# THE ADVANCED NATURAL GAS STORAGE (ANGAS) PROJECT AND EXPERIMENTAL LINED ROCK CAVERN IN JAPAN

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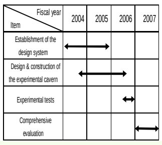
## 1. INTRODUCTION

The Japan Gas Association (JGA) has been studying technologies (Table 1, Fig.1) for an underground natural gas storage system, a Lined Rock Cavern (LRC) gas storage system called ANGAS (Advanced Natural GAs Storage), since 2004. We introduce the project and discuss the design of the experimental LRC based on the current work.

Table 1: Master schedule of ANGAS project



| Item \ Fiscal year | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|
| Establishment of the design system | ⟷ | ⟷ | | |
| Design & construction of the experimental cavern | ⟷ | ⟷ | ⟷ | |
| Experimental tests | | | ⟷ | |
| Comprehensive evaluation | | | | ⟷ |

## 2. LRC FOR JAPAN AND ANGAS PROJECT

### 2.1 Natural Gas Supply and Geological Conditions in Japan

- Insufficient development of city gas pipeline networks in Japan
- Demand and supply adjusted by spherical gas holders on small scale
- Demand for city gas in inland area is expected to increase in future (daily demand change; 200 times per year)
- Few sites such as aquifers and salt caverns
- Japanese rock mass is weaker and softer than its counterparts in Europe

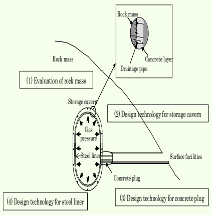


Fig. 1: Schematic view and key technologies of LRC

### 2.2 LRC System for Japan and ANGAS Project

- Principles of LRC:

A) Gas-tightness is ensured by steel liners.
B) Gas pressure is resisted by the surrounding rock mass.
C) Groundwater can be drained by drainage system

- Main design conditions for Japan (Key technologies; Fig. 1)

a. Maximum storage pressure: 20MPa
b. Maximum geometrical volume of the cavern: 20,000 m³
c. Number of cyclic loading: 10,000 cycles (200 cycles per year, service life 50 years)
d. Rock classes: the classes from middle-hard rock to hard rock
e. Thickness of the steel liner: less than 20mm

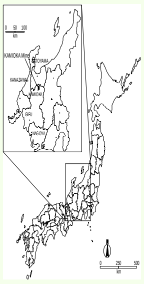


Fig. 2: Location of Kamioka Mine

## 3. EXPERIMENTAL SITE

### 3.1 Kamioka Mine (zinc and lead mine; Fig. 2)

- Confirmation of the validity of the LRC system and key technologies (Fig. 1)
- Experimental cavern (Test cavern; Fig. 3)

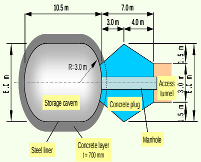


Fig. 3: Schematic view of test cavern

### 3.2 Geology

- Host rock of the Kamioka mine: the Hida gneiss or granitic rocks
- Test site's geology in the mine: the alternating layers of sandstone and mudstone (middle Jurassic to early Cretaceous Tedori Group )

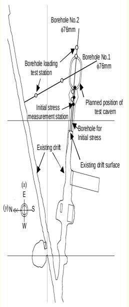
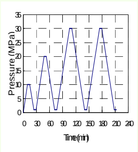


Fig. 4: Layout of test cavern and rock mass tests



## 4. PROPERTIES OF ROCK MASS

### 4.1 Borehole Survey (Horizontally drilled boreholes; Fig. 4)

- Investigations of core samples
- Hard rock ($C_H$) to Middle-hard rock ($C_M$) based on the typical Japanese rock mass classification

### 4.2 Tests for Rock Mass

- Borehole loading tests (Fig. 5), rigid plate loading tests, initial stress measurements, etc.
- Rock mass properties and initial stress for the design of the test cavern. (Table 2)

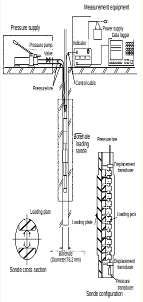


Fig. 5: Borehole loading test

Table 2: Rock mass properties and initial stress for design

| Property | | | Host rock | Excavation disturbed zone |
|---|---|---|---|---|
| Unit weight | | kN/m³ | 26.5 | |
| Thickness | | m | - | - |
| Angle of internal friction | | degree | 50 | 45 |
| Cohesion | | MPa | 2.5 | 1.9 |
| Deformation modulus | Initial loading | GPa | 10.0 | 4.0 |
| | During experiments | GPa | 8.47 | 3.38 |
| Poisson's ratio | | - | 0.3 | 0.4 |
| Creep ratio | | - | 0.180 | - |
| Residual displacement ratio | | - | 0.234 | - |

| | Measured value | Value for design |
|---|---|---|
| Longitudinal axis direction | 16.7 MPa | 16.7 MPa |
| Lateral direction (Horizontal) | 11.9 MPa | 9.5 MPa |
| Lateral direction (Vertical) | 9.5 MPa | |

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## 5. DESIGN OF EXPERIMENTAL LRC

### *5.1 Contents of Experiments* (Fig. 6)

- i. Exp.1: Pressure test (Water pressure)
- ii. Exp.2: Air tightness test (Air pressure)
- iii. Exp.3: Cyclic and long-term test (Water pressure)
- iv. Exp.4: Ultimate capability test (Water pressure)

### *5.2 Design Procedure*

- ➢ Main design procedure for test cavern (Fig. 7)
- ➢ Design analysis model; FEM (Fig. 8)

### *5.3 Deformation of Rock Cavern*

- ➢ Distribution of circumferential strain on concrete layer (Fig. 9)
- ➢ Maximum width of crack at representative positions of concrete layer (Table 3)

### *5.4 Deformation of Concrete Plug*

- ➢ Relative displacement between concrete layer and concrete plug (Fig. 10)

### *5.5 Stability and Deformation of Steel Liner*

- ➢ Selected specifications to be verified for liner and buffer (Table 4)
- ➢ Flow diagram of steel liner design (Fig. 11)
- i. Strain accumulation due to cyclic pressure load (Fig.12)
- ii. Overall buckling at the release of internal pressure (Fig. 13)
- iii. Local buckling (Fig. 14)
- iv. Strain concentration (Fig. 15)
- v. Fatigue failure (Discontinuous displacement between the concrete layer and the concrete plug; Fig. 16, 17, Table 5)

## 6. CLOSING REMARK

In conclusion, we were able to determine the specifications of the experimental cavern. We are now planning the measuring and monitoring system during the experiments. The cavern is under construction and will be completed within 2006. The results of these experiments will be useful for the construction of commercial LRC plants in Japan.

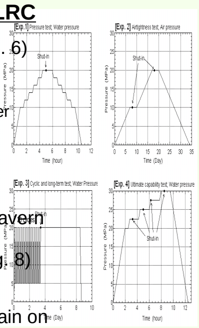

Fig. 6: Contents of experiments

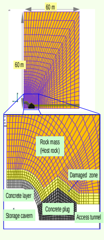

Fig. 8: Design analysis model (Axisymmetric model)

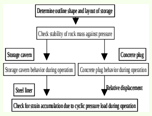

Fig. 7: Main design procedure

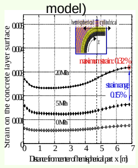

Fig. 9: Distribution of circumferential strain

Table 3: Maximum width of crack at representative positions of concrete layer

| Component | Position | Initial loading | During experiments | | |
|---|---|---|---|---|---|
| | | 20 MPa | 20 MPa | 5 MPa | 0 MPa (Pressure release) |
| Meridian direction | Center of hemispherical part | 1.17 | 1.35 | 0.79 | 0.32 |
| | Center of cylindrical part | 0.17 | 0.22 | 0.24 | 0.05 |
| Circumferential direction | Center of hemispherical part | 1.17 | 1.35 | 0.79 | 0.32 |
| | Center of cylindrical part | 1.36 | 1.59 | 0.82 | 0.37 |

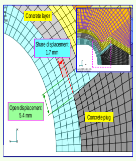

Fig. 10: Relative displacement between concrete layer and plug

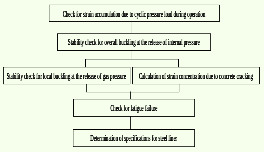

Fig. 11: Flow diagram of steel liner design

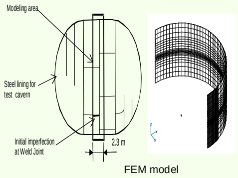

Fig. 14: Outline of analysis model for local buckling

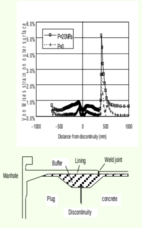

Fig. 16: Analysis model and strain distribution for discontinuous structure

Table 4: Selected specifications to be verified for liner and buffer

(a) Material specification

| Selected material | Thickness | Elastic modulus | Yield stress | Hardening factor | Poisson's ratio |
|---|---|---|---|---|---|
| Steel liner/ JIS SM400 (Carbon steel) | 6 mm | 205,800 MPa | 245 MPa | 680 MPa | 0.3 |
| Buffer/Polyurethane | 4 mm | 18.4 MPa | - | - | 0.43 |

(b) Friction coefficient of buffer

| Selected material | Against carbon steel | Against concrete |
|---|---|---|
| Polyurethane | 0.42 | 0.40 |

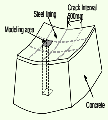

Fig. 15: Outline of analysis model for strain concentration due to concrete cracking

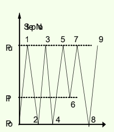

Fig. 17: Analysis step for discontinuous structure

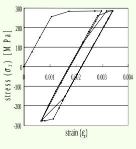

Fig. 12: Check for strain accumulation due to cyclic pressure

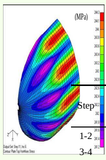

Fig. 13: Stability check for overall buckling at the release of internal pressure

Table 5: Verification of fatigue failure for discontinuous structure between concrete layer and concrete plug

| Step | Operating cycles | Strain range | Dressed | | | As welded | | |
|---|---|---|---|---|---|---|---|---|
| | | | Allowable cycles | Fatigue factor | Summary | Allowable cycles | Fatigue factor | Summary |
| 1-2 | 1 | 2.34% | 28 | 0.04 | **0.17** | 5 | 0.18 | **0.90** |
| 3-4 | 1 | 1.87% | 48 | 0.02 | | 9 | 0.11 | |
| 5-6 | 20 | 1.04% | 196 | 0.10 | | 37 | 0.54 | |
| 8-9 | 1 | 1.52% | 77 | 0.01 | | 15 | 0.07 | |