Elastic and elastic-plastic behaviour of a piping system during blowdown – Comparison of measurement and calculation

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1 INTRODUCTION

As part of the German HDR Safety Program, blowdown tests were performed /1/, /2/, /3/.

Fig. 1 shows the experimental loop on which the blow-down tests T21.1 and T21.3 were conducted. In the test T21.1 the safety-valve had an optimized damping characteristic, while it was almost undamped in the test T21.3. The undamped characteristic was used to induce very high pressure waves so that the piping response would also be on a higher level up to the plastic range.

Comparisons of former blowdown tests and corresponding precalculations have shown that it is difficult to distinguish in the set of modelling parameters those which are significant for possible deviations between test and analysis. For this reason some preliminary tests were conducted to check the accuracy of the structural model:

test	data compared
- static loading by single horizontal and vertical forces	- displacements, stresses
- snap-back test	- natural frequencies, mode shapes

With the informations from these tests the structural model could be optimized so that the precalculated elastic piping response would additionaly be influenced only by the pressure time histories and the method of application of the fluid-dynamic forces to the structural model.

2 STRUCTURAL MODEL

For simulation of the preliminary tests and for the precalculations of T21.1 the finite element program STARDYNE was used. The piping was modelled by beam elements with pipe cross-section using flexibility factors according to the Karman theory for the elbows, (Fig. 2). According to the mass-ratio the reactor pressure vessel could be decoupled from the piping, and so it could be neglected in the analysis. Only the flexibility of the RPV-nozzle was considered by

introducing local springs at the end of the pipe. The material behaviour was assumed to be linear elastic. For the dynamic analysis a damping value of 2 % was considered.

For the precalculations of T21.1 the load assumptions were given by the measured pressure time histories near the elbows. As a first step a linear interpolation /4/ was made from the measuring points to the centre points of the elbows. As a second step the differential forces of successive elbows were evaluated and applied to the structure between the corresponding elbows.

For the precalculations of the second blowdown experiment T21.3 the finite element piping program NONPIPE was used. This has the capability to simulate elastic-plastic material behaviour.

By using the same topology as for the test T21.1 one calculation was performed with elastic and one with elastic-plastic material behaviour.

3 MODEL CHECK WITH PRELIMINARY TESTS

In the static test the piping was displaced by a concentrated force in the lower part of the vertical line of the piping. Fig. 3 and Fig. 4 show the comparison of the measured and calculated deflections and stresses. The calculated stresses at the elbow are based on the slightly modified detailed analysis procedure of ASME /5/.

The first natural frequencies and mode-shapes are measured from the free vibrations of the piping, which was excited in a snap-back test. In Fig. 5 the first 5 natural frequencies are compared with the measured data.

A comparison of the measured and calculated data shows that the agreement of the static deflections and stresses, natural frequencies and mode shapes is quite good. Parameter variations with regard to the boundary conditions and the flexibility factors of the elbows did not change the overall agreement.

Thus for the further calculations the prescribed piping model was used without any modification.

4 BLOWDOWN TEST T21.1

This blowdown test was planned with an optimized damping characteristic of the valve, so that the piping response would be in the elastic range. But from the evaluation of the measured data it was possible to see that at two local positions plasticity had occured. Nevertheless the overall behaviour of the piping was nearly elastic so that the measured and calculated data are comparable. Fig. 6 shows the comparison of a typical displacement time history. The agreement of the two time histories up to 0.2 sec is very good; after this a slight shift of the fundamental frequency and an overestimation of the amplitudes in the precalculation can be seen.

The reason for this is established using the measured pressure time histories which include the natural frequencies of the piping system caused by fluid structure interaction. This frequency content leads to a pseudo resonance of the piping model.

Fig. 7 shows the maximum hoop stress time history in the centre of elbow 1. The stress calculation procedure is the same as used for the static precalculations, which leads to a reasonable good approximation of the measured data.

5 BLOWDOWN TEST T21.3

This second blowdown experiment was planned in such a way that the piping response would be at a higher level up to the plastic range.

For the simulation of this experiment, in contrast to T21.1 precalculated pressure time histories related to the elbow centre points were used so. Thus no special interpolation technique was necessary.

With the intention of qualifying simplified elastic-plastic calculation methods and of making a best estimate analysis, two precalculations were performed.

5.1 Simplified elastic-plastic precalculation

The aims of the present analysis were to describe the overall behaviour of the piping as characterized by the displacement, and the local behaviour as characterized by stresses and strains. In cases where plasticity occurs only in local regions, it was possible to adopt a linear elastic approach for simulation of the overall behaviour. Therefore as a first step the linear-elastic response of the piping was calculated. In a second step reduced Youngs moduli were introduced for those elements which were loaded over the yield point. Assuming that the overall data thus calculated represented a reasonable approximation, some additional studies were conducted on this basis for computing stresses and strains of the highly stressed parts of the piping.

Thus an additional static FEM-analysis for the elbow near the RPV was conducted using shell elements with material and geometrical nonlinearities. The results from this analysis were relationships between the rotation of the cross-sections at the ends of the elbow and the strains at different section points. On the basis of the time-dependent rotations of the elbow the strain time histories were calculated at these section points.

5.2 Elastic-plastic precalculation

The second precalculation was planned as a "best estimate analysis" taking into account the elastic-plastic material behaviour. For reasons of economy and in order to qualify more simplified approximations, pipe elements with nonlinear moment-curvature and moment-twist relationships were used for the model, and these were suitable for simulating the nonlinear material behaviour and the energy dissipation during cyclic loading. These elements are very effective for describing the global behaviour of the structure such as displacements and strains in beam sections. Compared to the more sophisticated finite element technique using incremental material laws a small error arises from the assumption that in the case of yielding, bending and torsional moments are decoupled. Because of the assumptions related to the beam theory only "beam strains" can be calculated.

5.3 Results

Fig. 8 shows a comparision of the measured displacements and the results of the two calculations. The results of the simplified elastic-plastic analysis still show a sufficient agreement with respect to the

maximum displacements. But after 0.1 sec the frequency content of the measured data is quite different, which is caused by the effects of plasticity.

The agreement of the elastic-plastic calculation is significantly better. For the other measuring points the same tendency can be seen with which in general the percentage deviation is greater at locations with smaller deflections. In elbow 1 the expected high strains did not occur, and so the strains remained nearly elastic. For this reason the strain amplitudes of the elastic-plastic calculation were derived from the detailed stress analysis prodecure according to /5/ using the moment-time histories. The results are compared in Fig. 9 where the elastic-plastic calculation is also the better approach, while the simplified analysis still gives reasonable results. In Fig. 10 the strains of the elastic-plastic calculation in the lower part of the piping are compared with the measured data. Reasons for the greater deviations have not yet been completely clarified. One reason may be local effects coming from the measured data because the strain gauges were only applied at one point on the circumference of the pipe section.

An additional analysis with the measured data is planned in order to study the influence of the precalculated pressure time histories.

6 CONCLUSIONS

The investigations according to the system identification show that the piping model using beam theory and flexibility factors according to the Karman theory are adequate for evaluating natural frequencies, mode shapes, static displacements and stresses.

The same accuracy can be seen by comparing the piping response due to blowdown within the elastic range

The simplified elastic-plastic analysis in general overestimates the maximum amplitudes while the frequency content is not simulated very well. For practical purposes, it can be an adequate tool in many cases.

The elastic-plastic analysis is the most expensive procedure but gives also the best results. The use of beam elements with multilinear moment-curvature relationsships results in a good approximation for the global behaviour (displacements). The strains according to this theory only include the beam deformation modes.

References

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/2/ Versuchsprotokoll Blowdownversuch mit Ventilschließen, Versuchsgruppe RORB, T21.3 PHDR-Arbeitsbericht 2.205/85

/3/ Quick-Look-Report, Versuche T21.0, T21.1, T21.3 Technischer Fachbericht PHDR 58-86

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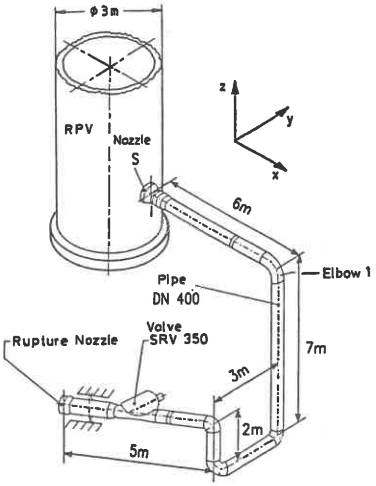

Fig. 1 Experimental Loop

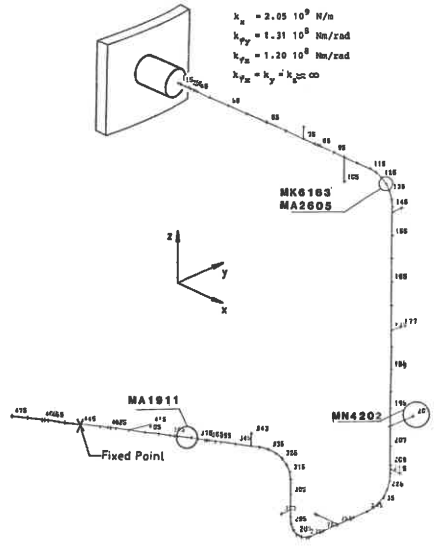

Fig. 2 Piping Model

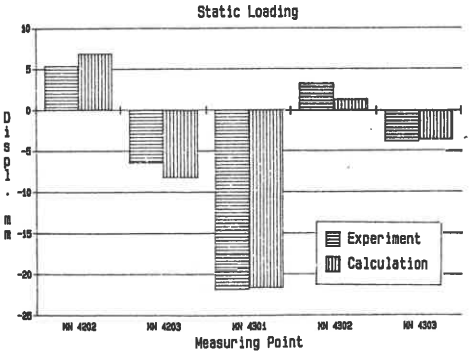

Fig. 3 Static Deflections

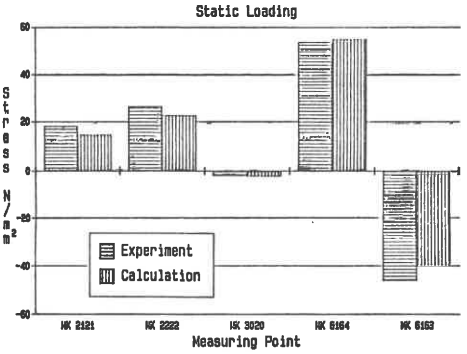

Fig. 4 Static Stresses

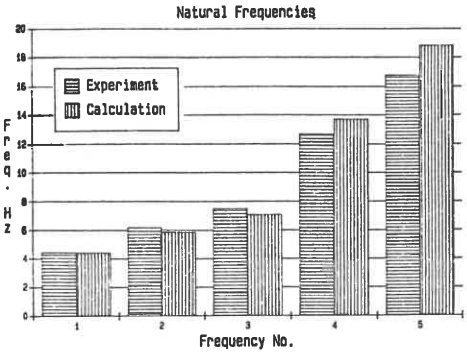

Fig. 5 Natural Frequencies

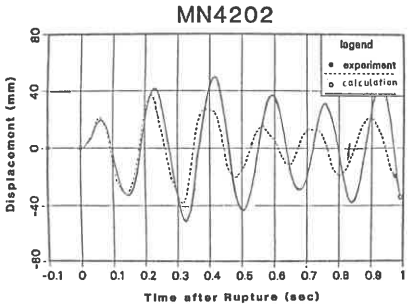

Fig. 6 T21.1: Displacement Time History

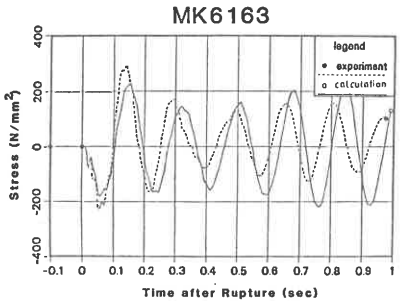

Fig. 7 T21.1: Stress Time History

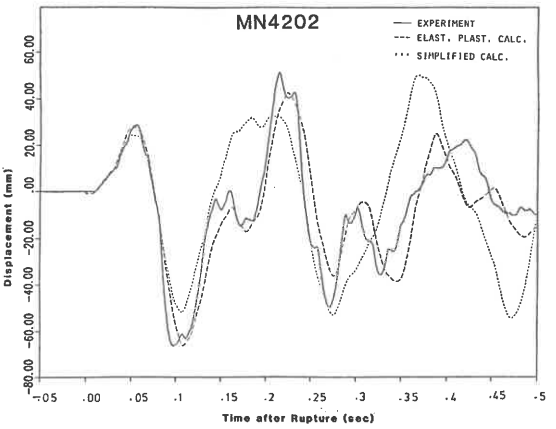

Fig. 8 T21.3: Displacement Time History

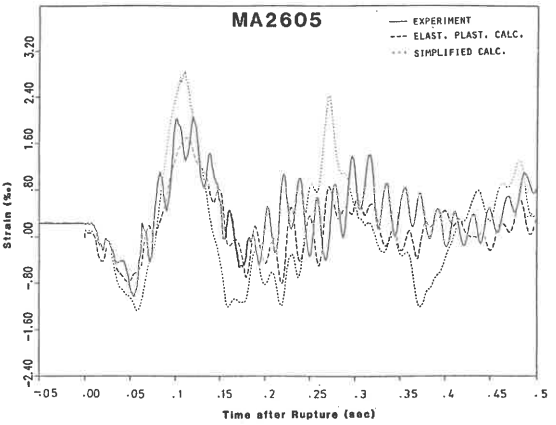

Fig. 9 T21.3: Strain Time History

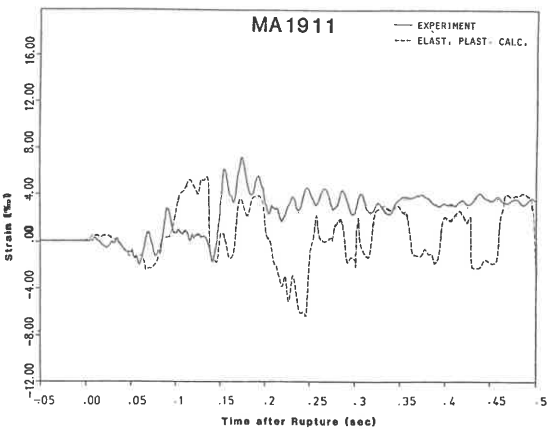

Fig. 10 T21.3: Strain Time History