

Underground Storage Project underneath an Artificial Island

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Abstract

An underground LPG (Liquefied Petroleum Gas) storage facility was constructed in the west-coast of Incheon, Korea. The facility was for the stable supply of LPG to the densely populated local metropolitan area. Considering the complicated geometry of the storage facility and the efficient use of the land with minimizing the environmental impact during and after the construction, the storage facility was constructed underneath an artificial island (mainly by landfill). The facility includes three propane caverns and two butane caverns. This presentation introduces the key issues considered during the design and construction of the facility: vertical shaft excavation, pre-grouting to control groundwater, and application of a new blasting pattern.

Keywords: Storage cavern, Artificial island, Blasting pattern, Slurry wall, Pre-grouting.

1. Introduction

Y-2 Project, a project for the construction of an underground LPG storage facility, was carried out for 3.5 years from January 1997 to July 2000 in the west-coast of Incheon, Korea. The facility was designed to comprise three propane caverns with the total capacity of 340,000 m³ and two butane caverns with the total capacity of 125,000 m³. This project was to partly meet the national stockpiling plan of hydrocarbon energy resources and to stably supply LPG to the highly populated nearby metropolitan area. Based on the accumulated experiences of construction of underground storage facilities for crude oil and LPG in Korea (Lee et al., 1997; Kim et al., 2000; Park et al., 1997; SKEC, 1999) and other countries (Aoki & Shiogama, 1993; Darling, 1993; Hamberger, 1991; Inada & Kohmura, 1991; Kjørholt & Broch, 1992; Sturk & Stille, 1995), Y-2 Project was successfully carried out.

The general overview and detailed shape of the storage caverns are presented in Figure 1. The main features of the underground works of the storage facility comprise the following items.

- Storage galleries located at -127 m in depth with the cross-sectional area of 343 m² and length to suit the designed storage capacity.
- Vertical construction shaft of 15.5 m in outer diameter and two operation shafts that connect surface equipments and underground facilities.
- Water curtain tunnels to meet the hydro-geological pressure requirement.
- Connection and construction tunnels required for mining the storage galleries.
- Pump pit for draining water.
- Plugs to seal the caverns.

Table 1 and 2 summarize the specification of tunnels and shafts excavated for the storage facility. The total length of the tunnels and shafts reached 3,814.3 m and 463 m, respectively.

2. Geology and geography

The construction site is located in an artificial island that is 8 km away from the coast of Incheon in the southwest direction. The landfill for the island started in 1993 by Korea Gas Corporation to build LNG (Liquefied Natural Gas) terminal and the additional landfill was made by LG-Caltex Co. for the Y-2 Project. The depth of water is 4.6 m on average and it varies on tide.

The rock types prevailing on the site consist of Precambrian metamorphic series and include banded gneiss and various mica schists. The general deposition is a succession of biotite banded gneiss or augen gneiss resting on a different series of coarse grained mica schist of mixed lithology, including andesite, granite porphyry and quartz porphyry. The coastal sedimentary layer is placed under the reclaimed layer (about 11 m) with 40-50 m thickness and is mostly composed of fine sand,

silt and clay. In the site investigation stage, many different types of field-scale test, borehole test, and laboratory test were carried out to obtain the mechanical and hydrological properties of the rock mass in the site. Results of rock mass classification and geological profile around the cavern are presented in Table 3 and Figure 2.

3. Technical consideration

The project had difficulties on account of location where the underground cavern was to be constructed underneath the artificial island in the sea. Due to the limited accessibility to the target depth from the surface of the island, it was not to construct typical access tunnels. A vertical construction shaft of 15.5 m in diameter was excavated facilitated with a proper mucking out system. In this site, a 127 m deep construction shaft was excavated after installation of slurry wall. The slurry wall construction down to the depth of 62 m was a technical challenge in this project. For fast and efficient mucking, car lift system was selected. Since the car lift system was applied in Korea for the first time, careful design and construction was made.

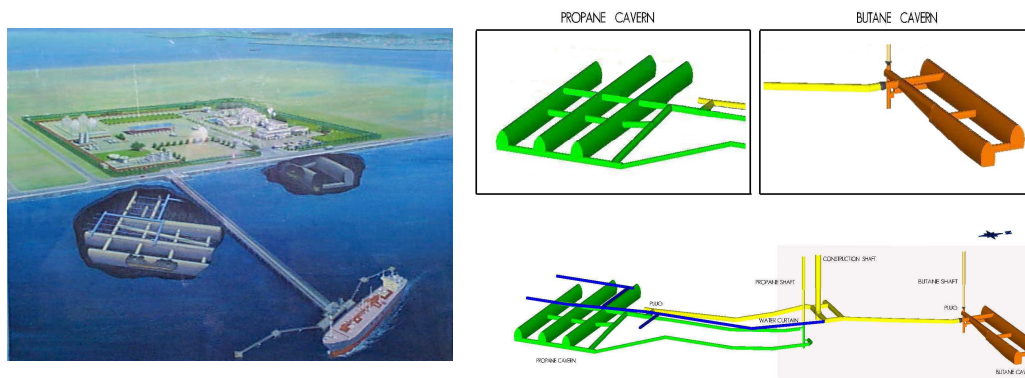


Figure 1. General overview and the detailed shape of the storage caverns

Table 1. Specification of the tunnels

Tunnel type	Cross-section (m)	Length (m) for propane	Length (m) for butane
Cavern	16.0 × 26.0 (H)	800.4	366.0
Construction	8.0 × 7.2 (H)	424.5	101.0
	8.0 × 6.5 (H)	-	168.0
Shaft connection	5.0 × 5.5 (H)	741.0	-
	7.0 × 6.5 (H)	-	26.0
Cavern connection	8.0 × 7.2 (H)	96.0	-
	7.0 × 7.2 (H)	-	131.0
	10.0 × 8.0 (H)	160.0	-
Water curtain	4.6 × 4.9 (H)	800.4	-

Table 2. Specification of the shafts

Shaft type	Total length (m)	Slurry wall specification				
		Length (m)	OD (m)	Wall thickness (m)	Lining (m)	thickness
Construction	127.0	62.0	15.5	1.2	1.0	
Propane	178.0	62.0	9.9	1.0	0.8	
Butane	158.0	71.0	9.9	1.0	0.8	

Table 3. Rock mass characteristics

Type	RMR	Q	Hydraulic gradient (cm/sec)
Butane cavern	49 - 57	9.7 - 23.2	$1.56 \times 10^{-8} - 1.13 \times 10^{-4}$
Propane cavern	43 - 49	4.4 - 9.3	$4.08 \times 10^{-8} - 9.4 \times 10^{-5}$

An overall hydro-geological site investigation was carried out to understand the complicated flow of groundwater. Systematic ground reinforcement such as pre-grouting was made to prevent water from flowing inside the vertical shaft as well as to prevent the water table from lowering down. A new blasting method (SAV-CUT) was developed and used in the site. The SAV-CUT had enhanced efficiency of blasting and advance rate.

4. Shaft excavation

In order to excavate a vertical construction shaft, a slurry wall was first installed in shallow depth. And then the ground inside the slurry wall was removed. For accurate and successful construction of slurry wall, steel joint plate method was applied in this site. The construction procedure of slurry wall is as follows: (1) guide trench construction, (2) improvement of ground, (3) excavation and disposing slime, (4) perpendicularity check, (5) construction of the steel cage and interlocking pipe, (6) installation of trench pipe, (7) concrete pouring, and (8) construction of connecting area. Excavation was made under the condition of sufficient bentonite suspension. In addition, ultrasonic measurement device was used to check its vertical inclination at the allowable inclination of 1/1,000. Backfill was later installed to prevent the deformation of the steel cage. The sequence of the slurry wall construction is shown in Figure 3.

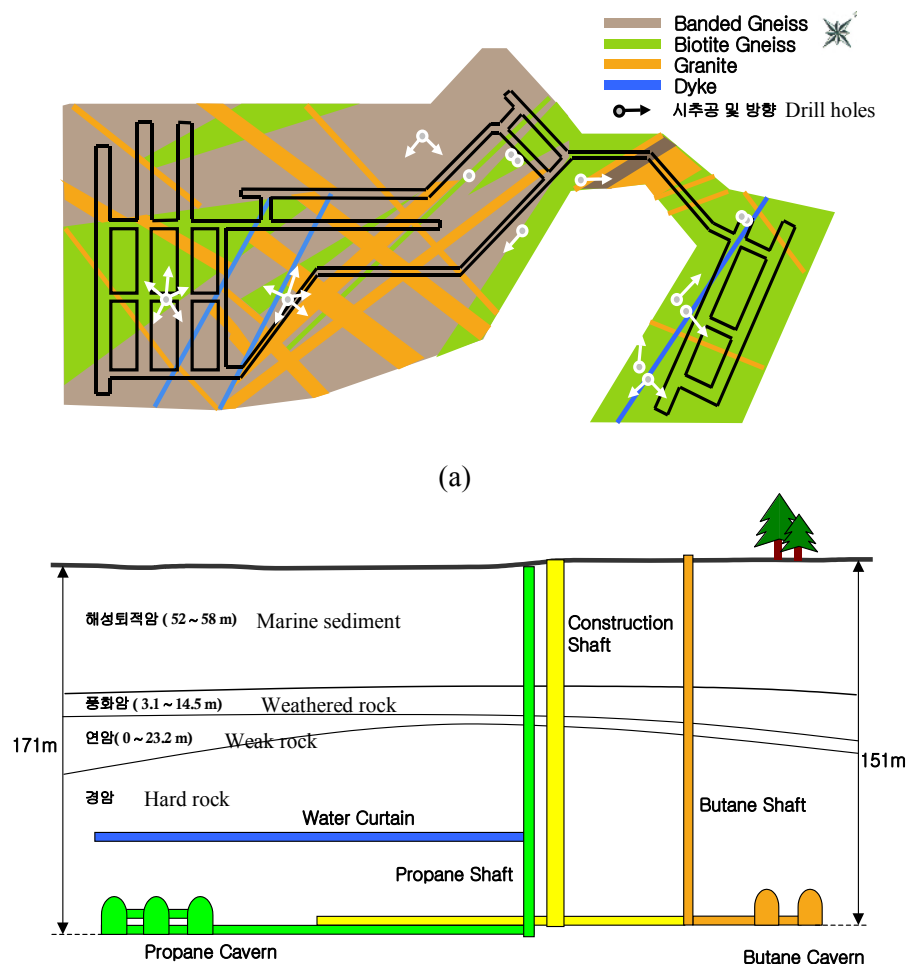


Figure 2. Geological profile at the construction site: (a) plan view and (b) cross-sectional view

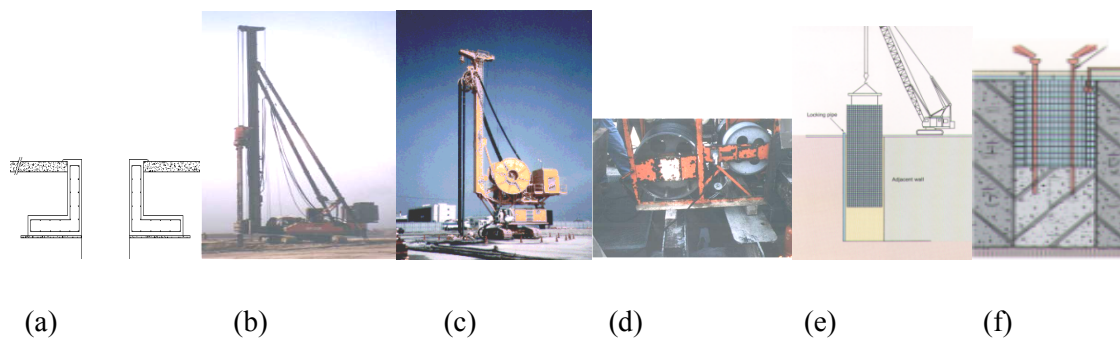


Figure 3. Construction sequence of shaft slurry wall: (a) installation of guide wall, (b) ground improvement, (c) excavation and slime disposing, (d) check of perpendicularity, (e) installation of steel cage, and (f) concrete pour

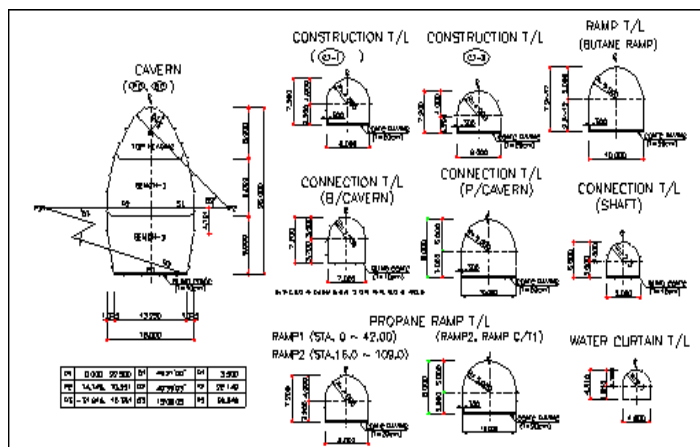
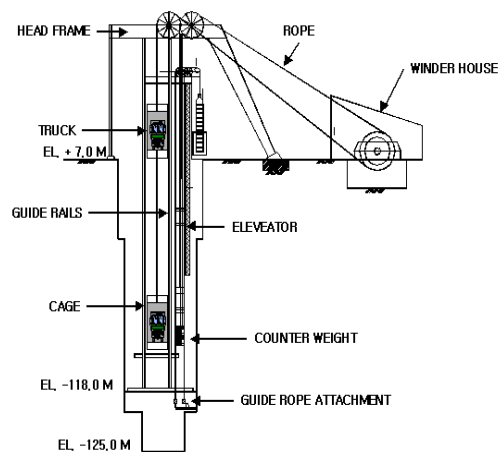


Figure 4. Car lift system in the vertical shaft Figure 5. Typical cross-sectional shapes of tunnels

5. Car lift system

Selection of a fast and efficient transporting system of excavation waste was a key issue. It was to convey 500,000 m³ of excavated material to the surface from caverns at -127 m in depth. Among a few candidate systems, cage-type car lift system was finally selected. In the selected system, the fragment size of blast waste was not critical and the down time of the machinery was expected to be minimized. The machineries for extracting muck were wheel type bucket loaders for loading, dump trucks for transporting, and backhoes for cleaning.

In this system, the optimal combination of equipment and volume control of generated muck were primary factors to consider. The maximum capacity of the car lift system was 30 ton and the muck generation rate was calculated to be 3,000 m³ per day. The calculated mucking rate was controlled and the operation of the machinery was carried out based on the critical path. Figure 4 presents the car lift system.

6. Pre-grouting to control underground water

Since the facility is located at -127 m under water table, high water pressure was of great concern. The main purpose of grouting was to control seepage to an acceptable level in order to prevent ground water table from lowering, to prevent excessive desaturation of the rock mass and to enable work to proceed without constraint. In this site, typical grouting did not work out because of great water pressure, water leakage (over 1,500 m³/day), and sudden change of hydraulic gradient. Instead of typical grouting, the long-hole grouting was performed in the zone at which large amount of ground

water inflow was expected and it was done by pre-grouting method fitted with strainer to maintain good intrusion of filling cement in the long holes.

7. New blasting method

Considering the various tunnel shapes (Figure 5) and rock conditions, it was decided that blasting was the most economical excavation method for the whole rock excavation. The V-CUT and LC-CUT blasting methods had been widely used, but it was disclosed that those methods had only 83% blasting efficiency. Accordingly, SAV-CUT method was developed and used to overcome the shortcomings of other methods. Figure 6 shows the blast hole pattern for the method. SAV-CUT had advantages in reducing the degree of charge concentration in the center of cut and blast vibration by using an additional blast hole with deck charge. The safety and performance were proved in the real blasts. Figure 7 presents the comparison of blast performance for three different blasting methods.

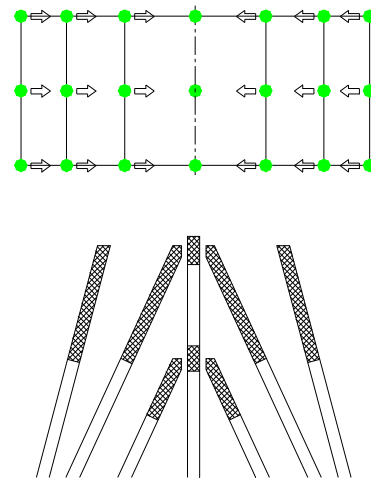


Figure 6. Blasting pattern of SAV-CUT

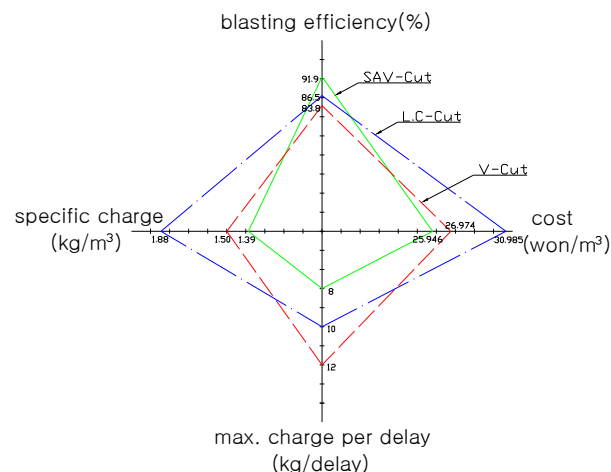


Figure 7. Comparison of three different blasting methods

8. Conclusions

New technologies and challenging tasks for the cavern construction in great depth with large span have been carried out in the Y-2 Project.

- Shaft slurry wall construction method was introduced for the first time in Korea and the task was challenging due to the depth of 62 m.
- Car lift system was successfully operated to provide with safe and efficient transporting means in the project.

- Efficient water leakage protection was possible by using long-hole grouting method fitted with strainer.
- SAV-CUT blasting method was developed and applied to increase the blasting performance.

Y-2 Project was completed successfully in July 2000, applying the various new technologies. The experience accumulated in this project will be of great help in the future project of similar type.

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