# ADVANCED STRESS ANALYSIS OF PWR CONTAINMENTS IN THE REGION OF NOZZLES

G. SCHAUER

*Technischer Überwachungs-Verein Stuttgart e.V.,*
*Bebelstrasse 48, D-7000 Stuttgart 1, Germany*

## SUMMARY

As an example of the stress analysis of a nozzle in a PWR steel containment, an advanced stress analysis of a personnel lock is presented. Contrary to the calculations by means of numerical shell programs usual till now, this advanced stress analysis was executed with the finite-element-method. Because of their theory, the shell programs compute mathematically exact results, but at the intersection of two shells the notch stresses cannot be analyzed well. A further disadvantage must be seen in the fact that there is a great distance between the real critical region near the intersection line and the calculation point, which lies on the neutral axis of the shell.

Large ratios of radius and wall thickness, which also exist in the present case, are not favorable. A complication of the problem is the situation of the personnel lock, whose axis is not directed to the center of the sphere of the containment so that there is no rotational symmetry. For the calculation a region of 2.5 m around the axis of the personnel lock was regarded. The spherical segment and the inclined cylinder in it were modelled with a finite shell element. Because of circumferential symmetry only one-half of the shell was modelled. The tied shells were loaded with the design pressure (6.3 bar). This calculation showed that the greatest stresses were located in the lower part of the intersection zone.

Finite shell elements have the disadvantage of not yielding exact stress values near intersections. The displacement values, on the contrary, are exact. The stress values are computed at the fictitious intersection line between the neutral axis of the sphere and the neutral axis of the cylinder wall and not at the real intersection line. To get the stresses nearest to the effective intersection line, the region of the highest stresses obtained from the first calculation was modelled once again, but this time by a very fine mesh. A 20-node 3-dimensional brick element was used. By this means, obtaining an exact stress distribution near the intersection curve is possible, because the chosen element type gives 3 slices with 9 stress values each. At the boundaries of the reduced structure the displacements which result from the first run are imposed. The advanced stress analysis shows that the maximum stress occurs on the lower spherical element near the intersection line. The results of the first run, which gave a mean value over a greater region, are now more detailed. For instance the maximum stress value was 2 times higher than before, while in the nearby cylindrical region at the intersection line the stress value was half that found before.

The study shows that the results obtained to date which are based on the shell theory and calculate stresses at a fictitious intersection line can be improved and that there is a possibility to get stress values adjacent to the real intersection line.

## 1. Introduction

The design of a PWR containment is governed by the faulted conditions, generally a loss of coolant accident (LOCA), because of the resulting high loads which in any case have to be endured. The containment discussed here is of steel construction.

The containment is subjected to high loads especially at such points where the closed sphere is penetrated by nozzles or locks, which produce high bending and notch strains.

As an example of the stress analysis of such a nozzle in a PWR containment an advanced stress analysis of a personnel lock is presented. Contrary to the calculations by means of numerical shell programs usual till now, this advanced stress analysis was executed with the finite-element-method. Because of their theory, the shell programs compute mathematically exact results, but at the intersection of two shells, the bending and notch stresses cannot be analyzed well. A further disadvantage must be seen in the fact that there is a relatively great distance between the real critical region near the intersection line and the calculation point, which lies on the neutral axis of the shell (Fig. 1). Large ratios of radius and wall thickness, which also exist in the present case, are not favorable.

## 2. Idealization of structure and load conditions

The structure regarded consists of a sphere (diameter 56 m = 190 ft., wall thickness 30 mm = 0.1 ft.) and a cylinder (diameter 3 m = 9.8 ft., wall thickness 112 mm = 0.36 ft.), whose axis is not directed to the center of the sphere of the containment so that there is no rotational symmetry. For the calculation a region of 2.5 m = 8.2 ft. around the axis of the personnel lock was regarded, to guarantee that the disturbing influence caused by the cylinder in the containment has disappeared. There is no rotational symmetry, but a circumferential symmetry so that only one-half of the shells has to be modelled.

The spherical segment and the inclined cylinder in it were modelled with the finite element type 4 (a curved quadrilateral thin-shell element) of the MARC-CDC-program /1/. 160 elements with 242 nodes were generated by using the automatic generation program MARC-MESH3D. The two structures (sphere and cylinder) were tied to join together the boundaries of the two intersecting shells.

Fig. 2 shows a perspective geometry plot of the neutral axis of the calotte, Fig. 3 a plot of the neutral axis of the cylinder wall.

The structure was loaded with the internal design pressure of 6.3 bar under the condition that the personnel lock was closed outside. External live loads were not considered. The boundary conditions were assumed so that the symmetry conditions were satisfied and a continuous transition of the calotte boundary to the containment was guaranteed.

## 3. Coarse stress analysis and conclusions

Given the afore-mentioned conditions a first coarse stress analysis was executed by means of the MARC-CDC-program. This calculation showed that the greatest stresses were located in the lower part of the intersection zone.

Finite shell elements have the disadvantage of not yielding exact stress values near intersections. The displacement values, on the contrary, are exact. Such a finite shell element is not the best solution for computing such a great, difficult structure, because only the neutral axis of the shells is considered and not the real intersection line. Additionally, there are limitations in computer capacity to create a necessary fine mesh of the structure.

To get the stresses very close to the effective intersection line, the region of the highest stresses, obtained from the first calculation, was modelled once again, but this time very fine. The isoparametric, three-dimensional 20-node brick element, type 21 of the MARC-CDC element library, was used. Fig. 4 shows the segment of 18 degress, which was analyzed once more, Fig. 5 showing a perspective geometry plot of this reduced structure. 25 elements with 228 nodes were chosen. By this means, an exact stress distribution near the intersection curve is possible, because the chosen element type gives three slices with 9 stress values each, i. e. 27 stresses. At the boundaries of the reduced structure the displacements which result from the first run are imposed at the corresponding nodes. For new intermediary nodes at the cut area, displacement values by interpolation were given.

## 4. Advanced stress analysis

The advanced stress analysis which was performed with the MARC-CDC program shows that the maximum stress occurs on the spherical element 21 near the

intersection line (see Fig. 6). The results of the first run, which gave a mean value over a greater region, are now more detailed. The maximum stress value was two times higher than before, while in the nearby cylindrical region at the intersection line (for example elements 1, 6, 11) stress values were half that found before. Fig. 7 shows the stress distribution for cut C-C (see Fig. 6), values increasing from 1 to 10.
The study shows that the results obtained to date which are based on the shell theory and calculate stresses at a fictitious intersection line can be improved and that there is a possibility to get stress values adjacent to the real intersection line.

## References

/1/ MARC-CDC, User Information Manual, Rev. G.

/2/ J. Putzeys et al.: Stress Analysis of Pressure Vessel Nozzles, 1st SMiRT-Conference

/3/ F. Cech et al.: Neueste Erfahrungen bei Berechnung und Konstruktion von Sicherheitsbehältern aus der Sicht des Herstellers, 2nd SMiRT-Conference

/4/ A. Biron, A. Courchesne: Limit Analysis of Cylinder Intersections. Nuclear Engineering and Design, Vol. 36 (1976) No. 1

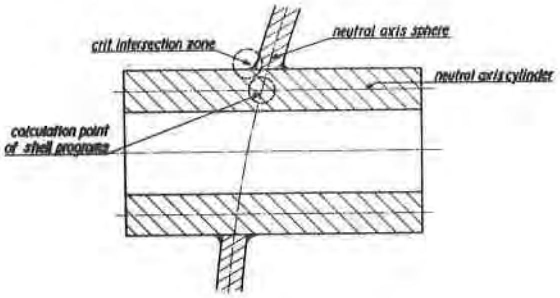

Fig. 1
Model of two intersecting shells

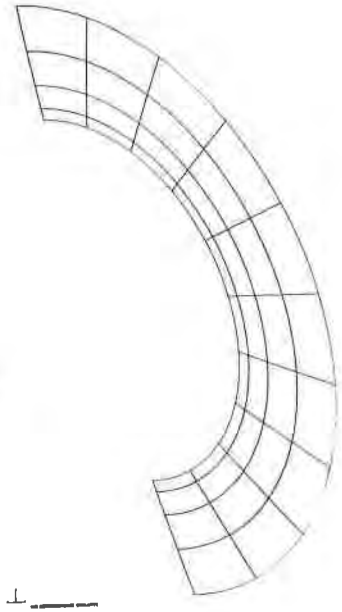

Fig. 2
Perspective plot of the calotte

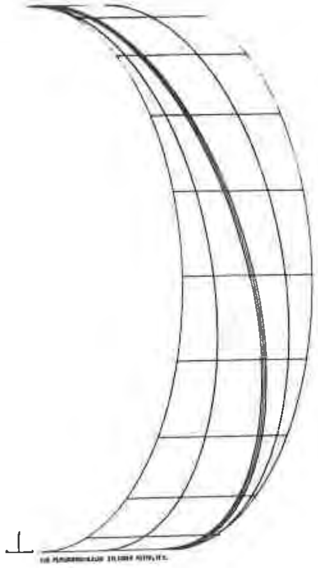

Fig. 3
Perspective plot of the cylinder wall

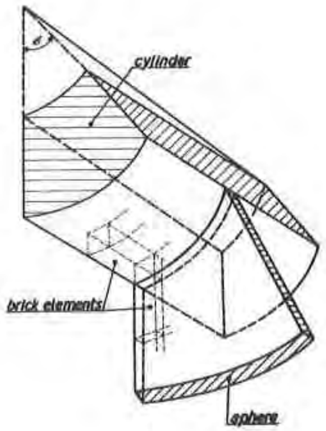

Fig. 4
schematic view of the reduced structure

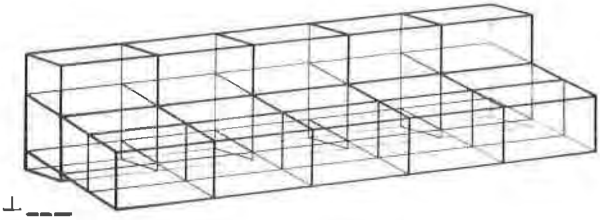

Fig. 5 Perspective plot of the reduced structure

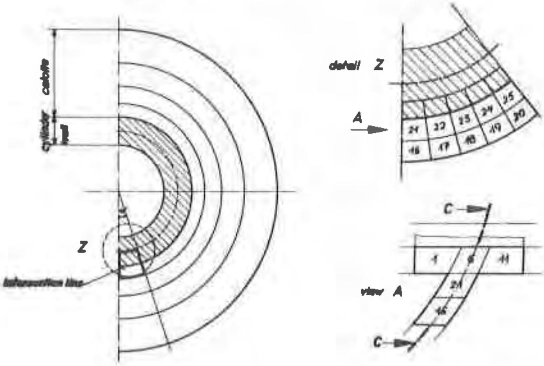

Fig. 6 Models for advanced stress analysis

Fig. 7 Stress distribution of the reduced structure
(cut C-C in Fig. 6)