1 Introduction

Norway has a long tradition of building large rock caverns for different purposes. During the 1970s, a series of studies, including some in situ testing, were initiated to investigate the feasibility of underground siting of nuclear power plants. The focus, at that time, was on the need for a reactor containment cavern with a hemispherical domed arch of at least 50 m diameter [1]. In the late 70s, another research project regarding large rock caverns was established. It was a pre-feasibility study for a large rock cavern at Liåsen, close to Oslo, with a very similar size to the Gjøvik rock cavern [2]. The planned cavern was to be 60 m wide, 127 m long and 20 m high. The project would give the Norwegian rock society an advantage internationally by demonstrating their talent for underground construction. Two sketches are presented in Figure 1 and show three tunnels above the cavern. These tunnels were planned to be used for rock support and instrumentation.

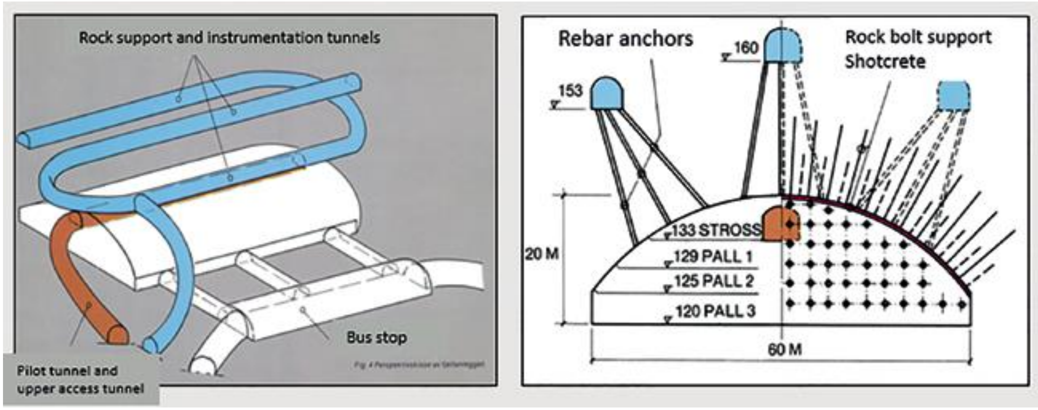

Figure 1. The Liåsen project [2]

In Seoul 1988, the IOC-president Juan Antonio Samaranch announced that Norway had been awarded the 17th Olympic Winter Games to be held in Lillehammer in 1994. Two ice hockey halls were needed for the games. Gjøvik already had an underground swimming pool that had been completed in 1974. The experience from the early investigations regarding large caverns in Liåsen and the presence of an underground swimming pool in the rock massive where the Gjøvik cavern could be located, gave the idea and the boldness to recommend that the world's largest underground cavern hosting an ice hockey arena could be built. Thanks to the pre-feasibility study at Liåsen, the Gjøvik cavern project could start directly with a detailed design. The first sketches were actually drawn on a napkin at a dinner in 1989 [3] and the overall lay-out is illustrated in Figure 2.

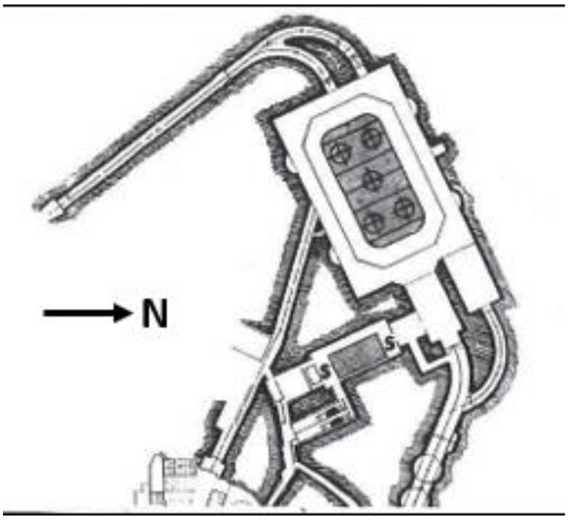

Figure 2. Plan view Gjøvik facilities.

Gjøvik rock cavern ground conditions and rock reinforcement

The Gjøvik Olympic Mountain Hall was excavated between 1991 and 1993. With a span of 61 m, a length of 95 m, and a height of 25 m, it is the largest man-made rock cavern for public use in the world. The total excavated volume was 140 000 m^3. See figure 3 for cross section and figure 4 that illustrates excavation sequence.

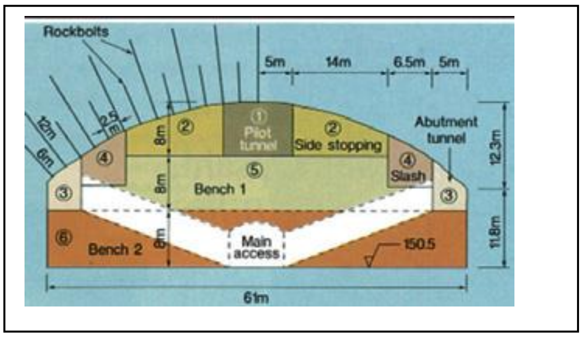

Figure 3. Cross section of the mountain hall

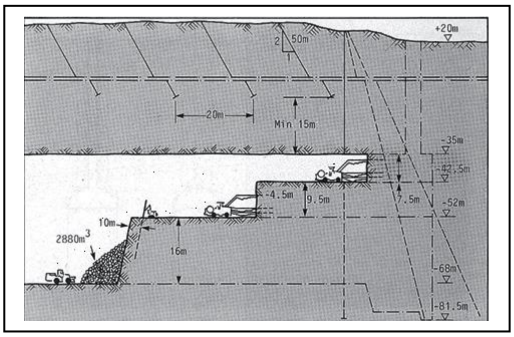

Figure 4. Excavation sequence

The width of the cavern is not the only exceptional feature of this project. Equally interesting is the fact that the rock cover varied between only 25 m and 55 m, i.e. the overburden above the underground cavern is mostly far less than its span. The rock at the site is a Precambrian gneiss. The rock has a network of tectonic micro-joints, which are often filled or coated with calcite or epidote, creating a well jointed rock mass with an average RQD of about 70.

The rock joints are typically persistent, with moderate to marked roughness, and normally without clay filling, i.e. positive characteristics when considering large spans. The Q-value is typically 30 ('good') for the best and 1 ('poor/very poor') for the poorest quality rock mass, with 12 (lower end of 'good') as an average value.

Experience from large span mining chambers in Norway indicated that an important prerequisite to obtain stable large span caverns without heavy rock support was a sufficiently high horizontal rock stress. Therefore, at a very early stage of planning, in-situ rock stress measurements were made from an existing tunnel. The results showed a major horizontal stress of the order of 3 – 5 MPa, with an E-W orientation. At a depth of 25 – 55 m the vertical stress due to gravity is less than 1 MPa, indicating that the horizontal stresses are generated by geological processes (tectonic stress). This was verified later by additional tests, conducted in several rounds, including both over-coring and hydraulic fracturing in vertical boreholes drilled from the surface above the hall. In this investigation the major horizontal stress direction was N-S. Based on these findings, it was decided to proceed with the investigations.

With reliable in-situ stress values from the stress measurements, numerical modelling was carried out, using various BEM, FEM, UDEC and FLAC codes. The final conclusion was that a stable and virtually self-supporting 62 m span could be constructed under the given geological and rock mechanics conditions. The maximum roof displacement was expected to be in the range of 5 – 10 mm. A key element of this entire process was the results of the in-situ stress measurements. Adjacent to the location of the proposed main cavern hall area, an underground swimming pool had already been constructed in 1974, thus the geology of the area was well known, and later this facility was included in the new construction. In addition, there was an underground telecommunication centre in close vicinity to the proposed Gjøvik mountain hall. To monitor roof deformations, a number of multiple position borehole extensometers (MPBX) were installed. Figure 6 shows the cavern layout and the position of seven, 3-anchor (position) MPBXs placed in boreholes drilled from the surface (marked E1-E7), and three placed in boreholes drilled vertically upwards in the cavern roof (marked S1 – S3). In addition, surface precision levelling was carried out on top of the three centre-line extensometers.

Readings were taken regularly throughout the construction period. Figure 6 shows typical readings for the central extensometer E4, with A1 being the anchor close to the cavern roof. After the full span was excavated in about 100 days, the deformations show a decreasing trend until they stabilized completely after some 300 days. The maximum displacement was less than 4 mm. By adding the readings from surface and roof extensometer and the surface levelling, the maximum displacement was estimated to be about 7 mm. This is well within the predicted values from the different numerical models. To check the roof stresses, 2D in-situ rock stress measurements were carried out mid-span close to the S1, S2 and S3 extensometer locations. They all showed compressive roof stresses in the range of 2 - 5 MPa, which are good indicators of stable conditions in the immediate vicinity of the roof.

The investigations clearly indicate that the roof "globally" is a self-supporting structure. The roof is, however, systematically reinforced by 6 m fully grouted 25 mm rebar bolts in a 2.5 m x 2.5 m grid, where every fourth bolt is substituted by a 12 m cable anchor. The rock surface is also reinforced by a 100 mm thickness of fibre reinforced shotcrete. Eight rebar bolts were instrumented by strain gauges, and the load change was monitored as the span was increased from 10 m, through 37 m to the final span of 61 m. Only three bolts showed any indication of being loaded. This happened close to the roof surface, with very moderate load in two cases (10 kN and 15 kN), while the third one showed 87 kN, which is about 40% of the yield load.

To check the performance of the fibre reinforced shotcrete, strain gauge rosettes specially made for concrete were installed at four locations. The readings indicated only very low tensile stresses, which are probably due to shrinkage of the shotcrete. The strength of the bond of the shotcrete to the rock was tested by a direct pull test on drill cores containing the intersection. The average tensile strength of the bond was 0.85 MPa, which was regarded as satisfactory. The main purpose of the shotcrete seems to be to bond the rock surface together, preventing smaller rock volumes from loosening and falling.

Based on this, it may be concluded that the need for the systematic pattern of 6 m and 12 m bolts and cables is questionable [7]. A systematic 2.5 m x 2.5 m pattern with 3 – 4 m fully grouted rock bolts, combined with 75 mm to 100 mm shotcrete will do the job even for a 50 m to 60 m span. However, horizontal stresses of sufficient magnitude are necessary to establish the global stability of the roof.

References

[1] Barton, N. et al., Prediction and Measured Performance of the 62 m Span Norwegian Olympic Ice Hockey Cavern in Gjøvik. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 31, No. 6, pp. 617-641, 1994.

[2] Oslo Municipality, Mountain resort in Liåsen, Søndre Nordstrand. Rock cavern with 60 m span used as ice halls, swimming pool, sports hall, and public shelter for Oslo municipality. May 1979.

[3] Book: Gjøvik Olympic Mountain Hall.

[4] Norwegian tunnelling methods. Presentations at the British Tunnelling Society. Reprinted from Tunnels & Tunnelling, June 1995.

[5] Aarvold, V. 1992, Gjøvik Colosseum, World Tunnelling and Subsurface Excavation, June 1992.

[6] Myrvang, A. 2004, Rock Stress Measurements and Deformation Monitoring, Norwegian Tunnelling Society NFF Publication No. 14.

[7] Grøv, E., Lu, M. 2015, Understanding and Utilizing in-situ rock stresses in designing and building large rock caverns. VietRock 2015

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