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CONTACT-HANDLED TRANSURANIC TRANSPORTATION SYSTEM STRUCTURAL ANALYSIS*

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The TRansUranic PACkage Transporter (TRUPACT) is a Type-B overpack under development at Sandia National Laboratories / Transportation Technology Center (SNL/TTC), Albuquerque, New Mexico, USA. The TRUPACT is to be used in the transportation of contact-handled transuranic (CH-TRU) waste for which the United States Department of Energy is responsible.

The leading concept for the transportation system calls for both a truck and rail transported version of the TRUPACT. The rail version, as currently envisioned, is shown in Figure 1. Its predominant features include inner and outer tubular steel frameworks which are sheathed with steel plate and separated by rigid polyurethane foam. Both frames are fitted with hinged doors which utilize elastomeric seals and which are bolted in place during transport. The entire structure weighs approximately 11 tonne, carries a maximum payload of 19 tonne, and measures 7.3 x 2.7 x 3.0 m (L x W x H) externally. The truck version, which is geometrically similar to the rail version, has external dimensions of

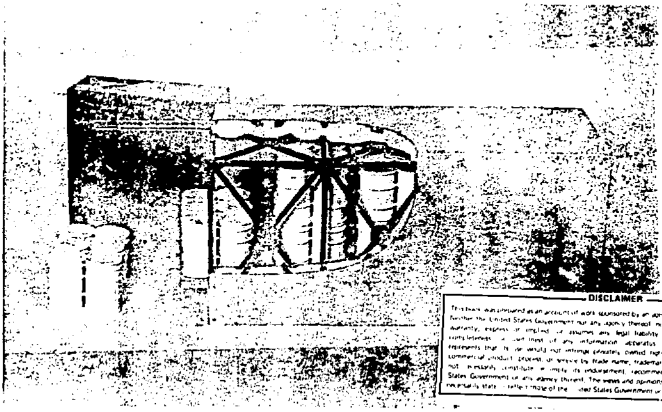

Figure 1. Photograph of a TRUPACT Model, Partial Cutaway Showing Internal Structure

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7.5 x 2.3 x 2.7 m, weighs 10 tonne, and has a maximum payload capacity of 13 tonne. The wall thickness of both the truck and rail versions is 36 cm on the sides and 91 cm on the ends.

Emphasis of the TRUPACT development program is currently on the rail version. However, since the two versions differ only in size and weight, analysis techniques, test procedures, and design concepts originated with the rail transported TRUPACT will also apply to the truck transported package.

The TRUPACT is being designed to provide structural and thermal protection to its contents in the simulated accident environments prescribed for Type-B packaging in transport regulations, such as IAEA Safety Series No. 6. Verification that the TRUPACT will survive these environments is being obtained through analysis and testing.

To date, end-on, side-on, and corner impacts of the loaded TRUPACT due to a 9 m drop onto an unyielding surface have been analyzed. In each case the analyses progressed from simplified hand approaches to successively more complex finite element calculations. The series of analyses for each of the three impact conditions are summarized in Table 1. The first analysis of each series represents the hand calculations which were carried out to obtain initial thicknesses of foam. The remaining analyses were performed using the dynamic and nonlinear analysis capabilities of ADINA, a structural analysis finite element computer program.[1]

TABLE I. TRUPACT Analyses Series for Three 9 m Drop Impact Orientations

SIMULATED IMPACT	ANALYSIS	MODEL COMPONENTS Outer Frame	 Foam	 Inner Frame	 Cargo
END-ON	1	-	Nonlinear Spring	Rigid Mass	Rigid Mass
	2	-	Truss Elements	3-D Truss Structure	Nodal Masses
	3	-	Truss Elements	3-D Truss Structure	Truss Elements
	4	3-D Truss Structure	3-D Solid Elements	3-D Truss Structure	Truss Elements
SIDE-ON	1	-	Nonlinear Spring	Rigid Mass	Rigid Mass
	2	-	Truss Elements	Nodal Mass	Truss Elements
	3	3-D Truss Structure	3-D Solid Elements	3-D Truss Structure	Truss Elements
CORNER	1	-	Nonlinear Spring	Rigid Mass	Rigid Mass
	2	3-D Truss Structure	3-D Solid Elements	3-D Truss Structure	Nodal Masses

The end-on impact analysis was initiated under the assumption that the inner and outer frames were structurally independent. That is, the outer frame would absorb its own impact energy by deforming plastically and could therefore be neglected when investigating the response of the inner frame. Initial foam dimensions and crush strengths were selected from the results of the hand calculations (analysis 1). The response to the 9 m end-on drop test was predicted assuming that the cargo was rigid and the frames were independent (analysis 2). Following this, a cargo model which allowed deformation and energy dissipation was included in the finite element model and the response of the foam and frame were reassessed, again under the assumption that the frames were not structurally coupled (analysis 3).

A comparison of the results from these two analyses revealed that the loads imparted to the inner frame were more severe for a deformable cargo model than for a rigid cargo. The foam crush for the flexible cargo was roughly half that for the rigid model. Further, the frame members nearest the impacting end yielded when the flexible cargo model was used but remained elastic for the rigid cargo calculation. This can be explained by the fact that while the cargo does not load the frame directly, it does affect the way in which the foam crushes. This, in turn, directly affects the deceleration of the inner frame. Since a rigid cargo will cause more foam crush than a deformable cargo, the rigid cargo will also cause smaller decelerations. Therefore, the loads transmitted to the inner frame during impact will be smaller for the rigid cargo model than for the deformable case.

To determine the extent of coupling between the two frames, a 1/4-scale model of the TRUPACT was fabricated and the inner frame was forced to move longitudinally relative to the outer frame in an essentially static manner. Since the magnitude of the force required to cause this motion was more than twice that theoretically necessary to crush the foam at the end of the model, it was evident that considerable shear forces were acting on the sides of the inner frame. This indicated that the coupling between frames was significant and should not be neglected. The final analysis of the series was then conducted using a model that consisted of both frames coupled together with three-dimensional solid elements which represented the foam (analysis 4). The foam crush versus time as predicted with this model is plotted in Figure 2. Also shown in this figure is the final foam crush predicted by an actual 9 m drop test of a quarter scale model TRUPACT which used a .345 MPa foam. Note that the foam only crushed 15 percent and 9 percent of its total available thickness of 0.9 m for the 0.345 MPa and 0.690 MPa cases, respectively. The comparison between analysis and test is within 3 percent for total crush.

While the analytical model produced excellent results with respect to the foam crush, it did not do as well when predicting strain levels in the inner frame. As an example, the strain history of the most severely stressed element of the inner frame, element 125, is plotted in Figure 3. This element was located nearest the impacting end and oriented parallel to the TRUPACT's motion prior to impact. The peak strain as taken from Figure 3 is approximately 1.5 percent. Since the truss member is 185 cm long this represents an overall reduction in length of the member of 2.8 cm. Although strain measurements were not taken during the quarter-scale 9 m drop test, inspection of the post-test model produced no visible evidence that the inner frame had yielded. The discrepancy can probably be attributed to the inexact way the frames were coupled together and the fact that the inner steel skin was neglected in the analytical model. Evaluation of the finite element results revealed that the inner frame had moved approximately 2 cm relative to the outer frame at peak foam crush. This indicates that the inner frame was, to some extent, driving into the frontal foam and thereby generating forces large enough to yield the members nearest the impact surface. However, the trace from a linear variable differential transformer (LVDT) used to measure actual relative motion between the frames during the 9 m drop test showed that essentially no movement took place. Thus it appears that in the analytical model, the coupling is not as rigid as it

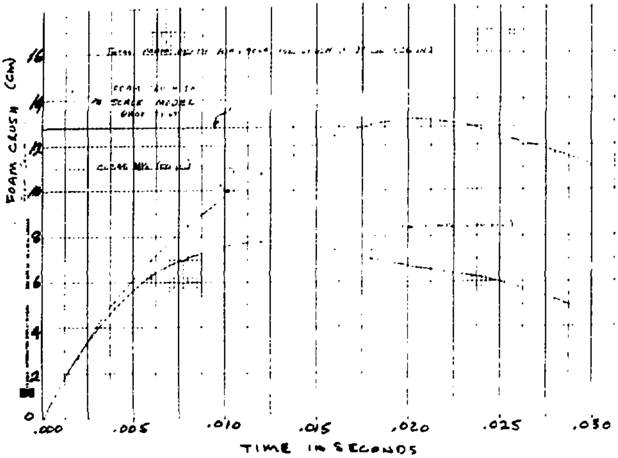

Figure 2. Plot of foam crush versus time as predicted by ADINA for the end-on impact 9 m drop test of the TRUPACT, for 0.345 and 0.690 MPa strength faoms.

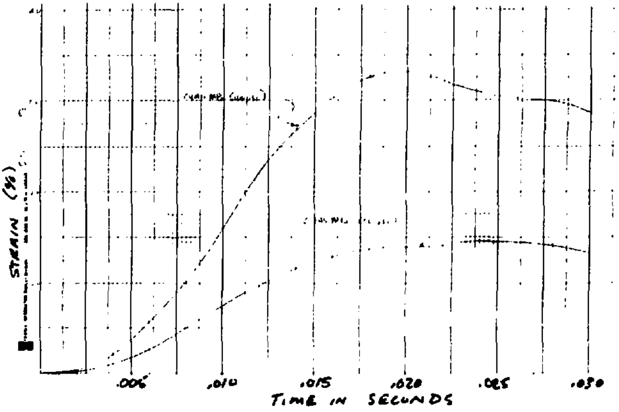

Figure 3. Plot of strain versus time as predicted by ADINA for the most severely stressed element of the inner frame due to the end-on impact 9 m drop test of the TRUPACT, for 0.345 and 0.690 MPa strength foams.

should be and artificially high loadings on the inner frame are predicted as a result.

In the case of the side-on impact, the second analysis was initiated to take into account the cargo response in selecting an initial crush strength of the foam. Since the frame is rigid compared to the cargo and foam, its response was neglected and the appropriate mass was concentrated at the node coupling the cargo elements to the foam element. Inasmuch as this was done under the assumption that the frames were independent, an additional analysis (Analysis 3) was completed to obtain a more accurate prediction of the overall frame response and foam crush. The predicted foam crush is plotted as a function of time in Figure 4. In this impact orientation the foam crushed a total of 28 percent of the total available thickness of 20 cm for the 0.345 MPa yield strength foam and 21 percent of the stronger foam.

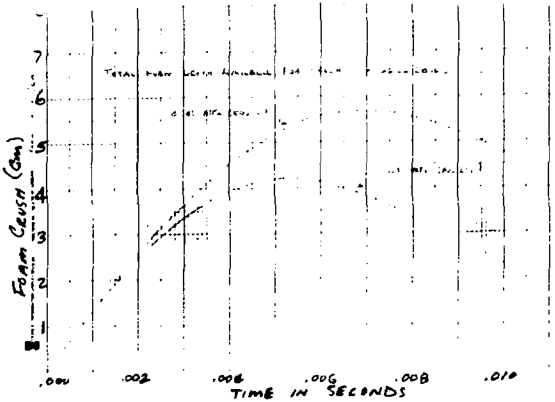

Figure 4. Plot of foam crush versus time as predicted by ADINA for the side-on impact 9 m drop test of the TRUPACT, for 0.345 and 0.690 MPa strength foams

The predicted strain histories for the most highly deformed element of the inner frame are plotted in Figure 5. This element (number 155) represents a diagonal frame member that is adjacent to the inner door and suffers a severe compressive loading due to the door mass. Although there are no experimental data to compare to the side impact analysis, the strains indicated in Figure 5 are thought to be excessive for the same reasons that the predicted strain levels in the end-on calculations were shown to be too high.

Several attempts were made to analyze the corner impact 9 m drop under the assumption that the frames were uncoupled. However, the deflections predicted with this method were excessive since the impact energy absorbed by the outer frame was neglected. These attempts were therefore discarded in favor of the more complex model which has yielded reasonable results. The results indicated that the impacting end of the TRUPACT in the 9 m corner drop would sustain considerable deformation. The degree of deformation is illustrated with the data shown in Figure 6. In this figure the approximate displacement of node 1 into the TRUPACT during impact is plotted as a function of time.

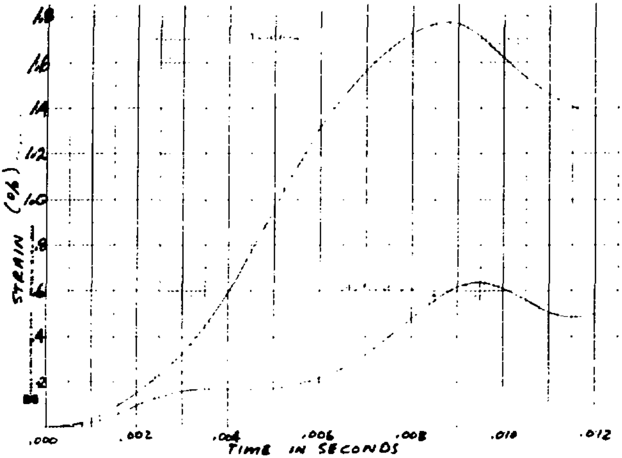

Figure 5. Plot of strain versus time as predicted by ADINA for the most severely stressed element of the inner frame due to the side-on impact 9 m drop test of the TRUPACT, for 0.345 and 0.690 MPa strength foams.

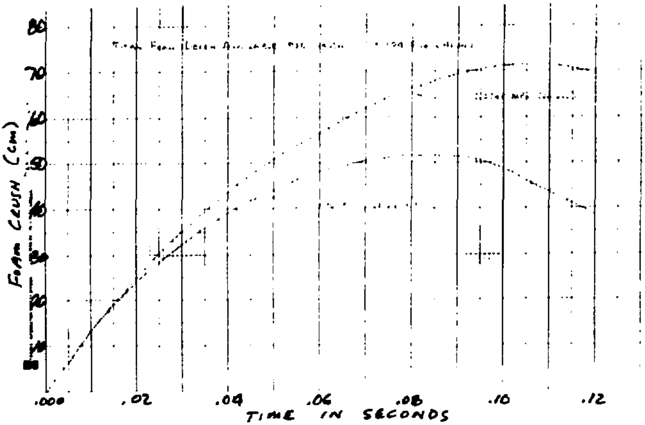

Figure 6. Plot of foam crush versus time as predicted by ADINA for the corner impact 9 m drop test of the TRUPACT, for 0.345 and 0.690 MPa strength foams.

For 0.345 MPa yield stress foam a maximum total displacement of node 1 is approximately 71 cm occurring 0.105 sec after impact. A maximum total displacement of 52 cm at 0.083 sec is predicted when 0.690 MPa foam is considered. As anticipated, the higher yield stress foam would decelerate the package more rapidly and lessens the total deflection achieved. These deflections indicate that 68 percent and 50 percent, respectively, of the total available foam thickness of 104 cm (the foam thickness between the impacting corner of the outer frame and the nearest corner of the inner frame) would be crushed for the low and high yield stress foams.

The strain history for element 125 (the longitudinal member of the inner frame nearest to the impacting corner) is presented in Figure 7. It is interesting to note that element 125 did not follow the trend of experiencing smaller strains for the lower strength foam than for the higher strength foam. Also of interest is the fact that the peak strains shown in Figure 7 are 5 and 10 times larger than those for the next highest stressed element of the inner frame for the 0.690 MPa and 0.345 MPa crush strength foams, respectively. This unlikely behavior probably came about because the two frames were not as rigidly tied together in the analytical model as they were in the actual structure. Thus when the inner frame began moving relative to the outer frame because of the inaccurate coupling, it collided with the foam being driven toward it by the impact. The impact forces were thereby concentrated at the corner of the inner box instead of being spread along its sides and element 125 received the brunt of this loading. Furthermore, the weaker coupling provided by the lower yield strength foam allowed larger forces to be concentrated at the corner of the inner frame and this, in turn, resulted in the higher strain levels seen in element 125 for the lower strength foam than for the higher.

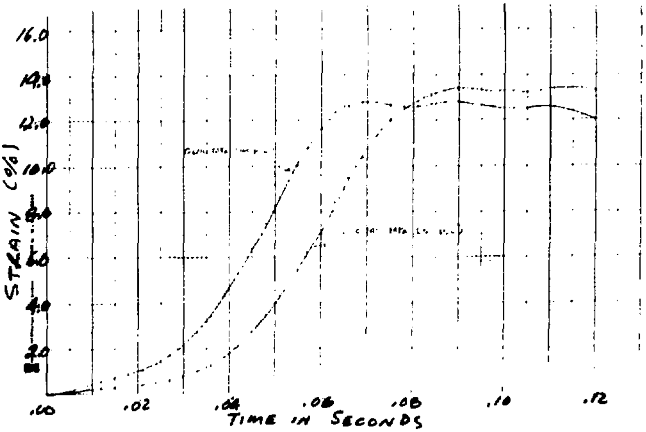

Figure 7. Plot of strain versus time as predicted by ADINA for the most severely stressed element of the inner frame due to the corner impact 9 m drop test of the TRUPACT, for 0.345 and 0.690 MPa strength foams.

Preliminary investigations concerning the resistance of the TRUPACT to the IAEA Safety Series No. 6 puncture test (a drop of 1 m onto a 15 cm diameter steel pin) have also been completed. Static analyses based on the small deflection theory of laterally loaded triangular and rectangular plates on elastic foundations were used to estimate the effect of plate shape and load location on the plate deflection achieved. The results indicated that plate geometry and load location were of minimal importance if the load center was more than one local diameter from the plate boundary.

A series of more appropriate dynamic analyses (based on energy conservation) were performed for centrally loaded circular plates on plastic foundations. In this approach it was necessary to postulate a deformed shape for the plate. In Figure 8 a plausible plate profile is shown. Also shown in the figure is the predicted peak deflection, W_0, of the plate for this profile as a function of plate and foam yield stresses for a plate 0.6 m in radius (r_b) and 0.35 cm thick. With this approach unacceptably large deflections are predicted (available thickness of 200 cm) and penetration of the TRUPACT containment is probable. The dynamic analysis has not yet been extended to include the puncture resistance offered by the plate on the inner frame of the TRUPACT or the possibility of additional plates in the package walls. A comprehensive test program is underway to confirm the validity of the current analysis approach in considering the puncture problem.

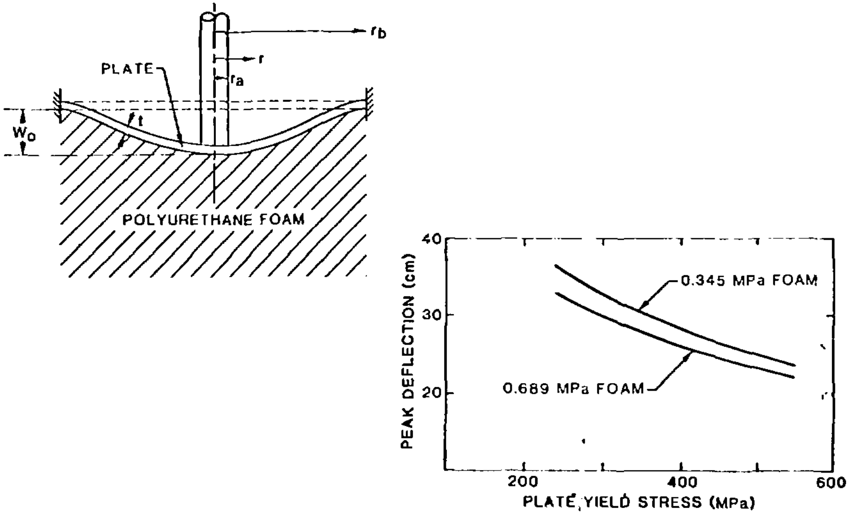

Figure 8. Plate profile assumed and predicted peak deflection of plate in TRUPACT puncture test analysis.

REFERENCE

1. K. Bathe, "ADINA - A finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis," Report 82448-1, Massachusetts Institute of Technology, Cambridge, MA, September 1975.