Sources of Error in the Computation of Side-Wall Deformation in the COVA Experiments

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Abstract

It is well known that the codes ASTARTE-4 and SEURBNUK-2 generally underpredict the deformation of vessels in the COVA experiments. This problem has been tackled by the study of the energy balances obtained from calculations made for the COVA WTØ experiment. It has been established for this experiment that the discrepancy between calculation and experiment is due to an incorrectly high level of dissipation of the explosive charge energy in the water and additionally, in the case of SEURBNUK-2, to code energy losses.

The dissipation error can be made negligibly small with the ASTARTE-4 code by a suitable choice of computational mesh, with the result that good agreement between experiment and calculation is obtained. With SEURBNUK-2 code changes to reduce the error are described but more extensive recoding will be necessary to achieve a more satisfactory agreement with experiment.

1. Introduction

The first reported tests of the COVA programme [1] indicated that the code ASTARTE underpredicted the vessel strains at charge height and this tendency was confirmed by further work [2] using both the ASTARTE and SEURBNUK codes. Despite a close scrutiny of the data being used in the codes [3], no entirely satisfactory explanation of the discrepancy has been advanced.

The present work was originally concerned with the checking of derivation of the Low Density Explosive (LDE) performance as at the time the evidence pointed to a common factor in both computer codes. However, despite the circumstantial evidence that the LDE charge was more energetic than suggested by the derived equation of state, a careful reappraisal of the characterisation procedure only served to confirm the accuracy of earlier work [4]. A second stage of the work on the charge characterisation was concerned with estimating the uncertainties to see if part of the discrepancy between the COVA experimental data and calculation could be explained in this way. To perform this analysis, it was the intention to use the simple COVA experiment WTØ (Fig 1) as the configuration on which the effects of various perturbations of charge performance could be compared. In the event, this work on

COVA WTØ gave an unexpected lead on the source of the error between experiment and calculation so the investigation into the uncertainties in the charge performance was set aside.

2. ASTARTE Calculations on the WTØ Configuration

At the time this work was being performed, it was considered that both ASTARTE and SEURBNUK exhibited the same order of error compared with experiment so either code could have been used as the method under test. Because of the availability of previous calculations, it seemed that SEURBNUK was the better choice. Now it was fully realised that the then current version of SEURBNUK would not represent correctly the boundary restraints at the ends of the deformable shell. In the experiment, the upper end cap was attached to a mounting frame that was supported from the floor. This prevented increases in vessel length, but vessel shortening caused by barrelling of the sidewalls was not restrained because the lower end cap could lift from the floor. In SEURBNUK this complex situation had to be approximated to by a fixed clamp at each end of the vessel wall. It can easily be shown that the levels of radial strain in the shell measured in the experiment would induce high tensile stresses in the axial direction if both ends were fixed and these stresses will tend to make the shell to strain rather less. Therefore before the SEURBNUK calculations could be usefully compared with experiment it was necessary to determine the reduction in shell strain resulting from the incorrect boundary conditions. This analysis was performed using ASTARTE because this code was more amenable to adhoc changes than SEURBNUK.

A preliminary calculation on the WTØ configuration was performed using ASTARTE using the recommended material properties and the standard equation of state of the LDE charge. This calculation employed a rectilinear computational mesh and the shell ends were fixed as in the SEURBNUK calculation. This calculation exhibited the usual severe mesh distortion as the charge bubble expanded so that the code stability criteria demanded a rapidly reducing timestep. The mid height circumferential strains from this calculation are shown plotted in Figure 2. This calculation was, at the time, considered satisfactory in that the calculated strains were less than the experimental values and much as was expected from earlier calculations with SEURBNUK. However, the high cost of the calculation due to the very small stable timestep was an embarrassment and it was not certain that the calculation could be continued up to 5 or 6 msec. To overcome these problems, a new mesh configuration was designed which used radial mesh arrangement round the charge (Fig 3). This pattern required the use of a pressure boundary to represent the LDE charge but otherwise the data used was identical to that of the first calculation. This calculation ran to 6 msec without any of the mesh distortion problems met in the first calculation. On plotting the shell strains and comparing them with experiment (Fig 2), it was immediately clear that the new strain prediction of 7.9% was much nearer the experimental value of 8.8% than an earlier SEURBNUK calculation [3] or the first ASTARTE calculation was described earlier. The reasons for this will be described later.

To complete this series of calculations a further ASTARTE run was performed using the same mesh pattern as the second calculation but with the dynamics of the end cap of WTØ correctly simulated [5]. This calculation ran without any problem and the resulting permanent hoop strain on the shell was given as 8.6% as against the measured value of 8.8%. Although this series of calculations achieved the objective of showing that the effect of the incorrect end conditions on the shell was to reduce the maximum hoop strain by about 0.7%, a perhaps more important result was the closeness of the calculated and experimental strains. This result was clearly anomalous and reasons for this behaviour were sought. In comparing the output data for the first and second ASTARTE calculations, it was noted that at 2.6 msec (the end of the first calculation) the internal energy of the fluids were very different, being 3.3 KJ and 0.3 KJ respectively. As the energy required to cause the shell mid-height radial strain to increase from 7% to 8% is about 3 KJ (note that the total strain energy - mid-height radial strain curve is non-linear so that the additional energy required to cause the final straining is only one half the average value), and calculations with the same code on the same problem can produce energy differences of the same order, it is clearly essential to determine what the correct level of energy in the water should be.

3. Energy Dissipation in the Water Surrounding an LDE Charge

The method used to determine the energy dissipated in the water surrounding an LDE charge was similar to that described in reference [6]. This involved two main stages: the determination of the shock strength from the LDE as a function of time or radius, and then from the water equation of state, the amount of energy dissipated. It should be noted that the energy dissipated in the water is a function of the cube of the shock strength and so it was essential to obtain accurate data on the shock strengths due to an LDE. This was achieved using the one dimensional Lagrangian code SIMLA [7]. Because the shock strength produced by an LDE is slightly different if it is modelled as a pressure boundary instead of a separate structure, two sets of results were computed and these are shown plotted on Figure 4.

From Figure 4, it can be seen that the amount of energy dissipation should be roughly 500J, so the low dissipation level of the third ASTARTE calculation (300J) is of the right order. Therefore the good agreement between this calculation and experiment is not due to an incorrectly low dissipation level compensating for errors occuring elsewhere.

4. SEURBNUK Calculations

To make certain that all the calculations used in this work used an identical set of data, the SEURBNUK calculations first reported in Reference [3] were repeated. In fact the results were indistinguishable from the earlier calculation (Fig 5). From the energy edit given in these results, it was immediately apparent that the dissipation levels were too high so that methods of correcting this were sought.

Because it seemed probable that the strong inherent damping due to the numerical scheme used SEURBNUK was partially reponsible for the excessive dissipation levels, some secondary calculations were performed to see if reducing the damping gave an improvement.

For reasons of economy, these calculations were performed using a model representing just the radial propagation of the initial shock from the LDE charge. This work showed that reducing the timestep or centering the difference equations both reduced the dissipation levels and it seemed quite practical to obtain a reduction of the dissipated energy down to one half of the original value.

The WTØ calculation was repeated using the version of SEURBNUK with a lower damping level and the results confirmed that less of the charge energy was absorbed in the water and more was given to the deformable wall, so giving a higher strain (Fig 5). It should be noted that because the boundary conditions imposed at the ends of the wall were only approximated to those in the experiment (see Section 2), in comparing the calculated and experimental strains, the SEURBNUK strains should be increased by 0.7%. Figure 5 shows that the agreement between calculation and experiment is still poor.

5. Energy Summary

The energy edits of the main calculations referred to in the text are summarised in Table 1. It is clear from this table that the percentage of the charge energy which is given to the deformable wall is much less for SEURBNUK than for ASTARTE and this difference is mainly due to energy loss in the code and dissipated energy. Thus an improvement of the agreement between calculation and experiment will require attention to the structure of the codes to reduce or eliminate these errors.

6. Conclusions

By examination of the results obtained from calculations using the codes ASTARTE and SEURBNUK it has been shown that two major causes of the well known discrepancy between calculation and experiment are an excessive level of dissipation of the energy of the LDE charge in the surrounding water and code energy losses. Although this work was performed only with the COVA experiment WTØ, and with the two codes commonly used in the UK, it is believed that these sources of error are also important in other COVA experiments and with other codes used in Containment Analysis.

Also because a calculation in which these errors were small gave strains close to the experimental values, it is inferred that the characterisation of the LDE charge as commonly used in the COVA analysis is not in serious error.

References

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TABLE 1

Energy Balances for Calculations Mentioned in Paper

Code	ASTARTE-4				SEURBNUK-2			
Calculation Type	Fixed End Caps		Moveable End Caps		Standard		With reduced Damping	
	Joules	%	Joules	%	Joules	%	Joules	%
Wall Deformation	46151	96.2	46490	97.7	39717	80.4	43746	88.0
Fluid Internal	99	0.2	111	0.2	6137	12.4	2851	5.7
Kinetic	209	0.4	238	0.5	318	0.6	172	0.4
Unaccounted for	1535	3.2	741	1.6	3207	6.6	2964	5.9
Charge Work	47994	100.0	47580	100.0	49379	100.0	49733	100.0

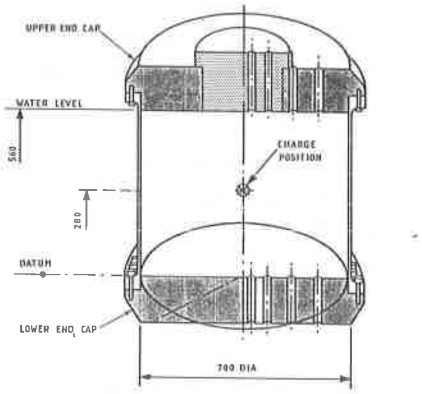

FIGURE 1 Experimental Arrangement of WTØ

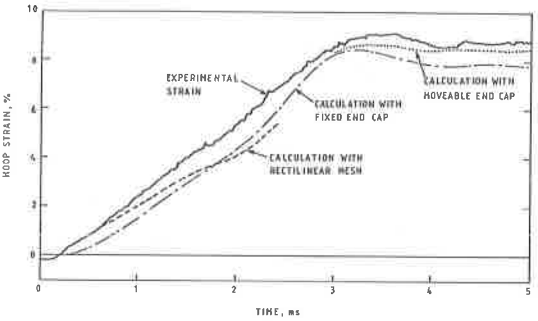

FIGURE 2 Comparison between ASTARTE Predictions and Experimental Strains for WTØ

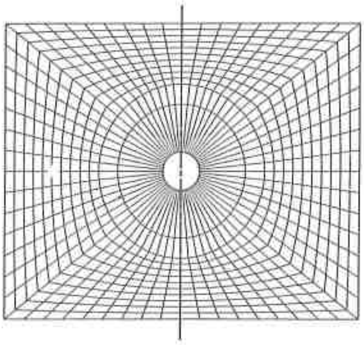

FIGURE 3 ASTARTE Mesh Pattern which avoids Distortion Problems

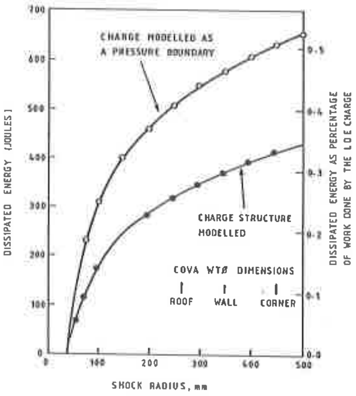

FIGURE 4 Total Energy Dissipated in Water Surrounding an LDE Charge

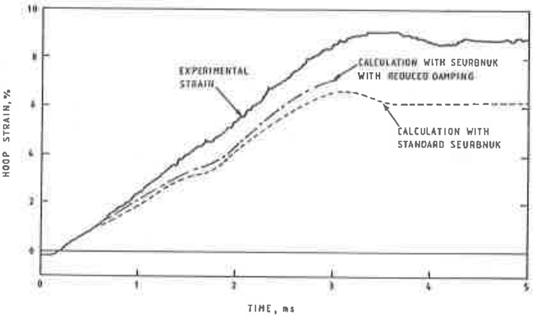

FIGURE 5 Comparison between SEURBNUK Predictions and Experimental Strains for WTØ