A Programme to Validate Computer Codes for Container Impact Analysis

A.J. Neilson, C.A. Cooper, N. Butler

AEA Technology, Winfrith, Dorchester, Dorset, United Kingdom

INTRODUCTION

The detailed analysis of containers during impacts to assess either margins to failure or the consequences of different design strategies, requires the use of sophisticated computer codes to model the interactions of the various structural components. The combination of plastic deformation, impact and sliding at interfaces and dynamic loading effects provides a severe test of both the skill of the analyst and the robustness of the computer codes. A programme of experiments has been under way at Winfrith since 1987 using extensively instrumented models to provide data for the validation of such codes.

Three finite element codes, DYNA3D, HONDO-II and ABAQUS, were selected as suitable tools to cover the range of conditions expected in typical impacts. The impact orientation, velocity and instrumentation locations for the experiments are specified by pre-test calculations using these codes. Post-test analyses using the actual impact orientations and velocities are carried out as necessary if significant discrepancies are found.

The experiments examine the performance of the codes in progressively more complex models and impact orientations so that self-cancelling errors can be identified. The initial experiments are based on monolithic steel flasks typical of those used for LWR spent-fuel transport. Attention has been directed at the loading mechanisms influencing deformation in the closure region. 16 tests have been carried out on empty models, on models with simulations of fuel carrier and fuel subassemblies and on models with shock absorbers protecting the lid closure. A further 8 tests have provided data on shock absorber behaviour under static loadings. Further tests are in progress examining the behaviour of different closure geometries and the transmission of loads to inert simulations of the fuel within the carrier together with the response of this simulated fuel to these loads.

The tests are carried out using the Winfrith Drop Test Facility (capable of lifting 90tons to 30m hook height) and the Horizontal Impact Facility (capable of launching 2ton models at up to 45m/s).

Selected tests and analyses are described in the following sections dealing with specific observations made during the programme to date.

LIMITATIONS OF AXISYMMETRIC MODELLING

The initial experiments were free drops of unprotected models (see figure 1) on to the steel-faced abutment of the Winfrith Drop Test Facility. Pre-test calculations using HONDO-II had indicated that the lid upstand would cease to protect the bolts at a drop height of 20m, and that body deformation would be restricted to a zone about 400mm from the lid-body join. Accordingly the strain gauges were concentrated in this region with reduced numbers further along the flask body, and were set out on three planes at 120-degree intervals to provide checks of the symmetry.

Three experiments were carried out using drop heights of 9m and 20m. In no test was a precisely perpendicular impact achieved, the two 9m drops occurring at angles of 0.9 and 1-degree and the 20m drop at 4-degrees. Although the circumferentially averaged values of residual deformation were well-estimated by the HONDO-II predictions, provided that the strain-rate effects were included (Cooper et al, 1988), the transient strains in the body and in the lid-fixing bolts showed significant asymmetries at even 0.9-degree obliquity.

Post-test calculations were performed with the DYNA3D code, using a mesh representing one half of the model and twelve fixing bolts in some detail. The actual obliquities were imposed on the simulated impacts and the results generally showed good agreement with the tests, although some detailed discrepancies were observed in the surface strains in the plastically deformed zone near the lid/body join where the strain gradients were very high.

The results for the outer-surface strains at a distance 900mm from the lid/body join and for the bolt straining opposite the impact point in the 20m drop are shown in figure 2. The HONDO-II predictions show an initial shock loading of the body and straining of the bolts during rebound. In contrast, the DYNA3D calculations reproduce the gradual loading imposed on the model, identify the bending response of the cylindrical body and show the sustained tensile loading experienced by the instrumented bolt.

Thus while detailed stress analysis require full 3-d simulations for even slight obliquities, axisymmetric calculations can be used to estimate residual deformations of the container (to an accuracy quite acceptable for design scoping studies) up to at least 4-degrees off-normal.

MODELLING FAILURE IN BOLTS

Pre-test predictions using the DYNA3D code for the impact of an empty model in the centre-of-gravity over lid-corner attitude indicated that unacceptable damage to the lid securing bolts would occur at an impact velocity of approximately 14m/s and the lid would remain attached to the body. A test was conducted with this impact attitude in the HIF and a velocity of 17m/s was actually achieved. 19 of the 24 securing bolts failed and were ejected from the model, and the 5 closest to the impact position which had experienced severe deformation of the heads remained intact. The lid remained attached to the body.

Post-test calculations examining the bolt deformations in greater detail, showed that adjustments such as modelling the reduced section of the core in the threaded region did not produce improved estimates of failure using the simple criterion of plastic strain. Use of a maximum principal stress criterion with failure initiated at the estimated failure stress of the high-strength bolt material was found to be more satisfactory. Figure 3 shows the stress in the bolts at twelve locations around the circumference. Plastic strains in the bolt shank are all well below any reasonable failure value, but maximum principal stresses are all significant and show tensile values exceeding the ultimate strength at the 90- and 180-degree positions. Adjacent to the impact point, however, the values are well below the ultimate strength indicating survival of the bolt.

MODELLING SHOCK ABSORBERS

The shock absorbers tested in these initial experiments were fabricated from two standard mild-steel dished-ends with a locating skirt to fit over the flask body or lid (see figure 4). In some tests, the void between the dished ends was filled with balsa wood.

Computer analysis of these shock absorbers under static loading was attempted using the ABAQUS code (version 4.5). The code worked successfully for empty shock absorbers loaded with platens and beams, giving good estimates of load amplitudes and response mechanisms. Calculations for the dynamic loading of empty shells were also completed satisfactorily. However, with balsa-filled shells, the results showed some problems with excessive penetration of the shell by the continuum elements representing the balsa, indicating that the sliding interface logic was not sufficient for large relative motions (Neilson et al 1988a). Although this problem was referred to the code authors, no real success has been achieved with this analysis or others including transient contact/sliding using subsequent versions of the code.

The DYNA3D code was used to estimate the impact velocities required to cause the shock absorbers to lock-up completely when mounted on the flask model. Satisfactory estimates of the velocities in axial, lateral and oblique attitudes were achieved using the simple, isotropic, crushable material model (see Neilson et al 1988b).

Test results for punch loadings show that the interaction between the steel shell and the balsa creates loads much higher than achieved by the balsa alone after puncture of the shell (see figure 5). Calculations with DYNA3D for impacts on a punch have shown that interactions between the shell elements representing the steel and continuum elements representing the punch could not be modelled satisfactorily (using version 'y' released from LLNL on 25/08/88) and that continuum element modelling of the shell in the loaded region seems to be required. Calculations with the DYNA3D in this mode have not yet been carried out, but scoping calculations using HONDO-II have been successful in identifying the interaction load between the shell and the infill.

CONCLUDING REMARKS

The test data produced so far have shown that two of the selected codes can be used to produce accurate estimates of limiting energy absorption capacity of complex interacting structures such as transport flasks. Relatively simple rules are being derived to ensure that meshes are designed sufficiently well to capture important detail.

The ABAQUS code has been found satisfactory only in static loading cases where significant relative motion of the structural components are small. For dynamic problems where contact surfaces change during the impact, the code has been found to be uneconomic as, even in gentle impacts, the time steps can be forced down to values much smaller than those required for explicit codes. This comment does not seem to be restricted to the ABAQUS code, since other users of both implicit and explicit structural analysis codes have expressed the same observation to the authors.

DYNA3D and HONDO-II have generally been found to perform satisfactorily for the analyses attempted so far. The two codes show some differences on detailed behaviour for identical simulations. The HONDO-II shows much greater sensitivity to strain-rate effects than DYNA3D and seems to produce much higher frequency components in the estimates of accelerations imposed on the models. The mean level of acceleration in one particular comparison was a factor of 10 higher with HONDO-II that with DYNA3D. This is attributed to the different element formulations in the two codes - DYNA3D using constant stress hexahedra with hourglass and bulk viscosities to control stability, and HONDO-II using four-node bilinear quadrilaterals with only bulk viscosity to control instabilities. A similar observation was made in a comparison between results from HONDO-II and DYNA2D (McCreesh, 1988).

REFERENCES

Cooper, C.A., Neilson, A.J., Butler, N., Bazell, C.J., *Three Dimensional Effects in Flask Impact Testing*, AEEW-M 2520 (1988)

Neilson, A.J., Kendall, K.C., *Experience with DYNA3D for Simulating Shock Absorber Behaviour*, Proceedings of second DYNA3D user group conference, London (1988)

Neilson, A.J., Kendall, K.C., Attwood, G.J., *Use of ABAQUS for Impact Analysis*, Paper to second UK ABAQUS user group meeting (1988)

McCreesh, G., *BNFL*, Private Communication (1988)

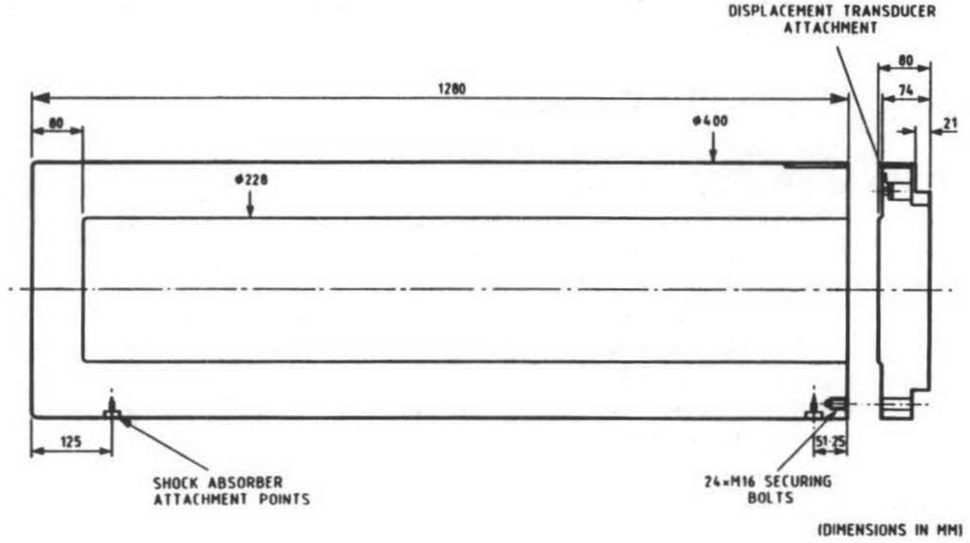


FIG.1 GENERIC FLASK MODEL

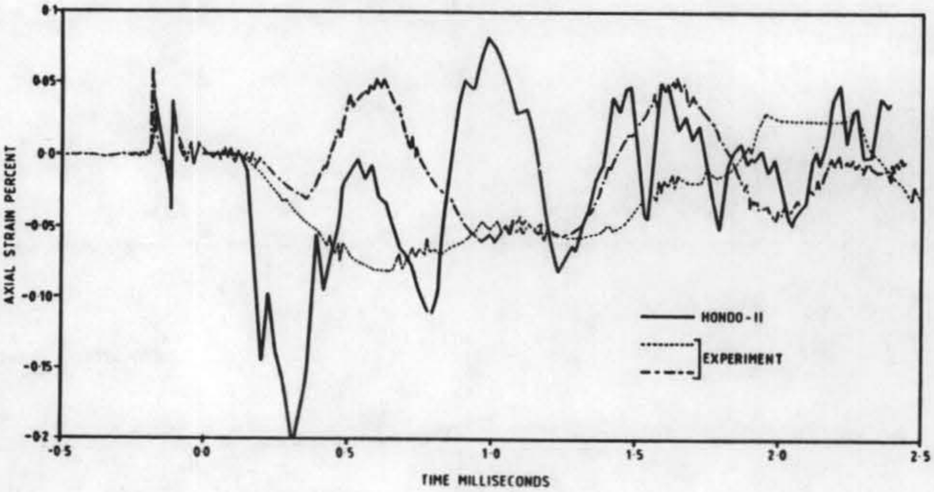


FIG.2a STRAINING ON OUTSIDE OF BODY, 20m DROP

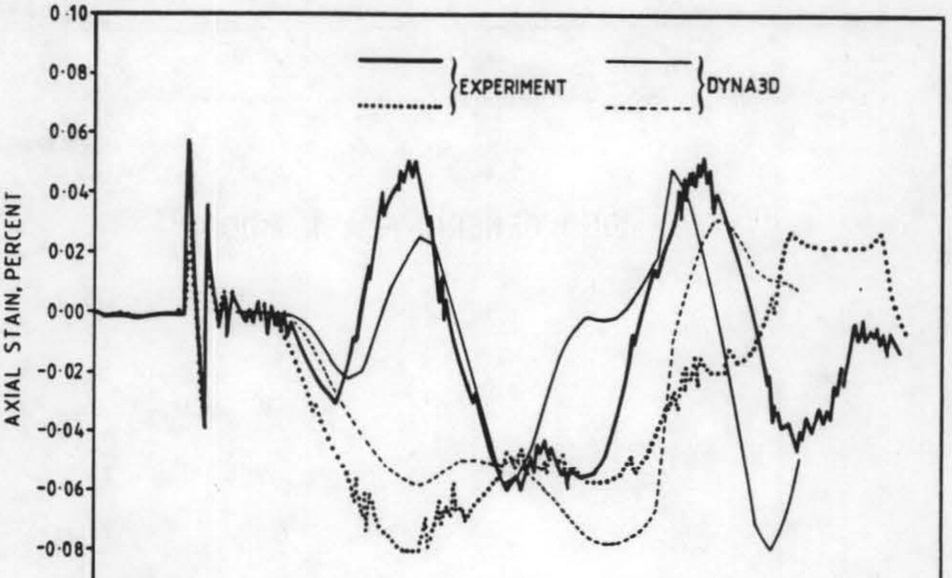


FIG.2b STRAINING ON OUTSIDE OF BODY, 20m DROP

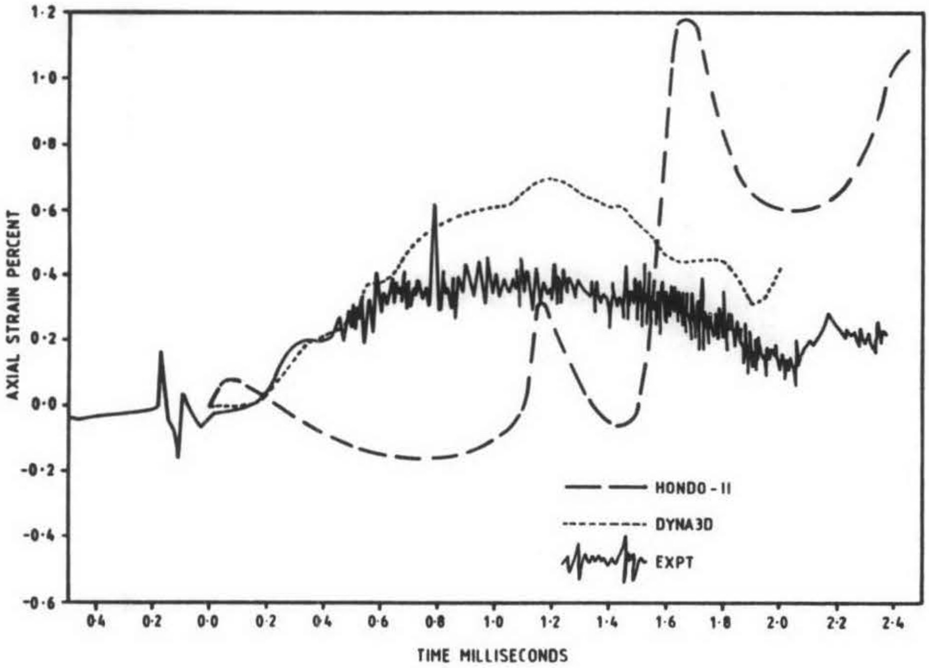


FIG.2c STRAINING IN LID BOLT 20m DROP

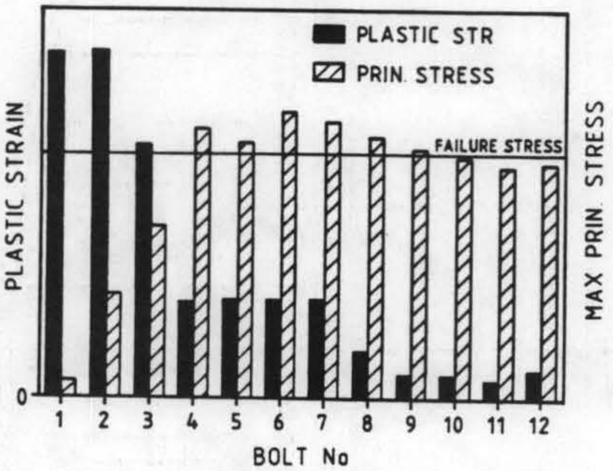
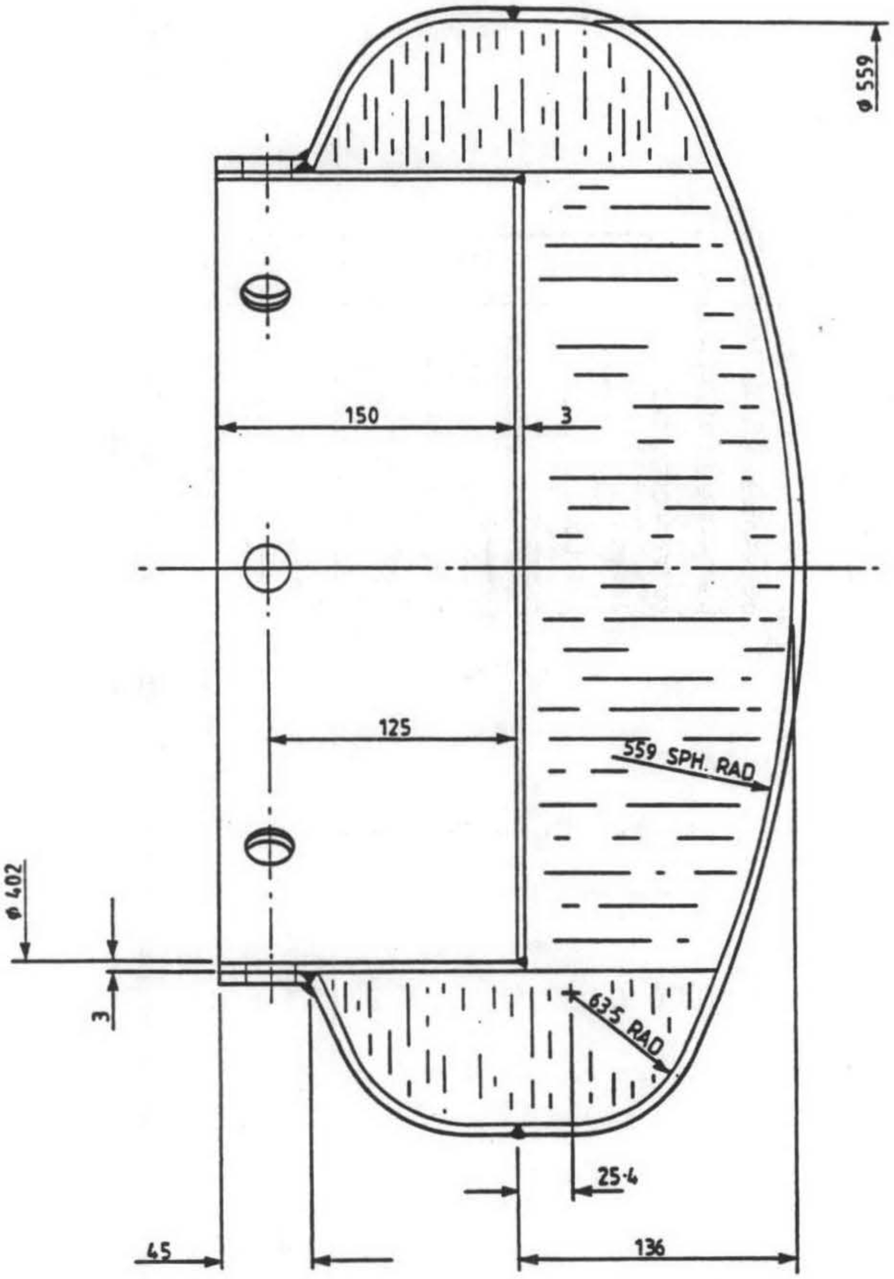


FIG.3 DAMAGE MEASURES IN LID BOLTS



(DIMENSIONS IN MM)

FIG.4 SHOCK ABSORBER MODEL

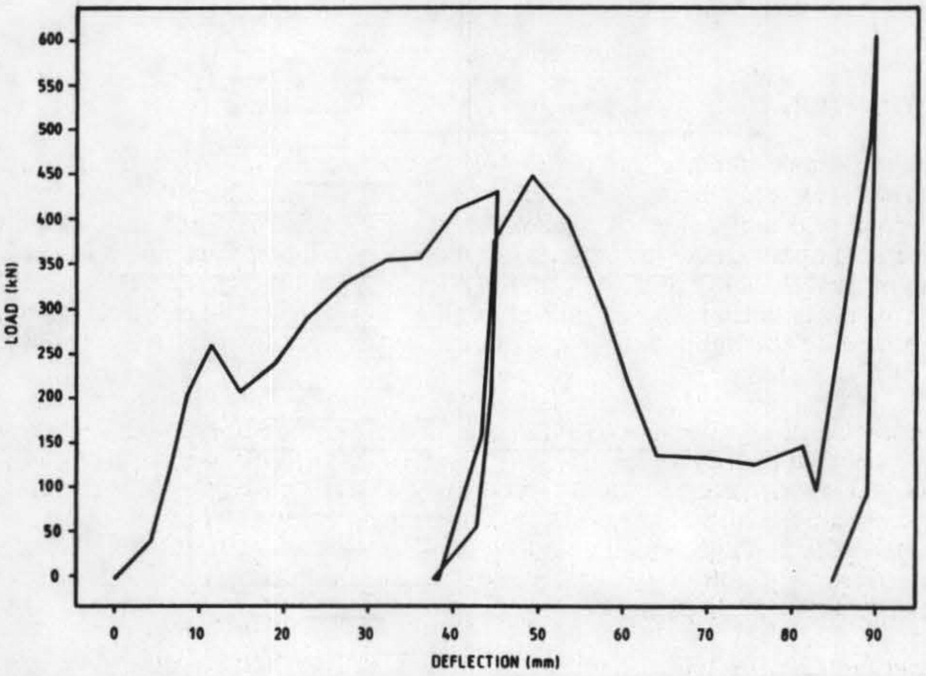


FIG.5 PUNCH LOADING OBLIQUELY ON BALSA-FILLED SHELL