

SUMMARY OF THE MEETING

The Research Co-ordination Meeting held in Vienna, 16-17 November 1993, was attended by participants from France, India, Italy, Japan and the Russian Federation. The meeting was held to discuss and compare the results obtained by various organizations for the analysis of Italian tests on PEC mock-ups.

The background paper by A. Martelli, et al., Italy, entitled Fluid-Structure Interaction Experiments of PEC Core Mock-ups and Numerical Analysis Performed by ENEA presented details on the Italian PEC (Prova Elementi di Combustibile, i.e. Fuel Element Test Facility) test data for the benchmark.

Several papers were presented on the analytical investigations of the PEC reactor core experiments. The paper by M. Morishita, Japan, entitled Seismic Response Analysis of PEC Reactor Core Mock-up, gives a brief review of the Japanese data on the Monju mock-up core experiment which had been distributed to the participating countries through the IAEA.

Discussion of calculation results, conclusions

Analysis performed by Japanese organizations

Four Japanese organizations — Power Reactor and Nuclear Fuel Development Corporation (PNC), Mitsubishi, Hitachi and Toshiba — participated in the CRP and compared the computer codes used, the analysis methodologies and the main results of the Italian PEC problems. PNC used the FINDS code while Toshiba used the SALCON code. For the seismic test unit 19 fuel and reflecting elements in water, both PNC and Toshiba could get quite a good result compared to the experimental data, although they used different calculation methodologies and assumptions. For the displacement response, the difference of maximum values between analysis and experiment was small, and the profiles of the overall time histories are quite similar to each other. Also, the acceleration response by analysis with low pass filtration was in a good accordance with the experiment. Shock force by analysis was given although no relevant data was provided by the experiment. Mitsubishi used the FINDS code to analyse PEC experiments of a 19 assembly mock-up exciting case. It was explained that FINDS has capabilities of inelastic and multi-row analyses and can be used for both PWRs and FBRs. In calculations, added mass, virtual mass, damping and rows were changed to survey exact models by comparing analytical results with the measured data. The case B which adopted 4% damping and diagonal added mass had the most consistency with data both in displacements and in accelerations. It was noted that PEC experiments can be reasonably analysed by the computer code FINDS with high damping and normal virtual mass model. The 3-row results showed consistency with the single-row results. Hitachi used the SAFA code whose special feature is to adopt a matrix-type added-mass model in addition to a concentrated added-mass model. SAFA predicted a little smaller response both in displacements and in accelerations. It was noted that it is possible to use larger damping (5% for the 1st mode, 15% for the 2nd mode) and higher mass distributions. It was stressed that the PEC assembly has a small damping of nearly 1% in contrast to 4 or 5% damping which all Japanese participants used, and that if they include non-diagonal added mass matrix they can get good agreement with data even though they use 1% damping.

Analysis performed by BARC, Bombay (India)

This analysis was performed using a general purpose computer code COSMOS. 3-D elastic beam elements were used to model the fuel and reflector elements. Stiffness of the

spike was adjusted to match the natural frequency observed during the experiment. Gaps with springs modelled the interaction at the pads. Shock damping was not considered. A model super-position method with 3 (no blank) modes was used for the calculations. The time step used was 1 ms, which was considered adequate for finding the displacement response. For a small portion of the excitation, however, the analysis was repeated with a smaller time step (0.1 ms). As expected, it was found that although the acceleration response did change, the displacements were not affected at all.

For the all fuel configurations, there was no contact at the pad locations and it was adequate to analyse a single element. The maximum and the RMs values of the response matched well with the experimental values. For the 19 element mixed configuration, the calculated displacements were within 20% of the experimental values, but the discrepancy in acceleration was much larger. A possible explanation for this is the absence of a shock damper, which may result in higher interaction force and therefore, in high acceleration. It was stated that a non-linear analysis with direct integration method including the shock damper is possible but was not performed due to large computer time required. However, an attempt is being made to perform this analysis for a limited duration of excitation.

Comparison in frequency domain using Fourier transform analysis showed a peculiar phenomenon. The analysis with a time step of 1 ms showed a peak at 3.3 Hz, the first fundamental frequency, whereas the experimental results show a peak at about 20 Hz, the second mode frequency. Analysis with the reduced time step (0.1 ms) has reproduced this peak. However, it was noted that, although a peak may be expected at the second mode frequency because the second mode is excited following impact at pad, most of the energy will be concentrated in the first mode. This will be investigated further.

Analysis performed by IGCAR, Kalpakkam (India)

This analysis was performed by using the specially developed code CORE-SEIS. The features of this code are:

- 3-D elastic beam elements
- gap with spring and damper to model the contact at pads
- added mass to account for fluid effect
- Rayleigh damping
- Direct integration with variable time step.

For the PEC test, 5% damping was used for the first two modes. The boundary condition at the base was tuned to get the experimentally observed natural frequency in air. Time steps of 5 ms were used for the single element analysis and 0.5 ms for the elements with gaps. For the all fuel configurations, it was adequate to analyse a single assembly. A parametric study with some variations in the properties did not result in significant change in the response. The maximum values of the calculated response matched well with the experimental values. The Fourier transforms of the measured and the computed responses also matched well. For the 19 element mixed configuration, the comparison with respect to displacements is good, but the nature of variation of the response seems to be rather odd. This is being investigated. The displacement response of the 3 adjacent elements was also plotted to verify that the impact phenomenon is modelled correctly.

Analysis performed by ENEA (Italy)

It was stressed that due to the general features of fast reactors and the specific geometry of the PEC reactor block, the ground motion is considerably amplified at the diagrid level.

Therefore, a wide ranging program of numerical analyses and experimental tests was carried out by ENEA. Although many tests were carried out, the participants were asked to analyse four tests in water only (tests 1, 16, 18 and 47). This was decided during the consultancy held in Bergamo, April 1992 and the data was supplied to the participants after the meeting. The tank size was deliberately made large and its walls were made stiff, so that the complications of fluid structure interaction were reduced (no fluid coupling). Only added mass (diagonal and non diagonal) between core and tank walls is required to be considered. This has been confirmed by the analyses carried out. The calculations were performed using the codes CORALIE (in which motion in the direction of excitation alone is considered) and CLASM (in which simultaneous motions in both directions were considered). It was found that there were no significant 2-D effects and 1-D calculations were adequate. Regarding damping, it was clarified that when the added mass is considered for only the diagonal terms of the mass matrix, damping of 4-5% of critical may be reasonable but when the reduction in seismic load due to non diagonal terms of mass matrix is considered, 1% is the correct value.

Analysis performed in the Russian Federation

The DINARA code describes shock phenomena by spring-damper systems, that are applied to the axial nodes of possible contact and start acting as soon as contacts occur. The dissipative effects are assumed to be included in damping coefficients. The fluid-structure interaction effects due to the presence of water among elements and at the sides of the core were simulated by an increase of damping coefficients, to 5%. The amplification factors were compared with experimental results. The difference between the amplification values was about 20%. The results of these analysis will be corrected in the future investigations.

CEA (France) activities

The computer code used is CASTEM 2000 which is able to study a single row. In this case the method and the results are similar to CORALIE, a code already presented within the CRP. It is also able to study clusters taking into account the bidirectional motion of the assemblies. The results which were shown are maximum displacements and maximum forces. They were compared to the experimental results. The variation with time of the pad displacement and impact forces was also given. On the single row configuration, a great discrepancy can be noticed for the maximal impact forces at the lower pad level. The experimental values are very low while in the calculation they are similar to the upper values. Two causes for this discrepancy have been suggested: (1) the great value of the gap taken in the calculation for the diagrid level (1 mm instead of 0.1 mm), and (2) the use of a theoretical accelerogram instead of the real measured one. In addition it was indicated that the test and calculation comparison can be completed only if the experimental data, at least for displacements and shaking table accelerogram, can be provided on diskettes. Indeed, the comparison cannot be limited to maximal values but must be done both in home domain and frequency domain.

For the *Hexagonal cluster* configuration the maximal displacements obtained by calculation and test are not far from the geometrical limit (sum of the gaps) which indicates that the analysis based on maximum values is not as rich as for row layout. This emphasizes the need for frequency and time domain comparison. During the discussion, it was specified that the calculation takes into account the 2D motion in the plane (X and 4), as a 3D mesh based on beams was established and impacts were modelled for each pad.

Conclusions

The following issues were stressed in the papers:

- The need for not limiting comparison between calculations and measurements to maximal response values, but also to make use of root-mean-square values, time histories and some frequency response parameters. To this aim, France suggested spectra of the response displacement and Italy provided the transfer function between diagrid acceleration and element response displacement;
- The better adequacy of displacements, rather than accelerations, for contribution purposes, when analyzing the Italian results at least;
- The need to account for the non-diagonal term of the added mass matrix (M_{ND}) related to the coupling between the core and external vessel in the seismic load and to adjust the damping coefficient accordingly;
- The need to compare the results of analysis performed for the PEC core mock-up to those of the ENEA numerical study;
- The need for having available on diskette recorded time-history of the acceleration actually applied to the tested mock-ups and those of responses, as the only way for a correct analysis of experimental data.