

Influence of Fluid-Shell Interaction on Load and Displacement Time Histories Using the FLEXWALL Computer Code for HDR Pretest Calculations and Comparison thereof with Experimental Results

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Abstract

The computer code FLEXWALL under development at KWU was used to predict both HDR Snap-Back-tests in air and water and the short time behaviour of a HDR blowdown experiment, the later being analyzed with and without fluid-structure interaction. The static and dynamic displacement of the core barrel was predicted very well for the test in air. The Snap-Back-test in water indicates, that accounting for the missing vessel displacement and the flexibility of the core barrel flange additionally will improve calculational results. The beam mode frequency in water was predicted within 20 % compared to the experiment. Since the coupled FLEXWALL blowdown prediction compares well to the experiment and show by far a greater degree of agreement with measured data then the calculation with no feedback, only coupled analyses or equivalent methods will exhibit a good blowdown loads evaluation procedure. Some need for further FLEXWALL improvement as modelling of local threedimensional effects and approximating nonequilibrium fluid dynamic could be derived from experimental data.

1 Introduction

KWU has for some time been working with a computer code called FLEXWALL which is intended to describe as well as possible the phenomena occurring during the initial phase of a LOCA of a PWR. Already during the planning and implementation stage of the RS-16/B project, work had been performed on calculational and instrumentational evaluation of fluid-structural interaction. In addition to confirming the necessity of using local three-dimensional fluid dynamics or thermodynamic non-equilibrium, these experiments also confirmed the need for coupled fluid-structural calculations / 3 /.

2 The FLEXWALL Code

The objective of FLEXWALL is not only to calculate relatively simple geometries, such as those of the HDR, but also to solve real problems relating to KWU PWR plants. It must thus also be possible to calculate local flashing, different types and sizes of breaks, heat addition, pump behaviour etc.

These considerations resulted in the modular structure of FLEXWALL, outlined below. The code consists of the following (ref. Fig. 1):

1. a one-dimensional blowdown pipe
2. a two-dimensional annular downcomer with variable gap width
3. the core barrel and
4. a network model, a modified version of the LOCA-Code LECK-V4, for the interior of the core barrel and the rest of the system to describe the complete primary circuit of a PWR.

Source terms in the two-dimensional regions are then used to couple this region to the blowdown pipe. Fluid-shell interaction is considered by taking into account variations in downcomer width as well as changes in node volumes caused by transient displacement of the core barrel. A homogeneous equilibrium model is used everywhere to describe fluid characteristics. This calculation produces systems of quasilinear hyperbolic differential equations which are solved using LAX-WENDROFF procedures; EPISODE is used to integrate all systems of ordinary differential equations.

The core barrel is treated as an elastic cylindrical shell, in the case of HDR rigidly fixed at its upper boundary, and with a rigid massive ring attached to its lower boundary. Other shell boundary conditions can be prescribed if necessary.

The basic Flügge shell equations are solved using an explicit finite-difference procedure. The time-dependent pressure difference across the shell wall thus acts as a spatially dependent load on the core barrel. Vessel motion is not currently considered. All of the previously mentioned modules are coupled at each time step. A limiting time step has been derived for the coupled system which is slightly below that of the shell. Coupling only after two structural time steps resulted in serious stability problems. Additional details might be found in / 2 /.

3 Pretest calculations of HDR-SNAP-BACK Tests with FLEXWALL

During the SNAP-BACK-Test series the HDR core barrel was statically displaced in various kinds and then suddenly released. Tests both in air and water has been run. Details might be found in / 1 /.

3.1 FLEXWALL Prediction of Test V 59.1.3 (Test in air)

The aim of this experiment was to test the structural part of coupled codes like FLEXWALL. The core barrel was displaced at the lower end and then released.

The static displacement behaviour of the shell was well predicted by this code with some underestimation near the flange. The overall dynamic displacement predictions (see Fig. 2) is in very good agreement with the experiment. The strain amplitudes near the flange on the other hand are overpredicted by FLEXWALL by a factor of two, together with the static displacement distribution a strong indication, that a replacement of the "stiff" upper boundary condition of the shell by a more realistic, flexible model of the flange and including vessel motion will improve the situation considerably. Another point is that higher frequencies are missing so that not only the flange/vessel flexibility but also discretisation and damping must be studied in detail. Nevertheless, the static and transient shell behaviour in air was predicted very well by FLEXWALL.

3.2 Prediction of SNAP-BACK-TEST V 59.2.3 (Test in Water)

Again the HDR core barrel was displaced near the lower end mass ring and suddenly released, but the vessel was filled with highly subcooled water of 20 bars / 1, Section 8 /.

The static behaviour was discussed above.

Fig. 3 shows the predicted pressure difference across the core barrel 2 m above the mass ring compared to the experiment. In general, FLEXWALL shortened the pressure ground vibration period a bit, again higher frequencies are missing and peak amplitudes are somewhat underpredicted at the beginning of the barrel motion. The typical "decompression" behaviour due to barrel displacement is predicted very well by FLEXWALL.

The beam mode frequency was overestimated about 20 % and again the predicted strains near the flange are about 70 % to high. The reasons for these discrepancies have partly be discussed above, additional background will be found in the modelling of the fluid in the barrel interior and the lower plenum and by studying the decompression waves in the water emanating from the breaking and accelerating displacement device itself.

Again, the overall FLEXWALL predictions are - except for the strain behaviour near the flange - quite acceptable; some deadlines for code improvements can be deduced from this experiment.

4 FLEXWALL Prediction of the Blowdown Test V 31.1

In this experiment, the water in the HDR vessel with internals (see Fig. 1) was heated to 260/305 °C at a pressure of 108 bars. The blowdown was initiated via a rupture disc close to the end of the blowdown pipe. Details could be found in / 1, Section 7 /.

4.1 Blowdown nozzle behaviour

The comparison of the pretest calculations with experimental results indicates that in the area of the blowdown nozzle it is not possible to properly calculate the pressure transient during the first 30 msec with an equilibrium code, although the calculated mass flow was in general very well predicted by FLEXWALL. Facts as pressure under-shoots not explainable by equilibrium theory, missing of highly frequent recompression phenomena combined with a sharp temperature decrease near the break can only be attributed to the nonequilibrium behaviour of the fluid, which could not be accounted for in LAXWE-1.

(Comparative calculations with TRAC-PD2 here showed excellent agreement between these calculations and the experiment. On the other hand a comparative analysis with a node model showed the superior behaviour of LAXWE-1 over these types of codes with a static flow model involved.) Other points of investigation are, that the blowdown is started inside the pipe and the critical plane is transferred to the real pipe exit at later times and that the influence of the travelling rupture disc on the mass flow itself can be deduced from the traced mass flow.

4.2 Pressure in the downcomer, pressure differences across the core barrel

As already noted in the pretest calculation phase, the short term pressure drop at the annulus-nozzle connection point is calculated far too high. Since this location is entirely within the 3D flow region a somewhat idealized dynamic pressure should perhaps here be compared with the actual value measured at the wall. The FLEXWALL predicted pressure difference therefore was seemingly far overestimated combined with a completely overpredicted local shell strain. At all other locations within the annulus there is a very good agreement with the coupled pretest calculations. Fig. 4 shows the excellent predicted pressure difference at a point in the mid of the downcomer. The slightly high temperature used in the RPV upper section and the there attached piping in the pretest calculation is responsible for the small discrepancies in values calculated after approx. 70 msec.

4.3 Pressures in the barrel interior and piping

As already mentioned, the somewhat high chosen temperature in the hottest part of the system are partly responsible for the pressure deviations after approx. 70 msec. Post test calculations with the measured temperature distribution improved the agreement FLEXWALL/Experiment up to 90 msec. The deviation in the pressure time histories from that time on again can only be explained by nonequilibrium water behaviour inside the core barrel / 1 /. Calculations with a nonequilibrium code running at KWU confirmed both frequency and amplitude of the relatively long undershoot.

4.4 Core barrel behaviour

The core barrel displacement slightly below the nozzle determined with FLEXWALL is far too small. Since, however, the strains measured at this point are in relatively good agreement, see Fig. 5, and the barrel displacements closer to the lower end of the downcomer and therefore to the vessel support again are in relatively good agreement with the experiment, the discrepancy can only have been caused by the rather marked deformation of the vessel which has, as yet, not been incorporated in FLEXWALL. The flexibility of the barrel flange, which has not been accounted for in the pretest calculation, combined with the vessel motion will considerably improve the calculational results. Using a flexible vessel, the force generated by the rupturing disc must be accounted for in the future, as it is done in real plants behaviour evaluation.

4.5 Comparison between a coupled and a calculation without feedback

Besides a coupled calculation with an elastic shell although a calculation with rigid walls - no feedback - has been performed.

As already observed with RS 16/B, the coupled calculation produced a considerably more stable and somewhat flatter curve for depressurization, in particular in the annulus.

The calculation with rigid walls - with approximately identical maxima - produced there non-measured atypical high-frequently pressure differences. These results confirm experience gained on RS- 16/B. Inside the barrel, the "stiff" calculation exhibits plateaus, which are again not confirmed by the experimental results.

The calculated flow rate for the coupled case was slightly higher and in addition it was noted that the high frequency pressure peaks in the blowdown nozzle, calculated with the equilibrium model, and none of them confirmed by the experiment, were slightly increased by shell deformation.

As not expected otherwise the coupled FLEXWALL calculation - although not perfect - is a marginally improvement over the stiff analysis and only a coupled analysis or an equivalent procedure / 4 / will exhibit good results in blowdown loads evaluation.

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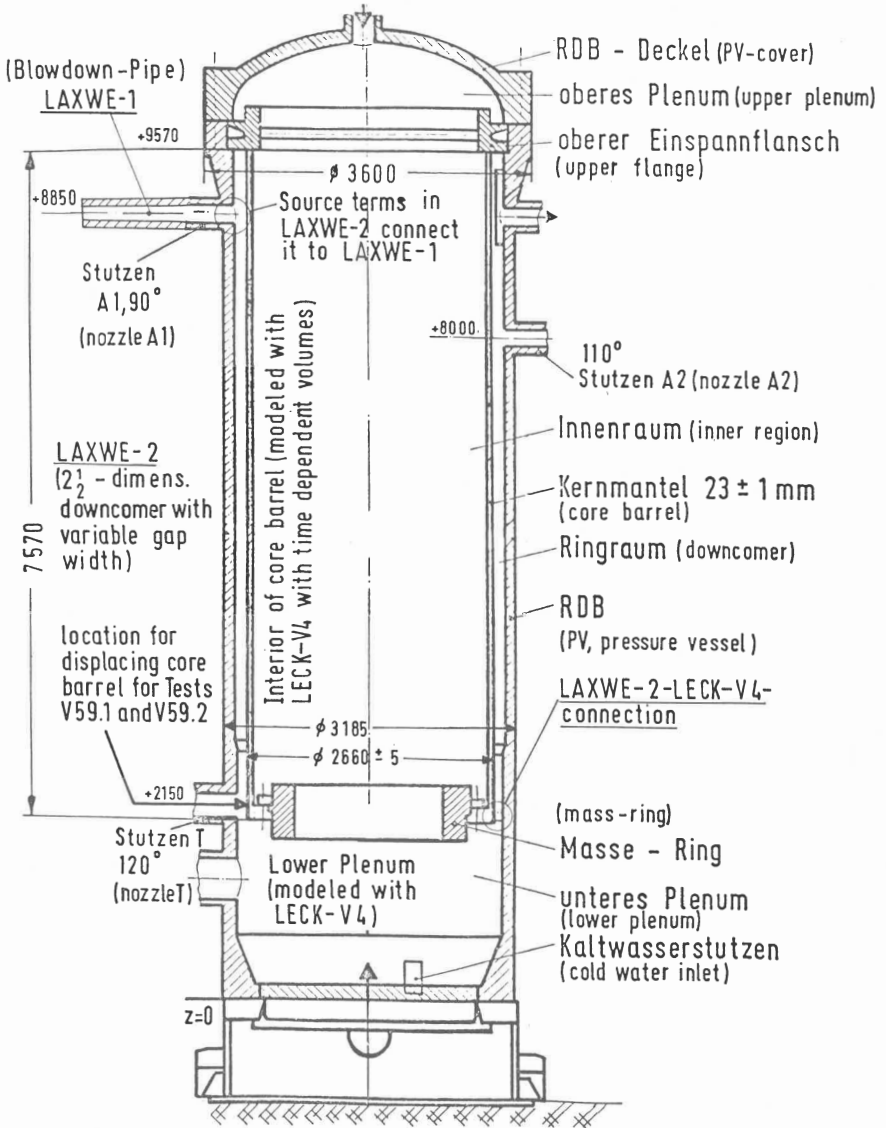
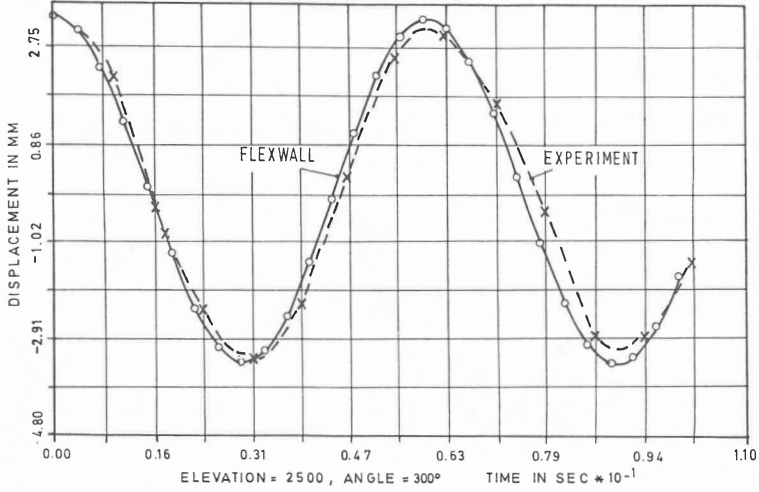


Fig. 1 : Schematic view of the HDR-Vessel and its modelling with FLEXWALL

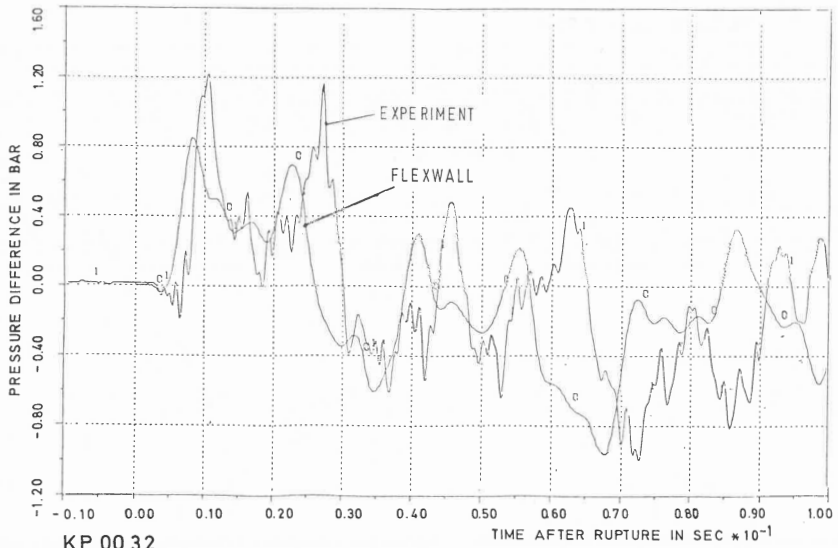
FLEXWALL - V 59.1.3



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FIG. 2

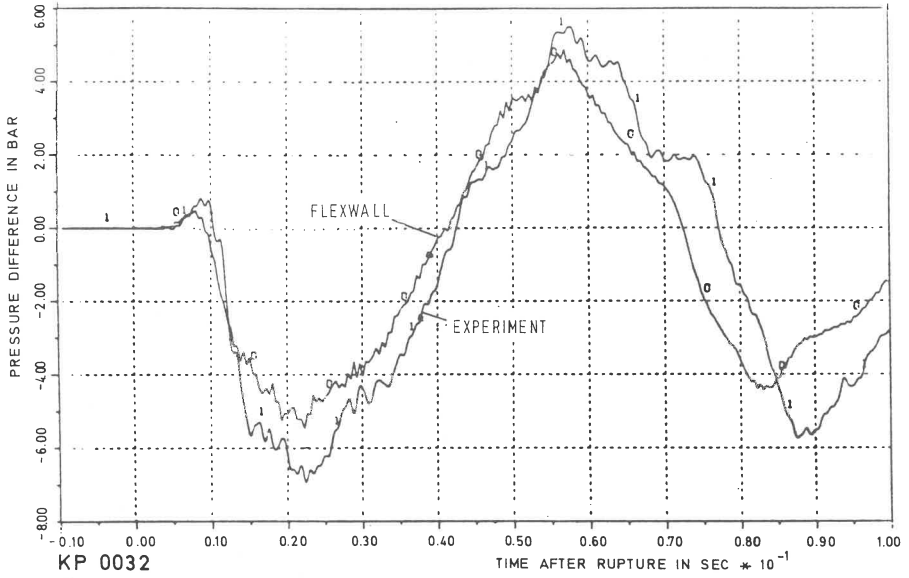
FLEXWALL - V 59.2.3



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FIG. 3

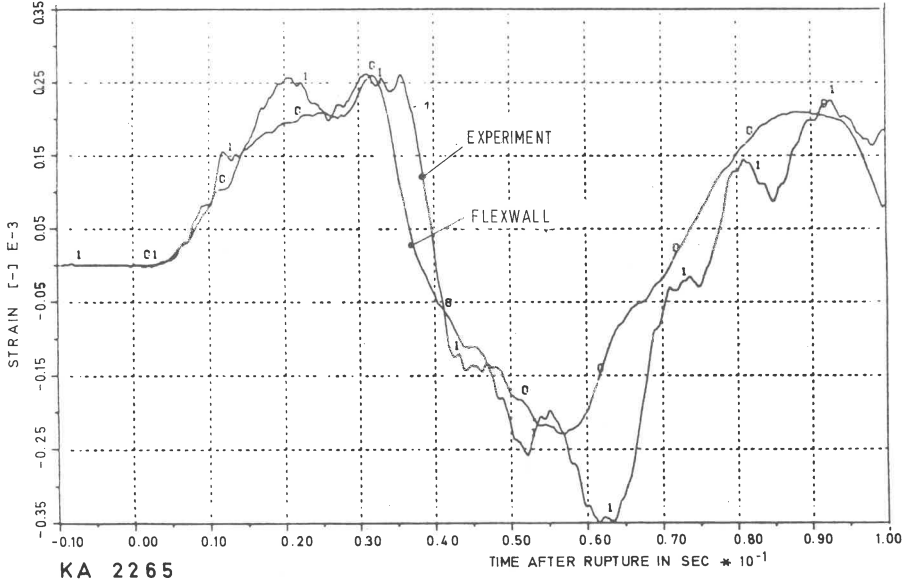
FLEXWALL - V 31.1



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FIG. 4

FLEXWALL - V 31.1



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FIG. 5