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Seismic behaviour of a PWR piping

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ABSTRACT : Seismic tests were performed on a PWR piping system. The piping was tested until important deformations occurred but the failure was not reached. In parallel, calculations were performed and validated by comparison with tests.

1 INTRODUCTION

This study was performed in order to improve the qualification methods used for PWR piping systems under high seismic loading. Several research programs were initiated in the U.S.A. in order to examine the conservatism inherent in code rules for the design of piping systems (L.K. Severud, 1988).

Nuclear power plant piping systems are currently designed to resist high level loading of dynamic events as earthquakes by considering a linear behavior of the piping. Current design rules do not account for the favorable effects of energy absorption caused by material ductility that occurs in piping systems loaded beyond the material elastic limits.

In order to achieve this study, seismic tests were performed on a PWR piping system scale one. The piping was chosen because of its important sensitivity to earthquakes. The piping was tested until important deformation occurred but the failure was not reached.

The aim of this paper is to present the results of the tests and the comparison with calculations.

2 TEST SYSTEM CHARACTERISTICS AND TEST LOADING

The piping system was filled with unpressurized water and consisted of a 114.3 mm outside diameter, 8.56 mm thickness, carbon steel TU42C. It contains three elbows and a valve (120 kg) which represents more than 30 % of the total mass (see figure 1). One end of the pipe was fixed and the other was supported by a guide which prevented the displacement in the X and Y directions. We modelled a snubber which limited the displacements in the Z direction and placed it at the node 33.

The tests were performed on the shaking table AZALEE of the CEA Laboratory TAMARIS and consisted of a time history dynamic loading in the X direction. The maximum acceleration of the input motion is 0.32g for the low level test and reaches 2.8g for the last test with plastic deformations. Response spectrum corresponding to the low level is shown in figure 2 for 2 % damping. The yield point strength was reached for a maximum acceleration of 1 g.

3 TEST RESULTS

Static tests were performed on the system without the snubber. The piping remained elastic. A force was applied near the valve, in a direction perpendicular to the (X,Y) plane. The maximum stress was obtained in the elbow 102-104 and the maximum displacement occurred between the elbows 122-124 and 128-130 in the X-direction. A second test was done with a force in the Z-direction. An important in plane moment appeared in the elbow 102-104 and the maximum displacement was obtained near the guide in the Z-direction.

Modal analysis of the system showed two low-frequency modes. The lowest one was a mode about 5.1 Hz, involving principally motion of the "lyre" in the X and Y directions. The second mode (its frequency is about 6.6. Hz) implied the displacement of the straight portion of the pipe in the Z direction.

During the seismic tests, the maximum stress occurred in the elbow 102-104 ; it is associated to an important out of plane moment and induced a permanent local deformation. For the high level test, this deformation reached about 1 %. Near the fixed point, a significant torsion component was measured. The elbows 122-124 and 128-130 exhibited both in plane deformations. Plastic deformations appeared also in these regions.

The analysis of the spectra and decrease of the response after the loading gives a damping value for low level tests equal to 1.5 %. For the high level tests, this value does not change.

4 CASTEM 2000 CALCULATIONS AND COMPARISON WITH TESTS

4.1 Comparison with static tests

Post-test calculations were made to determine the maximum local strain and the displacement during the two static tests. For the "(X,Y) test", the maximum normalized strain was induced by out of plane moment in the elbow 102-104 and was equal to 1.6 10^{-7} /N. The maximum normalized displacement in the X-direction was equal to 5.9 10^{-3} mm/N. Static analysis predicted the correct locations and the calculated values were 1.55 10^{-7} /N for the maximum stress and 5.6 10^{-3} mm/N for the displacement. For the "Z test", the results were also in good agreement with the experiment.

4.2 Comparison with modal tests

Calculations gave three modes at 5.3 Hz, 5.9 Hz and 6.3 Hz. The first mode and the last one, which correspond to those obtained during the modal test, were very sensitive to the boundary conditions at the fixed point. It was assumed that this point was not perfectly fixed and we showed that a little modification of the rotational flexibility at this location had a great influence on the frequency values of the first and third modes. Moreover it seemed that some friction was possible at the guide zone for very low excitation level like during modal tests. Later we found that during seismic tests the displacements in the Z direction near the guide were very noise-infested. We established that the calculated second mode at 5.9 Hz disappeared when a moderate stiffness is introduced in the Z direction at the guide. In conclusion the difficulties we have met in calculations were due to the boundary conditions modelling. These conditions which had been chosen in agreement with these of the real PWR pipe were not perfectly realized in test.

4.3 Comparison with seismic tests

For low level excitation the calculations were made using the conventional linear elastic analysis method. The same seismic behavior was observed in the experiments and in calculations. The first mode is predominant in the response of the lyre while the straight portion in Z direction is dominated by the modes at 5 Hz and 6.3 Hz. In these calculations, the contribution of the 5.9 Hz mode is negligible, consequently the calculated displacements were in good agreement with the measured ones. For example, in the figure 3, we compared the test and calculation displacements near the valve in the X direction. We also found, as for the experiments, a maximum stress in the elbow 102-104 with a predominant out of plane deformation. The comparison between the calculated and measured deformations was good. The maximum torsion component near the fixed point is about 2.9 10^{-4} in the test while calculations predict 2.7 10^{-4}. We noted that the responses were very sensitive to the values of the frequencies. This important sensitivity is due to the small damping ratio.

For the high level excitation, the calculations were carried out by the non linear time history method and were made with a bilinear stress-strain relation (until 1%) and an effective yield point equal to 295 Mpa.

Calculations predict a plastic deformation in the elbow 102-104 as it had been observed in the test. The same value for the maximum torsion component was found in test and calculations. The relationship in calculations between this component and the displacement near the valve in the X direction is represented in the figure 4. This relation which is not linear is typical of the energy dissipation caused by the plastic work in addition to the viscous damping. The shape of loops is similar to those observed in the test. It proves that the non linear behavior of the structure is well accounted in calculations.

Concerning the response details, the agreement with the test is not as good as for the linear results. For example in figure 5, we compared the spectra of the measured and calculated displacement near the valve in the X direction. We can observe that the 5.9 Hz mode contribution in calculation is not negligible. We can also note a shift of the first mode frequency towards the low values. We think that this phenomena is not due to the plastic deformations in the structure (these are too small) but to an influence of the boundary conditions. As in linear calculations, the responses were very sensitive to the values of the frequencies.

For the calculated deformations, as a global model is used, we have only access to the generalized stresses and strains while in the tests, we measure local responses. So it is difficult to compare directly the test and calculated time history responses, except for the torsion component which is constant in the pipe section. The agreement between calculation and test for this entity near the fixed node is good.

For the others deformation entities, we can only compare the response shapes. For example the figure 6 shows the compared in plane deformation response spectra in the elbow 122-124.

5 CONCLUSION

We have performed two seismic tests. The second one has been done at the maximum capacities of the shaking table AZALEE. These tests permitted to have a good idea of the seismic behavior of the piping.

Calculations gave a good agreement with the experiments for the low level excitation as for high level one.

The next step consists in the examination of the design rule conservatisms as the maximum allowable acceleration is 1g and the test shows no failure for acceleration level up to 2.8g. Consequently modifications to design rules have to be proposed keeping margins associated to the unknowns (seismic input, construction,...) and taking into account such test results.

REFERENCES

L.K. Severud, M.J. Anderson, M.R. Lindquist, S.E. Wagner, E.O. Weiner, NUREG/CR-5023, WHC-EP-0081, High-Level Seismic Response and Failure Prediction Methods for Piping (1988)

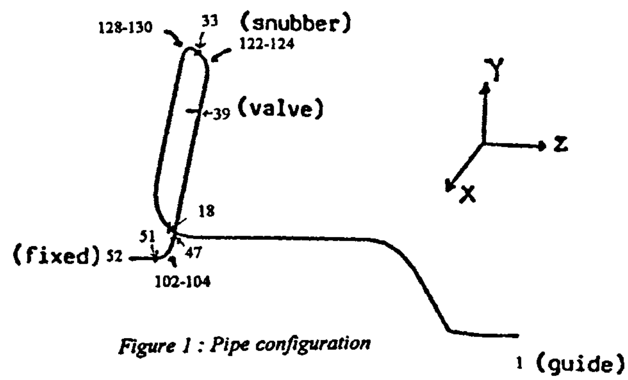

Figure 1 : Pipe configuration

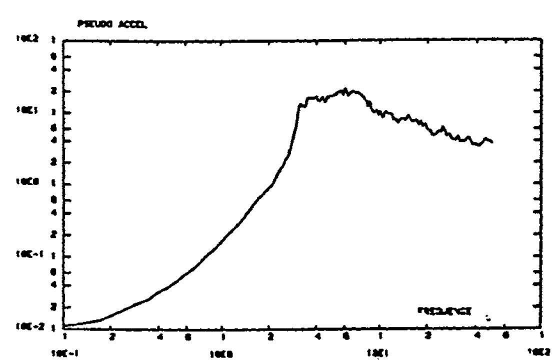

Figure 2 : Response spectrum (low level test)

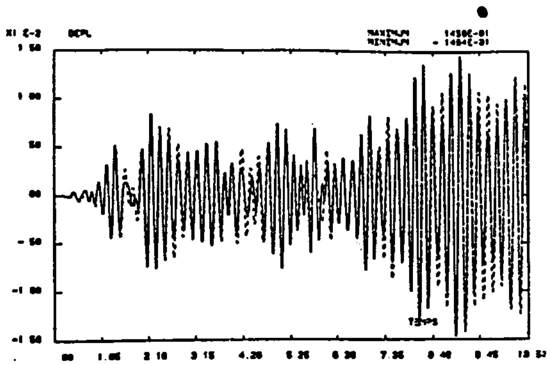

Figure 3 : Displacement X near the valve (low level test)
(- - - : test ;— : calculation)

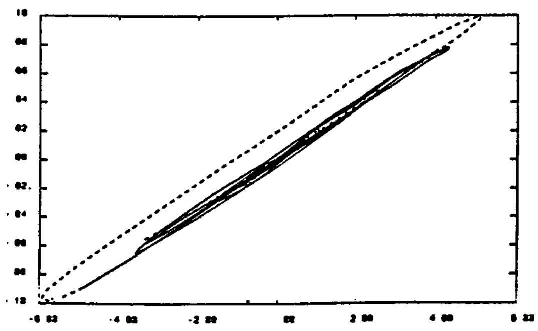

Figure 4 : Relationship between torsion near the fixed node and displacemement X near the valve

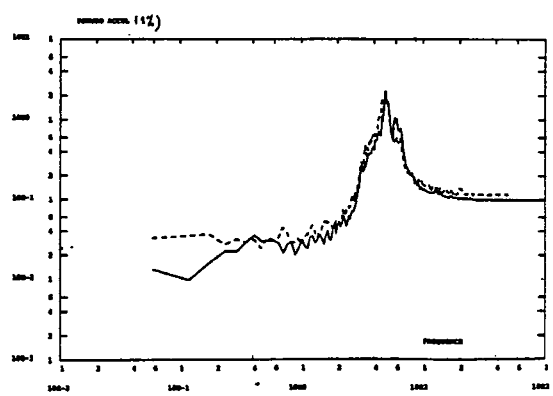

Figure 5 : Spectrum of the displacement X near the valve
(- - - : test ;— : calculation)

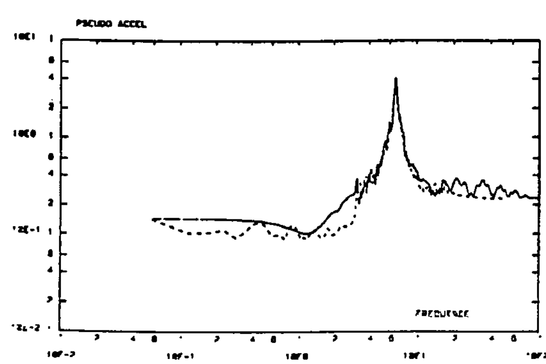

Figure 6: Spectrum of the in plane deformation in elbow 122-124
(- - - : test ;— : calculation)