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Planning and utilisation of rock caverns and tunnels in Norway

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ABSTRACT

This paper describes the extensive use of rock caverns and tunnels in Norway. Caverns are used for a variety of storage purposes such as storing of food, drinking water, oil and other liquid hydrocarbons, pressurised gas and air and industrial waste. Caverns are also used for industrial and municipal installations such as hydropower caverns and water and sewage treatment plants. A third main category of use in Norway involves dual purpose caverns used as civil defence shelters in war time and for entertainment and recreation (e.g. sports halls and swimming pools) in peace time. The intent of this paper is to discuss why these various underground space applications developed, to show the typical layout considerations for the different types of application and to introduce reference examples from the Norwegian experience.

1. Introduction

During the last decades there has been a rapid development in excavation techniques for rock masses. Simultaneously there has also been a rapid growth of our cities, and an increasing awareness of the need to preserve the quality of our environment. This has led to an almost exponential increase in use of the underground. This is clearly demonstrated by the fact that, during the last 40–50 years, the number of cities with underground metros has increased from approximately 30 to more than 100. Thus, going underground is an everyday experience for a large number of people around the world.

Utilisation of the underground for other purposes than traffic tunnels is not so well known for the general public. This presentation will, therefore, first of all try to demonstrate how caverns excavated in rock may be used in urbanised areas for a wide variety of other purposes such as:

- Storing of food, water, oil, pressurised gas, industrial waste and several other products.
- Industrial installations like powerhouses, factories, telecommunication centres.
- Municipal installations like treatment plants for drinking water and sewage, and car parks.
- Entertainment and recreation like sports halls, swimming pools, art centres, theatres, etc.
- War protection – Air raid shelters.

In the succeeding sections, examples of the different uses will be described. As all examples are from Norway. It is important that the reader is aware that the bedrock in this country is dominated by Precambrian and Paleozoic gneisses and granites. A difference to be aware of is also that the zone of weathering is deeper in the rocks in many countries than in Norway as the Norwegian rock surface has been exposed to a late glacial erosion which the rocks in other countries may not have been.

Another factor of importance which should be kept in mind when Norwegian experience is being evaluated, is the enormous amount of tunnelling and rock excavation which has been carried out in Norway during the last 50 years. A few figures may illustrate this:

- Norway has today 200 underground powerhouses and 4000 km of tunnels for the hydro-power industry only.
- The number of railway tunnels is approximately 750, the longest being 14 km, and the number of road tunnels is approximately 1200, the longest being 24.5 km.
- The World's largest cavern for public use, the Gjøvik Olympic Mountain Hall has a span of 61 m and can seat 5500 persons.

In a highly competitive market, this has led to very cost-effective construction methods. In spite of high salaries to the tunnel workers, Norwegian contractors are probably producing the

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cheapest tunnels and rock caverns in the world. This clearly favours underground solutions for many purposes.

In 1982 the Norwegian Tunnelling Society (Norsk Forening for Fjellsprengningsteknikk – NFF) published its first international collection of English language articles describing Norwegian tunnelling technology. During the last 10–15 years a new publication has been produced every year and presented at the annual World Tunnel Congress. The publications are in A4 format and consist of about 100 pages. The main topic varies from year to year. Publication No. 24 it titled "Health, safety and environment in Norwegian tunnelling" and was published in 2015. No. 25 covers "Norwegian Rock Caverns" and will be published in 2016. All publications are available for downloading at www.tunnel.no.

2. Caverns for storage

Caverns are being used to store:

- Oil and other liquid hydrocarbons
- Pressurised gas and air
- Water
- Food
  - Grains and vegetables at refrigerator temperatures.
  - Fish, meat, ice cream, etc., at deep freezer temperatures.
- Industrial waste
- Others: Coal, sand, archives, art, wine, beer, etc.

Only a few selected aspects of storage in caverns can be dealt with in this paper but man has for centuries used the underground for storage purposes. Good protection and a constant climate have been important factors. Today, some additional factors may favour the choice. It may be desirable to get, for instance, large tank farms for oil and other hydrocarbon products out of sight. There may also simply be a lack of land in built up areas. But the most important factor is, of course, the cost of the storage.

Excavation techniques for large rock caverns have been constantly improved over the last decades, and hence the relative costs have decreased. Cost comparisons carried out in Scandinavia between rock caverns and concrete or steel tanks for storage of liquids, indicate that when the volume to be stored exceeds approximately 5000 m^3, the cavern gives the cheapest solution. Cost curves also show that the cost per m^3 of cavern is reduced by 50% when the volume increases from 10,000 m^3 to 100,000 m^3, (Broch and Ødegaard, 1983).

2.1. Oil and other liquid hydrocarbons

Storing large quantities of oil in unlined rock caverns is a fully accepted technique all over the world today, and will thus not be described in this paper. The interested reader can easily find related literature. Let it only be briefly mentioned that oil caverns in reasonably good rocks normally have spans of 17–20 m, heights of 25–30 m and lengths from 200 to 500 m. Two to five parallel caverns are quite common. To prevent leakage of oil and/or gas through the rock mass, a so-called water curtain is usually established above and around the caverns.

2.2. Pressurised gas and air

There are basically two ways of storing large quantities of natural gas economically; either by compressing the gas, or by cooling down the gas – in the ultimate case down to −160 to 170 °C where the gas turns into liquefied natural gas, LNG.

So far storage of LNG in rock caverns has not been successful. There is some very challenging research ahead which has to be done before commercial applications are possible. Our basic knowledge about how rock masses behave when exposed to these extreme temperatures needs to be improved. Such research can only partly be done in the laboratory, and even then with great difficulties. Reliable design parameters can only be obtained after testing done at a reasonable scale in the field. Also, better knowledge about heat transfer in and around LNG caverns is needed. Storing gas in a compressed condition has for some time been done, but so far only for pressures up to approximately 10 bars. If natural gas is to be stored in rock caverns, pressures in the order of 100–200 bars will be needed to give economical solutions.

In Norway, so-called air cushions have been used to replace surge shafts and surge towers at several underground powerhouses for 40 years. Unlined caverns with volumes of more than 100,000 m^3 and pressures of 78 bars are successfully operating without any air loss through the rock mass. Three out of ten air cushions have been equipped with a water curtain or water umbrella, (Goodall et al., 1988). Pressurised air caverns are also an important part of the so-called CAES-concept (Compressed Air Energy Storage) for production of peak hour electric energy (Goodall et al., 1990).

2.3. Drinking water

Next to the storage of oil and gas in caverns, the most important storage application is for drinking water. Fig. 1 shows the layout of an unlined rock cavern tank in Trondheim. The capacity of the tank, 22,000 m^3, was obtained by the excavation of two caverns with a width of 12 m, a height of 10 m and lengths of 85 m and 110 m respectively. Also, the service section is put underground, but is not in daily use as the operation is remotely controlled (see Fig. 2).

Additional factors which may favour an underground solution for drinking water tanks are:

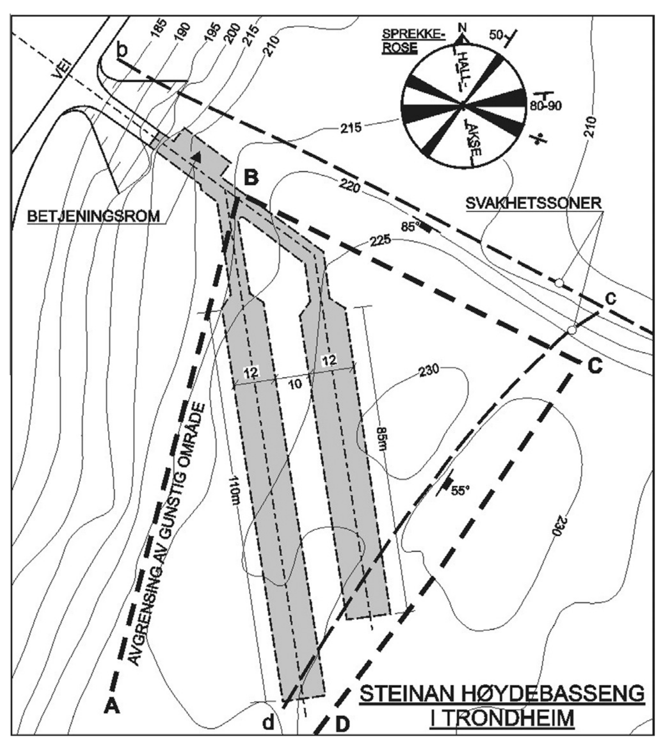

Fig. 1. The Steinan rock cavern tank in Trondheim. Total capacity 22,000 m^3. The dotted lines indicate the topographical (A–B) and the geological (B–D) restrictions for a favourable location (Broch and Ødegaard, 1983).

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