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A case study on the efficiency test of groundwater drainage system for Taejon LNG Pilot Cavern

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Abstract: For Taejon LNG Pilot Cavern being constructed to verify the technical aspects for storing LNG in lined rock cavern, efficiency tests of groundwater drainage system composed of many pumps and boreholes were performed around the cavern before and after the construction of concrete lining. Through evaluation of water balance and monitoring of pressures and flowrates, even if the present drainage system is very good for reducing water entries into the cavern, non-negligible water is still flowing in the floor of the cavern concrete due to heavy rainfall. To improve the drainage efficiency, additional drainage holes and some grouting were planned.

1. Introduction

Many attempts have been made to store LNG underground but few were successful. In ground storage failures were due to thermal stresses generating cracks in the host soil and thermal cracks contributed to induce gas leaves and to increase in heat flux between LNG and ground. Facilities were then decommissioned due to their excess boil-off rate. To provide a safe and cost-effective solution, GEOSTOCK and SN TECHNIGAZ from France have worked during last several years in developing a new concept storing LNG in a hard rock lined cavern. And with the support of SKEC from Korea providing a convenient rock site (Taejon KIGAM) and participating to detail design, construction and operation, Taejon LNG Pilot Cavern project is carrying out nowadays. The basic concept developed is based on the combination of: - a containment system to insure LNG containment and rock protection against thermal shock, - a drainage system used during the first months of the storage operation, before the surrounding rock is frozen, to drain water around cavern and prevent hydrostatic pressure acting against containment system. When sufficient thickness of rock has been chilled around the cavern to adsorb the hydrostatic loads, drainage pumps are stopped to allow water to seep into the cold rock and form, in a controlled manner, an impervious ring of ice (i.e. forming a double barrier concept).

The drainage system during the second test is composed of 18 boreholes (15 for first test): seven (7) boreholes (D4, D7, D9, D10, D11, D12 and D17) are downwards below the cavern floor (six (6) boreholes for first test), two (2) boreholes (D6 and D18) are horizontal beside the cavern wall (only D6 for first test), nine (9) boreholes (D1, D2, D3, D5, D8, D14, D15, D16 and D19) are upwards above the cavern roof (eight (8) holes for first test). Fig. 1 shows the overall arrangement of drainage holes around the cavern.

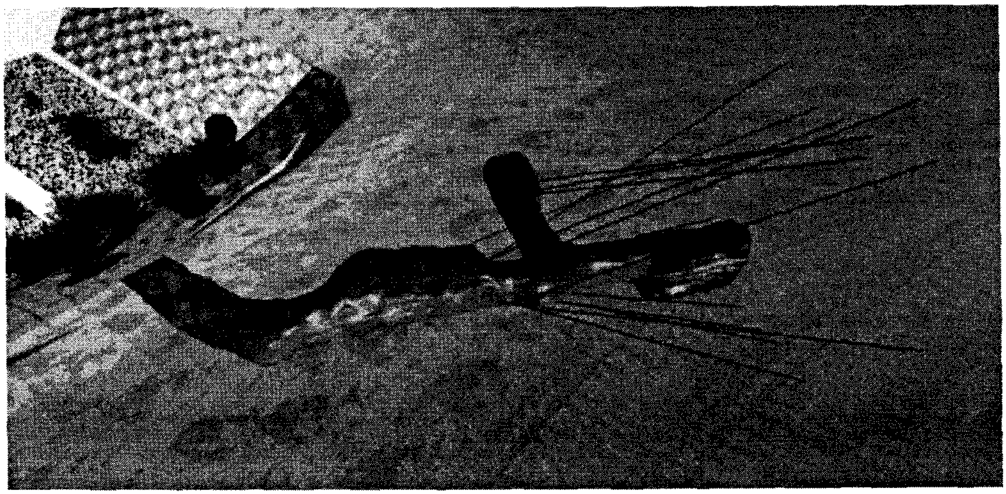

Fig. 1. Overall arrangement of drainage holes for Taejon LNG Pilot Cavern.

To test the efficiency of the drainage system, two tests were performed before and after the construction of the concrete lining. The purpose of the first efficiency test (performed on April 2003) is to test, before concrete casting and cooling phase, the objectives of the drainage system. The purpose of the second efficiency test (performed on August 2003) is to test the efficiency of the drainage system to reduce the water entries in the cavern, after the concrete casting and before the cooling phase, and to compare the results with the first test. The procedure of the test was the same as for first test, composed of four successive phases:

Phase 1: Initial hydro-geological status. All the boreholes are filled with water then closed. Wellhead pressure on each borehole, water level in surface piezometers and R1 recharge hole, and seepage flowrates in Pilot Cavern and galleries are measured four times a day until the stabilization.

Phase 2: Drainage of one hole out of two. One hole out of two is open for water drainage and the other holes remain close. The upward holes are opened to atmospheric pressure, while the downward holes are pumped using electrical pumps. Wellhead pressure on each borehole, water level in surface piezometers and R1 recharge hole and seepage flowrates in Pilot Cavern/Galleries and individual flowrates on open holes are measured four times a day.

Phase 3: Full drainage. The 18 holes are open for water drainage. All test programs are similar to Phase 2.

Phase 4: Full drainage and Recharge on R1. The phase-3 drainage holes status is maintained and the R1 recharge hole is injected with water coming from an underground tank located on the top of the hill. Wellhead pressure on each borehole, water level in surface piezometers, wellhead pressure and injection flowrate on R1 hole and seepage flowrates in Pilot cavern/Galleries and individual flowrates on all holes are measured 4 times a day until the stabilization.

During all these operations, total water flow balance was carefully recorded in order to evaluate as accurately as possible the net water seepage rates.

2. Results of the efficiency tests

Analysis of water balance

The results of the test obtained during the four phases can be summarized in the following Table 1 presenting the water balance of the site in liter/hour and the efficiency of the drainage system compared to the first test. Figure 2 shows flowrates in cavern and galleries according to duration time of the second test.

Table 1. Water balance of the Taejon LNG Pilot Cavern site during the efficiency tests (l/hr).

	Phase 1		Phase 2		Phase 3		Phase 4	
	April 03	Aug. 03	April 03	Aug. 03	April 03	Aug. 03	April 03	Aug. 03
Q Pilot cavern	70	280	10	12	7	85	200	105
Q Daejon galleries	5	820	3	220	2	900	16	620
Q Drainage	0	0	200	1000	250	1700	1350	3200
Q water table	-75	-1100	-213	-1232	-259	-2685	154	-2375
Q R1	0	0	0	0	0	0	-1720	-1550
Efficiency on cavern seepage	-	-	-86%	-96%	-90%	-70%	+186%	-63%
Efficiency on galleries seepage	-	-	-40%	-73%	-60%	+10%	+220%	-24%

The second test of August 2003 shows a very good efficiency in Phase 2 and even better than the one observed during the first test of April 2003. 96 % of reduction of the cavern water entries compared to 86% and 73% instead of 40% when considering galleries water entries.

Due to heavy rainfalls recorded at the end of Phase 2 and beginning of Phase 3, the efficiency of second test in Phase 3 cannot be calculated. It should be theoretically little better than in Phase 2 (refer to first test) so more than

96% compared to 90% in April 2003. The relative efficiency taking into account the influence of rainfalls is around 70% for cavern seepage. The analysis of the water balance leads to the following results:

- In phase 2: upon the 1000 l/hr drained by the 9 holes, 868 l/hr (87%) correspond to the reduction of water seepage in Pilot Cavern and Galleries, and 132 l/hr (13%) comes from the water table surround the cavern. This result is much better than for first test where the ratio were respectively of 31 and 69%. This improved efficiency is due to 3 additional drainage holes drilled on the right side of the cavern to cross the two main joints encountered in cavern in several points after the first test.
- In phase 3: during the first test, upon the 250 l/hr drained by the 15 holes, 66 l/hr (26%) correspond to the reduction of water seepage in Pilot Cavern and Galleries, and 184 l/hr (74%) come from the water table surrounding the cavern. However, during the second test, upon the 1700 l/hr drained by the 18 holes, only 115 l/hr (7%) correspond to the reduction and 15865 l/hr (93%) come from the water table. This result is fully due to the influence of heavy rainfalls, which increased in cavern seepage and especially the seepage of the galleries. Instead of a decrease compared to Phase 2, we note an increase of 73 l/hr for the cavern seepage and an increase of 680 l/hr for the galleries seepage.
- In phase 4: upon the 1550 l/hr injected in R1, 1500 l/hr (96.8%) are drained by the 15 holes compared to phase 3 (3200-1700 l/hr). During the first test, the increase of drainage flowrates was only 1100 l/hr (64% of injected R1 flowrate). 20 l/hr (1.3%) are infiltrated in Pilot Cavern compared to phase 3 (105-85 l/hr). During the first test, the increase of seepage was 193 l/hr (11.2% of R1 flowrate) for Pilot Cavern and 14 l/hr (0.8% of R1 flowrate) for Galleries in April 2003. So the remaining 30 l/hr (1.9%) go to water table during the second test.

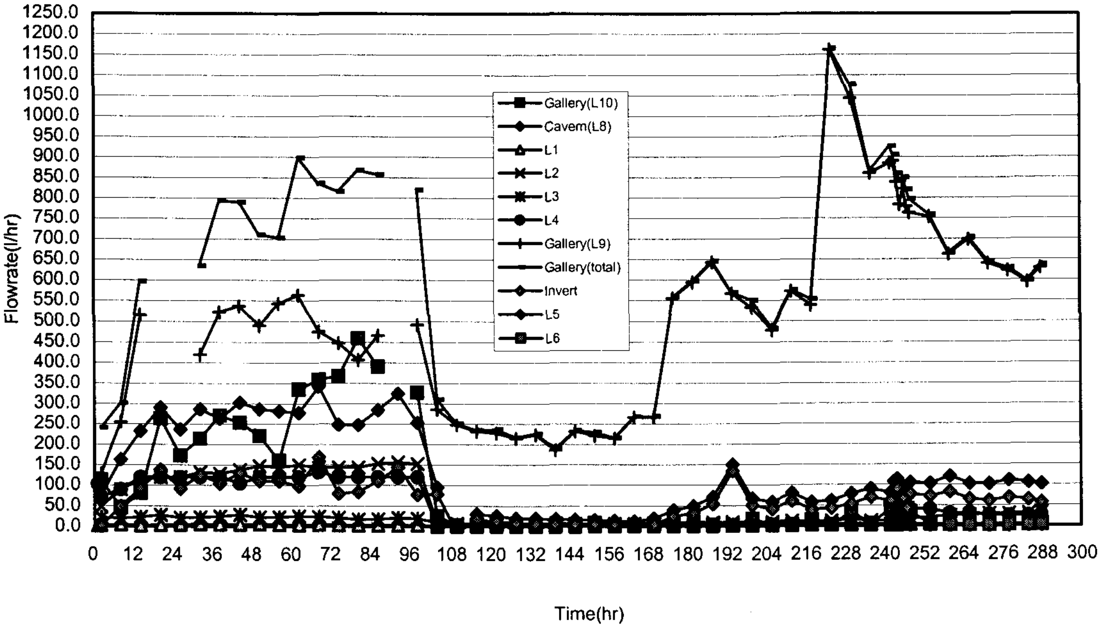

Fig. 2. Flowrates in Cavern, Galleries, Ditch and leakage points during the second test.

The global efficiency after the construction of the concrete lining of the new system with 18 boreholes is better than for the first test in April 2003 with 15 boreholes. However, in spite of the very good efficiency of the system and the important flowrate taken from the water table, we still observe a pressure of about 1.2 bar on upward borehole D8 at the end of Phase 3 and we do not observe a decrease of the recharge hole R1. Therefore, to reduce the pressure of D8, it is necessary to consider additional drainage holes close to D8 and/or the removal of wellhead of D8 to increase the flowrate. Also, even of the efficiency ratios for the cavern are very high for this second test and even for Phase 4, an important seepage increase is observed in case of high rainfalls. Moreover, the remaining water seepage (about 4 to 5 l/hr) in Phase 2 inside the cavern and below the invert drained to the ditch (about 1 to 65 l/hr), are not negligible regarding the detrimental formation of ice below both the membrane and the concrete floor during the cooling phase.

Influence of seasonal variation on static potential of drainage boreholes

Phase 1 can simulate initial hydrogeological status in rock mass around the cavern because all the boreholes are filled with water until stabilization of pressures and seepage rates. The first test seems to correspond to dry season without important rainfall because the test was performed in April. The second test seems to correspond to rainy season with heavy rainfalls, which was recorded in Taejon since July (576.3mm in July and 190.4mm in August). Therefore, we can evaluate the variation of hydraulic potentials acting on the rock according to seasonal variation.

Fig. 2 shows the static potentials referenced from the invert in all the boreholes after the stabilization in Phase 1 during both first and second test (height of 3.1m between roof and invert). The stable pressure measured on the boreholes appears higher than during the first efficiency test, corresponding to higher hydraulic head above the cavern (from –2.9 to +8.3 m of hydraulic head above the cavern roof compared to –3.4 to +4.1 m during the first efficiency test). These values are consistent with the surface piezometers and porepressure cells measurements, which show higher water table above the cavern roof. This status can be related to the cumulative effect of both influence of concrete lining construction, contact grouting and influence of the heavy rainfalls recorded in Taejon. As shown in Fig.2, especially D8, which was drilled upwards above the roof in left side rock mass, had 1.6m and 8.3 m of heads above the cavern roof during first and second test respectively.

It can be concluded that average 2 m of head will act on above the cavern roof during dry season, while average 5 m of head will act during rainy season and heavy rainfall. It means that increase of average 3 m of head above the cavern is due to heavy rainfall in Taejon site. These data will be reflected on the design of drainage stop and water injection system to be mobilized during the cooling-down operation period. The rock mass around the cavern will be drained until early few months of cooling down period to obtain dry status. When the cold front has advanced far enough, drainage can be stopped to allow water to re-invade the rock progressively and quickly form a thick ring of ice of about 1 to 2 meters around the cavern so withstanding the outer water pressure.

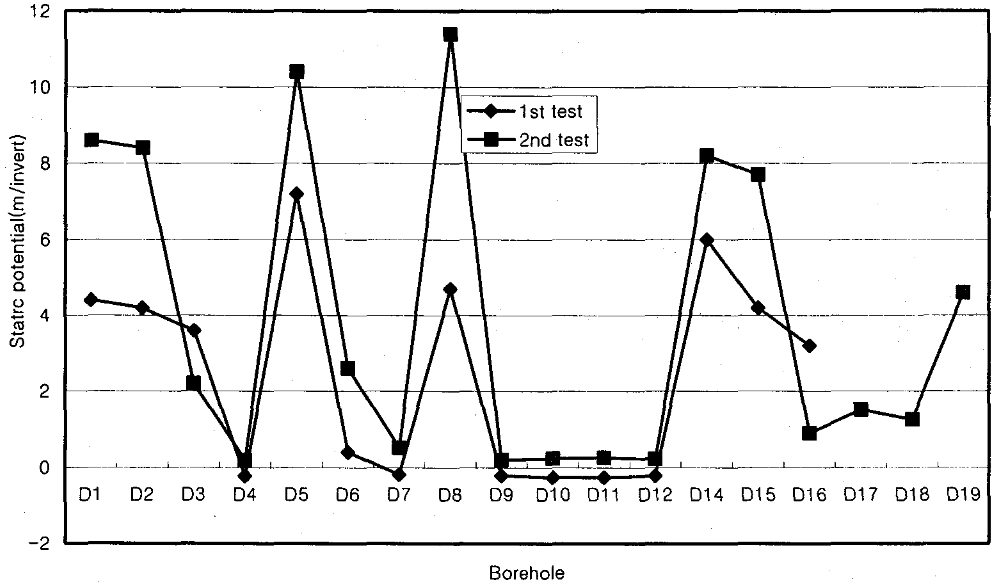

Fig. 3. Hydrostatic potentials in all drainage holes during the first and second test.

4. Conclusions

The efficiency of the present drainage system is very good for reducing the water entries in Pilot Cavern (refer to Phase 2 of the second test). The rate of water injected in recharge hole R1 flowing to the cavern is very low compared to the first test. However, even if the rate of water injected in R1 flowing to Pilot Cavern and Galleries is low more important seepage increase have been recorded in Phase 3 after high rainfalls (cavern seepage 7 times higher than in Phase 2 and galleries seepage 4 times higher). So the strong increase of the seepage due to rainfalls and especially the observation of non-negligible flows coming on the floor of the cavern and flows drained below the concrete invert, which will entail problems of ice formation during the cooling phase, leads us to recommend the following actions:

- Grouting of the drainage system below the concrete invert from the cavern ditch,
- Removal of wellhead of D8 hole to decrease the friction loss through packer and hose, and resultant improving of the drainage efficiency,
- Drilling of two additional downward drainage holes below the concrete invert to improve of drainage efficiency.

References

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