The Use of Computer Impact Analysis in Licensing a Container for the Transport of Fresh Nuclear Fuel

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INTRODUCTION

This paper describes the licensing of a container for the transport of fresh nuclear fuel. The package was classified as an Industrial Package (Fissile) in accordance with the IAEA Regulations for the Transport of Radioactive Materials [IAEA 1990]. Hence, it was necessary, among other things, to demonstrate that criticality safety criteria are satisfied under postulated impact conditions, i.e. the 9m drop test and the 1m punch test.

The unusual step taken in this project was to use computer impact analysis, supplemented with small component testing, as the means of demonstrating to the Competent Authority that the impact criteria could be satisfied. The UK Competent Authority is the Department of Transport (DOT).

The New Module Container (NMC), see Figure 1, was designed for the transportation of fresh fuel prior to the introduction of regulatory impact requirements. The aim of the project was to obtain a licence for the NMC by a finite element (FE) analysis route using LS-DYNA3D [OASYS Ltd 1994].

PACKAGE DESCRIPTION

The NMC is fabricated from mild steel and comprises an eight sided outer vessel which is split into two halves along its length and flanged for bolting the halves together. The two halves are bolted together with 54 bolts. The outer vessel is held in position by a system of webs, and plates, corner angles and shear plates as shown in Figure 1. Inside the container the fresh fuel module is located on four anti-vibration mounts.

The mass of the container is approximately 1.1tonne. It has an overall length of 3.6m and in cross section is 0.64m x 0.64m.

Following an initial impact assessment of the container balsa wood shock absorbers were designed to enhance its performance. These are located at both ends of the module, internally and externally for end impacts. Balsa blocks are also located internally along the length of the module for side impact protection.

IMPACT ANALYSIS

In the traditional approach the critical attitude(s) for drop testing are be selected on the basis of experience, reasoned argument supported by some FE analysis. Subsequently only a limited number of attitudes would be assessed. In this project a detailed FE model was used and a very wide range of attitudes assessed. The critical drop attitudes chosen are shown in Figure 2.

An analysis methodology that could be related to an actual drop test sequence was developed. It was concluded that if the container had been subjected to a 0.3m normal handling drop, followed by a 1.2m free fall, then a 9m drop on to its corner, this would be equivalent to a 10.5m drop on the basis of cumulative energy. The container was analyzed for a series of drop heights varying between 10.2m and 10.5m.

The key parameters for this work were criticality and number of bolt failures. The issue of criticality is directly related to knockback, i.e. the amount of deformation that the container suffers in an impact. It was essential that the module be retained within the container when subjected to the drop tests, hence only a limited number of bolt breakages were acceptable. Using hand calculations it was demonstrated that a 1m punch drop would not puncture the wall of the NMC and if the bolted flange was hit then local damage resulting in the loss of one to two bolts may occur.

One FE model was generated for the assessment of all attitudes. The key structural components were identified for each attitude and then an appropriate mesh designed. Optimum element sizes were determined by comparing the crushing and buckling behaviour of FE models for representative sections of the container with closed form solutions. The mesh for the skid rails was refined in the regions where crushing occurs, and the vertical webs refined for buckling. The FE model of the NMC is shown in Figure 3. The model consists of a total of 10,000 elements; the steel sections were represented using shell elements, whilst the balsa wood shock absorbers were modelled using solid elements. The inner fuel module was represented using solid elements and was assumed to be rigid.

The DOT recognised that LS-DYNA3D had been extensively used in the automotive and nuclear industries for impact problems involving the buckling and crushing of metal. These applications were validated following testing

[Ajayi et al. 1993; Smith et al. 1989]. However the modelling of bolts had not been developed within LS-DYNA3D. This presented a major challenge to the project team.

The task of representing the bolts in the container was further compounded by the fact that the nut was welded to the underside of the lower flange. The bolt was modelled in LS-DYNA3D by a spotweld and a series of springs; see Figure 4. The spotweld allows the axial and shear force interaction to be represented and limits the strength of the bolt to values determined in testing. The bolt to flange gaps and local flange ductility were represented by springs whose characteristics were determined from uniaxial load tests. Hence, the local behaviour of the flange is not represented explicitly for shear in two directions simultaneously. However in most attitudes it was found that one component of shear force was dominant and the effect of other components on the flange was not significant.

The following additional modelling assumptions were applied:

- Initial imperfections were not modelled in the skid rails. Hence, for all end impact orientations the initial peak forces will be overestimated, but the knockbacks on the skid rail should not be affected. For side impact orientations initial imperfections were included in the vertical support webs.

- The balsa strength used was either the upper or lower bound strength according to which impact orientation was analyzed and whether maximum knockback or maximum bolt forces were required.

- The shear lip was removed because it was not fully welded to the lower flange. The removal of the shear lip was shown to increase the shear forces in the bolts by 10%.

- The issue of non-uniform bolt/flange clearances during fit-up was addressed by selectively varying bolt/flange gaps.

Many of the above conservatizms are impractical to achieve on a physical model, but are readily accomplished using a computer model.

All attitudes in Figure 2 were analyzed using LS-DYNA3D and the NMC was shown to meet all the IAEA requirements. No bolt breakages were predicted to occur. A license application based on the results of this work was placed with the DOT. After extensive discussions with the DOT, the licence application hinged on the issue of bolt modelling. To demonstrate confidence in the modelling it was agreed that the three worst attitudes should be subject to physical testing.

TEST PROGRAM

The test program consisted of an end impact attitude, an end edge impact attitude and a side impact onto bolted flange attitude.

Three containers were tested. The free drop in the specified attitude was increased to 9.71m to demonstrate that there were no "cliff edge" effects. The container was initially subjected to a 0.3m normal handling drop test, a 1.2m free drop and finally a 9.71m drop in the specified attitudes

The container was instrumented with accelerometers at specified locations that corresponded to monitoring positions on the FE model. The 9.71m drops were also recorded on high-speed film.

COMPARISON OF TEST WITH PREDICTION

Owing to the volume of data generated during testing only a summary of the comparison between test and analysis can be given here.

Bolt Failure

The bolt representation in the FE model was based on the results of tests for a representative bolted connection. For all attitudes this model predicted no bolt failures, and there was adequate bolt capacity in hand. In the actual tests no bolts failed as was predicted. (Note: if no ductility incorporated, many failures predicted).

Knock-Back

A comparison of predicted knock-back from the analyses with that from the tests is shown in Table 1. In all cases there is good agreement between analysis and test. In Figure 5 the deformed geometry for the end edge impacts is shown.

Accelerations

For comparison of accelerations, data from the analysis was extracted from nodes adjacent to accelerometer positions. A 1kHz filter was used on both test and analytical data. In general, good agreement was obtained for the majority of accelerometers. Any differences that occurred were accounted for in terms of features or behaviour that were deliberately omitted from the FE model in order to be conservative. In Figures 6 a comparison of lid accelerations for the end edge impact attitude is shown; good agreement was achieved.

DISCUSSION

The example described has shown that computer impact analysis can be sufficiently reliable to demonstrate to Competent Authorities that a package is capable of meeting the specified impact criteria.

The advantages of computer impact analysis over physical testing are:

a) It is relatively quick and cheap.

b) Modifications (drop height, impact attitude, design features) can be analyzed quickly and at less cost.

d) A greater number of impact attitudes and sequences can be analyzed, thereby giving greater confidence that the worse case scenario has been identified.

Physical testing currently is the "gold standard". Until computer impact analysis becomes more widely used and confidence is gained in its use the results will not be considered to be as credible as those from physical test. This will be particularly true where the problems lie outside the range of experience, thus requiring additional physical tests.

REFERENCES

Ajayi F, et al, **Recent Advances in Computer Impact Analysis for Radioactive Materials Transport Containers**, International Journal of Radioactive Materials Transport, Vol 4, No 2, PP 125-131, 1993.

IAEA Regulations for the Safe Transport of Radioactive Material, Safety Series No. 6, 1985 Edition (as amended 1990), Vienna.

LS-DYNA3D, Version 6.0, OASYS Ltd, 13 Fitzroy St., London W1P 6BQ, 1994.

Smith MJS, et al, **The Development of Transport Container Designs for immobilizes Intermediate Level Waste**, PATRAM '89, Washington DC, 1989.

END IMPACT ATTITUDE : Component	Test (mm)	Analysis (mm)
Skid Rail Lid - Left	18	19
Right	20	19
Skid Rail Base - Left	27	22
- Right	33*	22
End Flange Deflection	13	12
Internal Balsa Knockback	17	18

* Additional damage due to secondary impact

TABLE 1 TEST AND ANALYSIS COMPARISON OF KNOCKBACK DAMAGE

Figure 1 New Module Container

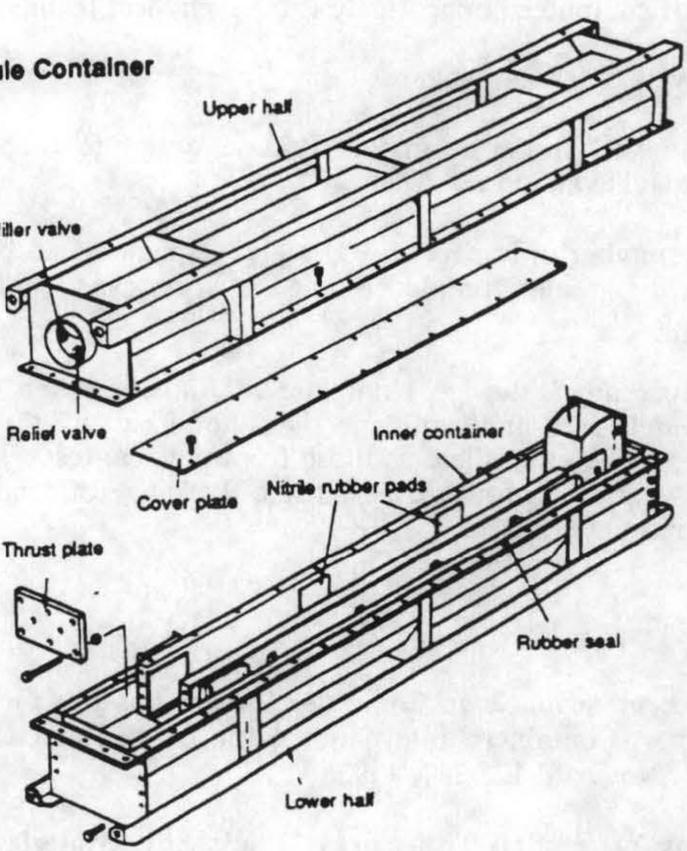
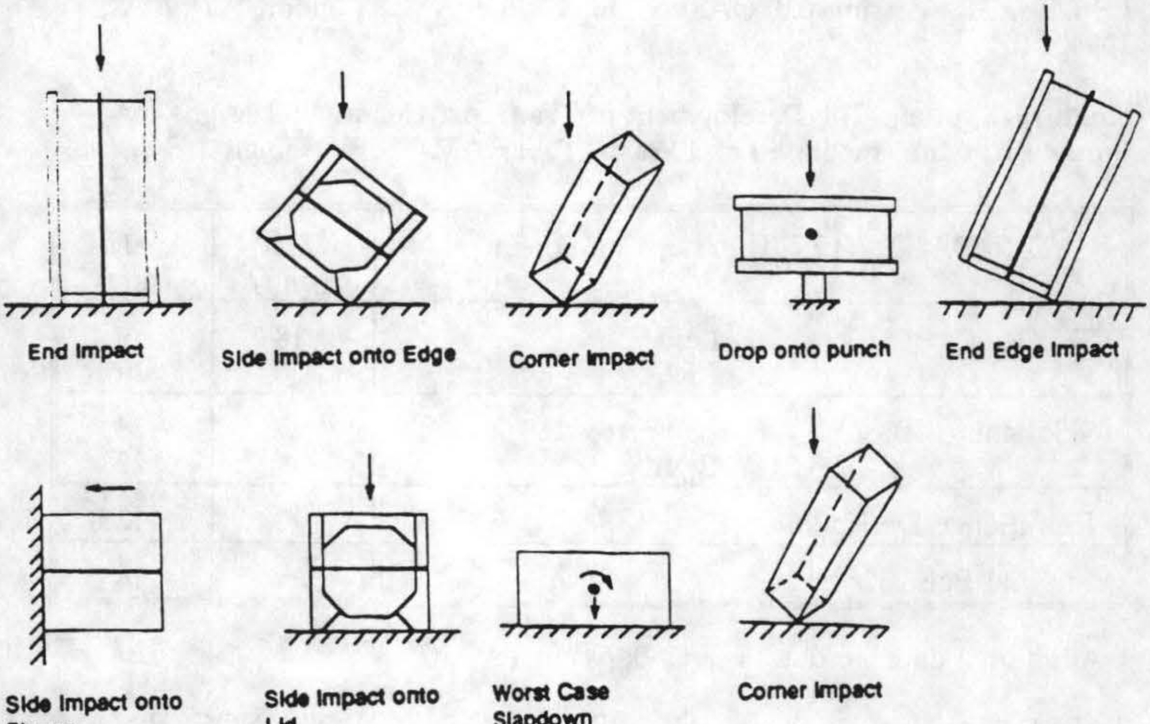


Figure2 Critical Drop Attitudes


End Impact

Side Impact onto Edge

Corner Impact

Drop onto punch

End Edge Impact

Side Impact onto Flange

Side Impact onto Lid

Worst Case Slapdown

Corner Impact

Figure 3 New Module Container FE Model

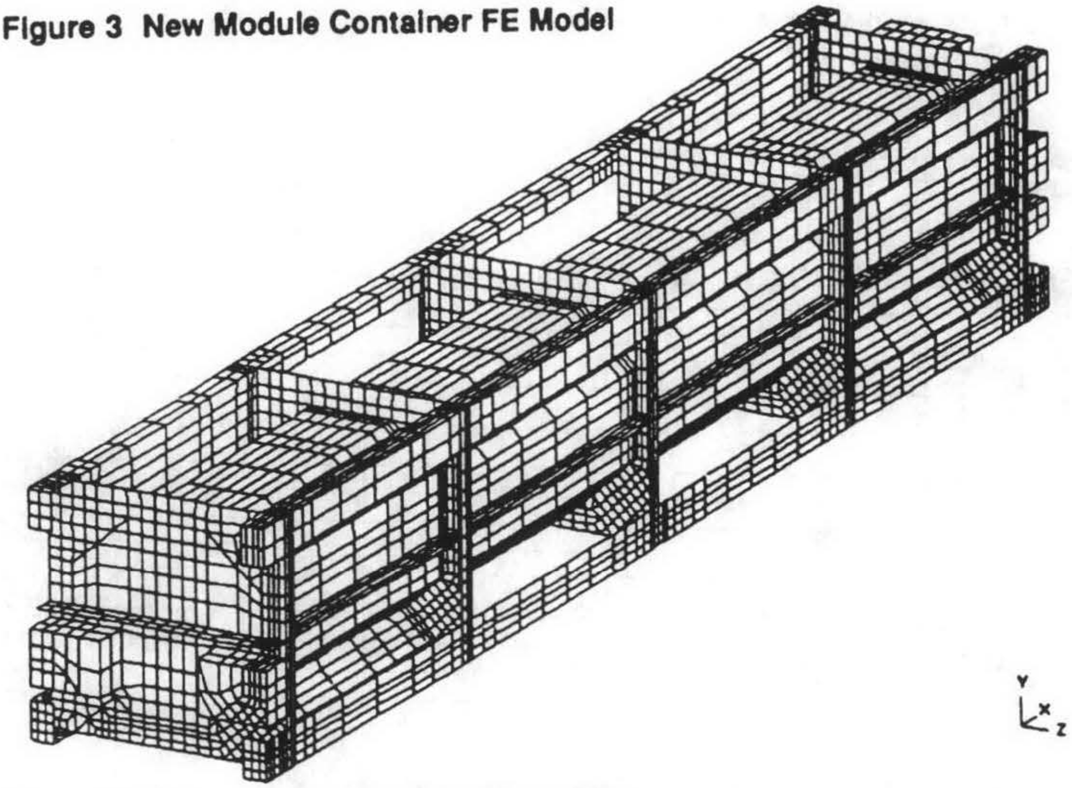


Figure 4 FE Representation of Bolted Connection

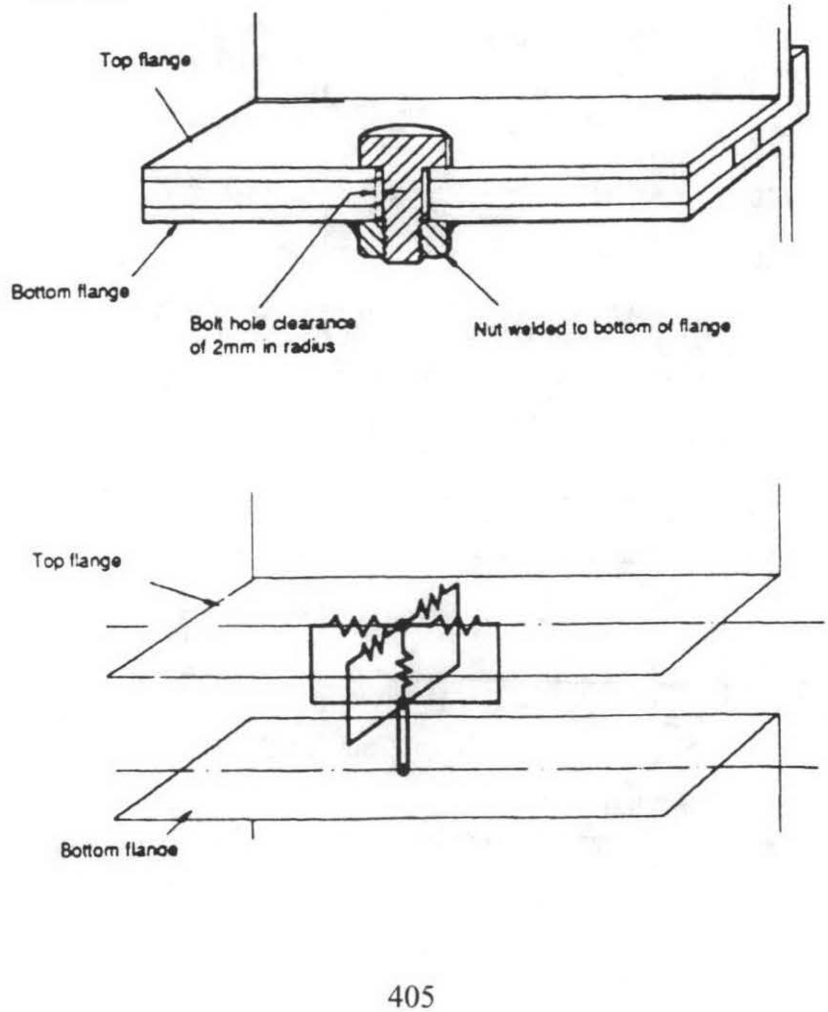


Figure 5 Deformed Geometry for End Edge Attitude

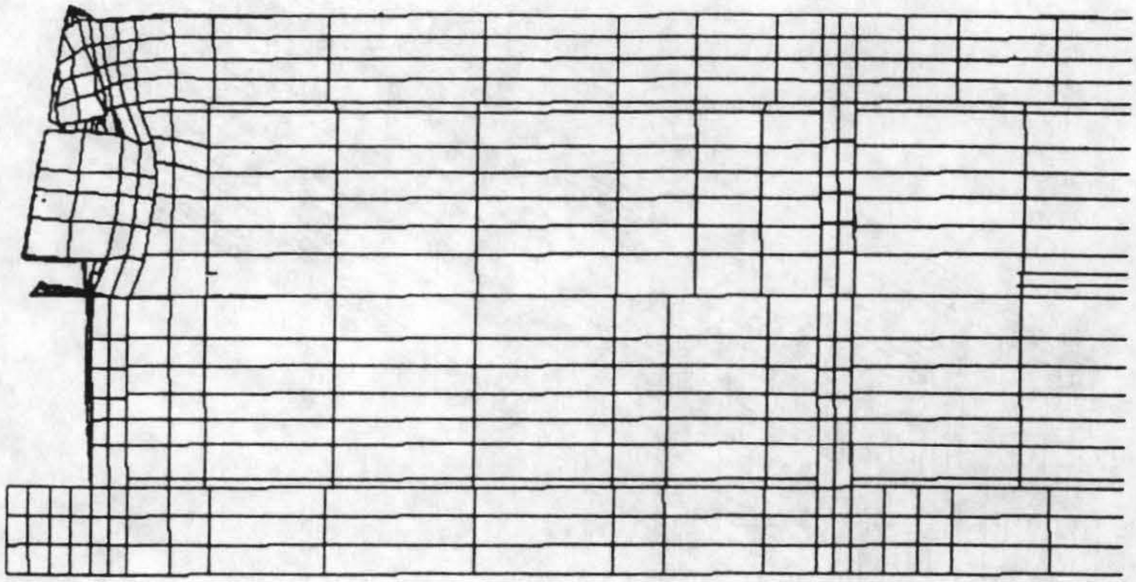


Figure 6 Comparison of Acceleration for End Edge Attitude