Evaluation of a German Standard Problem on the statics and dynamics of a large pipe

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1. INTRODUCTION

The German Ministry of Interior (BMI) is sponsoring a series of German Standard Problems to test the capability of codes to predict safety and licencing related problems in the nuclear field adequately. In a German Standard Problem engineering organizations working in the nuclear field are asked to perform "blind" pretest calculations on a large scale test and to submit the results to the GRS before the experimental data are distributed.

As part of the HDR test program static and dynamic tests on a recently constructed pipeline (length ≈ 20m, diameter ≈ 400mm, wall thickness ≈ 20mm) have been performed at the HDR test facility. These tests have been chosen as reference tests of the new German Standard Problem on piping systems. The objective of this new Standard Problem is to investigate the static modal and dynamic behaviour of a large piping system loaded in the elastic range.

Eleven German engineering firms took part in the Standard Problem, among these were reactor manufacturers and experts working in the licencing procedure. The codes they used are standard piping analysis codes.

The Standard Problem was divided into two parts:

- Part 1 investigates the static and modal behaviour of the piping system. The participants were asked to predict the static tests in which the piping system was displaced both horizontally and vertically by a force of 70 kN. In addition they were asked to give the first five eigenfrequencies and eigenmodes of the model used for these calculations.

- Part 2 investigates the structural dynamic response of the pipeline to pressure waves caused by check valve closure. The participants were provided with measured pressures and had to predict the time functions of the same data as in the static test. It was left up to the participants how to determine the load functions and where to apply them.

2. DESCRIPTION OF THE EXPERIMENTS

The three tests which are analyzed in this paper have been performend at the HDR test facility. It allows to run full scale tests under nuclear reactor conditions. Fig.1 shows the piping configuration.

The three tests selected for this paper are:

- HDR-tests T21.013 and T21.023 /1/

  This are static tests, in which the piping system filled with cold water has been loaded horizontally and vertically by 70 kN. After the static displacement the piping system was released and the free vibrations were measured. In these tests displacements and strains were measured. The free vibrations were used to determine eigenvalues and eigenmodes.

- HDR-test T21.1 /2/

  In this test the transient of the pipe system filled with subcooled water (p = 70 bar, T = 220°), caused by a pipe break and the following check valve closure, were studied. In this test pressures and other fluid quantities as well as structural displacements and strains were measured.

3. MODAL ANALYSIS

The first five experimental eigenfrequencies derived from free oszillations of the system are 4.46, 6.20, 7.52, 12.7 and 16.8 Hz. In fig. 1 the location and direction of the maximal amplitudes is given. The first eigenfrequency represents the horizontal motion of the complete system and the second eigenform represents the corresponding vertical motion. Thus the first eigenform is the displacement pattern of the horizontal load case while the second eigenform is the displacement pattern of the vertical load and the dynamic transient. In the transient the substantial effect of the pressure transient comes from the difference force on the vertical pipe.

Fig. 2 compares measured and calculated eigenfrequencies by giving the ratios f(calculated)/ f(measured).
Fig. 2 shows that most of the calculated eigenvalues are within an error of 10% and about 50% of the calculated eigenvalues are within an error of 5%. But the error varies from each participant and eigenvalues.
Typically for each participant the curve of ratios is not a straight line but U-shaped. The ratios for the first eigenvalue are higher than for the second and third which is almost the same while the ratio is increasing again with the fourth and fifth eigenvalue.
The second eigenvalue is approximated best by all models while there is a tendency to overestimate the first. This can be interpretated that the horizontal stiffness of the system is lower than predicted by a typical beam modell for some reasons that have not been identified.

4. STATIC ANALYSIS

In the static tests the piping system has been loaded in x-direction and z-direction by a force of 70 kN. In this paper we will consider the following data for comparison:

MN4201 = x-displacement (fig.1)
MN4203 = z-displacement (fig.1)
MK2121 = vertical bending stress (fig.1)
MK2222 = horizontal bending stress (fig.1),
The following table gives an overview over the results:

Participant	horizontal		vertical	
	MN 4201	MK 2222	MN 4203	MK 2121
EXP	-26,4	26,3	12,5	-50,9
A	-26,9	24,5	11,25	-51,7
B	-27,82	26,	11,78	-53,5
C	-35,12	25,2	13,69	-56,3
D	-25,42	24,7	10,99	-51,5
E	-35,6	29,1	16,4	-58,7
F	-28,4	0	13,91	0
G	-34,12	29,4	13,94	-58,9
H	-27,6	22,6	13,4	-42,0
I	-23,93	21,7	9,99	-44,1
J	-25,0	22,9	10,4	-47,1
K	-27,46	24,4	12,16	-48,6

This shows that the vertical direction is much stiffer resulting in higher bending stress.

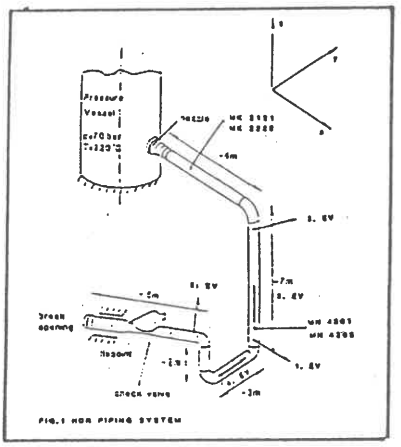
In the horizontal case most participants are within 10% of the measured displacement while three participants overestimate grossly by about 30%. For the corresponding stress MK2222 most participants are within 10% of the measured result, while even those participants which overestimated the displacement are within 15% of the measured data.

In the vertical case the general agreement is somewhat poorer than before. Only half of the participants are within the 10% range, while three underestimate the experimental results between 10 and 20% and three overestimate between 10% and 30%. For the corresponding stress MK2121 the agreement is better, two overestimate the bending stress (maximum +16%) and two underestimate (maximum -12%) by more than 10%.
From the above table it can be derived that the discrepancies in displacements and stresses are related but the error in the stresses is much lower. In no case displacements or stresses were grossly underestimated and some participants achieve a quite accurate prediction.

5. DYNAMIC ANALYSIS

The blind calculations of the dynamic test were performed after the test had been run but the structural results were kept secret. The only information the participants were provided were the pressure time histories at various locations along the pipe. The participants had to do the calculations in two steps

1) derive load functions from the measured data by interpolatior
2) perform a dynamic piping analysis.



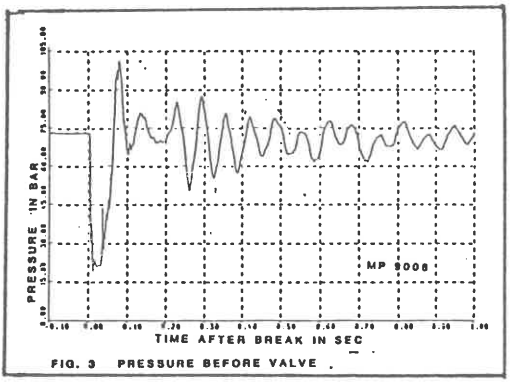


FIG. 3 PRESSURE BEFORE VALVE

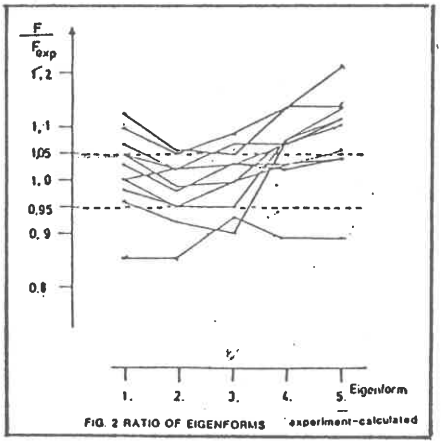


FIG. 2 RATIO OF EIGENFORMS experiment-calculated

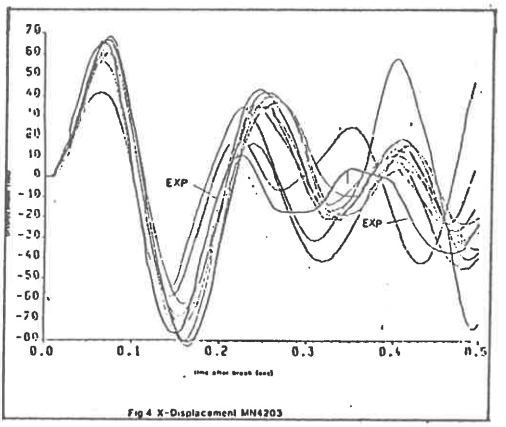


Fig 4 X-Displacement MN4203

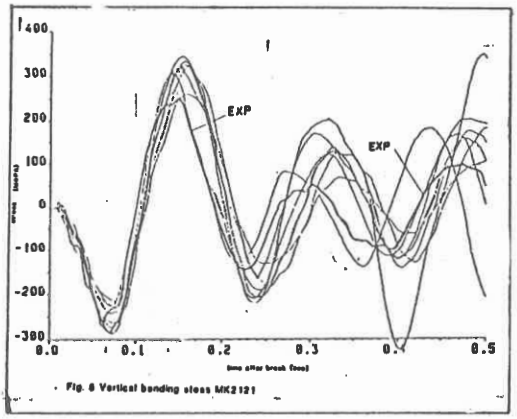
Most participants calculated load functions for the midpoints of the elbow by linear interpolation between pressure points and determining the forces by the formula

$$F = p \cdot A \quad (F \text{ force, } p \text{ pressure, } A \text{ area})$$

The substantial force acting on the piping system in the transient is the pressure difference along the vertical section of the pipe. A typical pressure is given in fig. 3. It shows that the main frequencies of the main force are essentially higher than the eigenfrequencies of the structure.

The highest displacements were reached by MN4203 with a maximum of -77.3 mm. Unfortunately at about 200 msec a slight plastification of the piping system occurred. Therefore the calculated and measured displacements are not comparable after that time.

Fig. 4 show the measured and calculated displacements MN4203. In the first 200 msec the agreement is qualitatively good but after this time the agreement between the participant is decreasing rapidly. For the first maximum all participants with one exception are in a range of + 36% to - 14.5% of the measured value. There are two important factors which lead to the gross differences at times after 200 sec:



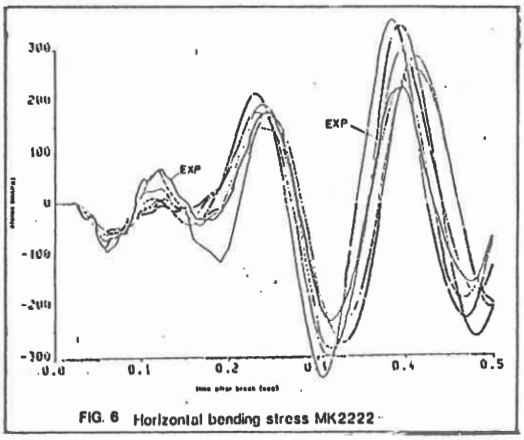


FIG. 6 Horizontal bending stress MK2222

1) The errors in the eigenfrequencies accumulate and affect both the height of the maxima and minima and the times at which they occur.

2) The effects of the different techniques of calculation and application of loads accumulate.

Due to the local plastification at 200 msec the calculated curves overestimate the measured data. The same holds for the stresses, where maximum values of stress are measured at MK2121 (fig. 5). For the first minimum all participant do quite well. But at later times the agreement is rather poor as could be expected from the displacements.
The main result from the transient analysis is that the first oscillation is adequately predicted by most participants but afterwards the differences in the eigenforms and eigenfrequencies of the models accumulate and lead to rather poor agreement of the calculated transients. If the main loading of the structure occurs at a later time as it is the case for MK2222 (fig. 6) this can lead to a gross under- or overprediction of the stresses. But even in this case the transient is predicted qualitatively, i.e. it can be seen from the calculation that the main loading occurs at a later time and the time span when it occurs is predicted adequately.

Conclusion

The HDR piping system under consideration is typical for a nuclear reactor. The techniques used to predict the structural behavior of the system are state-of-the-art. The comparison of measured and calculated data is a test for reliability of the calculational prediction in this environment.

The comparison demonstrates:

1) Eigenfrequencies and eigenforms are predicted adequately. Many participant's predictions are within 5% of the measured results.
2) Static displacements, too, are predicted adequately well, but the variation range is somewhat higher, with most participants within a 10% error bound.
3) The prediction of the bending stress is qualitatively comparable to the displacement but the differences between measured and calculated data is about half the amount that was found for the displacements.
4) The prediction of the transient is adequate only for the first 200 msec (first vibration). After this time the errors accumulate. As a consequence the agreement of the calculated curves degrades rapidly. After 200 msec the special features of the test results are predicted only in a qualitative sense while the quantitative agreement is rather poor.

The main sources of discrepancies are:

1) In the transient analysis several steps have to be carried out "by hand", and are not carried out automatically by the computer.
2) Several steps especially the evaluation of the pressures and the calculation of the load functions are not well established and left to the judgement of the analyst.

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