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HW/3

Design and erection of a large mock-up of containment under severe accidental conditions

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ABSTRACT

So that to experiment the behaviour of the inner wall of a double walled concrete structure under the simultaneous effects of the steam pressure and the steam temperature, a mock-up is built. This mock-up consists in a 5 meter high prestressed concrete cylinder with a radius equal to 8 m and a thickness equal to 1,20m.

1. SCOPE OF THE MOCK-UP

1.1. leak-tightness of the double walled containment structure

The scope of the nuclear power plant containment, is to prevent the escape of radioactive products into the environment in the event of a major accident. In France, the typical containment of the 1300-1400 MW consists of a double walled concrete structure, with an inner prestressed concrete wall without metallic liner which provides strength and tightness, and an outer reinforced wall which provides protection against external aggression.

The typical major internal accident consists in a rapid increase of temperature and pressure due to the steam losses inside the containment.

1.2. previous tests of containment under increasing air pressure

The behaviour of concrete containment under increasing air pressure has been thoroughly studied either by physical or numerical models. Thes test conditions for models are quite similar to test conditions for containment.

In particular, in 1980 Year a 1/10 scaled mock-up was built to study the rupture behaviour of the current part of the Paluel containment.

1.3. complexity of the behaviour under steam increasing pressure

No such information is available for true accidental situation. The phenomena are complex. Under accidental situation, the thermal, mechanical and leak tightness phenomena are combined.

So that to experiment the behaviour of the inner wall under the simultaneous effects of the steam pressure and the steam temperature and especially the effect of the propagation of the steam through the concrete, a mock-up is built.

The thermal properties, in particular the concrete conductivity, are dependent of the concrete hygrometry. A scope of the mock-up is to study the heat propagation in the concrete wall under air/steam mix.

Under thermal gradient, the concrete tensile stress at the outer side is dependent of the compressive Young's modulus of the hot concrete and of the tensile stiffness of the cracked cold concrete. A scope of the mock-up is to study the evolution of the concrete cracking characteristics under thermal gradient.

The air leak tightness can be estimated according to classical Poiseuille flow formula. The steam leak tightness is very much complicated to estimate because the water propagation inside the cracks can modify the air leak tightness parameter. A scope of the mock-up is to study the evolution of the air/steam tightness of the wall in term of cracking characteristics.

2. PRINCIPLE OF THE MODELISATION

2.1. modelisation of a containment current part

The mock-up is similar to a current part of the containment in which the bending moments and the shear forces are small. The tested part is a concrete 5 meter high cylinder which corresponds to the two lifts of the current part of the containment.

The cylinder is closed by two slabs. A lower circular slab (base mat) is sized on the rock, with two galleries for the vertical prestressing. An upper circular slab (cover) is located on the cylinder. In order to minimize the slab bending moments, four columns are located in the central part of the mock-up.

The base and the top of the tested cylinder are on rubber bearings in order to minimize the bending moments and the shear forces at the cylinder extremities.

The leak-tightness between the slabs and the cylinder is assured by torical seals.

A 1400 mm diameter sleeve is fitted on the model in order to test the behaviour of concrete around a local penetration.

2.2. scale for the thermal and leak tightness behaviour

The thermal properties and the leak tightness properties are modelled with a scale ratio equal to 1. The mock-up thickness is the same as in the N4 nuclear containment (t = 1,20 m).

The typical arrangement of the ducts for prestress and of the rebars is the same as in a containment. The ducts diameter is 160 mm, as for 55 T 15 tendons. The horizontal tendons spacing is 0,38 m and the horizontal ducts are steel strip sheaths. The vertical tendons spacing is about 0,94 m, with locally spacing of 0,47 m. The vertical ducts are steel tubes.

2.3. scale for the mechanical behaviour

For the mechanical phenomenon, the scale ratio is equal to 1/3. The mock-up radius is equal to 8,00 m instead to 21,90m for the N4 containment.

The horizontal force due to the pressure is 1/3 of the actual force in a containment. The vertical force due to the pressure is partially equilibrated by the central columns.
So the prestressing force is about equal to 1/3 the actual force in a containment.

2.4. *area to be tested*

The ratio between the internal volume and the containment area is equal to 7 for a containment. This ratio determines the water percentage in the air quantities which can propagate throughout the containment.
In order to maintain the same water percentage for the mock-up, the ratio between the internal volume and the without liner tested area is equal to 7. So, the unlined tested area is equal to the half of the cylinder area.
An half of the cylindrical internal area is covered by a composite liner and the lower and upper slabs are covered by a metallic liner.

3. DESCRIPTION OF THE MOCK-UP

3.1. *geometry*

This mock-up consists in:

- a 5 meter high prestressed concrete cylinder with a scale 1/3 for the radius (model internal radius = 8 m) and a scale 1 for the thickness (thickness = 1,20m). The wall contains a 1400 mm diameter sleeve closed by a steel circular plate. Two quarters of the cylinder are covered by a composite liner.
- two prestressed concrete slabs with an internal metallic liner, each slab is isolated from the cylinder by rubber bearings and the tightness is assured by tightness seals. The relative movements between cylinder and slabs are free.
- four prestressed columns restrained at both ends in the slabs,
- vertical prestressed bars keep up the connection between the cylinder and the slabs.
- an external steel wall which creates six external rooms for the leak tightness measures, two external rooms are used to measure the leaktightness of the seals, two external rooms are used to measure the leaktightness of the lined concrete and the other rooms are used to measure the leaktightness of the unlined concrete.

The figures 1 and 2 show the plan view and the vertical section of the mock-up. Design pressure of the cylinder is 0.65 MPa absolute. It is the same pressure as for the European Pressurised Reactor project (EPR).

3.2. *prestressing*

The prestressing device in the cylinder consists in:

- two layers of horizontal tendons composed of 16 strands of 150 mm², with 0,76 m spacing, on radius 8,64 m and 8,96 m. The ultimate strength of a tendon is 4,46 MN. The tendons are stressed to 0,75 time the ultimate strength.
- a layer of 70 vertical bars of 75 mm diameter on radius 8,40 m. The ultimate strength of a bar is 4,31 MN. The bars are stressed to 0,7 time the ultimate strength.

The lower and the upper slabs are prestressed by tendons composed of 37 strands of 150 mm², stressed to 0,8 time the ultimate strength.
Each column is prestressed by 16 vertical bars of 75 mm diameter, stressed to 0,7 time the ultimate strength.

3.3. *test procedure*

The experimentation consists in testing the mechanical and thermal behaviour and the leak tightness of the wall under:

- a pressure air-test at 0.65 MPa absolute very similar to test condition within a containment,
- a pressure steam-test at 0,65 MPa and a temperature of 162 °C,
- a pressure air-test at 1 MPa, (about 1,5 time the pressure design)
- and a pressure steam-test at 1 MPa and a temperature of 180 °C.

The figure 3 shows the expected pressure and temperature evolution.

After these tests, a composite liner is then applied to the second half of the cylindrical internal area and the pressure air test and the pressure steam-test at 1 MPa are again applied. In the final stage, an hydraulic test up to rupture is considered.

3.4. *instrumentation device*

The model is monitored by two instrumentation devices, one in order to measure the leakage through different parts of the cylinder (see paragraphe 5), and another in order to analyse the concrete behaviour during the pressure and temperature tests (deformation and cracking).

The concrete's instrumentation device consists of:

- 120 acoustic strains gauges for the concrete deformation, including 18 for the cracks opening measures,
- 175 thermometers for the heat propagation measures including 42 measured on the strains gauges and 8 located on the Ø 1400 penetration,
- 30 optic fibers for the deformations measures and for the cracks openings measures,
- 8 pendulums for the displacement measures,
- 2 vertical dynamometers for the bars forces measures.

4. DESIGN OF THE MOCK-UP

The prestressing force is designed in order to represent the actual behaviour of a containment. The prestressing force is designed, as for an unlined concrete containment, to assure a concrete compressive stress equal to 1 MPa under the design pressure (0,65 absolute MPa).

The reinforcement bars are designed to resist to the thermal bending moment in accidental situation, with concrete cracks opening, but without rebar steel plastification.

According to the prestressing force and to the reinforced rebars, the rupture pressure of the current part is estimated.

The upper and the lower slabs are designed in order to resist at this maximal rupture pressure of the cylinder part and to resist during all the test phases, with limited concrete cracks openings. The circular steel plate which closes the opening is designed to resist with normal safety factor to the cylinder rupture pressure.

The design pressure of the slabs is about 1,8 MPa absolute.

5. LEAK TIGHTNESS MEASURES

The leak tightness measures are assured by thermometers, hygrometers and pressure sensors located in the rooms outside the concrete cylinder in order to measure the air and steam inflow, by calculating the evolution of the dry air mass and the steam mass.

The internal volume is equipped with 8 thermometers, 2 hygrometers and 2 manometers.

For each one of the two external rooms, which are used to measure the leaktightness of the unlined concrete, one line is equipped with:

- 3 thermometers, 2 hygrometers, 2 manometers, 1 flowmeter for the sweeping part of the line,
- 2 thermometers, 2 hygrometers, 2 manometers, 1 flowmeter for the flow measurement part,
- 1 volumetric flowmeter for the emptying part of the line.

6. PLANNING OF THE ERECTION

Construction of the model is in progress in France near POITIERS, up to mid 1997. Testing is expected to follow up to end 1997.

phases	sub-phases	dates
concrete pouring		
	base mat (lower slab)	July 96
	columns	August to September 96
	cylinder - first lift cylinder - second lift	December 96 January 97
	cover (upper slab):	April 97
prestressing		
	horizontal tendons of the cylinder	April 97
	horizontal tendons of the base mat	May 97
	horizontal tendons of the cover	May 97
	vertical bars of the columns	May 97
	vertical bars of the cylinder	May 97
tests		August to November 97

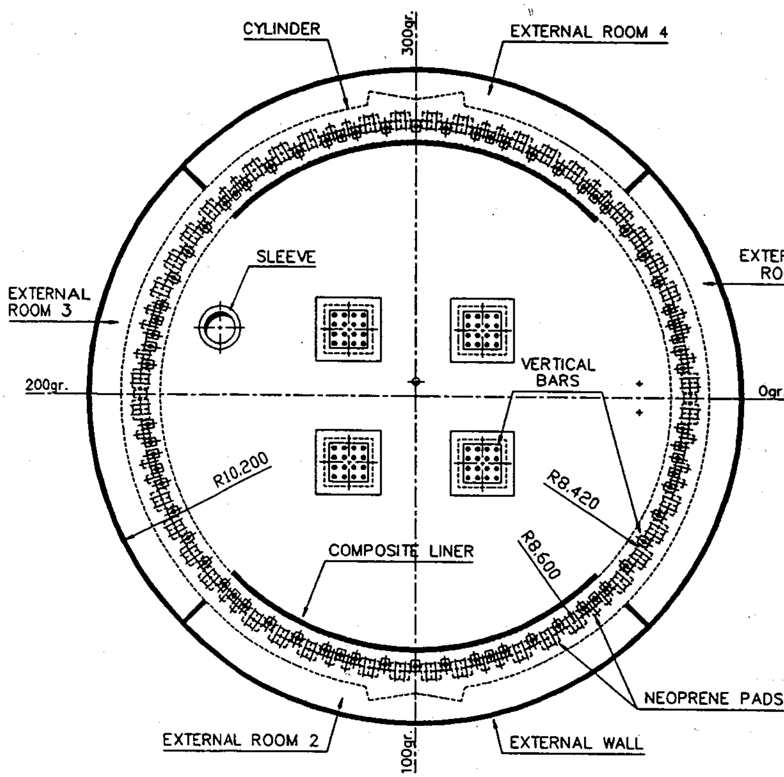

figure 1: plan view of the mock-up.

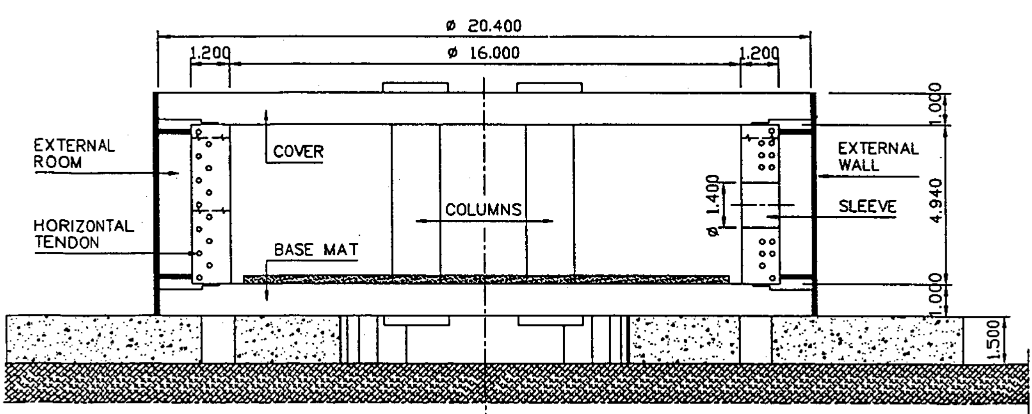

figure 2: vertical section of the mock-up.

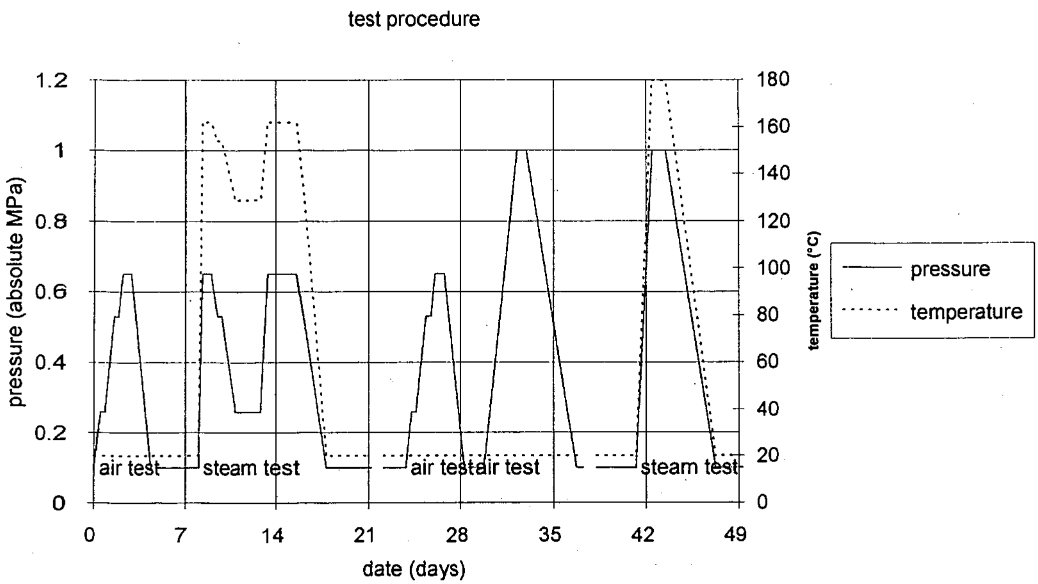

figure 3: pressure and temperature evolution during the test