NUMERICAL SIMULATION OF DYNAMIC DEFORMATION OF AIR TRANSPORT PACKAGE IN HIGH-SPEED ACCIDENTAL IMPACT

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ABSTRACT

In accordance with IAEA regulations, a package for air transportation of radioactive materials (a Type C package) must meet certain strict requirements. One of these requirements is that the package must be strong enough to withstand an impact with a hard surface at any angle and at a speed of at least 90 meters per second (m/s).

On the one hand experimental testing of resistance of air transportation packages is very expensive. Therefore, experimental tests with the real packages need to be carried out only after overall detailed computer simulations of dynamic behavior of the structure during impacts at different angles, which define the “weakest” elements of the structure and the most dangerous direction of impact. On the other hand it is necessary to involve any available experimental data for verification of results of numerical modeling because the problem is really complicated. Dynamic deformation of the structure under high-speed impact with the hard surface is an extremely non-linear process, which has several specific aspects as follows:

- large displacements (huge changes of initial structure shape);
- high levels of plastic strains;
- multiple contact interactions between structures elements and hard target.

Practical solution of this problem with acceptable accuracy could be obtained by using the finite element code LEGAK-DK developed at RFNC-VNIIEF.

The brief description of the code LEGAK-DK and its application for analyzing the large deformations dynamic response of structures is presented in the paper. The results of numerical investigation of the Type C package accidental impact with the hard surface at a speed of 90 m/s are also presented. Comparison of the calculated deformed package shape with experimental data shows that they are in a good agreement.

INTRODUCTION

The development of a protective container for the air transportation of the radioactive materials is a difficult engineering and scientific problem. According to IAEA regulations, the container must withstand 90 m/s accidental impacts at different angles with the hard surface. There is a cost-effective way for the solution of these difficult problems - it is an application of computer codes for numerical simulation of the dynamic deformation of the structures [1-3]. At present RFNC-VNIIEF develops new computer code LEGAK-DK [4], intended for simulation of such type of problems. During developing of the code LEGAK-DK significant amount of time is spent for testing of the code and comparing of obtained results with analytical solutions, some commercial codes results and experimental data.

DESCRIPTION OF LEGAK-DK CODE

The Russian finite element code LEGAK-DK is intended to simulation of coupled 3D problems of structures and fluid dynamics and heat transfer. The code is based on the finite element method in Lagrangian, Eulerian and ALE formulations using an unstructured computational grid.

The main features of LEGAK-DK code are the following:

- Application of ALE method on the unstructured computational grid using the finite element method to build the approximating equations;
- Application of the concentration method for interfaces tracking;
- Application of the contact-impact algorithm using sliding, rebound or friction.

The spatial discretization is achieved by the use of one integration point and fully integrated 2D and 3D solid elements, shell elements and beam elements.

Boundary and loading conditions are the following: pressure, concentrated point loads, distributed pressures, translational and rotational boundary constraints, sliding plane, prescribed velocities, initial temperatures etc.

LEGAK-DK capabilities allow simulating such process as the dynamic deformation of the air transport package under the high-speed impact with the hard surface.

THE COMPUTER MODEL

Consider the problem of the dynamic deformation of the impact-proof container for air transport of fissile materials in conditions of high-speed impact with the hard surface. The cross-section of the container is shown in Fig. 1. The container consists of:

- outer casing (1), consisting of two hemispheres, joined by a nut (6);
- damping wood layer (2);
- inner casing (3), consisting of two bolted hemispheres;
- radiation absorbing material layer (4);
- payload (5).

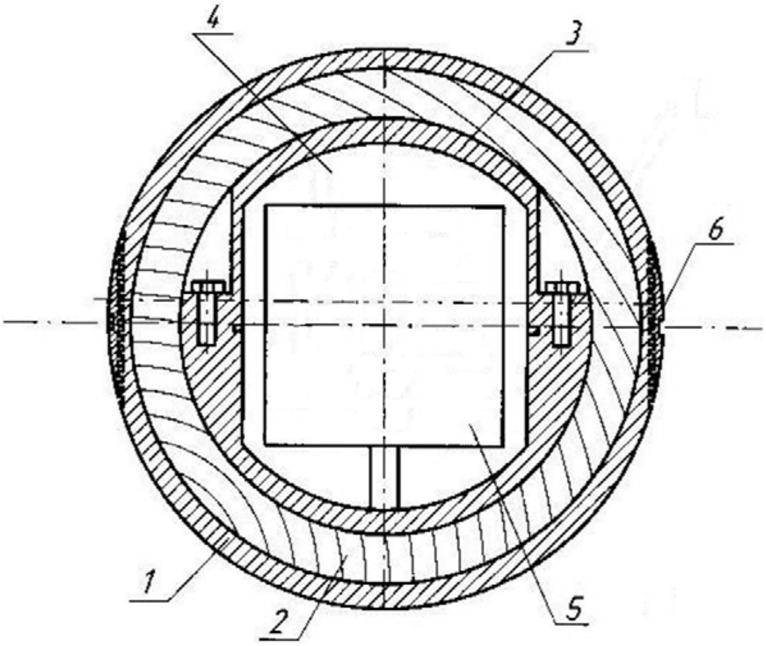

Fig. 1 Cross section of the container

A 3D computer model of the construction was created for the numerical simulation. The model consists of about 1,025,000 solid finite elements and considers all the essential features of the container and its materials, namely:

- exact geometry of the container elements;
- threads of outer casing hemispheres and nut;
- bolts of inner casing;
- contact interaction of all the container elements;
- elastoplastic properties of the materials with strain rate dependency;
- possibility of failure of container elements.

The computer model is represented in Fig. 2.

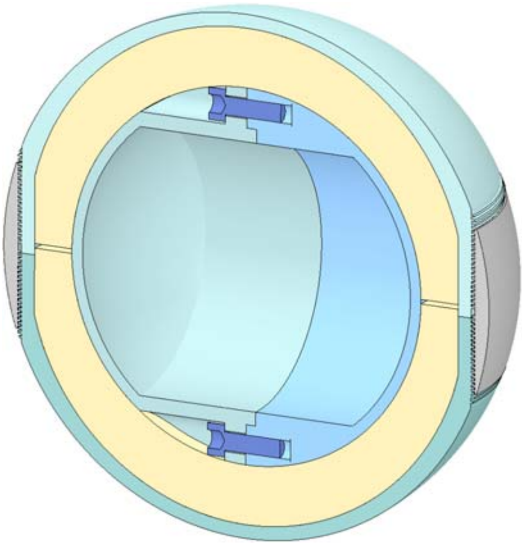

Fig. 2 Section view of the computer model

A piecewise linear plasticity model with strain-rate dependency properties is used to simulate the behavior of steel materials. The properties of the material for different strain rates were obtained beforehand using a modified Kolsky method with a split Hopkinson pressure bar. The material failure criteria are used as the maximal effective strain level. Wood material model, presented in paper [8], is used for the damping layer. The inner casing bolts are modeled using simplified model without thread, described in paper [9].

EXPERIMENTAL RESULTS

In 2006 full-scale model of the container was tested using RFNC-VNIIEF test facilities. Tested model of the container does not include radiation absorbing material layer and the payload, i.e. cavity of inner casing was empty. Registered velocity of the container before the impact was 89.8 m/s [7].

As a result of the impact, the following was observed:

- outer casing was significantly deformed. The nut lost gearing with one of hemispheres of the casing. The part of the nut's thread was sheared;
- half of the wood damping layer from the side of the impact was completely destroyed, whereas the other half was almost undamaged;
- inner casing was also significantly deformed. 12 of 24 inner casing bolts were ruptured.

Fig. 3 shows post-impact photos of the container. Post-impact deformed shapes of the container elements and their residual sizes, which will be used for verification of the simulations results, are presented in Fig. 4-5. Dimensionless values of the residual sizes, divided by outer diameter of the container, are given in Table 1.

Fig. 3 The container, post-impact

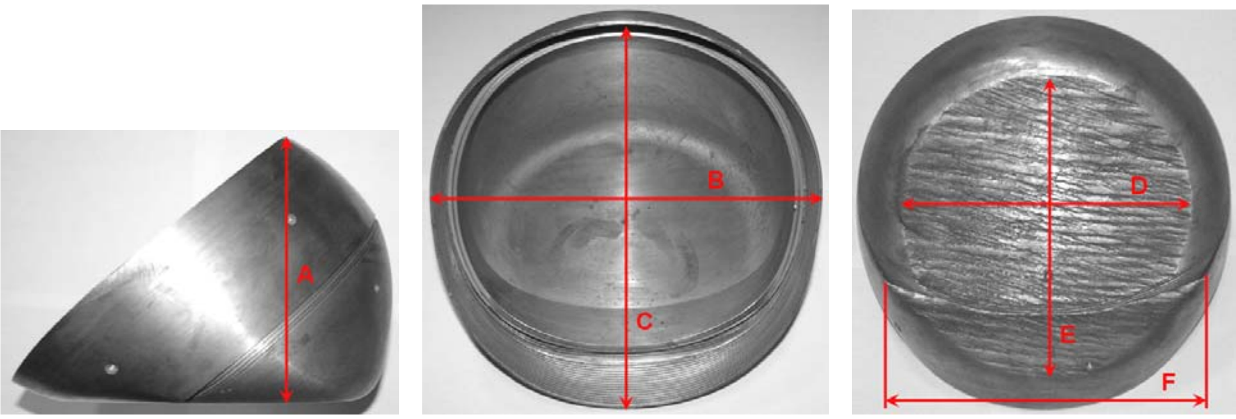

Fig. 4 Lower hemisphere and nut of outer casing, post-impact

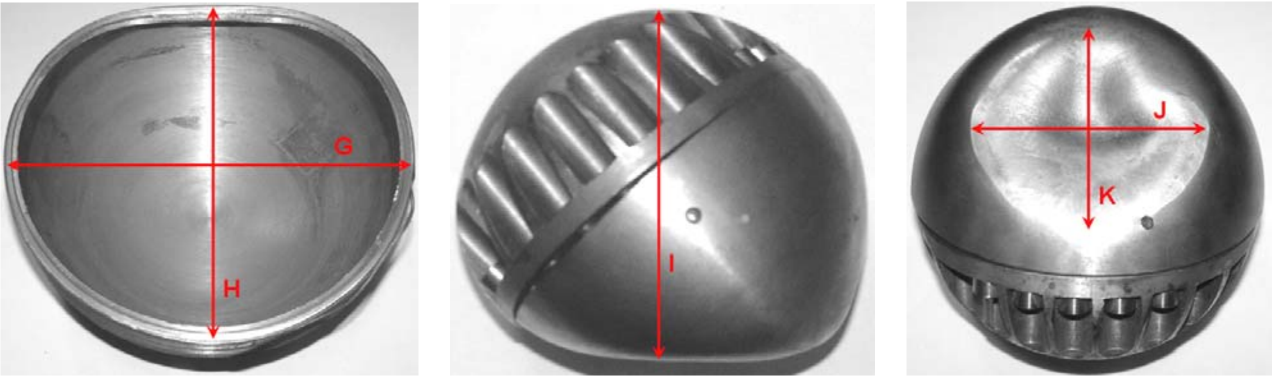

Fig. 5 Upper hemisphere of outer casing (left) and inner casing (center, right), post-impact

Table 1 Post-impact residual sizes of the container elements

Size	A	B	C	D	E	F
Value (relative units)	0.728	0.974	0.991	0.746	0.798	0.816
Size	**G**	**H**	**I**	**J**	**K**	
Value (relative units)	0.943	0.860	0.596	0.456	0.425	

RESULTS OF NUMERICAL SIMULATION

The simulation was conducted using 64 cores of a parallel computer cluster system. A large amount of the information has been obtained from numerical simulation of the container deformation. Some of this information is presented and analyzed below.

Figures 6÷9 show calculated and experimental deformed shapes of the container elements. Comparison of the results shows that they are in a good agreement. Number of the inner casing bolts, survived during the impact, is the same for calculations and experiment and is equal to 12. But dispositions of the survived bolts differ: 5 bolts from the side of the impact and 7 bolts from the other side survived in experiment, whereas 3 bolts from the side of the impact and 9 bolts from the other side survived in calculation (see Fig. 8). Possible cause of this difference is that the calculation does not involve tightening of the bolts.

Comparison of calculated and experimental dimensionless values of the residual sizes of the container elements is shown in Table 2. Analysis of the table shows, that the results of calculations are very close to the experimental data. Thus, the maximum difference is for the residual size J and is equal to 4.8%. The difference for the size H is equal to 2.0%. The differences for all the other sizes are less than 2%.

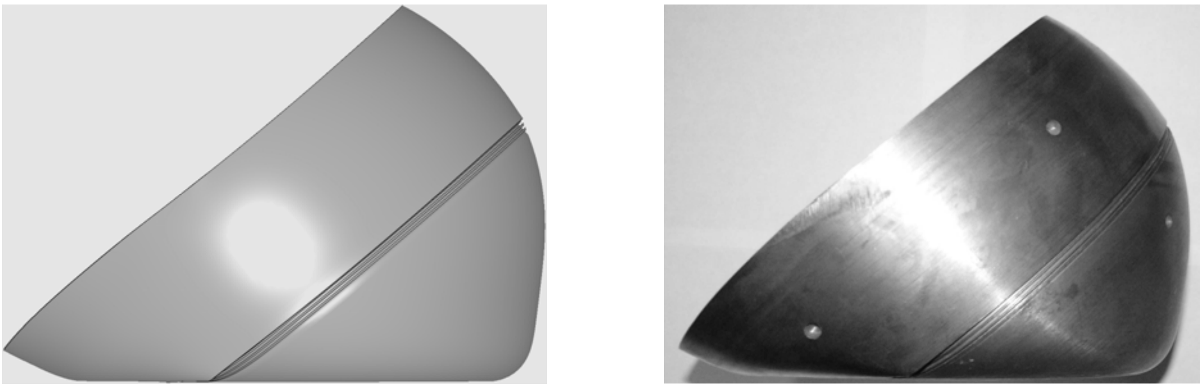
Simulation Experiment

Fig. 6 The lower hemisphere and the nut of the outer casing

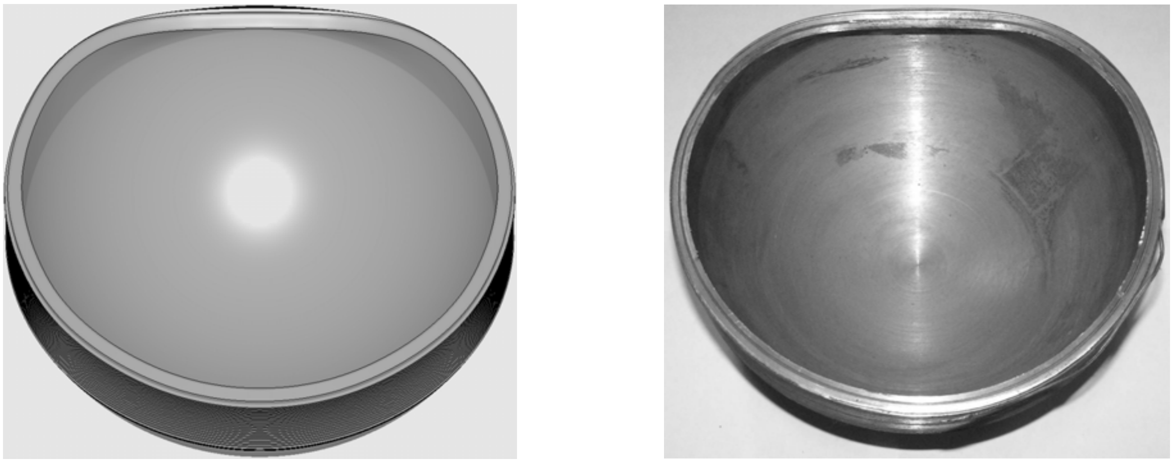
Simulation Experiment

Fig. 7 The upper hemisphere of the outer casing

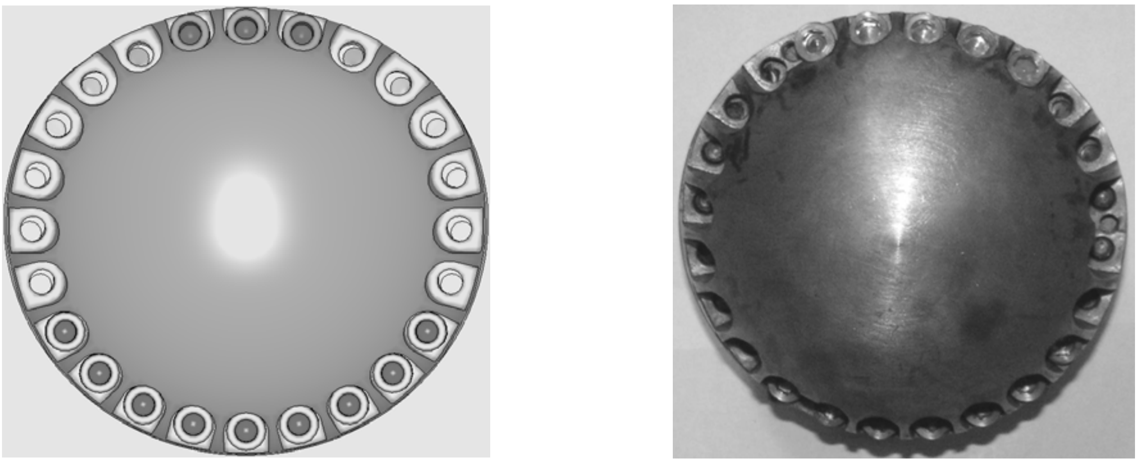
Simulation Experiment

Fig. 8 Inner casing (top view)

Simulation Experiment

Fig. 9 Inner casing (side view)

Table 2 Comparison of calculations results and experimental data

Size	A	B	C	D	E	F
Experimental value (relative units)	0.728	0.974	0.991	0.746	0.798	0.816
Calculated value (relative units)	0.719	0.978	1.004	0.737	0.798	0.825
Difference (%)	-1.2	+0.4	+1.3	-1.2	0.0	+1.1
Size	**G**	**H**	**I**	**J**	**K**	
Experimental value (relative units)	0.943	0.860	0.596	0.456	0.425	
Calculated value (relative units)	0.939	0.877	0.592	0.478	0.430	
Difference (%)	-0.4	+2.0	-0.7	+4.8	+1.2	

CONCLUSIONS

Numerical simulation of dynamic deformation of the air transportation container in 89.8 m/s impact with hard surface is conducted using CAE finite element code LEGAK-DK. The code has been developing in Russian Federal Nuclear Center VNIIEF and is intended to simulation of coupled 3D problems of structures and fluid dynamics and heat transfer on parallel computing cluster systems. Comparison of the simulations results shows that they are quantitatively and qualitatively close to the experimental data. The differences for 11 controlled residual sizes of the container elements are less than 5%. Moreover, differences for 9 of the sizes are less than 2%.

Analysis of the results shows that finite element code LEGAK-DK allows to conduct high-accuracy numerical simulations of dynamic deformation of type C packages in high-speed impact with hard surface.

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