Advanced Natural Gas Storage (ANGAS) Project and Verification Tests of Experimental Lined Rock Cavern in Japan

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Abstract:

The Japan Gas Association (JGA) has been studying technologies of an underground natural gas storage system, a Lined Rock Cavern (LRC) gas storage system called ANGAS (Advanced Natural GAs Storage), since 2004. In this paper, we introduce the project and discuss some results of the verification tests of an experimental LRC (test cavern) based on the current work.

The ANGAS project has been performed for 4 years from 2004 to 2007. The purpose of the project is to develop a suitable LRC system for Japan, and to contribute to expanding use of natural gas. For example, it is necessary to study measures to shave off the daily peak load of natural gas through pipelines because, as a special characteristic in Japan, there is a large daily fluctuation of gas supply in a day and we expect the ANGAS is one of key countermeasures for peak shaving. Then, there is a possibility of LRC as a new storage system for inland areas.

In the project, our goal is to ensure the design method for commercial types of the LRC system, under the Japanese geological conditions of the limited distribution of hard rock, referring to the results of the experiments using the test cavern.

Main design conditions for the commercial types are shown as follows:

a) Maximum storage pressure: 20MPa

b) Maximum geometrical volume of the cavern: 20,000 m^3

c) Number of cyclic loading: 10,000 cycles

d) Rock classes: the classes from middle-hard rock to hard rock

e) Thickness of the steel lining: less than 20mm

According to the design method examined in previous researches conducted for 3 years from 2000, the main procedures of the design and numerical analysis are as follows:

1) Resistance of the rock mass against uplift force
2) Stability of the rock cavern and the support system under the condition of excavation
3) Behavior of the rock cavern under the condition of operation
4) Behavior of the steel lining under the condition of operation
5) Behavior of the plug under the condition of operation
6) Discontinuous displacement between the cavern and the plug under the condition of operation
7) Stability of the manhole under the condition of operation
8) Temperature variation of the cavern during injection and withdrawal

Using the above design method and procedures, we designed the small test cavern which is located at the Kamioka mine, the midland of Japan, and which was completed in 2006. The location is showed in Figure 1. The test cavern of 6.0 m in diameter, 10.5 m in length and about 240 m^3 in volume was excavated through an existing mine drift face at the depth of 400 m below the ground surface. The test cavern is surrounded by a sedimentary rock mass called the Tedori Group which consists of mainly sandstone and mudstone. The schematic view of the test cavern is shown in Figure 2.

Based on the results of the geological survey, the core samples taken from some boreholes, the borehole expansion tests and the rigid plate loading tests, the important mechanical properties for the design, such as a modulus of deformation, a creep ratio and a residual strain ratio of the in situ rock mass, were evaluated. In addition, the initial stress of the rock mass was measured.

Basically, each commercial type of the LRC system is shaped like a cylinder vessel with a hemispherical top and bottom, whose longitudinal axis is in the vertical direction. However, we must keep a certain constrained size of the plug even though that is a small LRC, because it is constrained by the sizes of the access tunnel and the manhole which is constructed in the plug. As a result, the ratio of the size of the plug to the cavern of the small LRC is relatively larger than the commercial type's. Therefore, the influence of the large ratio on the behavior of the steel lining and the concrete should be

restricted within a certain narrow area and ideal boundary conditions are desirable to correctly evaluate the results of the experiments. From these perspectives, the test cavern was finally shaped like a cylinder vessel with one of the hemispherical ends connected to the plug as showed in Figure 2. Then, the boundary conditions of the cavern and the plug are almost axisymmetric along the same horizontal axis. Except the hemispherical end connected to the plug, the other part is predicted to have less influence of the plug. Photo 1～4 show the test cavern and the facilities.

The internal design pressure of the test cavern is 20MPa. The tests were performed in order to confirm the validity of the LRC system for Japan. The main contents of the tests are shown in Figure 3. The tests include a water pressure test (20MPa), an airtight test (20MPa), a cyclic and long-term test and a 30MPa-water pressure test. The behavior of the test cavern had been monitored during these tests using many measuring instruments, and the resistivity and airtightness for internal pressure up to 20MPa were confirmed. In addition, the resistivity up to 30MPa was estimated by the 30MPa-water pressure test.

The main measuring instruments are showed in Figure 4. The internal pressure, the temperatures and the pore pressures in the rock mass had been measured during each test, in addition to the measuring of the displacements and strains of the rock mass, the backfill concrete and the steel lining.

For example, the strains of the steel lining in the cross and longitudinal sections are showed in Figure 5. These strains in each of the section had been measured using an optical fiber strain sensing system. As a result, we were able to estimate that the steel lining was deformed up to plastic zone and the displacements of the surrounding rock mass were stable. The internal pressure and temperature measured during the airtight test are showed in Figure 6. We were able to estimate the air-tightness of the test cavern by the precise analysis of these data. The details of these results will be showed in our full paper.

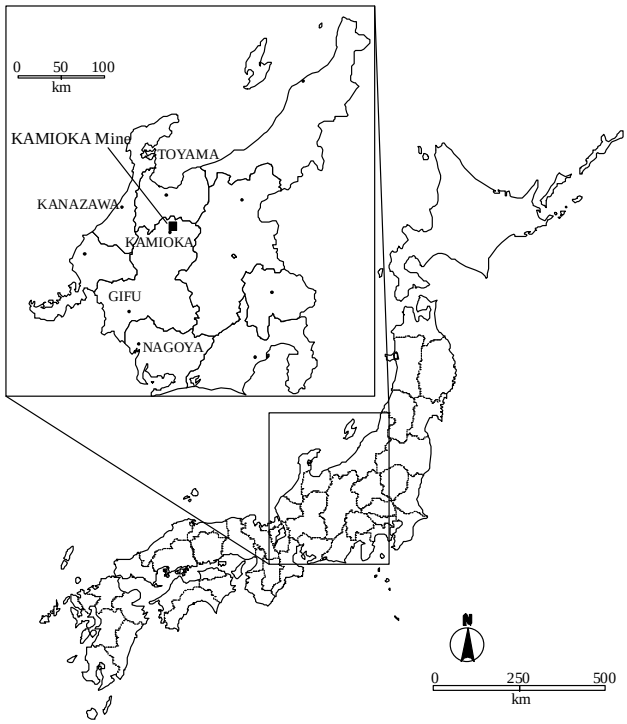

Figure 1: Location of Kamioka mine

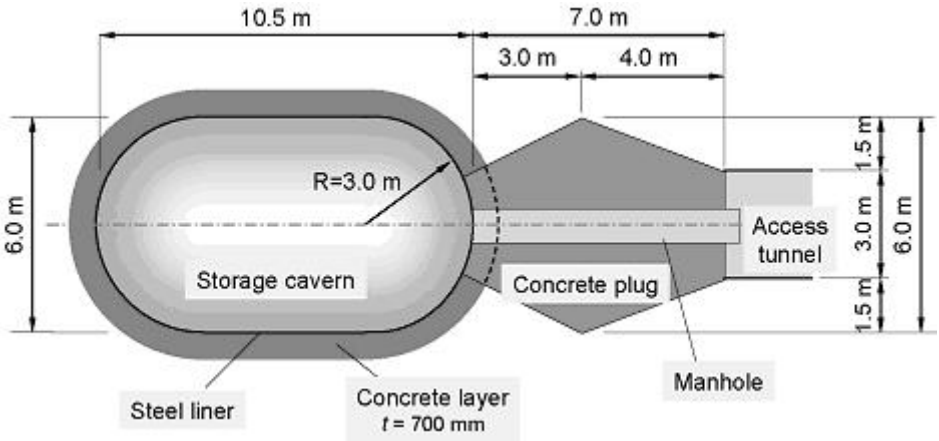

Figure 2: Schematic view of test cavern

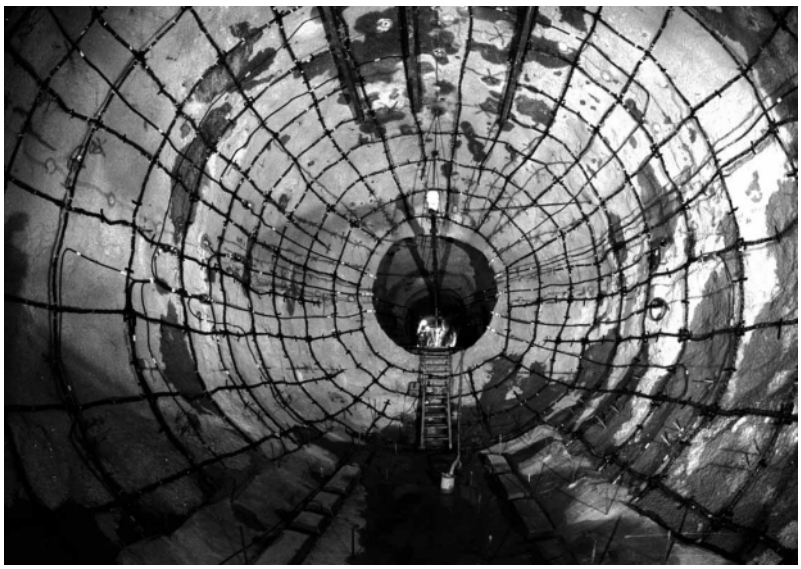

Photo 1: Excavated test cavern

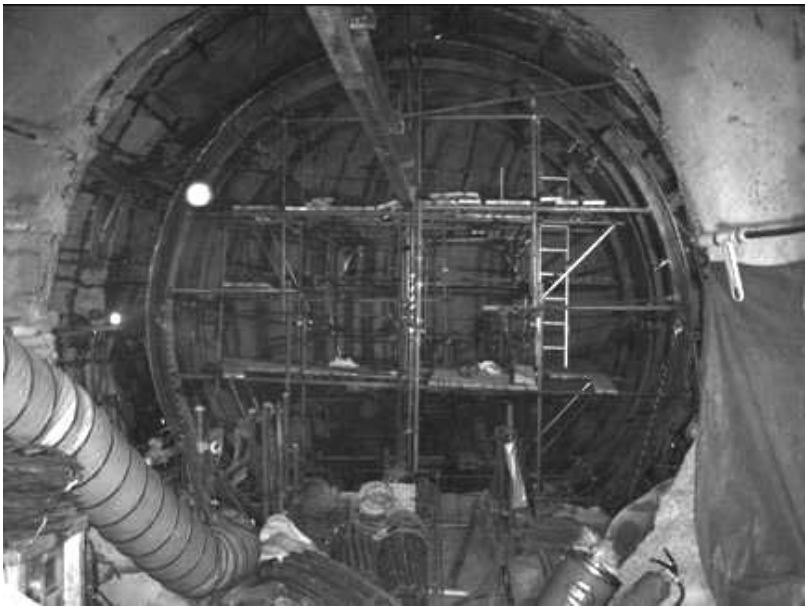

Photo 2: Steel lining during construction in test cavern

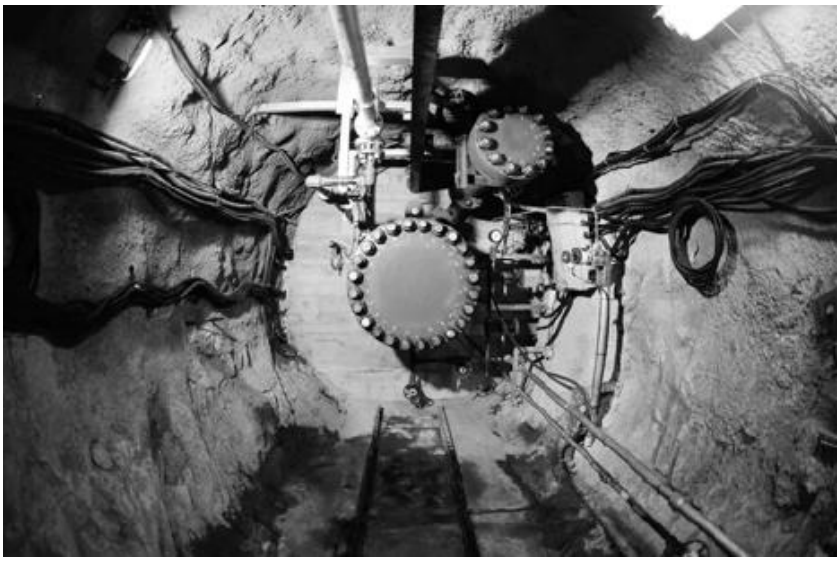

Photo 3: Plug of test cavern

Photo 4: Pump and Compressor for pressurization of test cavern

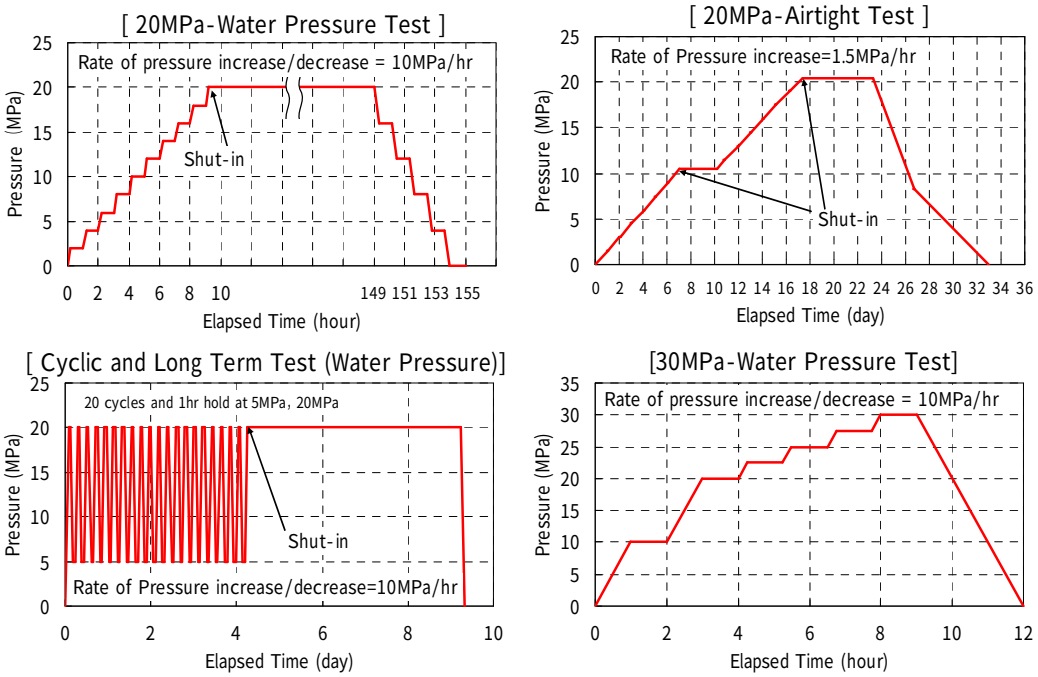

Figure 3: Contents of tests

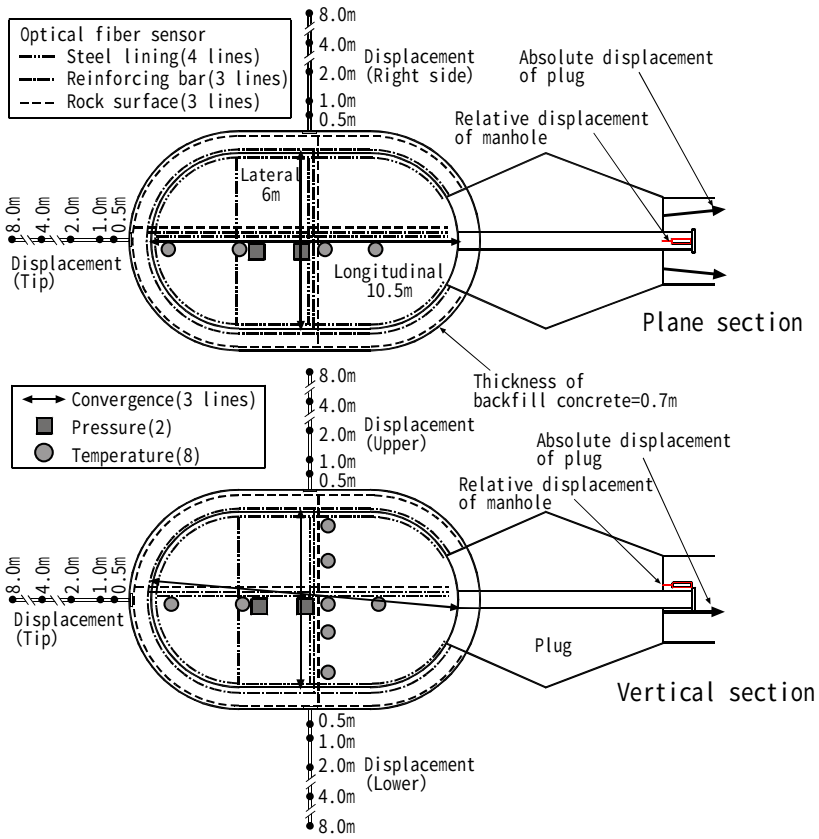

Figure 4: Main measuring instruments

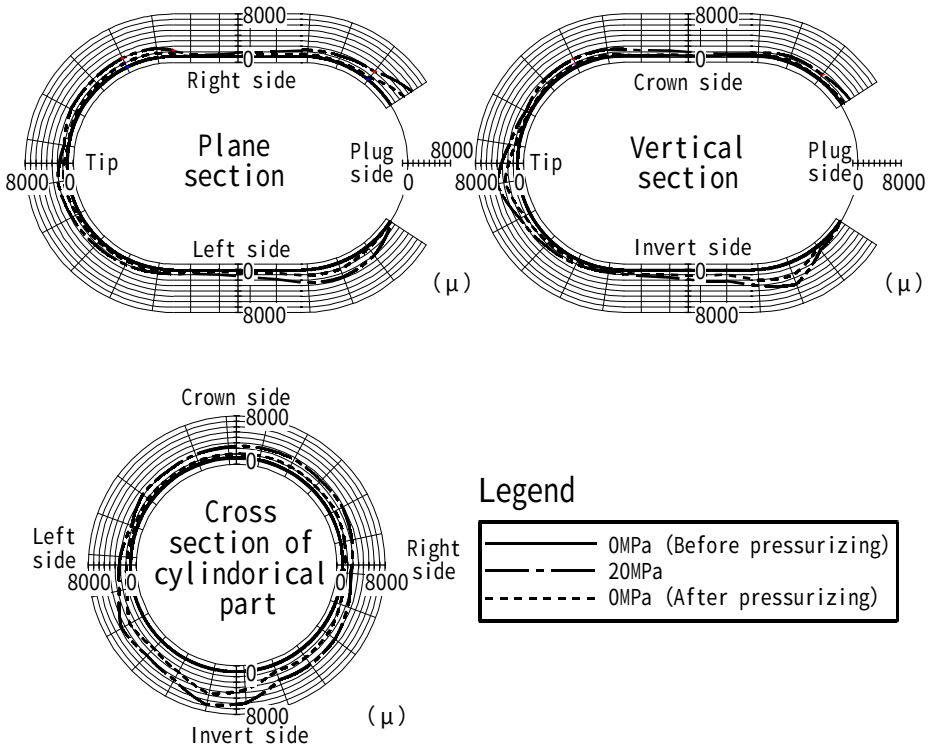

Figure 5: Strain of steel lining during 20MPa-water pressure test

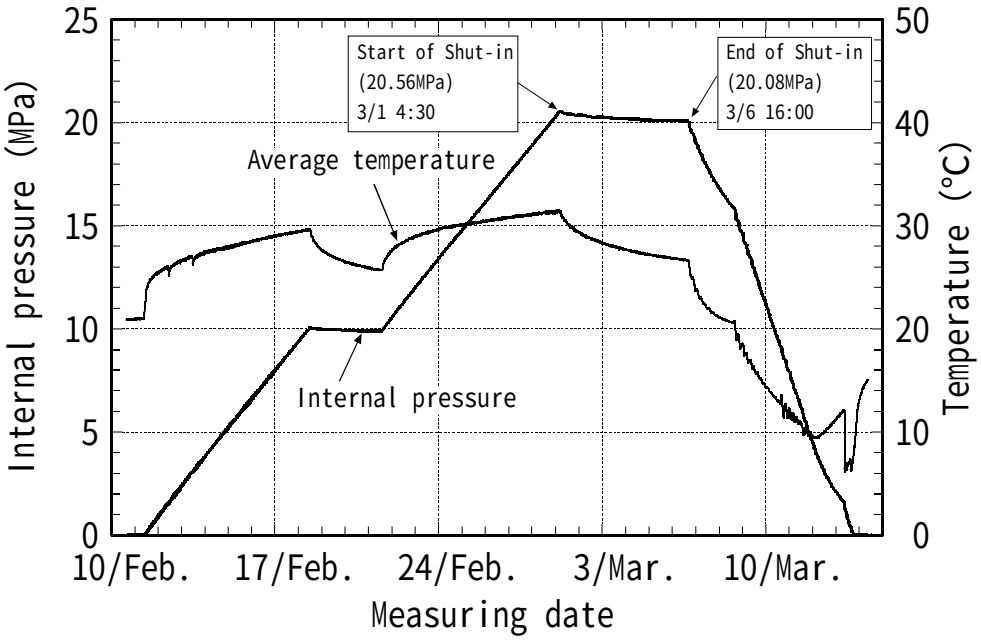

Figure 6: Internal pressure and temperature during 20MPa-airtight test