Delegation Visit to
Finland and Norway
23 - 29 September 2012

Study of Technology and Experience on the Development and
Use of Underground Space in Finland and Norway

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1 INTRODUCTION

The HKIE Geotechnical Division organized a delegation visit to Finland and Norway between 23 and 29 September 2012. The delegation is one of the activities under the project entitled “Study of Technology and Experience on the Development and Use of Underground Space in Finland and Norway”, funded by the Professional Services Development Assistance Scheme (PSDAS) of the HKSAR Government. This delegation comprised 30 members of the HKIE, led by Ir Edwin K F CHUNG (Immediate Past Chairman of Geotechnical Division), Mr Mark I WALLACE, Ir Rupert K Y LEUNG and Ir Sammy P Y CHEUNG.

The delegation provided a learning platform for local engineers to learn about the technology and experience on the use of underground space, especially on the planning, design and construction of rock caverns in Finland and Norway. These two countries have successfully developed various underground space uses for more than 40 years and they were built for various reasons, including strategic civil defense and energy efficiency purposes and uses for transportation infrastructures, industrial and municipal installations, recreation and entertainment facilities. The delegation thus provided valuable opportunities for Hong Kong engineers to learn from the practitioners in the Scandinavia the latest technological advancement in constructing rock caverns, managing risk and hazard associated with the construction and operation of rock cavern.

The delegation was warmly received by the representatives of the Finnish Tunneling Association (FTA) and Finnish Geotechnical Society (SGY) in Finland, together with Norwegian Tunnelling Society (NFF) and Norwegian Geotechnical Institute (NGI) in Norway. The delegation trip included visits to existing underground facilities, construction sites and consultant firms. The programme of the 7-day trip is summarized in Table 1 and details of the technical visit will be described in the following sections.
Table 1 – Programme of Delegation

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2 VISITS IN HELSINKI, FINLAND

2.1 The Rock Church (or Temppeliaukion Kirkko)

2.1.1 Introduction
The delegation visited the famous Rock Church (“The Church in the Rock” or “Temppeliaukio kirkko”) in Helsinki on 23 September 2012. The Rock Church (Plate 2.1.1) was built in 1968 to 1969 by cut and cover method in Toolo, which is near Helsinki.

2.1.2 Acoustic Design of the Church
This church was designed by J. S. Siren in 1930 but stopped due to World War II in 1939. Two architects, Timo and Tuomo Suomalainen, took over the design in 1961. The rock walls did not exist in the original design. Fortunately, Conductor Paavo Berglund and acoustical engineer Mauri Parjo shared their idea to maintain the acoustical quality in the church by rock wall. Therefore the rock surface was remaining exposed and becomes a key element to lead the church to be a favorite place for concerts. The delegation experienced the high sound quality due to advancing of sound reflection by the exposed rock walls. In addition, the special design helped this church becoming one of the most famous sightseeing spots in Finland.

Plate 2.1.1 – The Rock Church (or Temppeliaukio kirkko)
2.2 New Underground Parking Tunnels underneath Finlandia Hall

2.2.1 Introduction
On 24 September 2012, the delegation visited the construction site of the new underground parking tunnels for the Finlandia Hall and new Music Centre of Helsinki.

2.2.2 Objectives of the Project
In light of fulfilling the needs of parking space for the Finlandia Hall and the new Music Centre, this project has been initiated in order to provide more than 650 parking spaces. After completion, the car parking area at the back of Finlandia Hall would be moved to the underground car parking space that it would serve all nearby buildings. More space would be provided for more pedestrian activities use.

2.2.3 Construction Cost and Time
The client and the contractor of this project are the City of Helsinki and Lemminkainen Infra Oy respectively. This is a design and build contract that it approximately costs EUR 35.0 million. The construction of this project has been started since 2010 and part of the parking areas had been opened during this delegation visit. In order to maintain the space on ground to the people in the city, the underground parking spaces with service tunnels are proposed in a 150,000 m$^3$ underground rock cavern that the original ground parking areas are transferred to the new underground parking spaces. The rock cavern can also become an air-raid shelter for 3,800 people if necessary.

2.2.4 Briefing Session
The site visit was separated into two parts. The first part was a briefing session of the project by a resident site staff, as shown in Plate 2.2.1. In his presentation, he mentioned one major challenge of this project was to protect the artistic treasures particularly the ceiling fresco inside the National Museum because of blasting works. Extensive monitoring scheme with a tight vibration limit (about 10 mm/s) helped the engineer to measure the vibration induced to the sensitive receivers. Blasting works were only allowed within 7:00am – 10:00pm. In case the vibration exceeded the limit, blasting works would be suspended and the artistries would be checked to ensure no damage had been induced.
2.2.5 Site Visit

In the second part of the visit, the delegation was led to visit the underground car parking area that the construction work has been finished. As introduced, Q-system was adopted in design and no structural lining was provided to support the cavern (Plate 2.2.2). The rock surface of cavern was only covered by steel-fiber-reinforced spray concrete with a thickness ranging from 90mm to 150mm. To maintain the air quality inside the underground parking area, smoke extraction and exchange systems were in place so as to provide a comprehensive ventilation system. Pipe lines were placed on the rock surface with coverage by shotcrete which functioned as a drainage system to divert water leakage to the ground. Besides, facilities such as fire sprinklers, fire extinguishers and flood gates (Plate 2.2.3) were provided to ensure the safety in the underground parking area during emergency situations, such as on fire or flooding.

Plate 2.2.1 – Briefing Session of New Underground Parking Tunnels under Finlandia Hall
Plate 2.2.2 – View inside the New Underground Parking Tunnels underneath Finlandia Hall

Plate 2.2.3 – Flood Gate for the New Underground Parking Tunnels underneath Finlandia Hall
2.3 West Metro Project

2.3.1 Introduction
After the visit to the new underground parking tunnels underneath the Finlandia Hall, the delegation visited the construction site of West Metro Project.

2.3.2 Background
The project aimed to construct an extension of the existing Helsinki metro to the city of Espoo. It was steered by Espoo city council and Helsinki city board in 2007. Owing to minimizing the disturbance to traffic above ground, automated metro traffic would be located in two parallel rock tunnels with length of 13.9 km. Eight stations would be constructed in rock and 15 vertical shafts, at every 600m of the tunnel, with emergency exits would serve technical needs such as pressure stabilization, air circulation and smoke extraction. This project is targeted to be completed at the end of 2015 that the access and track tunnels have been excavated approximately 90% and 60% of the total distance respectively. After completion, the new West Metro system would be able to carry more than 100,000 passengers from Matinkyla to Ruoholahti in 16 minutes every day.

2.3.3 Site Investigation at Design Stage
In order to ensure the feasibility and validate the design solution, an early stage site investigation was conducted before the design which studied the topography and the quality of bedrock around the metro station area. It helped the designer to choose the best location for the metro station and minimize the use of reinforcement and concrete during construction.

The geological conditions in the vicinity of the construction areas were studied. The designers used the old survey data to study the geological conditions at the start of project. New and more concise ground information was later obtained by numerous types of geological survey (such as ground penetration radar, seismic profiling, percussion drilling, geotechnical drilling, diamond drilling, rock stress measurement, and borehole imaging) during the principal design to validate the interpretation of geological conditions.

2.3.4 Briefing Session
2.3.4.1 Briefing on Project Background
The delegation visited one of the West Metro construction sites in Keilaniemi. Before the site visit, a briefing session was conducted by a representative of Lansimetro Oy talking about the background and planning of the West Metro Project (*Plate 2.3.1*).

### 2.3.4.2 Discussion of Construction Challenges

In addition to the representative’s introduction, some contractor’s site staff also supplemented with some information about the challenges encountered during the construction of tunnels in Keilaniemi. For example, one major challenge in the project was the unforeseen ground conditions. Although a comprehensive site investigation had been conducted in design stage, the actual ground condition was still not 100% foreseen. Due to the presence of a weak rock zone near the original tunnel alignment, a design amendment of tunnel alignment was made and a delay of progress was resulted.

### 2.3.5 Site Visit

After the briefing session, the delegation was led to the construction site. In the site visit, it was observed that a ventilation system with smoke extraction fans (*Plate 2.3.2*) was provided in the tunnel to maintain good air quality inside the confined working space. Since the tunnel was designed as a drained tunnel, drainage layers were found to be installed along the tunnels to reduce the water pressure at the interface of rock and fiber-reinforced shotcrete lining (*Plate 2.3.3*).

### 2.3.6 Comparison with Hong Kong

Based on delegation’s observations, the tunnel construction methodology in Finland was quite similar to Hong Kong. Two common rock classification systems, Rock Mass Rating (RMR) and Q-system, were adopted in the project to determine the rock supporting system. Same as Hong Kong’s practice, the blasting cycle included pre-grouting, drilling, blasting, mucking out and scaling.
Plate 2.3.1 – Briefing Session of the West Metro Project

Plate 2.3.2 – Ventilation System for the Excavating Tunnels
Plate 2.3.3 – Drainage Layer between excavated surface and shotcrete lining
2.4 Seminar with Finnish Tunneling Association (FTA) and Finnish Geotechnical Society (SGY)

2.4.1 Introduction

The seminar was held on the afternoon of 24 September 2012. It was jointly organized with the Finnish Tunneling Association (FTA), the Finnish Geotechnical Society (SGY) and the HKIE Geotechnical Division. This workshop aimed at exchanging ideas of underground development in caverns with local practitioners which are able to be used as a reference for future underground development in Hong Kong. The seminar comprised five presentations about the underground development in Finland and Hong Kong.

2.4.2 Welcoming Speech by Mr. Kari J Korhonen (President of FTA)

Mr. Kari J Korhonen, the president of the Finnish Tunneling Association, delivered a welcoming speech and an introductory presentation about the current underground development in Finland (Plate 2.4.1).

2.4.3 Talk 1 – “Enhanced Use of Underground Space in Hong Kong (HK)” by Mr. Mark Wallace (ARUP)

The first speaker, Mr. Mark Wallace, the organizing committee member of this delegation, discussed the Strategic Plan of Geotechnical Engineering Office (GEO) for 2010-2015, which promoted and facilitated planned use of underground space in Hong Kong (Plate 2.4.2). The strategic plan consisted of undertaking a strategic planning and technical study, as well as preparing meetings with the stakeholders of enhanced use of rock caverns. In his presentation, he discussed the selection criteria of potential sites in the strategic plan. He also suggested some steps to enhance the use of underground space in Hong Kong.

2.4.4 Talk 2 – “Current and New Railway Projects in Hong Kong: Opportunities and Challenges” by Dr. Alan Kwong (MTRCL)

The second speaker, Mr. Alan Kwong, the senior geotechnical engineer of MTRC, presented the current and future strategy of railway development in Hong Kong (Plate 2.4.3). At the beginning of his presentation, he introduced his company, MTR Corporation Limited (MTRCL), to the audience. He highlighted the contributions of MTRCL in the development of rail transportation in Hong Kong by discussing the current and potential railway projects undertaken by MTRCL in the region.
2.4.5  Talk 3 – “Master Planning for Underground Space Use” by Mr. Ilkka Vähäaho (City of Helsinki Real Estate Department)

The third speaker, Mr. Ilkka Vähäaho, the Head of Geotechnical Division in City of Helsinki real Estate Department and Vice President of FTA, talked about the underground master plan of Helsinki (Plate 2.4.4). He told the audience that the underground master plan of Helsinki reserved designated space for public utilities and important private utilities in various underground areas of bedrock over the long term. The master plan also provided a framework for managing and controlling the city’s underground construction work, and allowed suitable locations to be allocated for underground facilities.

In his presentation, Viikinmaki wastewater treatment plant was highlighted as a successful example in which more than 10 smaller treatment plants were replaced in order to free the land for more valuable use. He also discussed important aspects like rock conditions, accessibility, land ownership which were necessary to be considered while selecting the locations for future rock cavern developments. Dilemmas of underground space development were also discussed in this presentation.

During his presentation, the guests and delegation had discussions on various topics such as the ownership of the development under private sectors and how to attract the private sectors to participate and invest for the underground space development. The law in Finland did not specify the vertical extent of ownership which may become an obstacle for underground development. As a result, the extent of ownership of underground space was bounded (i.e. 6m below ground) but the private sectors only required to pay 50% of the corresponding ground-level for the rent if they were willing to use the underground space.

2.4.6  Talk 4 – “Underground Space Uses in Finland – New Construction Techniques and Approach” by Mr. Ari Laitinen (SANDVIK)

The last speaker, Mr. Ari Laitinen, area manager of Sandvik, presented his company’s technology of drilling machines and software packages to enhance the drilling accuracy (Plate 2.4.5). The technologies included accurate drilling, sound cracking control and hardness detection by drilling jumbo. He claimed that, with the assistance of the precise drilling technologies, engineers could create the blast design which was able to increase the productivity and minimize
overbreak. In addition, the sensor of the drilling rods in the new drilling jumbo could detect the hardness and quality of rock by correlating the drilling torque and speed read from the drilling jumbo.

Plate 2.4.1 – Welcoming Speech by Mr. Kari J Korhonen

Plate 2.4.2 – Talk 1 by Mr. Mark Wallace
Plate 2.4.3 – Talk 2 by Dr. Alan Kwong

Plate 2.4.4 – Talk 3 by Mr. Ilkka Vähäaho
Plate 2.4.5 – Talk 4 by Mr. Ari Laitinen
2.5 Viikinmaki Wastewater Treatment Plant

2.5.1 Introduction
On the morning of 25 September 2012, the delegation visited the Viikinmaki Wastewater Treatment Plant. The Viikinmaki plant is the largest wastewater treatment underground facilities (about 15-hectare) in Finland. The visit was separated into two parts – the first part was a briefing session, while the second part was a site walk.

2.5.2 Background
Viikinmaki plant purifies the domestic and industrial wastewater from more than 800,000 inhabitants from six towns, including Helsinki, Kerava, Tuusula, Jarvenpaa, Sipoo and the central & eastern part of Vantaa, in Finland. In general, approximate 270,000 m$^3$ of wastewater flow to the plant through the longest sewage tunnels in the world per day (about 120 km), and the plant is capable to treat 100 million m$^3$ of wastewater per year. This plant removes 95% of solid, oxygen-consuming materials and phosphorus, and 89% of nitrogen in wastewater that the emission of phosphorus, organic and nitrogen to Baltic Sea is sufficiently reduced. This plant is also quite sustainable that the biogas produced from treatment process produces 50% of electricity and heat needed by the plant itself. In addition, the excavated rock was crushed and recycled as construction material during construction, which was an environmental friendly act.

2.5.3 Favorable Geology for Underground Space Development
Regarding the geology in the vicinity, the hard granite and mica gneiss bedrock provides a suitable ground condition for a cost effective underground space development. In addition, in light of the protection by the rock cover, the plant is able to maintain the production rate even under extreme weather conditions in winter. These factors favored Viikinmaki to be the largest wastewater treatment plant in Finland.

2.5.4 Design of Cavern
The cavern was constructed by drill and blast method that the exposed rock surface is supported by rockbolts and reinforced shotcrete with typical thickness of 25 mm. To suit the needs to store the wastewater treatment facilities and machines in huge sizes, about 1 million m$^3$ of rock was excavated for the cavern construction that each room has 17 to 19 m span and each of them are
-separated by 10 to 12 m thick pillars. In order to reduce the maintenance cost due to influence of drip water corroding the machines, a drainage system, such as drainage mat, was placed on rock surfaces diverts the water leakage from the rock fissure to the ground.

2.5.5 Briefing Session
Prior to the site walk, the delegation was given a briefing session \(\text{(Plate 2.5.1)}\) which introduced the planning of this wastewater treatment scheme, the purification process of the wastewater and the future plan of extension to suit the increasing of service demands. Moreover, the reuse of sludge, which is the side product in the wastewater treatment process, was also mentioned. The dried sludge (about 60,000 tonnes per year) was generally produced by the digested wastewater organics which generated digester gas (about 10 million m\(^3\) annually) and used to generate heat and electricity for the plant. The dried sludge was treated and sold in the market for landscaping.

2.5.6 Site Visit
After the briefing session, the delegation was led to the underground wastewater treatment facilities to understand the process of cleansing the wastewater \(\text{(Plate 2.5.2)}\). \text{Plate 2.5.3} shows part of the coring samples displaying in the plant. The rock core sample was taken at 83 to 91 m, 117 to 125 m and 185 to 193 m deep respectively and mainly consisted of Mica Gneiss, Granite Gneiss. The quality of the rock core was classified as good in accordance with the Nick Barton’s Q-system which was favorable for underground development. During the visit, except inside some of the areas, such as sedimentation tank \(\text{(Plate 2.5.4)}\), the ventilation system in the plant was found effective that no odor could be smelled. \text{Plate 2.5.5} and \text{Plate 2.5.6} show the extension of the plant as mentioned above. The proposed enlarging of the underground space was about 200,000 m\(^3\) which was able to house the de-nitrification filters and additional treatment lines after finished. This shows the advantage of cavern development that future extension becomes more flexible and feasible.
Plate 2.5.1 - Briefing Session at Viikinmaki Wastewater Treatment Plant

Plate 2.5.2 - Group Photo of Delegation at Viikinmaki Wastewater Treatment Plant
Plate 2.5.3 - Rock Core Sample at Viikinmaki Wastewater Treatment Plant

Plate 2.5.4 - Sedimentation Tank at Viikinmaki Wastewater Treatment Plant
Plate 2.5.5 - Extension of Viikinmaki Wastewater Treatment Plant (under construction)

Plate 2.5.6 - Extension of Viikinmaki Wastewater Treatment Plant (under construction)
2.6 Itakeskus Swimming Hall

2.6.1 Introduction

Followed with the visit to the Viikinmaki Wastewater Treatment Plant, the delegation visited the Itakeskus Swimming Hall in the afternoon. Itakeskus swimming hall (*Plate 2.6.1*) was constructed in 1993 at Olavinlinnantie. This is a two storey sport facility which serves about 400,000 visitors per year and it can be converted as air-raid shelter for 3,800 people if necessary. This swimming hall houses a 50 m long × 19 m wide swimming pool, a learner pool, a children pool, a Jacuzzi and miscellaneous facilities. The operation facilities (*Plate 2.6.2*) locate under the pool which controls the pool water circulation and sterilization. The delegation was led by the staff of the swimming hall to visit the swimming hall and the operation faculties. The advantage of utilizing cavern to be recreation facilities could be seen during the visit. The temperature is maintained inside the cavern that it save a lot of energy to control the room temperature in the hall during winter.

*Plate 2.6.1 - The Itakeskus Swimming Hall*
Plate 2.6.2 - Operating Facilities of the Itakeskus Swimming Hall
2.7 Underground Space System in Helsinki City Center

2.7.1 Introduction
After the visit to the Itakeskus swimming hall, the delegation visited the Underground Space System in Helsinki City Center.

2.7.2 Background
A long-term strategy of the underground city planning was initiated in the city center of Helsinki since 1970’s. In order to maintain the city area to be pedestrian-oriented and fulfill the future demands of sustainability development, the plan aimed to put numbers of facility to underground, such as parking, substation, shopping malls, etc.

2.7.3 Site Visit
The delegation visited one of the underground development areas under the Stockmann department store and Mannerheimintie street at the Helsinki city center (Plates 2.7.1 & 2.7.2 show). This is the iconic development in Helsinki city that it was included in the excursion program of the 37th ITA-AITES World Tunnel Congress held on 20 – 26 May, 2011.

The extension of Stockmann department to underground was carried out in 2006 and completed in 2010. After completion, a total volume of 65,000m$^3$ was excavated and about 10,000m$^3$ new rental space was created. The parking area under Mannerheimintie Street has the capacity of 600 cars in two 17 m wide $\times$ 160 m long rock caverns with approximately 160,000 m$^3$ volume.

With this underground world, activities in city would not be influenced even during winter or adverse weather. Figure 2.7 is a map of the underground world at Helsinki city centre. The delegation walked from underground book store, 30 m below Stockmann department store, to another shopping mall, Forum. The underground development area, orange areas in Figure 2.7, links between the metro station and various buildings and parking areas in the city center.
Plate 2.7.1 – Underground Walkway at Helsinki City Centre

Plate 2.7.2 – Underground Car Parks in Helsinki City Centre
Figure 2.7 – Map of Underground World in Helsinki City Centre
3 VISITS IN OSLO, NORWAY

3.1 Seminar at Norconsult Office

3.1.1 Introduction

On the morning of 26 September, the delegation left Helsinki and travelled to Oslo. Upon the arrival to Oslo, delegates visited Norconsult Office and attended a briefing session introducing some general Norwegian underground space technologies (Plate 3.1.1).

3.1.2 Briefing Session on Underground Space in Norway

The briefing session began with an introduction of Norconsult by Jørn Tyrdal (Project Director, International Division in Norconsult), followed by an address from Thor Skjeggedal (Secretary General, The Norwegian Tunnelling Society). Next, Jan Bergh-Christensen (Senior Engineering Geologist, Norconsult) talked about “Norwegian Underground Space Technologies”. In his presentation, a number of underground facilities in Norway were briefly introduced and discussed. This provided an overview on the use of underground space in Norway.

After Mr Christensen’s overview presentation, Morten Knudsmoen (Senior Civil Engineer, Norconsult) shared his experience in the Sandvika Heating and Cooling Facility to the delegation. The Sandvika Heating and Cooling Facility was a district heating and pumping system. It was an innovative design as it used energy recovered from sewage water for heating and for cooling purposes. The exploitation of energy from waste water pays an important contribution to the good quality of the air around Sandvika. The main machine room with the two heat pumps was located next to the waste water channel, inside a subterranean cavern, excavated from bedrock. Yet, to cope with peak load times, an existing heating station, with 3 oil burning vessels and a conventional refrigeration unit were integrated into the Sandvika energy production network. The part of energy originating from waste water took 52% of the total energy supply.

Followed with Mr Knudsmoen’s sharing, the briefing session ended with a presentation of souvenirs to the speakers as a token of thanks.
Plate 3.1.1 – Briefing Session at Norconsult Office
3.2 Gjøvik Olympic Mountain Hall

3.2.1 Introduction
On 27 September 2012, the delegation visited Gjøvik Olympic Mountain Hall, which was located at Gjøvik (130 km north of Oslo) (Plate 3.2.1 & 3.2.2). The Mountain Hall is a record-breaking structure in which it has a span of 61 m, a length of 91 m and a minimum rock cover of 25 m. Up till now, it remains the largest underground cavern for public use in the world. The hall was built for the 1994 Winter Olympics, where it hosted 16 ice hockey matches. The hall contains an ice hockey rink (Plate 3.2.3) with a capacity for 5,500 spectators, a 25-meter swimming pool (Plate 3.2.4) and telecommunications installations. A floor plan of the Mountain Hall is shown in Plate 3.2.5.

3.2.2 Construction Cost and Timeline
The contract was signed in January 1991 and construction works started in April 1991. By early December 1991, 140,000 m$^3$ of rock had been excavated. In April 1993, two years after the start of construction and four months ahead of schedule, the cavern, with all installations, was completed within a planned cost estimate of 134.6 million Norwegian krone (NOK). On 6 May 1993, the Gjøvik Olympic Mountain Hall was officially opened in the presence of His Majesty King Harald V of Norway.

3.2.3 Excavation Sequence
The cross-section in Figure 3.2 shows the blasting sequence. The roof was excavated to its full width from a center adit by side stoping. The final height was then blasted by benching in two steps. The rock cover varied between 25 m and 50 m, which was considerably less than the span.

3.2.4 Design of Supporting System
The Q-system was used as an early guide to possible rock reinforcement needs. However, the span exceeded the extreme limit of case records, and the final design of the roof support was actually based more on general experience from other large excavations than on sophisticated classification or computer methods.

Temporary support during excavation was 4-m mechanical shell anchor bolts as needed. The systematic permanent bolting consisted of alternate fully grouted 6-m rebar bolts and 12-m twin steel strand cables in a 2.5 m x 2.5 m pattern (see
Figure 3.2. The former have a diameter of 25 mm and capacity of 22 tonnes, while the latter have a diameter of 12.5 mm and a capacity (for each strand) of 16.7 tonnes at yield.

A 100 mm thick fibre-reinforced shotcrete cover was adopted to serve as a surface protection to the cavern. The shotcrete was mixed by a wet-mix process, using 50 kg/m$^3$ of 25-mm-long EE steel fibres, and with a concrete quality of 35 MPa.

Figure 3.2 – Excavation sequences for the Gjøvik Olympic Mountain Hall
Plate 3.2.1 – Group Photo of Delegation in front of the Gjøvik Olympic Mountain Hall

Plate 3.2.2 – Access Tunnel to the Gjøvik Olympic Mountain Hall

Plate 3.2.3 – Ice Hockey Rink in the Gjøvik Olympic Mountain Hall
Plate 3.2.4 – Swimming Pool in the Gjøvik Olympic Mountain Hall

Plate 3.2.5 – Plan of the Gjøvik Olympic Mountain Hall
3.3 E6-Dovre Line Joint Project

3.3.1 Introduction
After a visit to the Gjøvik Olympic Mountain Hall, the delegation visited the construction sites of the E6-Dovre Line Joint Project along a highway by a coach (Plate 3.3.1). The E6-Dovre Line Joint Project was one of the largest civil projects ever in Norway. It was a collaboration between the Norwegian Public Roads Administration and the Norwegian National Rail Administration. The project scope was to build a four-lane section of the E6 road and a double track section of the railway between Minnesund and Kleverud. The works included reclamation (Plate 3.3.2), site formation and tunneling works (Plate 3.3.3).

3.3.2 Reasons for Joint Project
The transport corridor along Lake Mjøsa was narrow, and the E6 road and the Dovre railway line were very close to each other. A practical solution expanding both road and railway simultaneously was therefore chosen. This solution would save the developers approximate NOK 400 million, compared with separated developments of road and rail by the two authorities. One major reason for the saving was the material taken from the road will be used in building the railway, thus achieving a good material balance in the project.

3.3.3 Construction Cost and Timeline
Three main contracts were signed under this project with a total sum of nearly NOK 5 billion. Nearly 1,500 persons were involved in this 17 km long stretch of highway and railway line. Supplementary contracts for rail and electrical installations will make the total contract sum of the project to NOK 8 billion.

A progress plan for the E6-Dovre Line Joint Project is shown in Figure 3.3. The excavation of the tunnels would take about one year, and at the most there were 9 blasting faces.
Figure 3.3 – Progress Plan for the E6-Dovre Line Joint Project

(Reference:
http://www.jernbaneverket.no/PageFiles/20167/The%20E6-Dovre%20Joint%20Project%20Screen.pdf?epslanguage=no)

Plate 3.3.1 – Visit to the E6-Dovre Line Joint Project
Plate 3.3.2 – Reclamation Works in the E6-Dovre Line Joint Project

Plate 3.3.3 – Tunneling Works in the E6-Dovre Line Joint Project
3.4 New Oset Water Treatment Plant

3.4.1 Introduction
On 28 September 2012, the delegates visited the New Oset Water Treatment Plant (Plate 3.4.1). It is Europe’s largest plant which is housed inside a mountain cavern. The new plant, as an extension to the Old Oset Water Treatment Plant, was built in two 150 m long, 28 m wide and 16 m high cavern halls. It produces 390,000 cubic metres of drinking water per day at a rate of 4,500 litres per second, serving about 90% of Oslo’s population with clean water which meets the requirements by the European Union.

Upon the delegation’s arrival to the New Oset Water Treatment Plant, a presentation (Plate 3.4.2) was given by the staff of the plant prior to the site visit. In the presentation, design considerations and construction of the treatment plant were introduced.

3.4.2 Design Considerations

3.4.2.1 Water Quality
Tap water is directly drinkable in Oslo. This public convenience requires a comprehensive drinking water treatment system to meet the EU requirements. Previously, chlorination was the only hygienic barrier in the old plant. However, Norwegian Drinking Water Regulations later required a minimum of two barriers in the water treatment. In order to meet the new regulation requirements, the new plant consequently adopts coagulation and filtration as the first barrier, together with UV-disinfection as the second barrier. The new plant uses a trace residual of chlorine and the old plant is maintained with the micro-strainers and chlorination as a back-up.

3.4.2.2 Reliability of Water Supply
To increase the reliability of the drinking water supply, the plant is constructed to access two different water sources: the main source from Maridalen Lake and the back-up source being planned in Langlia Lake. The New Oset Water Treatment Plant consists of two identical yet mutually independent plants that they can operate separately in case of operational or water source problems.

3.4.2.3 Reasons for Underground
The reasons for building the underground facility are as follows:

a) Compatibility to the Old Plant: The Old Oset Water Treatment Plant was built
underground. As an extension, the New Oset Water Treatment Plant was also constructed underground, adjacent to the old plant.

b) *Preservation of Forest:* The plant is located within a forest protection zone, where the size of building on surface is limited.

c) *Low Maintenance Cost:* Compared to a building on the ground surface, the maintenance cost (e.g. heating) is low in general.

d) *Better Security:* An underground facility is embedded into rock and has limited number of entrances/exits. It has less chance to be subject to sabotage.

### 3.4.3 Construction Cost and Timeline

The total project cost was €100M. 170 employees were involved in the project implementation, planning, building, and control. The construction period lasted for around 4 years (from 2004 to 2008). The timeline of the project is summarized in the following table:

<table>
<thead>
<tr>
<th>Date</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 2002</td>
<td><strong>Pre-construction</strong></td>
</tr>
<tr>
<td></td>
<td>City Council approved extension of Oset. Consortium AFS-Krüger awarded the total delivery contract (Turn-Key Contract). Oslo Water and Sewerage Works is project owner and project manager.</td>
</tr>
<tr>
<td>Nov 2003 – Feb 2004</td>
<td><strong>Initial building phase</strong></td>
</tr>
<tr>
<td>Spring 2004 – Jan 2005</td>
<td><strong>Blasting work</strong></td>
</tr>
<tr>
<td></td>
<td>Blasting of new mountain caverns and rock removal. 140,000 m³ of solid rock removed. Max. 13 trucks per hour.</td>
</tr>
<tr>
<td>Spring 2005</td>
<td><strong>Ground work</strong></td>
</tr>
<tr>
<td></td>
<td>Ground work for pipes of various dimensions.</td>
</tr>
<tr>
<td>Winter 2005 – Autumn 2006</td>
<td><strong>Cement work</strong></td>
</tr>
<tr>
<td></td>
<td>Ceiling tiles were mounted in both caverns to keep away from groundwater. Concrete structures for reservoirs and walls were built. (The walls are 5-10m high with 2,000 m³ concrete poured every month).</td>
</tr>
<tr>
<td>Autumn 2006 – Autumn 2007</td>
<td><strong>Installation work</strong></td>
</tr>
<tr>
<td></td>
<td>Installation of 15-20 nos. of tanks and silos.</td>
</tr>
<tr>
<td>Autumn 2007 – Summer 2008</td>
<td><strong>Testing and start-up</strong></td>
</tr>
<tr>
<td>Autumn 2008</td>
<td><strong>Official opening</strong></td>
</tr>
</tbody>
</table>
3.4.4 Water Treatment Process

Apart from the construction issues, delegates also learnt water treatment process in the New Oset water treatment plant. The treatment process is illustrated in Figure 3.4 and described as follows:

Step A. Coagulation:
Carbon dioxide (CO$_2$) and lime are added. An aluminium-based coagulant is then added, which binds itself to humic matter (loose organic matter).

Step B. Flocs formed:
Micro-sand is added (grain size approx. 0.1 mm). The aluminium flocs and micro-sand are mixed.

Step C. Polymer added:
Polymer (Plate 3.4.3) is added to attract the aluminium and sand, which forms larger, stronger and heavier flocs.

Step D. Flocs removed:
Sludge contains micro-sand that sinks to the bottom of a sedimentation reservoir (Plate 3.4.4) in the Actiflo treatment process. The sludge is led to hydro-cyclones where the microsand is recycled while the remaining sludge is taken out for sludge thickening. This sludge is further de-watered in a centrifuge. The reject water from the centrifuge is treated in a separate reject water treatment facility. Treated reject water is led to the sewage pipeline. The filters in the water treatment process are cleaned with compressed air and water. The filters are led directly back to the raw water and is reused.

Step E. UV-disinfection:
UV-disinfection is the second hygienic barrier at Oset. The UV-light penetrates the micro-organisms’ cells and damages their DNA so that the organisms cannot reproduce. UV-disinfection is effective against bacteria, virus, parasites, and spores.

Step F. Lime:
Lime is added so that the water will reach a pH of 8.0. The drinking water is
then less corrosive to metals such as copper and iron, which increases the lifespan of municipal and private pipes.

Figure 3.4 – Simplified Diagram of Water Treatment Process in New Oslo Water Treatment Plant

Plate 3.4.1 – Group Photo of delegation at the New Oset Water Treatment Plant
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Plate 3.4.2 – Presentation before Visit at the New Oset Water Treatment Plant.

Plate 3.4.3 – Storage of Polymers at the New Oset Water Treatment Plant.
Plate 3.4.4 – Sedimentation Basins at the New Oset Water Treatment Plant.
3.5 National Archives Building

3.5.1 Introduction
After the visit to the New Oset Water Treatment Plant, the delegation visited the National Archives' Central Office in Oslo. The National Archives Building was situated at the outskirt of Oslo, just outside the boundaries of Nordmarka (one of Oslo's recreation areas) but close to Sognsvann station, the terminus of the suburban railway line 3. The National Archives Building is owned, managed and maintained by Statsbygg, the government administration company.

3.5.2 Design of the Building
The whole building consists of an underground storage area and an administration building on the surface (Plate 3.5.1). The original parts of the building dated back to 1978. The underground storage area (Plate 3.5.2) was expanded in 1998 and 2009 and the administration building was expanded and partly rebuilt in 2005. The gross floor space for the whole plant is 31,700 m$^2$ that 9,900 m$^2$ belongs to the administration building, while the remaining 21,800 m$^2$ are located underground. In the underground area, around 154,000 shelf-metres of paper-archives are stored. Each cavern houses a four storey building with connections to adjacent caverns (Plate 3.5.3) on each floor. In addition to the paper-archives, invaluable items like photos, films, maps, pictures, drawings and digital archives are stored in special rooms.

3.5.3 Reasons for Underground
Main considerations of housing the facility in rock caverns are summarized as follows:

a) **Good Climate Control:** The underground location provides good climate control, especially in terms of humidity and temperature, which is vital to archiving.

b) **Good Security:** An underground facility is well-protected by rock (Plate 3.5.4). It has less chance to be subject to sabotage. There was a lesson learnt from the Second World War, in which major facilities were being bombarded by air raids.

c) **Preservation of Forest:** The facility is located within a green belt, in which the size of development on surface is limited.

d) **Potential for Expansion:** The number of archives is ever increasing. A facility in rock cavern allows expansion without disturbing the natural habitats.
Plate 3.5.1 – Outlook of the National Archives Building

Plate 3.5.2 – View from inside of the National Archives Building
Plate 3.5.3 – View inside the National Archives with drip collecting screen visible on the roof of cavern

Plate 3.5.4 – Access Tunnel to the National Archives Building
3.6 Seminar with Norwegian Tunnelling Society (NFF) and Norwegian Geotechnical Institute (NGI)

3.6.1 Introduction
On the afternoon of 28 September 2012, the delegation attended a seminar jointly organized by the Norwegian Tunnelling Society (NFF) and Norwegian Geotechnical Institute (NGI) and the HKIE Geotechnical Division. NFF is a professional association of the rock blasting and tunnelling industry of Norway, while NGI is a leading international centre for research and consulting within the geosciences. Around 40 Hong Kong and Norwegian delegates including professional engineers and geologists from government, design consultants, contractors and academic institutions interchanged their expertise in the seminar.

The Seminar comprised five presentations under the theme of underground construction and tunnelling projects. At the beginning of seminar, welcoming remarks and a brief introduction of NGI were given. After that, five presentations were delivered with content summarized in this section.

3.6.2 Talk 1 – “Enhanced Use of Underground Space in Hong Kong (HK)” by Mr. Mark Wallace (ARUP)
Mr. Wallace began his presentation with an introduction of HK’s natural hilly terrain and the Strategic Plan of Geotechnical Engineering Office (GEO) for 2010-2015 (Plate 3.6.1). He talked about the history of cavern study and construction in HK and showed the five strategic cavern areas – namely Tuen Mun (Lam Tei), Lantau, Mount Davis, Lion Rock and Sha Tin (Shek Mun). Next, ten proposed strategic sites were introduced with some discussion on the selection criteria. Finally, he recommended some suggested steps to improve Hong Kong’s use of underground space.

3.6.3 Talk 2 – “Current and New Railway Projects in Hong Kong: Opportunities and Challenges” by Dr. Alan Kwong (MTRCL)
Dr. Kwong first provided a business overview of MTR Corporation Limited (MTRCL) (Plate 3.6.2). He mentioned the existing nine domestic railway lines and the Airport Express Link, followed by an introduction of five ongoing construction projects (i.e. West Island Line, South Island Line, Kwun Tong Extension Line, Shatin to Central Link and Express Rail Link). Lastly, he introduced five potential schemes being considered for future development.
The schemes were: North Island Link, Causeway Bay North Station, Northern Link (an elevated railway), South Island Line (West), Central South Station, as well as Western Express Line (connecting HK and Shenzhen’s airports).

3.6.4 Talk 3 – “Norwegian Tunnelling Technology” by Ms. Ruth Gunlaug Haug (Leonhard Nilsen & Sønner AS)
Ms. Haug kicked off by a brief introduction of her company (Plate 3.6.3). Then, she talked about several major projects which her company had previously involved. The projects included the Global Seed Vault at Svalbard, the Dobbeltspor Lysaker-Sandvika and the Oslofjord Subsea Tunnel. The Oslofjord Tunnel was one of the longest undersea tunnels in Northern Europe. It was 7.2 km long and reached a depth of 134 metres below sea level, with a maximum gradient of 7%. Ms. Haug highlighted that, in the design stage, 3D tunnel models were adopted for analysis. In addition, she stressed the importance of water control and pre-excavation grouting during the construction.

3.6.5 Talk 4 – “Cavern Design and Construction” by Mr. Per Heimli
Mr. Heimli told the delegation that almost all caverns were unlined in Norway (Plate 3.6.4). The caverns were usually constructed by scaling, rockbolts and sprayed concrete. The usage of caverns in Norway included storage of crude oil / hydrocarbon products, warehousing, sports facilities, cold storage (-25°C) of food products, air-raid shelters, storage of drinking water, waste storage, underground hydropower facilities and car park.

3.6.6 Talk 5 – “TBM Tunnelling at 300m Water Depth in Sedimentary Rocks – Stretching the TBM Technology to Its Limits” by Prof. Eivind Grøv (SINTEF/NTNU)
Prof. Grøv discussed the major challenges of Tunnel construction in Norway (Plate 3.6.5). The challenges included:

a) Boundary fault between two kinds of rock (e.g. basement and cretaceous),
b) Very weak and unstable rock mass (e.g. running, swelling),
c) Stress related problems (e.g. squeezing),
d) Large water ingress due to high water pressure,
e) Gas pockets / shallow gas,
f) Mixed face conditions, and
g) Maintaining satisfactory advance rate.

Moreover, Prof. Grøv stressed that pre-injection was far more effective than
post-injection. Pre-grouting could secure that ground water level was unaffected by underground works. Large ground settlement due to water drawdown would therefore be minimized. The cost of pre-injection was usually around 10 to 50 times less expensive in stopping water ingress when compared to post-injection. The high cost of post-grouting was often due to the following reasons:

a) Specialized teams were employed;
b) Relative expensive chemical resins were normally used;
c) Time consuming as water seepage were required to be traced place to place.
Plate 3.6.2 – Talk 2 by Dr. Alan Kwong

Plate 3.6.3 – Talk 3 by Ms. Ruth Gunlaug Haug

Plate 3.6.4 – Talk 4 by Mr. Per Heimli
Plate 3.6.5 – Talk 5 by Prof. Eivind Grøv

Plate 3.6.6 – Souvenir Presentation to NGI
4 CONCLUDING REMARKS

The delegation was well-organized and rewarding. It successfully provided a useful platform for knowledge exchange between Finnish/Norwegian and Hong Kong practitioners.

Via the technical visits and seminars, the delegation learnt the rationales and advantages of cavern development in Finland and Norway. Moreover, delegates appreciated the innovative uses of caverns and the relevant techniques there. In particular, the delegation was impressed by the underground master plan of Helsinki and the largest underground cavern for public use in the world (i.e. Gjøvik Olympic Mountain Hall in Oslo).

In return, the delegation also shared their experiences on topics like underground excavation and water treatment with the Finnish and Norwegian practitioners. Through the interactions among delegates with the Finnish and Norwegian practitioners, friendship were built up which enhances knowledge exchange and further collaboration in the future.

5 ACKNOWLEDGEMENT

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✧ Norwegian Tunnelling Society (NFF)
✧ Norwegian Geotechnical Institute (NGI)

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THE END