NUMERICAL SIMULATIONS OF DYNAMIC DEFORMATION OF AIR TRANSPORT FRESH FUEL PACKAGE IN ACCIDENTAL IMPACTS

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ABSTRACT

Results of numerical investigations of dynamic deformations of packages for air transportation of fresh nuclear fuel from Nuclear Power Plants are presented for the cases of axis and on-side impacts with hard surface at a speed of 90 meters/second (m/s). Modeling results on deformed structure shapes and kinematical parameters (displacements, decelerations, cramping) for axis impact are compared with experimental data. Use of this numerical-experimental technology gives new capabilities to analyze correctly the safety of such a package in accidents through modeling, which does not require implantation of expensive testing, thereby saving money.

INTRODUCTION

In the new revision of “Regulations of Safety Transportation of Radioactive Materials” of the International Atomic Energy Agency, IAEA-96, the new regulations are presented for air transportation packages of radioactive materials. Particularly, such a packages must be strong enough over impact to a hard surface at the speed level no less than 90 m/s. Experimental testing of resistance of air transportation packages is very expensive; therefore, experimental tests with real packages need to be curried 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.

Dynamic deformation of the structure under high-speed impact to a hard surface is an extremely non-lianer process, which has several specific aspects as follows:

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

Practical solution of this problem with acceptable accuracy could be obtained by using modern software of high-speed deformation simulations. In advanced countries, the well-known computer code LS-DYNA [1-3] is widely used for numerical analysis of resistant containers. At present, Russian Sarov Open Computing Center (SOCC) uses a Russian code DINAMIKA-2/3 [4,5], which is oriented to simulations of 2D and 3D dynamic deformation problems. This code is certified by GOSSTANDART – Certification Center of Russian Federation. In this paper, some results of using DINAMIKA-2/3 are presented in application to air transportation package safety analysis.

DESCRIPTION OF CONSTRUCTION

The structure schematic drawing of the air transportation package for fresh nuclear fuel of NPP [6] is presented in Fig 1. The package consists of four steel tubes covered by lids at the ends of the tubes. The tubes are connected to each other by plate support panels and by a central spacing rib. Fresh fuel bundles with zirconium six-edged cases are packaged inside every tube in wood damping elements. The tube lids are fixed on the flanges by bolting. There are special steel shock absorbers installed at every lid.

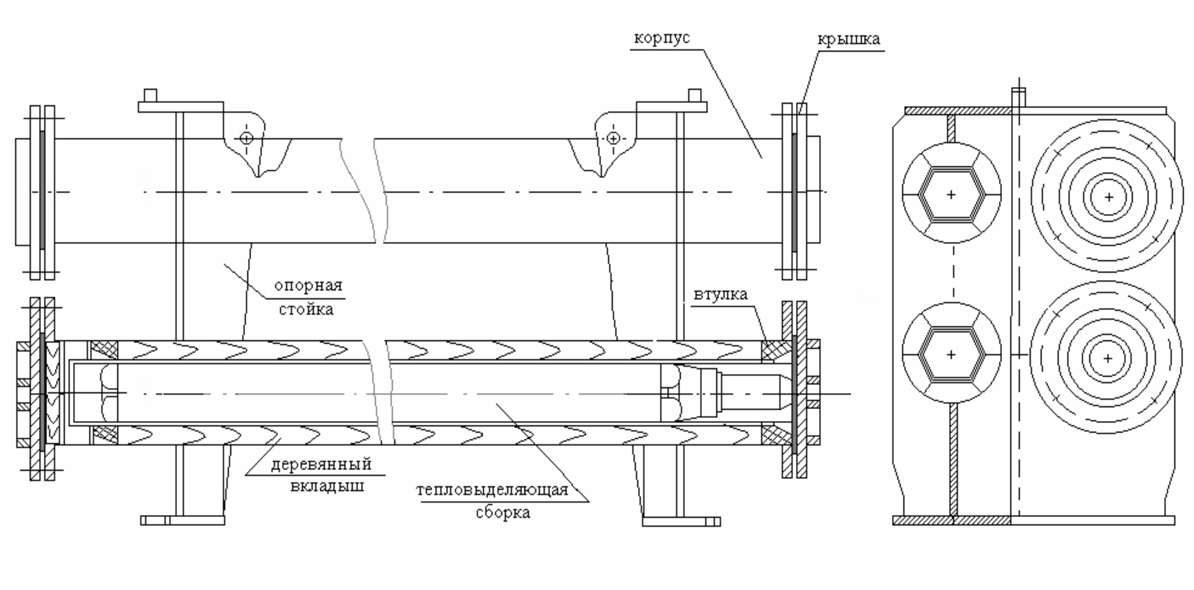

Fig. 1. Schematic Structure Drawing of Air Transportation Package.

COMPUTING MODEL

Numerical investigations have been implemented for two impacts of package to the hard target:

- axial loading (tube axis are perpendicular to the hard surface of target);
- on side loading (tube axis are parallel to the hard surface of the target).

A three-dimensional computer model has been developed for numerical simulations. Because of symmetry only part of the structure was created (Fig. 2). The computing model consists of $45 \cdot 10^3$ finite elements nodes. Mesh has smaller elements in the zone of contact interaction with the target. Rod bundles are simulated by solid bodies of hexahedron cross section, changing along the axis of the bundle. Mechanical properties of the rod bundles model were selected on the basis of numerical-experimental research results, which have been obtained before.

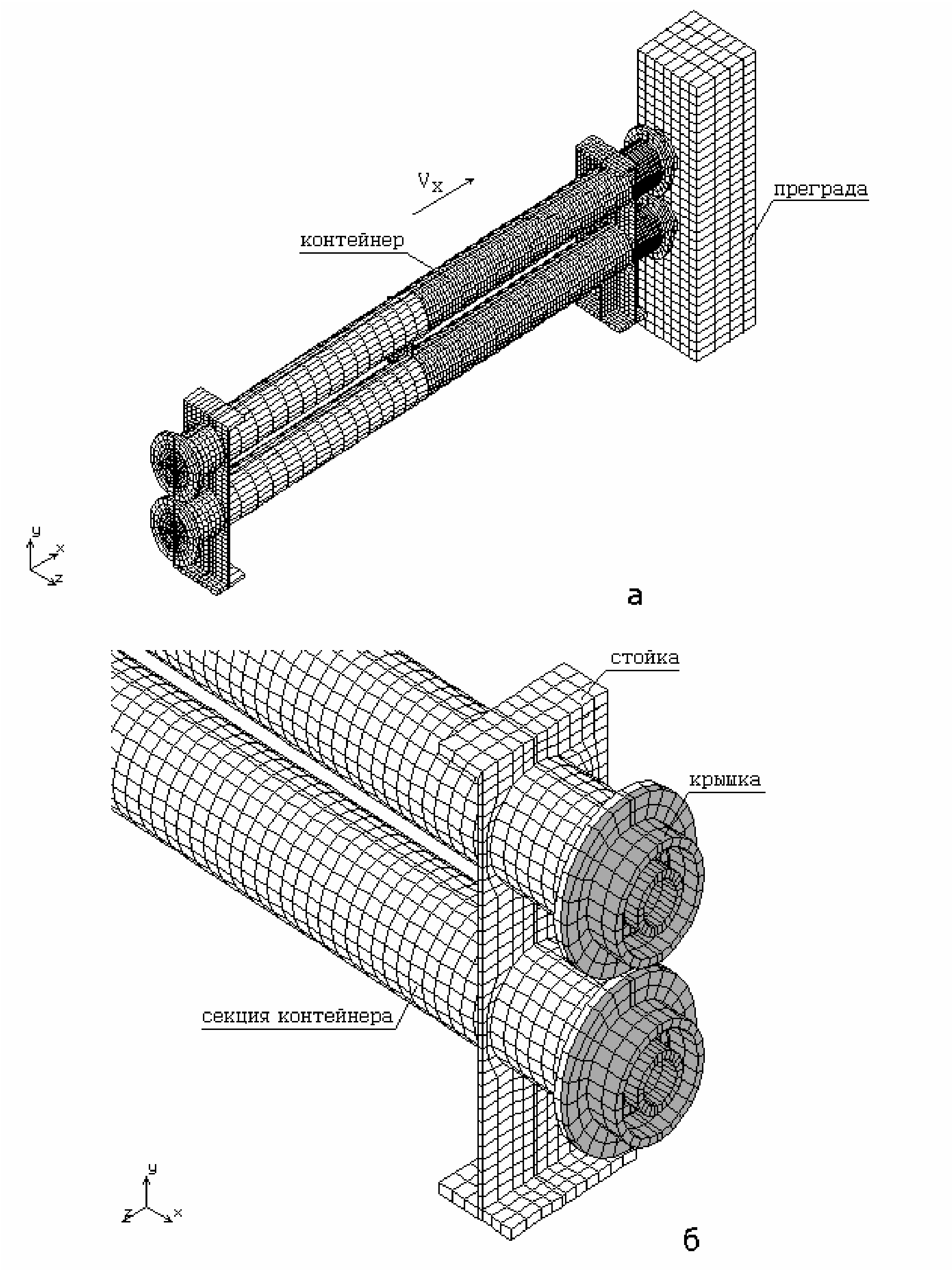

Fig. 2. Computing Model for Axial Loading Simulations.

RESULTS OF NUMERICAL SIMULATION

Results of the numerical simulations for the axial loading show that tubes of the package are greatly deformed in elastic-plastic range, forming several ring buckles in the zone of impact (Fig 3). The duration of the impact process is about 5 ms. Plate support panels also are bent in the direction of the impact, and in the central part of the first support panel the huge crimp appears. Damping elements on the lids are somewhat deformed (~5-6mm). The cramping of tubes is about 267-275mm. Analysis of deceleration levels shows that they have significant differences for various parts of the structure. In the region of impact interaction with the target before the appearance of the first buckle, deceleration reached the level of 8000÷9000. In the middle and in the top part of the structure, levels are close to 4000÷6000. Maximum deceleration takes place in the rod bundles model and reached the level of about 20000.

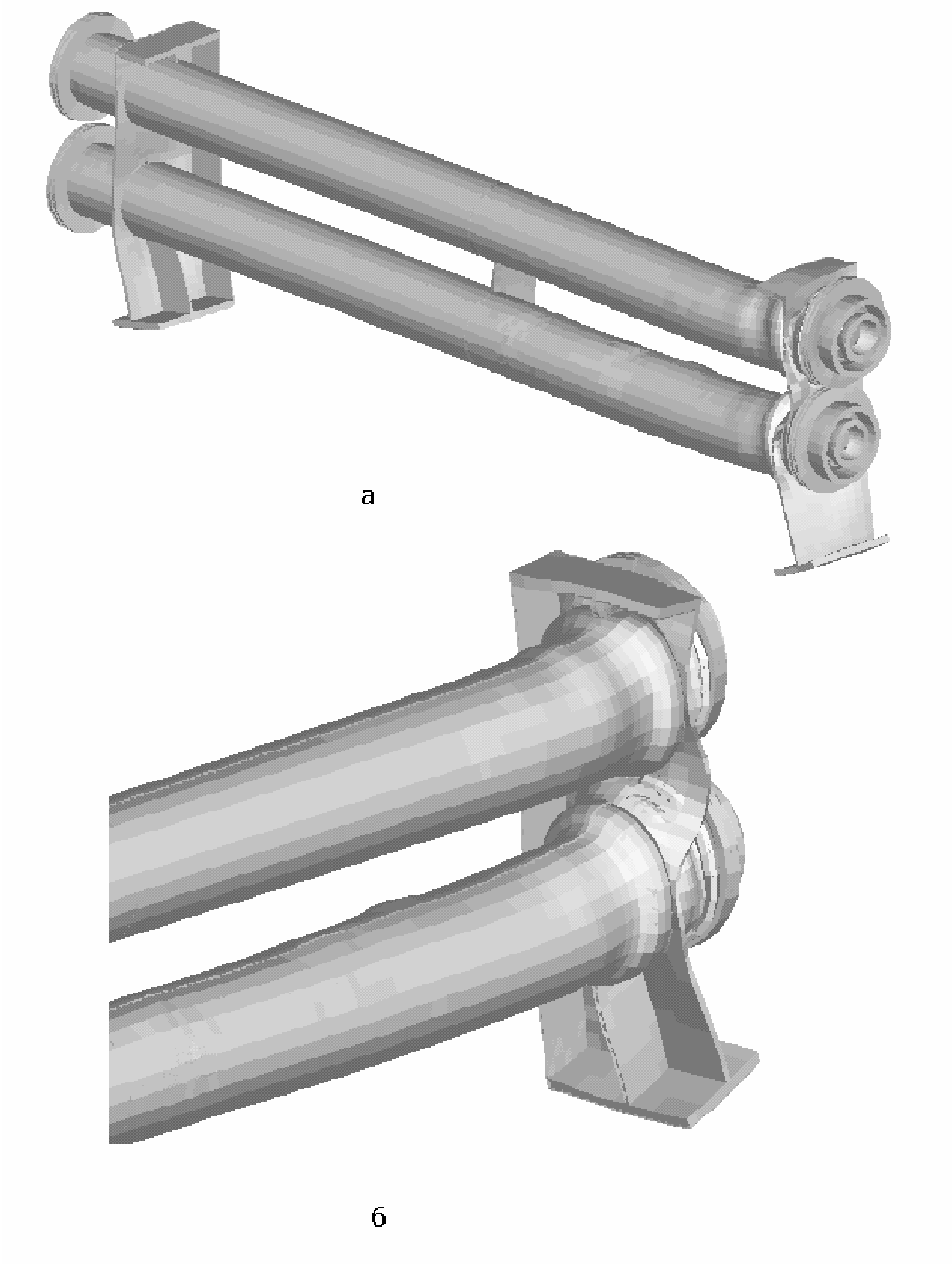

Fig. 3. Deformed Shape of Package After Axis Impact

Analysis of strain rates demonstrates that maximum values are about $\dot{e}^{max}$ ~1700 s^{-1} in the impact zone of absorbers. In the lids of the package, the strain rates are much less. In radial and axial directions, they are no higher than 65÷80 s^{-1} in the beginning of the deceleration process.

In flanges, the level of axial compression strain rates do not exceed about 80 s^{-1}, but the level of circular tension strain rates is in the range of $\dot{e}^{max}$ = 130÷250 s^{-1}. In the tubes the maximums strain rates in different points are in the following intervals:

- in axial direction (compression): 400 ÷ 700 s^{-1};
- in circular direction (tension): 150 ÷ 370 s^{-1}.

The distribution of strains in the tubes after impact loading has a greatly non-uniform character. The length of tubes with high plastic deformations is about 1200mm. The level of maximum strain in the absorber elements is about 10÷11 %. In local zones of first and second buckles, the level of plastic deformation is about 42% and one can say that this demonstrates the possibility of local cracking, because maximum strain for the tube material is only 30%. In other parts of the buckles, maximum strains are in the range of 21÷30%. Comparison of experimental and numerical results is presented in the Table 1 for the case of axial loading [6]. Table 1 demonstrates that computing and test results are close enough.

Table I. Computing and Experimental Results for Axial Loading of Air Transportation Package

Parameter	Computing	Experiment
Number of Buckles	3	4
Altitude of Buckles, mm	32÷51	Up to 50
Tube Contortion, mm	267 ÷ 275	245
Absorber Deformation, mm	5÷ 6	A Little
Deceleration Levels		
In Impact Zone:		
Bottom Tube	9200	8300 (≥7500)
Top Tube	8250	—
In the Middle Zone:		
Bottom Tube	4700	4000÷6000
Top Tube	4200	4700÷5500
In Opposite of Impact Zone		
Bottom Tube	4600	4200÷6300
Top Tube	4300	4700÷7000

For the on-side impact loading near the same computing model has been used as for the axis loading case. There were some differences in mesh density distribution of this model, which has smaller finite elements in zones of on side contacts with target.

Duration of the "on side" impact is nearly the same as in the axis case, about 6ms. In the "on side" impact, the deformation process is characterized by the large changing of the shape of the support panels, spacing rib and banding of the tubes leading to their contact interactions (Fig. 4). Contact of the bottom tube with the surface takes place after 2.5 ms, and contact between the bottom and top tubes appears in 3 ms. The middle part of the top tube has the most displacement in impact direction, about 400 mm. Cross sections of the tubes after impact showed an elliptical shape. In this case, the reduction of the diameter of the bottom tube in the region of the right support panel is about 70 mm, while in the middle part of the tube, it is about 11 mm. The levels of the tube's decelerations prior to contact with the target is about 5000 and, after contact, reach 10^4. The decelerations of the fuel bundles inside tubes are about 16000÷19000.

The majority of plastic deformations are concentrated in the bottom parts of the support panels near the target and in areas where the tubes and support panels are welded. In the support panels, the maximum level is about 60%, which means that they will be ruptured. In the tubes, the maximum level of plastic strain does not exceed 18÷23 %, so the tubes will keep their integrity.

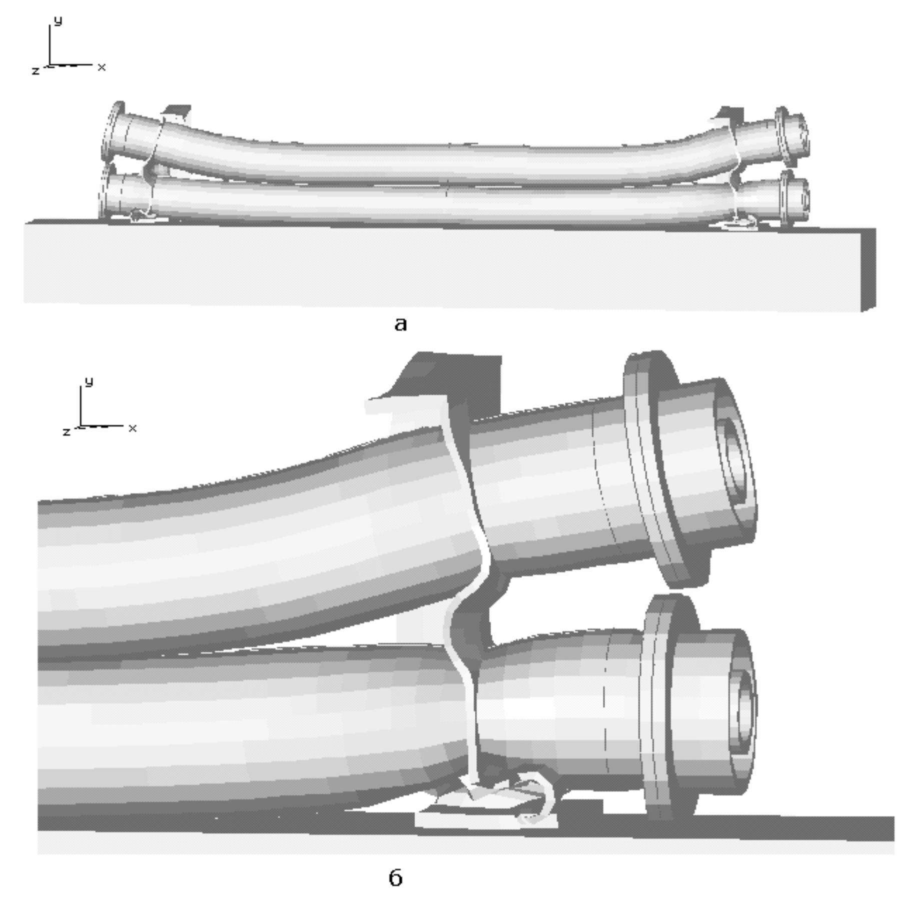

Fig. 4. Deformed Shape of Package After On Side Impact

CONCLUSIONS

On the basis of implemented numerical investigations, the following conclusions can be made:

1. In axial and on-side impacts of the package at a speed of 90 m/s, the tubes keep their integrity. In these cases, there is some possibility for local cracking of the tubes only. These results show that fuel rod bundles will be kept inside the tubes during such an accident.

2. The butt-end absorber does not provide proper protection over the axis impact and must be modified.

Obtained numerical results were part of the analysis of the package's resistance in the event of an aviation crash. The results supported the activity for certification of this package. The modified structure is now used for air transportation of fresh nuclear fuel of Nuclear Power Plants from Russia to foreign countries.

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