IMPACT ANALYSIS OF TRANSPORT FLASKS

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ABSTRACT

This paper presents a methodology, based on the computer programs NOVA2D and NOVA3D, for carrying out the dynamic non-linear analyses required for impact assessment of spent nuclear fuel transport flasks. The procedures implemented are able to treat both geometrical non-linearities (such as contact interfaces, large strains and rotations) and constitutive non-linearities (including non-linear strain hardening and strain-rate dependence).

As an example, some analyses of a generic cylindrical flask are undertaken. The 9m drops onto unyielding targets are presented both for a flat-on-end drop (axisymmetric analysis) and for an edge drop (three-dimensional analysis). A 36m edge drop is also studied for comparison. It is concluded that the flat-on-end lid drop is not too far from elastic and leads to high decelerations for the flask internals, while the substantial localised plasticity induced in corner drops has a shock absorbing effect leading to much lower decelerations.

1. INTRODUCTION

The transport of radioactive materials and, in particular, of spent nuclear fuel, is carried out in heavy flasks which provide containment and shielding. In order to ensure the safety of the public, transport flasks are designed to withstand all credible accidents, including impact.

The ultimate impact assessment of flasks is usually conducted by means of full-scale physical tests following the International Atomic Energy Agency Guidelines. Nevertheless, analytical studies of flask impacts are still a necessary requirement for a number of reasons, some of which are:
- "worst" impact attitudes for physical tests may not be completely obvious without analytical studies

- it is often useful to know the margin between the design basis drop and that which would lead to unacceptable consequences

- a calculational model, validated by experimental results, permits sensitivity studies to be carried out more efficiently than physical tests

- calculations are always far less expensive than physical drop tests.

In this paper, a methodology is presented for solving numerically the equations governing impact, particularly as they apply to the impact of spent fuel transport flasks. The methodology has been implemented in the computer programs NOVA2D and NOVA3D which are designed to provide accurate and inexpensive solutions to flask impact problems.

2. NUMERICAL METHODOLOGY

The numerical methodology adopted is generally that of explicit Lagrangian finite-differences following procedures which have evolved from the ideas of Wilkins (1964) and Cundall (1976).

As it is well known, the domain to be modelled is discretised by elements and their mass is lumped at the grid-points or nodes. All even-order tensors (including scalars) are referred to element centroids and taken to be constant within the element. All odd-order tensors are referred to grid-points. Temperatures and stresses are examples of the former while velocities and accelerations are examples of the latter.

In the context of the discretisation, it is worth mentioning that some meshes (e.g. constant strain triangles in two dimensions, or tetrahedrons in three) lead to artificial hardening of the mesh. To avoid such hardening and avoid at the same time potential hourglassing problems, the mixed-discretisation method first proposed by Marti and Cundall (1982) has been corrected by Goicoeia (1985). The latter approach is used here.
flat end of the flask is therefore parallel to the target plane at impact and the problem is consequently axisymmetric.

In the other two impacts, the flask falls on an edge with the centre of mass directly above the point of initial contact. This ensures minimum conversion of linear to angular momentum, a condition which generally results in maximum deformation effects.

The flask is assumed to be made of steel, with a density of 7800kg/m$^3$. Its elastic properties were chosen as 210GPa for the Young's modulus and 0.3 for the Poisson's ratio. For the idealised case at hand, a very simple material description was selected as the form of eq. 4, namely that of linear hardening:

$$Y = A + Bc^p$$  \( (5) \)

with $A = 260$MPa and $B = 2.6$MPa.

The results of the calculations are presented in the next sections.

4. AXISYMMETRIC IMPACT

The flat-on-lid impact represents the most favorable attitude from the view point of deformations of the flask. The large contact area leads to very limited plastification of the flask and a fast rebound. In exchange for the very limited plastic deformations caused to the flask body, the decelerations imposed on the flask internals are large, which is a potentially important consideration depending on the flask contents.

The mesh utilised in the numerical model of the flask appears in Fig. 1. It is formed with 204 nodes and 300 triangular toroidal elements (the figure represents only quadrilaterals composed of two triangles each).

The events taking place are easily observed in Fig. 2 which presents the history of forces of interaction. As can be seen, the amount of plastification is small. This is implied by the fact that the contact duration is not much longer than the time which compressional waves require to travel up and down the flask length. The same conclusion can be deduced from the relatively little hardening which appears in the force history. The
sudden deceleration of the lower plate is represented by the first high peak in the force history.

Overall, the flask behaves almost as an elastic uniform bar with two single-degree-of-freedom systems, one at each end; the lower one is obviously prevented from penetrating the target while the contact lasts. All of this can be observed in Fig. 3 which depicts the velocity histories at the bottom and the top edges, respectively.

Deformed meshes are not included here for brevity. Their inspection simply confirms the previous findings. Incidentally, plotted displacements require at least a ten-fold magnification before they are readily observable.

Similar statements can be made about plots depicting plastic strain contours. Very little plasticity is achieved; that occurring takes place in the upper central part of the bottom plate, the bottom corner and the inner bottom part of the cylindrical wall.

5. CORNER DROPS

Corner drops must be treated as three-dimensional problems, the only simplification being that a plane of symmetry exists: this is the plane defined by the flask axis and the impact velocity. The three-dimensional mesh used for the two corner drops can be seen in Fig. 4. The mesh representing half flask has 646 nodes 2538 and tetrahedrons (the figure represents only pentahedrons and hexahedrons).

Corner drops invariably impose much greater deformations on the flask than flat-on-lid drops. It is in that sense that they can be considered more demanding in structural strength. However, gross plastification of the impacted corner leads to a much longer duration of impact and, hence, to much smaller deceleration values. In effect, the yielding corner acts as a shock absorber. As mentioned earlier, these smaller decelerations may be a significant advantage in respect of the flask internals.

Again, an inspection of the history of the force of interaction for the 9m drop (Fig. 5) provides many of the clues for understanding the chain of events. In contrast with the axisymmetric impact, the force history starts from zero as a consequence of a zero initial contact area. The growth of the force is partially a consequence of hardening (no longer unimportant as in the lid drop) and, to a greater extent, of the increase in contact area.
Final unloading simply corresponds to the elastic recovery of stored energy. The force history is quasi-static, as implied by the moderate values of the dynamic peaks. This is the consequence of the fact that the impact duration is now several times longer than wave travel times along the flask.

It is also interesting to note that the area under the force history (impulse, or change in momentum) was greater in the case of the flat impact. The reason is that the latter was more elastic than the corner impact, hence rebound velocity was greater and overall momentum change during the impact was also greater.

The vertical velocity histories of the bottom and top corners can be seen in Fig. 6. They confirm the plastic character of the impact. Figure 7 presents a view of the final deformations of the mesh in which plastic strains have been contoured.

Finally, the force of interaction and vertical velocity histories corresponding to a 36m drop are shown in Figs. 8 and 9. Final deformations appear in Fig. 10. As can be seen, the 36m drop is, in this case, qualitatively similar to the 9m drop, the differences simply being the duration of the impact and maximum values of the variables reached in the impact process. The reason for repeating the analysis at twice the design velocity is to assess whether the previous statement can indeed be made. In other more complex cases, structural failures (e.g., bolts) may be responsible for a notably different impact behaviour at the higher speed. It may then be very important to find out at what impact velocity such unfavorable behaviour is triggered, even though this velocity exceeds the design velocity.

6. Conclusions

A number of conclusions can be drawn from the work reported in the previous sections:

- Explicit finite difference methods provide an efficient and robust methodology for studying the impact problems posed to the designer of spent fuel transport flasks.

- The flat-on-end 9m drop of a typical cylindrical transport flask is not too far from elastic; the contact time is not much larger than expected in elastic impacts.
and plastic strains remain very small. However, it leads to very high deceleration values for the flask internals.

- The corner drop leads to substantial plastification of the corner involved. Such deformations are highly localised and their development has a beneficial shock-absorbing effect in relation to the decelerations imposed on the rest of the flask and the flask internals. However, adequate steps must be taken to ensure that the plastification of the corner does not affect the overall structural integrity of the flask.

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