The Civil Defence has provided shelters for more than 50% of the population. Some of these shelters are placed in rock.

Since rock installations provide good resistance to weapon effects and also with advantage can be used for other purposes in peacetime, an interesting development has taken place in the last decades.

In towns and cities can be found sports arenas, swimming pools, bowing arenas and shooting ranges, etc., in rock. Installations that can easily be converted into civil defence shelters.

The tables underneath give figures for ten typical projects(Fortifikasjon A/S) and the typical split of cost for such installations.

Ten typical dual purpose rock installations in Norway: (Fortifikasjon A/S)

Name of project	Finished year	Max span (m)	Volume (m^3)	Rock type
1. Odda, sport hall	1972	25	27,000	granite
2. Lykkeberg, swimming pool	1970	16	4,000	granite
3. Gjovik, swimming pool	1975	20	17,000	gneiss
4. Vassoyholtet, bowling shooting range	1979	12	5,500	gneiss
5. Skaarer, sport hall, swimming pool	1981	25	25,600	granite
6. Holmen, sport hall (enlarged)	1981 1988	25	35,000	shale & limestone
7. Taerud, sport hall	1982	25	27,500	gneiss
8. Vaagan, sport hall	1983	25	21,100	monzonite
9. Holmlia, sport hall & swimming pool	1983	25	53,000	gneiss
10. Gjoevik Olympic Mountain Hall	1993	61	160,000	gneiss/ granite

Split of cost. Typical installation(Holmlia)

Excavation(drill & blast)	13.0%
Rock support and mucking out	5.5%
Civil works	34.8%
Electrical installations	7.2%
Lifts	0.3%
Emergency power system	1.0%
Ventilation/cooling	5.0%
Sanitary and heating	4.5%
Water cleaning syst. for swimming pool	0.7%
Mapping & geological investigations	0.5%
Engineering	7.2%
Management, administration	2.2%
Taxes	17.8%
Total	100.0%

The Gjoevik Olympic Mountain Hall is described in detail in the attached brochure.

Figures 22, 23, 24, 25, 26 and 27 are examples of dual purpose facilities.

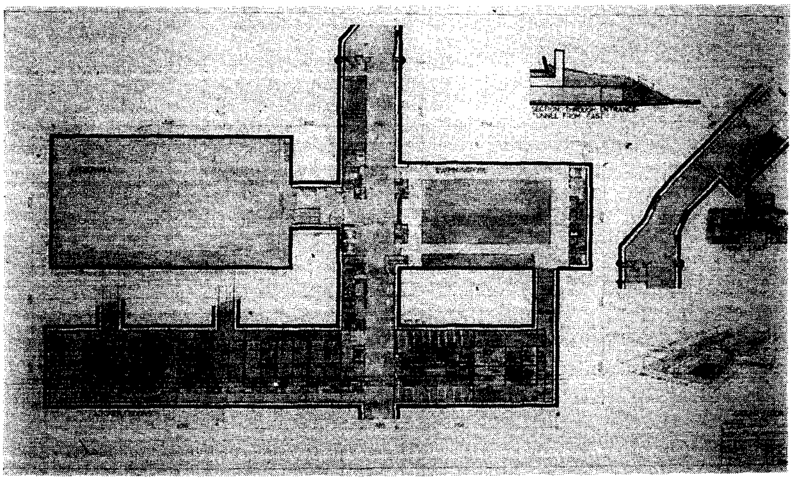


Fig. 22
Lay-out of Holmlia Sports facility in rock.
Sprots arena 25 × 45m
Swimmingpool 20 × 37.5m
Locker-rooms and saunas. (Fortifikasjon)

Fig. 23
Swimmingpool in rock, Holmlia.
(Fortifikasjon)

Fig. 24

Holmen Sports arena in Rock

(Fortifikasjon)

Fig. 25

Holmen, Assembly and Cinema-room.

(Fortifikasjon)

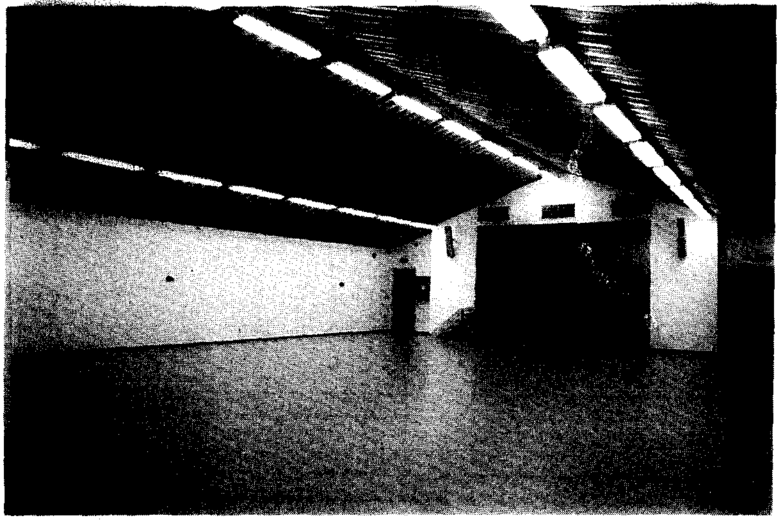


Fig. 26

Shooting range in Rock.

Vassoyholtet.

(Fortifikasjon)

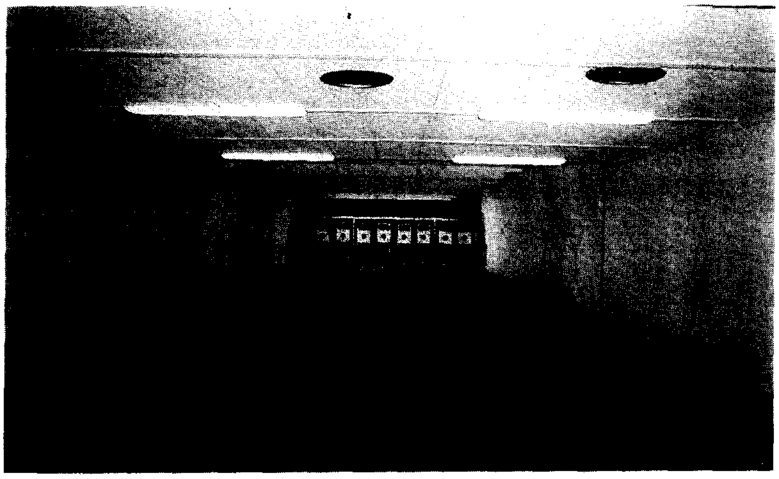
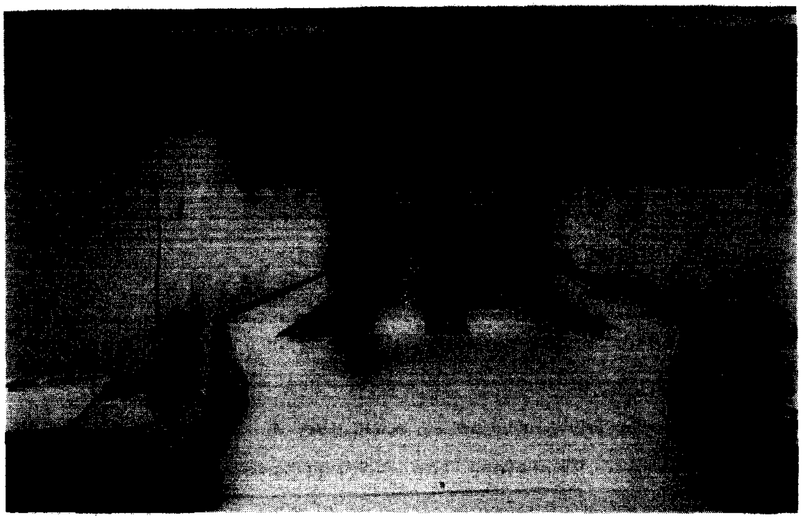


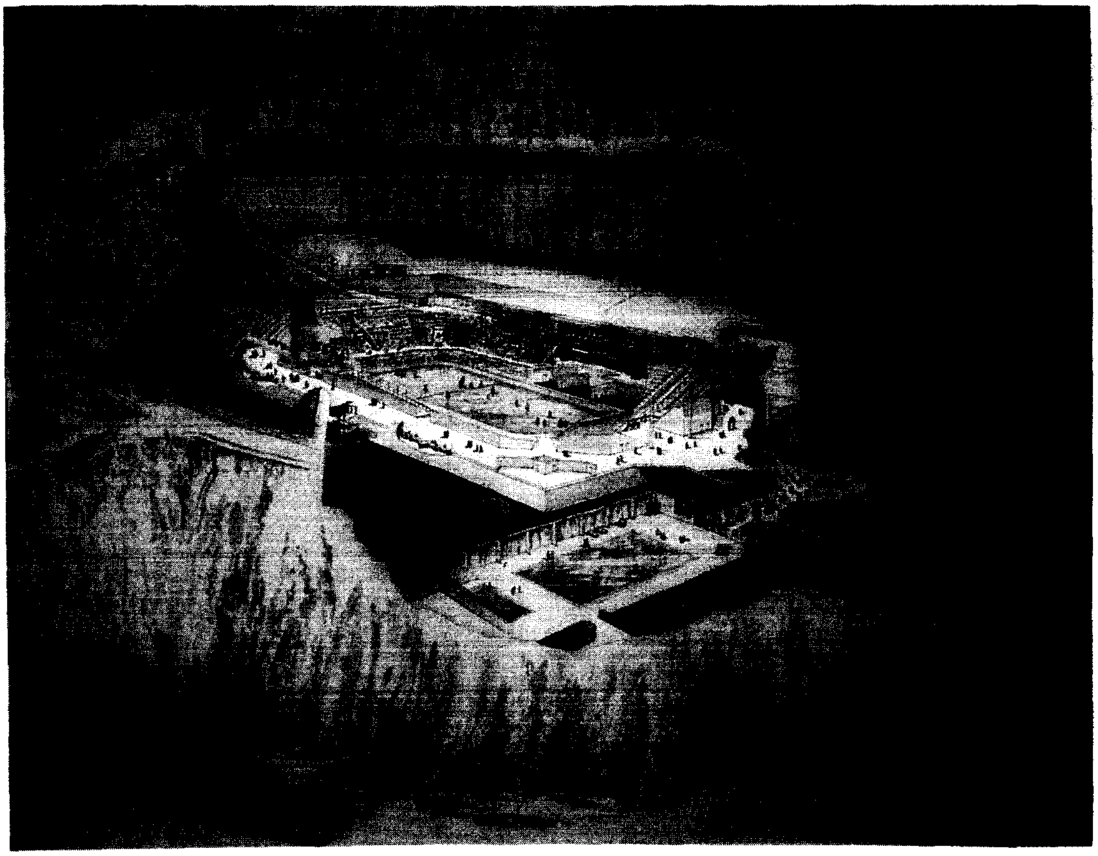
Fig. 27

Bowing in rock.

Vassoyholtet.

(Fortifikasjon)





World's largest sports facility in Rock.

Gjoevik Olympic Arena 1993.

(Fortifikasjon)

5.8 Military Installations

The Gulf war has focused on the weapon-technology, exposing weapon with great accuracy and ability to penetrate even the thickest concrete roofs. Installations in rock will more than ever be the best alternative to protect vital military or civilian installations against weapon effects. For obvious reasons the Norwegian defence philosophy is based on strong defence of strategic areas. In this concept installations in rock play a significant role. Therefore the Norwegian army, navy and air force are all users of underground installations.

For the army:

Headquarters, land fortresses, ammunition depots, workshops for vehicles and guns, general stores, communication facilities, close in defence systems etc.

For the navy:

Docking facilities, work-shops, oil and fuel stores, ammunition stores, headquarters, general stores, communication facilities, radars etc.

The coastal defence:

Gun-emplacements, torpedo-batteries, control room for controlled mine fields, radars etc.

For the air force:

Shelters for air-crafts, air defence positions, workshops, ammunition stores, headquarters, communication facilities, refuelling systems, liquid oxygen systems etc.

The construction of all these installations are based on the Norwegian practice for hardened structured, which give excellent protection against weapon-effects from conventional-and very good protection against effects from unclear weapons. Figures 28, 29, 30 and 31 show examples.

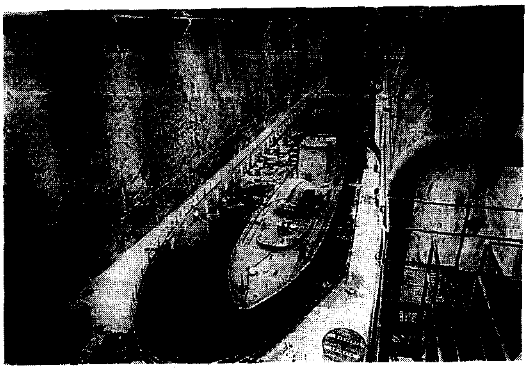


Fig. 28 Docking and repair facilities in rock.

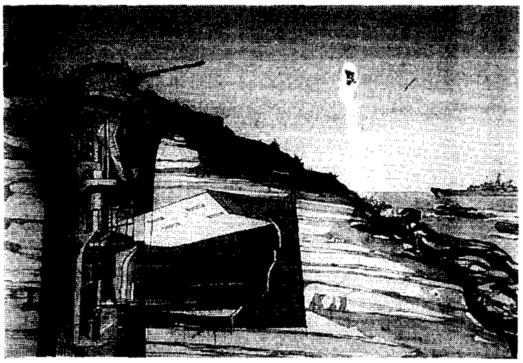


Fig. 29 Coastal artillery emplacement in rock.

Fig. 30 Ammunition or dry storage in rock. (Fortifikasjon).
Note the elegant solution with inner lining of plastic fabric. Also used for military hospitals in rock.

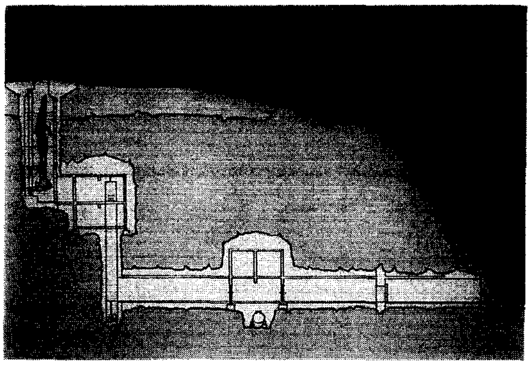


Fig. 31 "Pop-up" antennas in rock.

6. RESEARCH AND DEVELOPMENT

Both the University of Trondheim and the Norwegian Geotechnical Institute, SINTEF and NTNF(Royal Norwegian Concil for Scientific and Industrial Research) as well as several other institutes and private companies have through the years carried out large programmes in research and development concerning both the field of engineering geology as well as rock mechanics.

Of special interest to be mentioned are the large programmes in this field connected to the large Olympic Rock Facility in Gjoevik, Norway(1990~95). This programme has all together 17 projects dealing with these main topics:

1. Energy, safety and fire.
2. Engineering geology and rock mechanics.
3. Psychology, environment, safety and documentation.

These programmes will make the foundation of the new updated national requirements for Norway concerning construction and use of the underground space.

7. FINAL REMARKS

The experience in extensive use of underground installations in Norway has shown that success is depending on vital factors as:

- Well proven technical specifications.
- Planning and design are carried out by engineers with the right educational background and long experience.
- Experienced contractors for hardened construction.
- Manuals for the right use and maintenance are produced and available for the user.
- Education of the staff in use and maintenance of the installation.

Experience has shown that faults done both in planning as well as construction, cause more trouble and will also be more costly to improve than in similar aboveground installation. Do well therefore from the early beginning.

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- Hydrocarbon storage in unlined rock caverns. (Syver Frϕyse)
- Storing water in Rock Caverns.
  (Broch. ϕdegård)
- Energy savings in Oil stores, Cold stores and Sport Halls in rock. (Magne Dϕrum)
- The Oslofjord Waste-Water Authority.
  (Finn Medbϕe)