

Design, Analysis and Testing of an Original Material Hatch for a Nuclear Reactor Primary Containment Vessel

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Summary

An original design is used for the material hatch of the primary containment vessel of the Belgian Nuclear Power Plants Doel Unit 3 and Doel Unit 4. Apart from construction and erection savings, the main advantage is obtained in the substantial reduction of the handling space and time required for the opening of the hatch.

The ASME justification is based on a finite element calculation supported by tests on a (1/5.65)-th scale model and measurements on the hatch during the Doel containment pneumatic test.

The results of the calculation and the tests are compared and discussed.

1. Introduction

The units 3 and 4 of the Doel Nuclear Station are three-loop, PWR type plants with a double containment. The primary containment is a prestressed concrete vessel, with internal steel liner ; the material hatch belongs to this pressure boundary ; moreover, it is to be sized for handling and possible removal of primary equipments (steam generator, reactor coolant pump). The main requirements for this purpose were the following :

- a flat hatch (*) was wished for minimizing the required handling space ; the general shape needed was rectangular with rounded corners ;
- the size of the equipments determined the dimension of the opening (roughly 7 m x 9 m) ;
- the design pressure of the hatch is the internal pressure in case of LOCA, i.e. 3.5 bar (50 psi)
- the design must accommodate the relative displacements of the lips of the opening in the concrete vessel ;
- the leaktightness must be guaranteed and easy to verify.

The allowed leak is much lower than the usual values (air flow lower than $3 \cdot 10^{-3}$ Nm³/h under 3.5 bar pressure difference).

2. Design

2.1. Structural design

2.1.1. General description of the actual solution

The hatch has been designed by TRACTIONEL as a caisson made from thick plates crossed with tubes, forming a kind of sandwich plate with discontinuous web (fig. 1).

This plate is bolted to a flange welded to a "nozzle" tied to the reinforcement structure of the primary containment vessel.

The leaktightness is obtained with a double triangular massive silicon rubber gasket (the hatch is self-tightening).

2.1.2. Comparison with standard beam design

Usually, a such large flat door designed to sustain a significant pressure difference is made as a lock coffer-dam : the structural resistance is supplied through crossed beams in a rectangular net ; a cover plate is used to close the holes in between.

This design yields manufacturing problems (the webs must be cut in pieces and weld together to create the net). Moreover, the weight is important.

In the design proposed here, the flanges are continuous, yielding an "integral type" design ; the volume of weld is minimized, and the geometrical precision is much easier to obtain ; the hatch behaves globally as a plate, simply supported along its boundary.

(*) which excludes a membrane-type solution.

Design details emphasize (fig. 2) the careful attention paid to structural efficiency and ASME code compliance (type of welds, provision for weld inspection, etc).

2.1.3. Design of the flange

As shown on fig. 3, the flange is a massive rectangular block (A) supported with a cylindrical plate (B). In order to accommodate the circumferential relative displacements of the lips of the opening in the concrete - which appear mostly along the symmetry axes - the thickness of the plate B is decreased in the straight part of the boundaries. The hatch rests only on the rounded parts of the boundary : a gap is introduced in the radial direction in the straight parts (no metal - metal contact) and the rounded corners are reinforced with stiffeners to avoid buckling.

2.1.4. Leaktightness

The leaktightness is obtained with a massive silicone rubber gasket (fig. 3) of triangular shape. The material and the shape have been qualified to aging (thermal, irradiation, etc...) through specific tests in a real geometry. The space between the two gaskets is used for the periodic leaktightness tests.

3. Analysis

A finite element analysis has been performed on a quarter of the hatch, with the SAP 4 program, using plate elements (fig. 4). The tubes are represented by square tubes made with rectangular plate elements.

Two load cases are analysed ; a normal pressure corresponding to the LOCA accidental pressure is considered as a primary load (*), and a thermal differential expansion of hatch faces corresponding to the temperature difference between the primary containment inner volume and the intermediate space between primary and secondary containment during the LOCA is considered as a secondary load (*).

The table I summarizes the stress results. It can be seen that :

- as expected the maximum membrane stress in the main faces of the hatch appear at the center, while the bending is maximum in the plate and in the tubes at the lateral boundary, along the axes of symmetry.
- the level of general membrane vs local membrane and bending stresses confirms a performant use of the material.
- the thermal loading (resulting in secondary stresses) is the most stringent.

The fig. 6 shows the displacement along the horizontal symmetry axes : as it can be seen, the assumed global sandwich plate behaviour is satisfied, with a critical zone along the boundary.

(* Primary and secondary refer to the ASME terminology.

4. Testing

Two experimental verifications have been performed :

- a) a (1/5.65)th scale model has been manufactured with the hatch. The scale is selected for availability purposes of standard elements (1 1/2 in sch 80 tubes to simulate 10 in sch 160 real tubes, 7 mm thick plates to simulate 38 mm real plates). The scale model has been instrumented (displacement transducers, strain gauges) and pressure tested, to the nominal pressure first, and then to failure.
- b) measurements (displacements, strain gauges) have been done on the hatch during the pneumatic test of the containment vessel.

5. Comparison of results

5.1. Displacements

It can be seen from the displacement plot (fig. 6) that the scale model gives a very good prediction of the global behaviour, such as the elastic sag (N.B. the results are rescaled to the real size). Departure from linearity appears slightly above the design pressure, exactly as for the actual hatch, and as expected from the stress prediction substantiated in the ASME stress report : primary bending stresses due to the design pressure are limited to 1.5 Sm, which corresponds precisely to the yield limit.

The model shows a further stable behaviour : plasticity takes place through a very progressive process up to three times the design pressure.

The comparison with the finite element is not so good, probably due to the rather rough mesh size and the element selection (modélisation of pipe by 4 plates). The FE model appears too stiff : the measured sag is 30 % higher than the calculated.

5.2. Stresses

Contrary to displacements, the stress measurements on the scale model by means of strain gauges appeared to be absolutely not representative, in spite of careful installation and test procedures. This has been attributed to residual stresses (the model had not been heat treated).

However, the comparison between the results of the finite elements calculations and the stress measurements performed on the actual hatch during the pneumatic tests are very good (differences lower than 10 %).

6. Conclusions

The sandwich plate design in lieu of crossed beams allows to save weight and welds, and appears finally as an economical solution, even with including the test costs.

The scale model gives a very good prediction of sag and unusable stresses while the FE model results in a good prediction of stresses and a rather poor value of sag.

The actual leak, measured during the pneumatic test of containment, is $0.07 \cdot 10^{-3}$ Nm³/h at 3.5 bar.

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TABLE I - CALCULATED STRESSES

Type of stress	Maximum calculated stress (MPa)		Allowable stress (MPa)	Location of the maximum
	Internal	External		
<u>Main faces</u>				
General primary membrane (Pm)	68	64	140	center of face
Local primary membrane stress (Pl)	70	65	210	near central tubes
Local primary (membrane + bending) stress (Pl + Pb)	194	194	210	near boundary
(Primary + secondary) (membrane + bending) stress (Pl + Pb + Pe + Q)	386	487 (1)	420	near boundary
<u>Tubes</u>				
General primary membrane stress (Pm)	5.4		113	Tube near corner
Primary (membrane + bending) stress (Pm + Pb)	170		170	tube near corner
(Primary + secondary) (membrane + bending) stress (Pl + Pc + Pb + Q)	190		339	tube near corner
<u>Lateral faces</u>				
General Primary membrane stress (Pm)	104		140	close to element 136
(Primary + secondary) (membrane + bending) stress (Pl + pb + Pe + Q)	501 (1)		420	On symmetry axes

(1) The ASME limit may be exceeded under some conditions, satisfied in the present case.

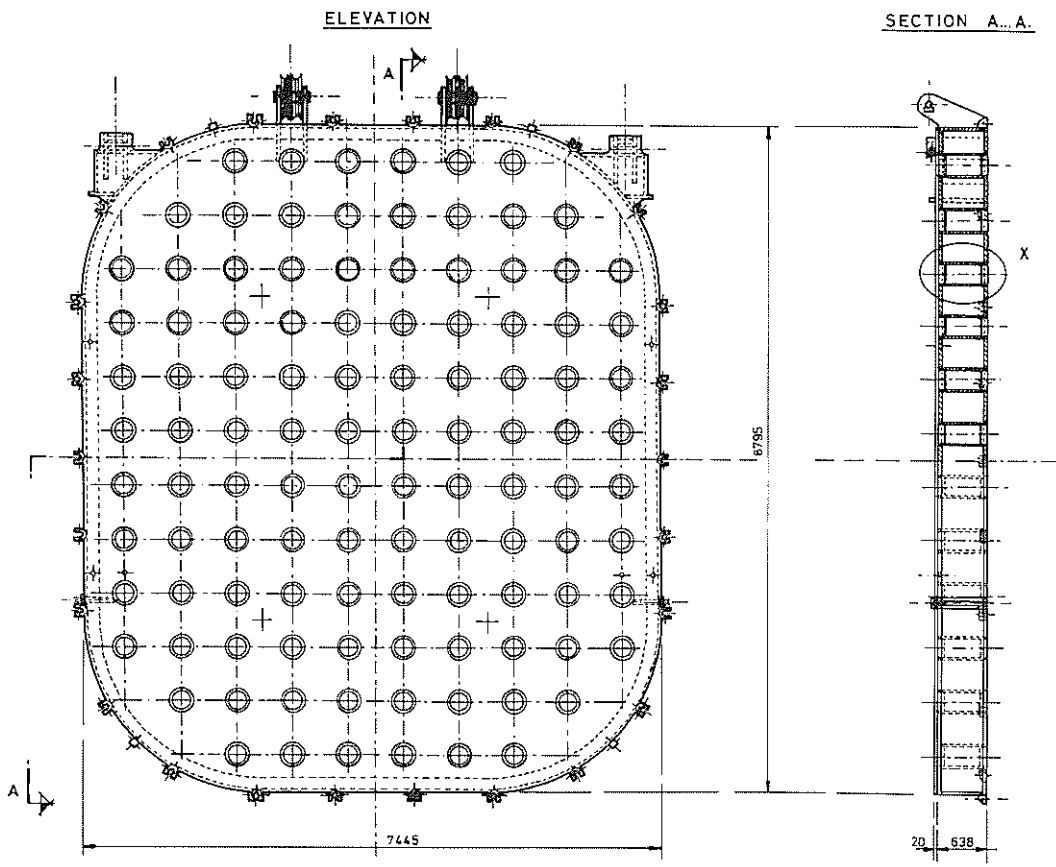
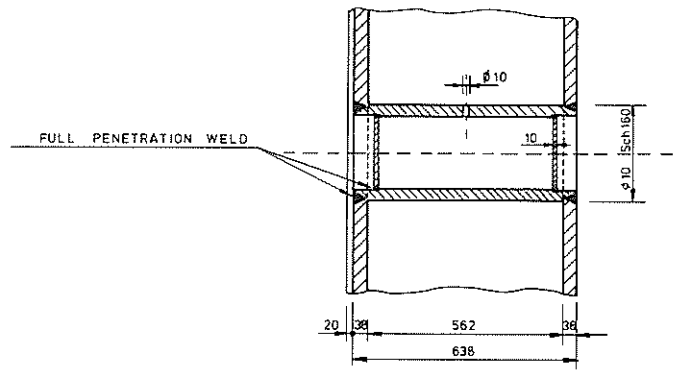


Figure 1 Hatch - Main view

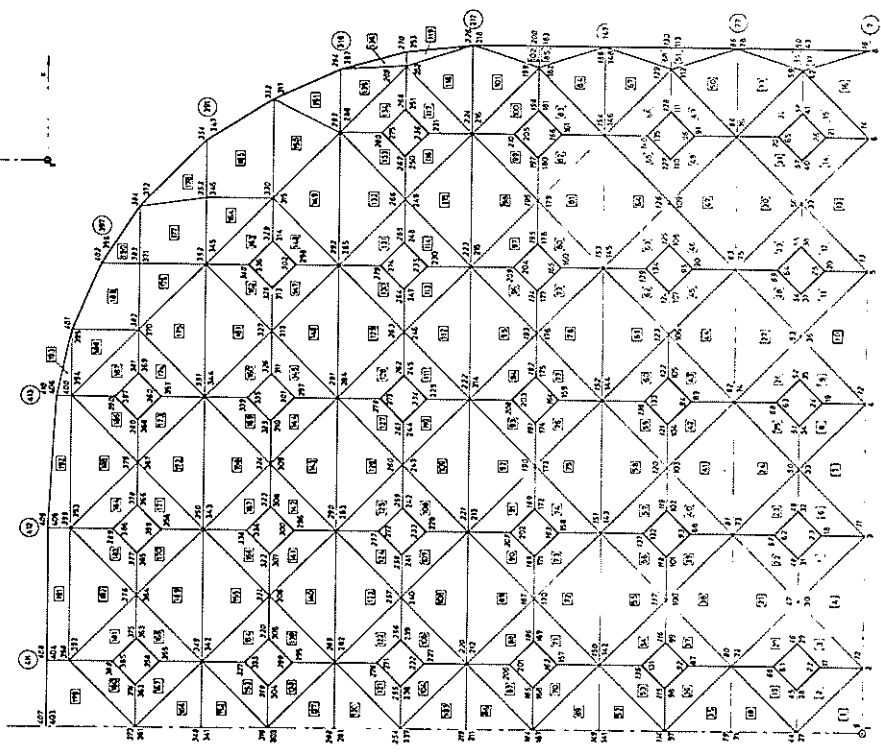


DETAIL X.

FIG 2.

Figure 2 Detail of tube-to-plate junction

MATERIAALPOORT
KERNCENTRALE DOEL 3



LES NUMERES EN CARACTERES DROITS CORRESPONDENT AUX NOMBRES DE LA PLACHE SUPERIEURE
LES NUMERES EN CARACTERES DROITS CORRESPONDENT AUX NOMBRES DE LA PLACHE INFERIEURE

EGEGE 1 m

Figure 3 Flange

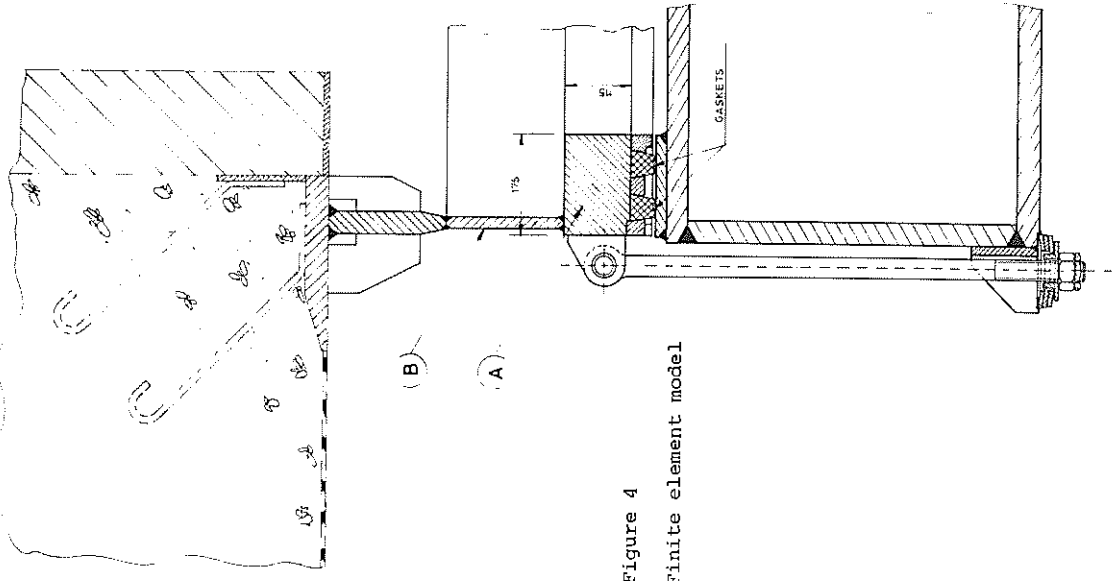


Figure 4
Finite element model

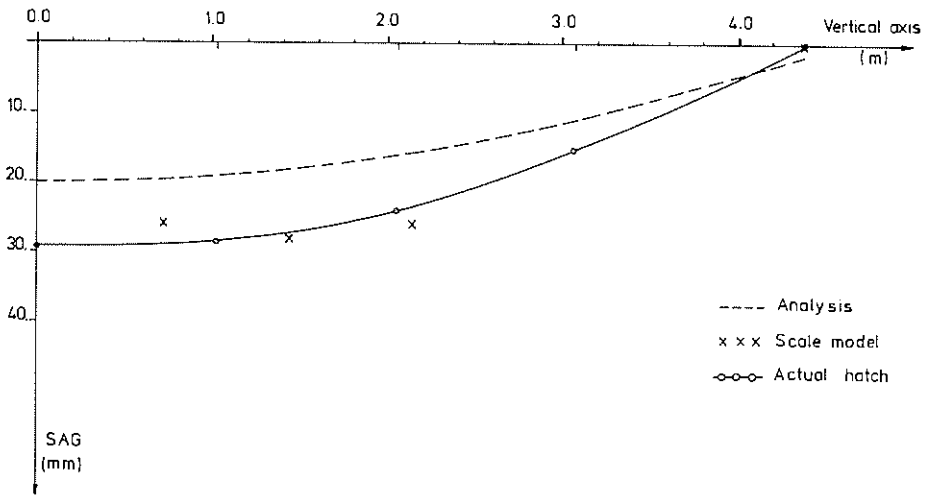


Figure 5 Deflection due to pressure (along the vertical axes of symmetry)

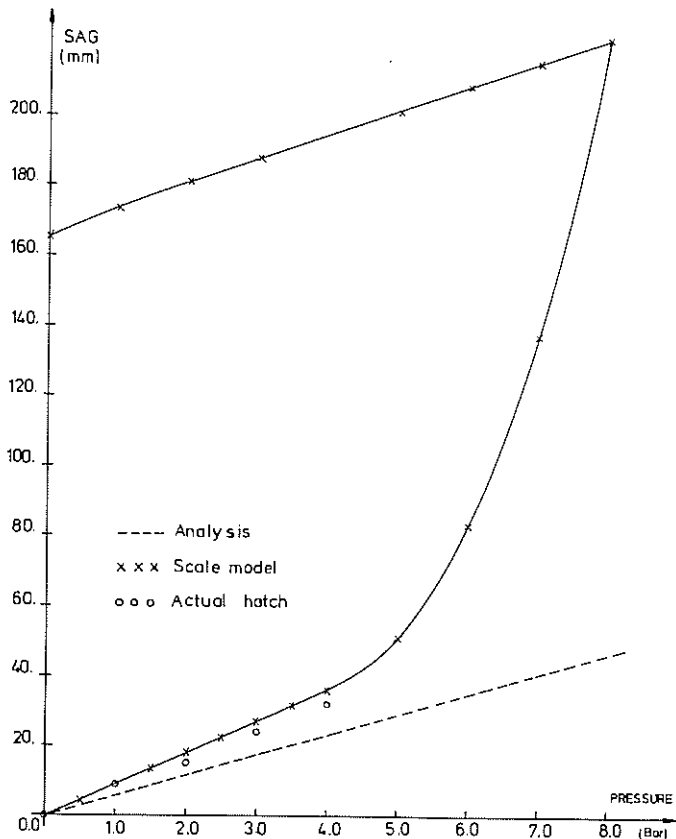


Figure 6 Evolution of central displacement with pressure