Use of the Underground in the City of Trondheim, Norway

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ABSTRACT

In Trondheim water is conveyed through tunnels and stored in several rock caverns around the city. The sewage is transported in long tunnels and treated in caverns in two underground treatment plants. Oil is stored in underground caverns in the harbour area, and food is stored at deep-freezer temperatures in a rock cavern. Brief descriptions are given of these underground structures.

1. INTRODUCTION

Trondheim is a city of 160,000 inhabitants located at the outlet of the river Nidelv in the central part of Norway. The old city centre on the river delta is surrounded by old (Paleozoic) crystalline rocks, mainly greenstone and quartzdiorite (Trondhjemite). Topographically the rock mass reaches heights of more than 500 m.a.s.l. in the near surroundings of the city centre, - see map in Figure 1 (Gråkallen, +551). The oldest underground works date back approximately one century and are tunnels for the railway. Today there are several highway tunnels through the hills in the city and works for an immersed tunnel in the harbour area have recently started.

50 years ago the first underground water tank was taken into use. It is a cavern with a storage capacity of 1,000 m³, - Herlofsenløypa in Figure 1. In 1979 and 1993 the second and third underground water tanks were commissioned, both with a storage capacity of 22,000 m³, and both consisting of two parallel caverns, - Steinan and Høgåsen respectively in Figure 1. The latest underground water tank, Reppesåsen, was commissioned in 1997, and has a capacity of 5,000 m³. Comparing costs of storing water supplies in underground caverns and storing in conventional aboveground tanks shows that if the volume is more than a couple of thousand m³, the underground solution is the cheapest.

Sewage is conveyed in several long tunnels in rock, - the oldest excavated by TBM in 1970-72. More than 90 % of all sewage in Trondheim is treated in two large and complex underground treatment plants, - one on the west side, Hørvingen, and one on the east side, Ladehammeren, of the bay area. The first underground plant was commissioned in 1978. It has recently been rebuild and expanded in accordance with new requirements for sewage treatment.

In 1972 an underground hydropower station was commissioned and today a second underground station is being constructed close to the river a few kilometres south of the old city centre.

2. CAVERNS FOR STORING

In Trondheim caverns are being used to store: (1) Oil and other liquid hydrocarbons, (2) Water and (3) Food
Fig. 1. Map of Trondheim showing the source of water, the lake Jonsvatnet, the tunnel that conveys the water to the city (blue lines) and the water storage caverns and tanks. Also shown are the sewage collector tunnel (red line lines) and the location of the underground sewage treatment plants.

Only a few selected aspects of storage in caverns can be dealt with in this paper. 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 more then twenty years ago in Scandinavia between rock caverns and concrete or steel tanks for storage of liquid, indicated that when the volume to be stored exceeds approximately 5,000 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 & 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 has a span of 17 - 20 m, a height 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.
Fig. 2. The first picture shows oil tanks in the hillside west of the harbour. Most of the oil is, however, stored in underground caverns, and the second picture shows oil being transported out from such caverns.

2.2. Drinking water

Next to the storage of oil in caverns the most important is the storage of drinking water. Figure 3 shows the lay-out 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 length 85 m and 110 m respectively. Also the service section is put underground. This is well accepted, but is not in daily use as the operation is remotely controlled.

Fig 3. The Steinan rock cavern tank with a 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 & Ødegaard, 1983).
Additional factors which may favour an underground solution for drinking water tanks are:

- High degree of safety, also against war hazards, sabotage and pollution.
- Constant and low water temperature.
- Low or no addition in price for a two chamber solution.
- The excavated rock masses may be used for other purposes.
- Very low maintenance costs.

Fig. 4. Pictures showing the entrance to the Steinan rock cavern tank and the inside with water pipe, concrete dam wall and shotcreted rock walls.

Fig. 5. The Høgåsen rock cavern tank with a total capacity 22,000 m³.

2.3. Cold store caverns for food

Favourable temperature conditions are one reason for choosing the subsurface alternative. Another reason can be the favourable insulation that rock masses around a cavern can provide. The "walls" can, in many cases, be regarded as being of infinite thickness. Thus rock caverns have for some time been used as cold stores where, for instance, fruits and vegetables have been stored at normal
refrigerator temperature, \(+2\, -5\)°C, and frozen food like fish, meat and ice-cream have been stored at so-called deep freezer temperatures, \(-20\, -25\)°C.

In Scandinavia the energy consumption for deep freezer stores is 75% and for refrigerator stores only 25% of similar surface stores. The peak energy requirements, and thus the installations, are even more favourable. The deep freezer storage will need 50% and the refrigerator storage only 20% capacity of similar surface stores, (Broch et al.1994).

Strongly reduced insurance rates are also favouring the subsurface solution for cold stores. This is due to the fact that the rock mass surrounding the storage caverns contain a big cold reservoir. In case of a breakdown in the cooling machinery, this will act as a reserve. Experience has shown that with cooling machinery out of function for a couple of weeks, an increase in the temperature of only 2 - 3°C is measured in underground deep freezer stores.

Fig. 6. The picture shows the entrance to the Staur deep freeze storage cavern south of the city centre (near Liaåsen on the map). The cavern was commissioned in 1978 and has a volume of 10,000 m³. The entrance tunnel is 35 long and the span of the cavern is 15 m and the max. height is 8.6 m. Only 10 - 15 rock bolts was used in the roof of the cavern and no significant instability have been experienced.

3. SEWAGE TREATMENT PLANTS.

The first stage of the Høvringen sewage treatment plant was completed in 1978 as a primary treatment facility consisting of trashracks, sand traps and fat skimmers. Recently the plant has been extended and chemical treatment has been included. The marine outfall in the Trondheim-fjord has a depth of 50 m and is located 100 m from the shore. Due to turbulence and mixing as well as the stratification of the sea, the outlet does not give any nuisance to the marine environment. The second underground sewage treatment plant in Trondheim, the Ladehammeren on the east side of the bay, was commissioned in 1992 and consists of three parallel caverns with a span of 15 m. The total length of the caverns is 450 m and the total excavated volume is 10,000 m³.

Even though cost estimations may have shown that construction costs for underground treatment plants are higher than for similar on-the-ground plants, the underground solutions have been chosen in many of the cities and towns in Norway. Favouring this choice is first of all the wish to avoid the
impact such big installations may have on the environment. A valuable additional benefit is the produced rock masses which there always is a need for in an urban area.

Fig. 7. Lay-out of the Høvringen underground sewage treatment plant. 1 – Sewage tunnel, 3 – Trash racks, 4 and 6 – Caverns for various treatment, 8 – Outlet tunnel, 17 – Access tunnel

4. CONCLUDING REMARKS

Mountains and hills have often been regarded as obstacles by city planners. There is no doubt in this author’s mind that the underground will become a more and more valuable resource in cities and urban areas. Thus cities and towns with easy accessible rocks of a reasonable quality should have a great advantage. This presentation has indicated some examples of how the underground may be used in urban areas. However, only the fantasy sets a limit to how the underground may be used.

REFERENCES