Feasibility Study of Underground LNG Storage System in Rock Cavern

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ABSTRACT

It is difficult to solve problems regarding the adjustment on demand and supply of liquefied natural gas (LNG) due to seasonal variations of domestic demand of LNG, discordance among import pattern, limits of storage facilities, and so on. Therefore, it is very important to secure large LNG storage facilities and to stabilize LNG supply management on a long term basis. A new concept of storing LNG in a lined rock cavern with containment system has been developed by Geostock, SKEC and SN Technigaz with the help of KIGAM. To demonstrate the feasibility of this concept and validate numerical modelling and calculations, a pilot plant was constructed at KIGAM in Daejeon Science Complex in 2003, which had been under operation for storing LN2 (Boiling Temperature: -196°C) since January 2004, and now been decommissioned. The objective of this study is to examine the real-scale applicability of a lined underground rock storage system, which has been verified by a successful operation of the Daejeon LNG pilot plant. The new technology has many advantages of better economy, safety and environment protection, for above-ground and in-ground storage systems. The results of this study may promote the first ever real scale underground LNG storage system in a rock cavern.

1. INTRODUCTION

Nowadays the demand of LNG in Korea is growing rapidly. But it is difficult to solve problems regarding the adjustment on demand and supply of LNG due to seasonal variations of domestic demand of LNG, discordance among import pattern, limits of storage facilities, and so on. Also there may be instability in LNG supply due to chances of accidents at LNG producing areas. Therefore, it is very important to secure large LNG storage facilities and to stabilize LNG supply management on a long term basis.

In general above-ground tank or in-ground tank type have been used worldwide to store LNG. These types have some problems such as need of large site for storage tanks, ground settlement, high operating costs, and so on. So some attempts were tried in the past to store LNG underground in unlined containment but were not successful. The failure of underground storage cavern was due to the thermal stresses generating cracks in the host rock and thermal cracks contributing to induce gas leakage and to an increase in heat flux between LNG and the ground. Facilities were therefore decommissioned due to their excess boil-off rate of the stored LNG.

A new concept of storing LNG in a lined rock cavern with containment system has been developed by Geostock, SKEC and SN Technigaz with the help of KIGAM. To demonstrate the feasibility of this concept and validate numerical modelling and calculations, a pilot plant was constructed at KIGAM in Daejeon Science Complex in 2003, which had been under operation for storing LN2 (Boiling Temperature: -196°C) since January 2004, and now been decommissioned.

The objective of this study is to examine the real-scale applicability of a lined underground rock storage system, which has been verified by a successful operation of the Daejeon LNG pilot plant.

2. CONCEPT OF LNG LINED ROCK CAVERN SYSTEM

The basic concept of the system is based on the combination of a containment system to ensure for LNG with rock protection against thermal shock and a drainage system during the early months of the storage operation and before the freezing of the surrounding rock. This drainage will be used to drain groundwater around the cavity and prevent hydrostatic pressure from acting against the containment system.
When the rock mass around the cavern has been chilled up to an expected depth to absorb the hydrostatic loads, the drainage pumps are stopped to allow water to seep into the cold rock and form, in a controlled manner, an impervious ring of ice, forming a double thermal barrier. The concept also consists of protecting the host rock from an extremely low temperature by using a containment system with gas-tight steel liner and insulation panels as illustrated in figure 1. Moreover, the moderated and controlled frost development in the surrounded rock mass contributes to create an ice ring, acting as a secondary barrier against any possible leakage.

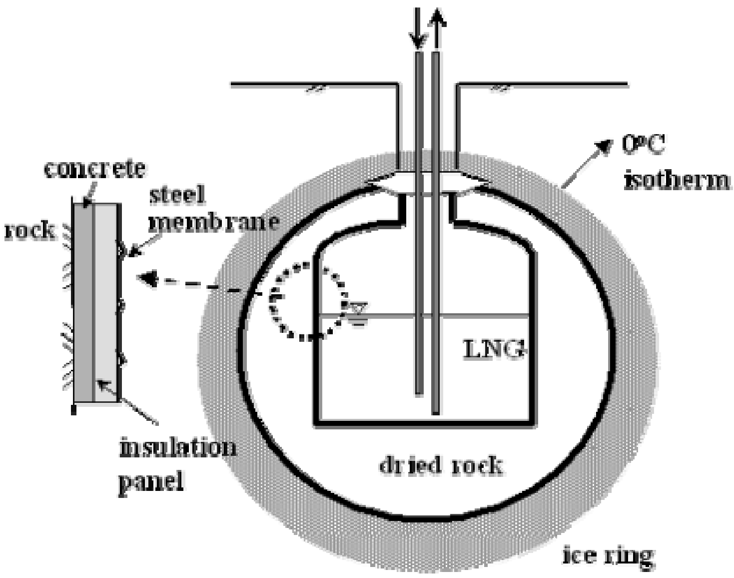
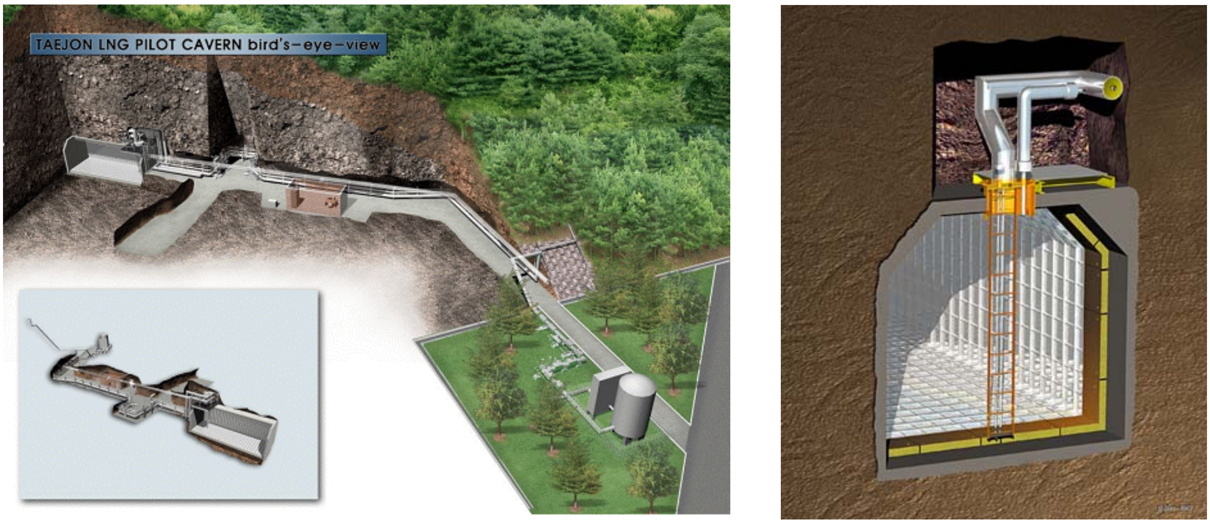


Fig. 1. Schematic structure of an underground LNG storage cavern.

3. THE LNG PILOT CAVERN

The objectives of this pilot project are: to demonstrate the feasibility of the technology, to check adequacy between the results of previous computations and laboratory tests regarding in-situ measurements, to test the overall performance of the storage and to have an efficient return of experience to improve design and construction of industrial scale projects.
The LNG pilot cavern is located in Daejeon, about 200 km south of Seoul, in an existing cavern implemented within KIGAM research centre area. The experimental cavern roof lies at a depth of about 20 m below the ground surface. In order to have the containment system completed, a concrete wall closes the entrance of the cavern. Additionally, a platform above the entrance of the cavern is made to install instruments, manhole and piping. The internal dimensions of the completed pilot plant have a sectional dimension of 3.5m x 3.5 m, a length of 10 m, amounting to a working volume of 110 m^3 (see figure 2).
The containment system, which is used for underground lined rock caverns, is similar to the one used and improved by SN Technigaz since 1962 for the membrane type LNG storage tanks and LNG carriers. The modular structure of the containment system makes it very flexible, improving construction and adaptation to cavern geometry. The thickness of the insulating panels can be chosen

as per the requirement of the thermal efficiency and the nearly unstressed membrane permits its usage in very large scale future projects.
The containment system is composed of several layers, from rock to LNG (see figure 3) as follows. A concrete structure ensures the transition between the containment system and the rock. It is made of reinforced cast in place concrete for the Daejeon LNG pilot cavern. Insulating panels made of foam are sandwiched between plywood sheets and are bonded on the concrete using load-bearing mastic. The insulation panel thickness is 300 mm so that the rock temperature will not fall below –50°C after 30 years and the boil-off rate will stay at acceptable limit. Finally, a 1.2 mm thick stainless steel corrugated membrane attached to the insulation panel provides gas tightness at low temperature. All the surfaces (e.g. bottom, walls, chambers and vault) are covered with concrete lining, insulating panels and the stainless steel membrane sheets.



(a) (b)

Fig. 2. A bird's-eye-view (a) and cross section (b) of the Daejeon pilot cavern.

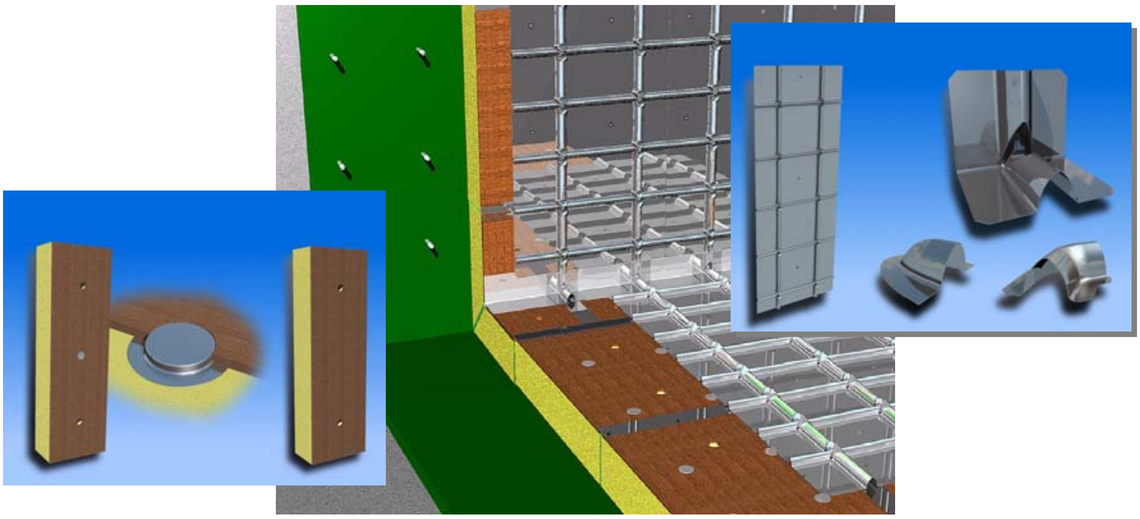


Fig. 3. Containment system used for the pilot cavern.

4. PROCESS AND THE PILOT INSTRUMENTATION

For safety and practical reasons, liquid nitrogen is used instead of LNG. The cryogenic pilot is operated from a laboratory room located in the access tunnel. It houses the Data Control System (DCS) for the process of the cryogenic pilot and for the geotechnical monitoring. An LN2 plant is

installed outside in a fenced site, containing one LN2 storage tank, a vaporizer and associated control systems in order to inert, cool down the cryogenic pilot, fill it completely with LN2 and compensate for the gaseous N2 boil-off (see figure 4).
These operations use two insulated pipes from this dedicated site to the cryogenic pilot through the access tunnel and the special local enlargement in the cavern roof to go over the plug and penetrate inside the cavern. The additional line is necessary to release overpressures if they happen. Some instruments installed in the containment system and cavern permit to follow the main parameters (inner pressure and temperature, LN2 level, containment deformation) and to operate the pilot.

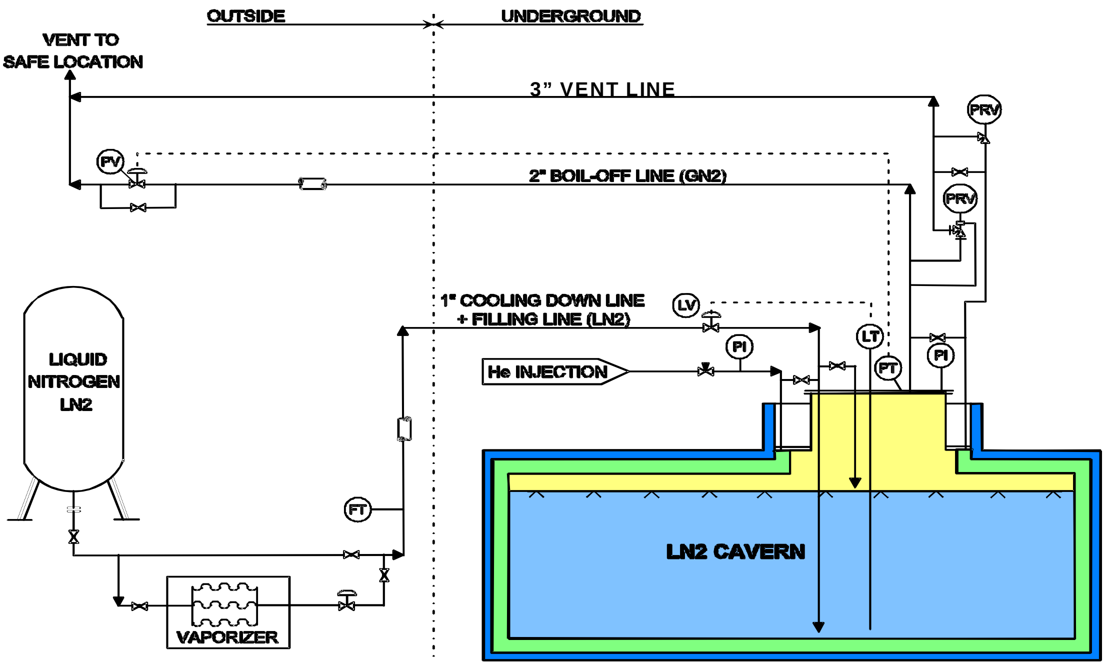


Fig. 4. Daejeon Pilot Cavern – Schematic process flow diagram.

5. PILOT TESTS

A comprehensive monitoring system was provided for measuring temperature, thermo-mechanical and groundwater responses of the rock and concrete during the implementation of the LNG storage. Also numerous parameters such as LN2 level, temperatures, pressure and boil off rate for the containment system were monitored during the operation. The behaviour of surrounding rock and the containment system was recorded during three successive phases of operation: a) first six months duration during which a full level is maintained by filling with LN2 in order to compensate for loss of boil-off, b) second six months during which no more filling is performed allowing the cavern to empty naturally, and c) third six months during which the empty cavern is heated up till the ambient temperature is reached and the pilot cavern is decommissioned.
The results from the pilot test confirmed that both construction and operation of underground LNG storage in lined rock caverns are technically feasible. Major conclusions of the test can be summarized as follows:

a) Thermal responses of the rock mass under very low temperature of about -30°C around the rock cavern could be well predicted by numerical models.
b) Thermal stress-induced displacements occurred toward inner rock mass, which is favorable to stability aspects of the cavern (see figure 5). And conventional rock reinforcements such as rockbolt and shotcrete remain effective at very low temperature during the pilot operation.

c) From the results of hydro-thermal analysis, ice ring can be formed easily based on the assumption that average distance of zero degree isotherm reaches 3 or 4 meter from the cavern wall in rock mass with the hydraulic conductivity of 10^{-7} to 10^{-6} m/s by controlling groundwater drainage system (see figure 6). In order to keep the continuous propagation of zero degree isotherms, groundwater close to cavern end faces should be effectively drained. Furthermore, any insulation or equivalent material should be applied carefully on such end faces of cavern.

d) By comparing Boil off gas ratio (BOR) occurred during operation of the pilot with estimated ones, BOR from underground LNG storage cavern can be estimated by numerical and theoretical methods (see figure 7).

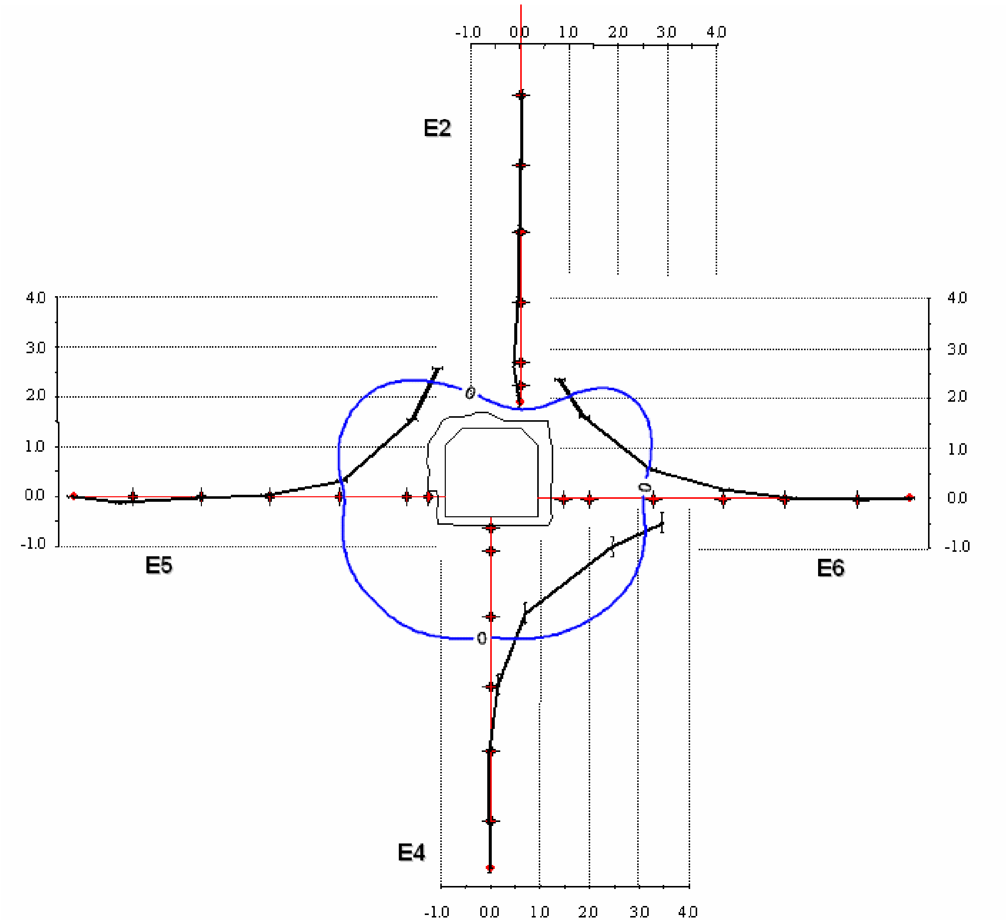


Fig. 5. Displacements in rock mass around the pilot cavern (+: toward rock mass, -: toward cavern).

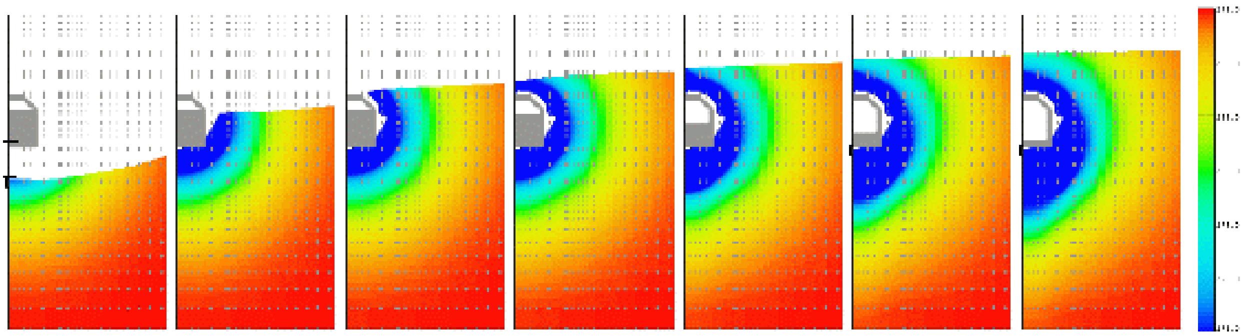


Fig. 6. Simulation results for ice ring formation around the pilot cavern.

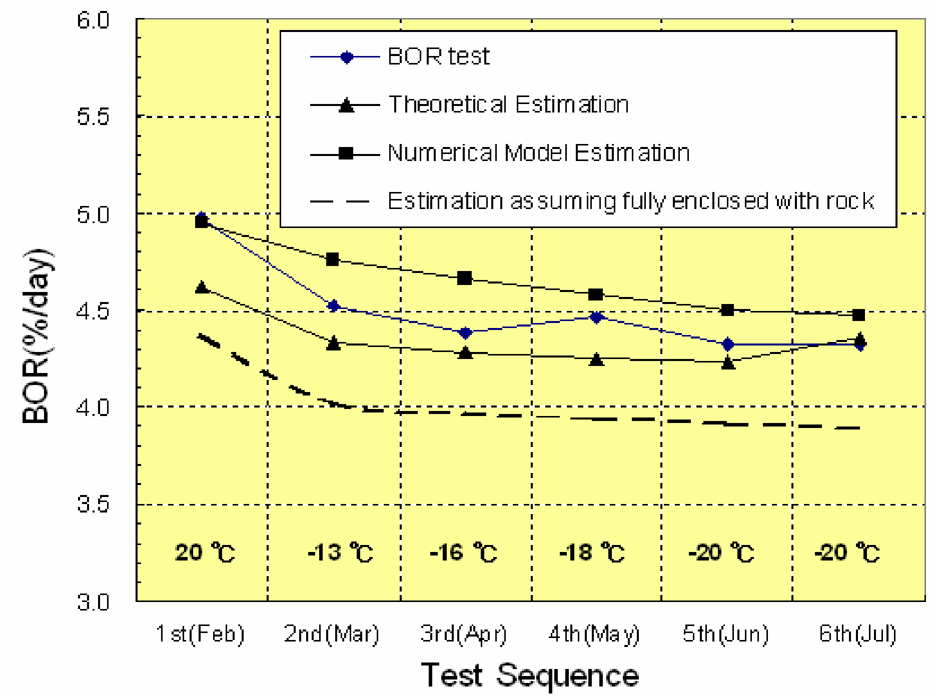


Fig. 7. Boil-off gas ratio occurred during operation of the pilot cavern.

6. CONCLUSIONS

In this paper, the real scale applicability of a lined underground rock storage system has been evaluated by the results from a successful operation of the Daejeon LNG pilot plant. The results from the pilot test confirmed that both construction and operation of underground LNG storage in lined rock caverns would be technically feasible. The new technology has many advantages of better economy, safety and environment protection compared with above-ground and in-ground storage systems. The results of this study may promote the first ever real scale underground LNG storage system in a rock cavern.

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