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Upgrading of WWER-1000 NPP Safety on Spent Fuel Transportation.

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ABSTRACT

Transportation process for the WWER-1000 Spent Fuel Assemblies consists of three main steps:

- Lifting of unloaded Cask on the elevation of + 38.05 m;
- Loading of Spent Fuel Assemblies into the Cask;
- Loaded cask lowering to the conveyer located in the transport corridor on the elevation 0.00 m.

The most hazardous situation within described process for the Cask itself and Reactor Building Structures is an accidental drop of the Cask from the height of 38.05 m to the Transport Corridor floor due to failure of traverse or crane's cable break.

According to International Practice and Standards' Requirements the Cask shall be designed for the drop from 9 meters height to a rigid plate. However, preliminary analysis have shown that in case of 38 m drop the value of g-loads are several times more than allowable limits. Additionally, strength capacity of the foundation slab of the reactor building is not guaranteed.

Using of special damping device that is capable to bring dynamic loads to allowable limits could mitigate the catastrophic consequences of Cask's 38.05 meters drop.

The paper presents a basic design of the special damping platform and discusses results of analyses of different modes of Cask drops and efficiency of the proposed solution.

KEY WORDS: Cask, 38.05 meters drop, damping platform.

INTRODUCTION

Transportation of containers (Casks) with Fuel Elements Assemblies (FEA) of WWER-1000 reactor at Kalinin NPP and Novo-Voronez NPP is connected with lifting of loaded container between upper deck elevation +38.05 m and 0.00 m to the transportation corridor.

Dropping down of the container from elevations of +9.00 to +38.05 m range to the floor of the transportation corridor carries potential risk of radiation accident due to possible fault of traverse or/and cable: disintegration of the Cask and FEA with damage of building structures, systems and components. Mitigation of the consequences of such an accident could be achieved by using while moving at a big heights of a special damping platform decreases interaction g-loads up to acceptable limit.

In the current paper is described the general design of the platform and results of analysis that obviously illustrated the advantages of dampening platform implementation.

1. MAIN SAFETY DEMANDS

Transportation of WWER-1000 FEA at Kalinin and Novo-Voronez NPPs is connected with lifting of free container to the Reactor Building (RB) elevation +38.05 m, then loading of container by FEA and its lowering to the railway train transporter in the transport corridor elevation 0.00 m.

Dropping down of the container from elevations +9.00 to +38.05 m to the floor of the transportation corridor due to fault of traverse or/and cable carries potential risk of radiation accident: disintegration of the CASK and FEA with damage of building structures, systems and equipment. [1,2]. Mitigation of the consequences of such an accident could be achieved by using while lifting of special damping platform (DP) for decreasing of interaction g-loads up to an accepted limits forced on container itself, building structures and system, elements and equipment in RB.

In accordance with demands of documents [3] and [4] containers shall be able to maintain integrity, strength and protection ability while dropped from a height of 9.0 m on a rigid plate in any possible horizontal, rocking (angle) and vertical positions. The certification of containers ТК-10 и ТК-13 by Nuclear Authorities definitely means that they already met all the requirements and demands of standards and g-loads does not bring any critical overloading in container's dropping down from 9.0 m height on a rigid plate.

Preliminary analysis has shown that in case of dropping down of a Cask from a height of 38.05 m on a floor of transportation corridor shall definitely cause more than 3 times overloading of the container itself and RB foundation plate could be severely damaged.

According to the Technical Task Programme and General Technical Terms when using DP the following demands on Nuclear and Radiation Safety shall be covered in operation procedures with Casks loaded by FEA:

1.The allowable limits of g-loads for the different cases of containers TK-10, TK-13 and CASTOR dropping down shall be in the limits of Table 1.

2.Dynamic loads acting on a RB foundation plate shall be in a range of acceptable loads. The value of allowable distributed bending moment for RB foundation plate is defined as 11 556 kN*m/m.

3.Actual Weight and Dimensions of DP shall not exceed corresponding limits.

Table 1. Allowable Cask's g-loads

Type of Container	Position of the Cask's vertical axe	Allowable limit of g-load
TK-13	Vertical	197
	Horizontal	176
	Angle	186
TK-10	Vertical	228
	Horizontal	135
	Angle	246
CASTOR	Vertical	120
	Horizontal	120
	Angle	120

2. DESCRIPTION OF THE DP GENERAL DESIGN AND DP ANALYSIS MODEL

The definition of general parameters of the main elements of DP was performed in the NPO CKTI on the basis of preliminary dynamic analysis of container deceleration considering required safety criteria [5].

The main idea consists of shock interaction dampening by using wood material working in compression mode. Fig.1 explains non-linear "force-deformation" curve of a wood sample under compression.

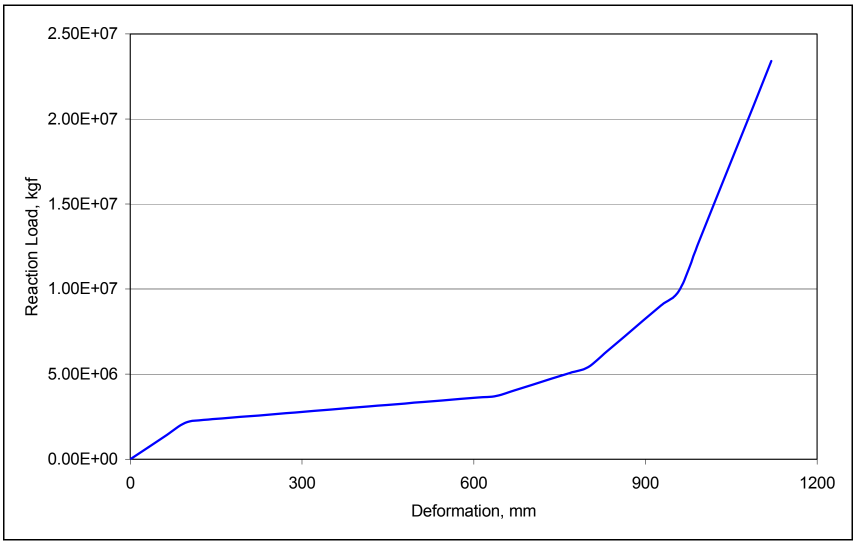


Fig. 1. "Force-Deformation" influence for the wood sample compression

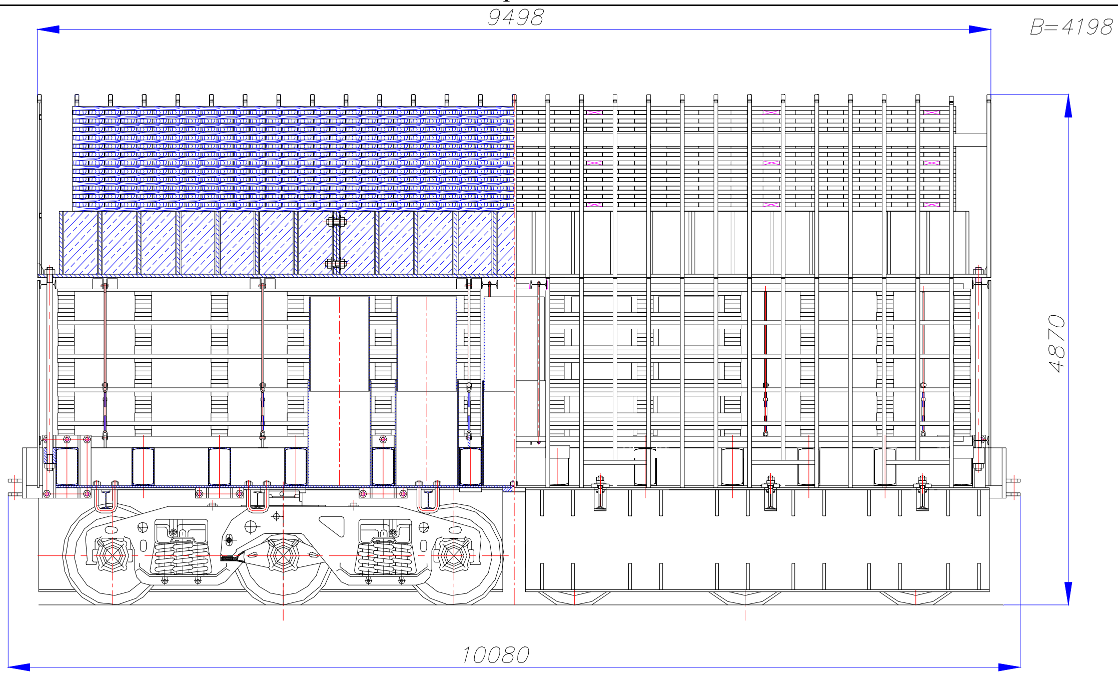
On the Fig. 2A and 2B is shown the General Design and main elements of DP.

"Hard" damping layer (2) represents solid volume of wood based on massive intermediate plate (3).

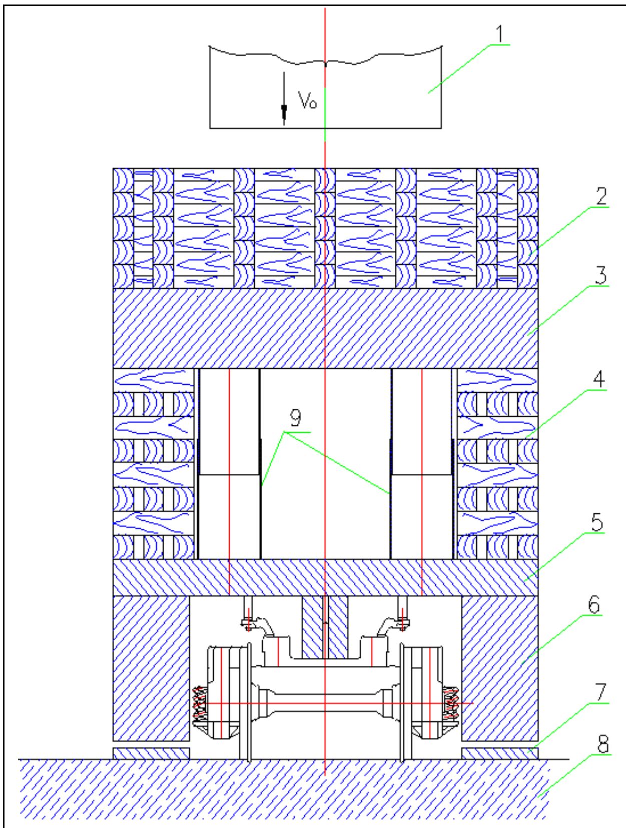
Intermediate plate (3) consists of beams system welded to each other and connected with steel sheet plates. Providing of necessary mass to the plate is achieved by concrete casting.

"Soft" damping layer (4) is located between intermediate plate (3) and bearing frame (5) and consists of wooden breaks based on the frame (5).

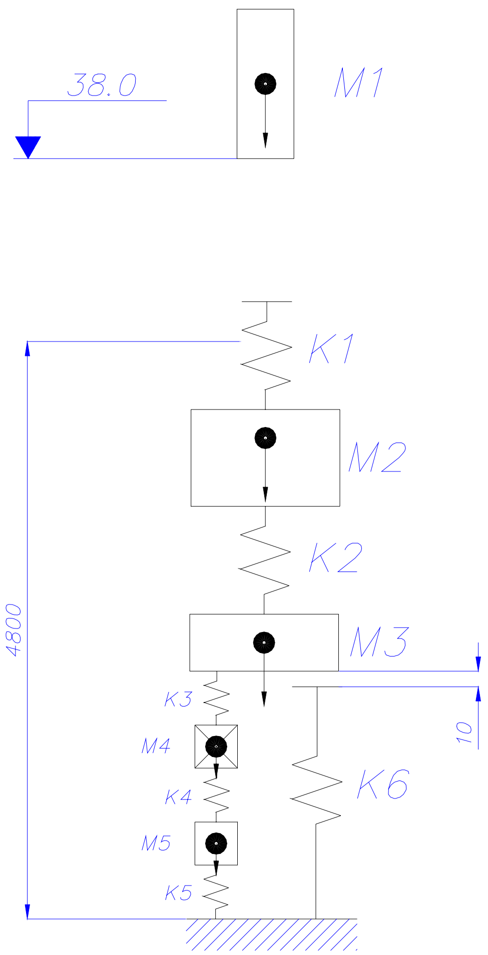
Frame (5) is constructed from system of longitudinal and cross-member beams and located on a running wheel platform.



A. General View of DP



1 - container, 2 - wooden “hard” damping layer,
3 - intermediate plate,
4- wooden “soft” damping layer,
5 – frame, 6 - supporting pedestal,
7 - wooden bricks, 8 – floor, 9 - cylinders



B. Main elements of DP | C. DP Analysis Model

Fig. 2. General view and analysis model of DP

The directed vertical movement of the intermediate plate (3) is served by 10 cylinders (9), which entered to the guiding tubes of the bearing frame.

From the lateral sides the frame (5) has stiff vertical supporting pedestals (6), which in initial position have a clearance with the floor of transportation corridor.

In working "CASK-DP" interaction state the pedestals (6) stand on the floor preventing running wheel platform from excessive loads and passing load path impulse just on the floor.

Under the pedestals with 10 mm gap is located wooden bricks (7), making necessary load distribution on the floor.

In the analysis model shown on the Fig. 2C the following descriptions of mass and stiffness parameters are used:

- M1 – container's mass;
- M2 – masses of the plate and "stiff" damping layer;
- M3 – masses of the supporting pedestals, "soft" damping layer and part of the frame;
- M4 – partial mass of the frame not included in mass M3 and part of running wheel platform attached to the frame;
- M5 – mass of wheels and part of running wheel platform attached to the wheels;
- K1 – describes non-linear "force-deformation" influence of the "stiff" layer. Depends on a container's position while dropping on DP;
- K2 - describes non-linear "force-deformation" influence of the "soft" layer;
- K3 – stiffness of the frame beams;
- K4 – stiffness of the running wheel platform springs;
- K5 – stiffness of the railway;
- K6 - describes non-linear "force-deformation" influence of the wooden bricks with 10 mm gap between pedestals and bricks.

A comprehensive dynamic analysis of DP operation in different modes of loading with definition of actual capacity of DP elements was performed by "CKTI-Vibroseism" company using original verified «SEISM198» software code. The features and description of the code is presented in the Verification Manual [6].

3. ANALYSIS RESULTS

Implementation of DP provides dramatic decreasing of the g-load for the all types of containers used on Kalinin and Novo-Voronez NPPs. Safety factor for overloading (relation of capacity-allowable to demand-analysis) for the all containers' types are higher 1.0 (Fig. 3). At the same time relatively smooth distribution of the load on the floor of transportation corridor is achieved independently on container's type and its position when dropping on DP.

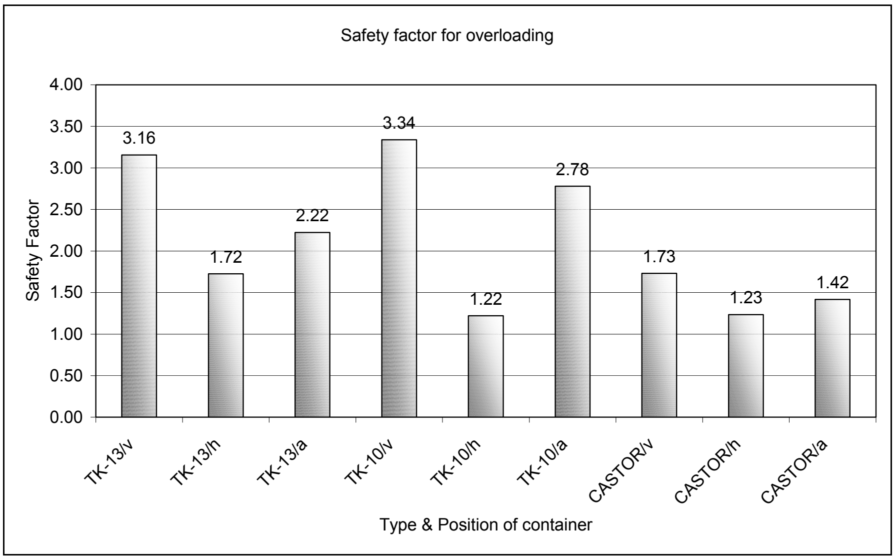


Fig. 3. G-load Safety Factor
Container's Position: v – vertical, h – horizontal, a - angle

4. REACTOR BUILDING BEHAVIOUR UNDER LOADING BY DROPPING CONTAINER

The dynamic loading of RB by dropping TK-13 container from elevation +38.05 m was set by distributed load on the transportation corridor floor square in the contact spots of support's pedestals with the floor.

Analysis was carried out by computer code "SOLVIA-99.0" of "SOLVIA Engineering AB" company [7, 8].

Just in the contact space three layers of 3D finite elements modeled the RB foundation plate. Parts of the plate and the wall attached to the mentioned zone were modeled by "shell" elements (Fig. 4). The Finite Element Model of the internal structure and general view of RB model is shown on the Fig. 5. Evaluations of the RB basement stiffness with actual soil conditions consideration were performed by ASC SASSI Code [9] and on the basis of ASCE Recommendations [10]. In the final evaluation the results obtained by ASC SASSI Methodology were used that guaranteed higher enveloping spectra (higher safety factor).

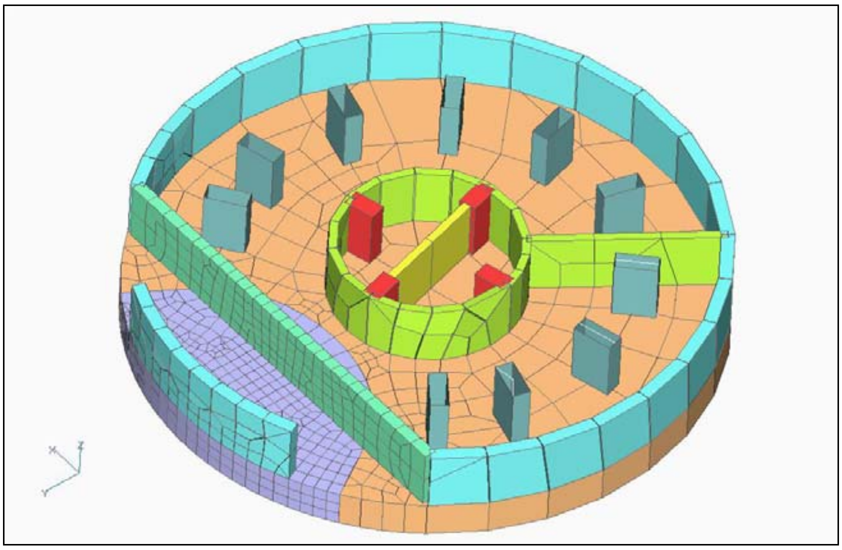
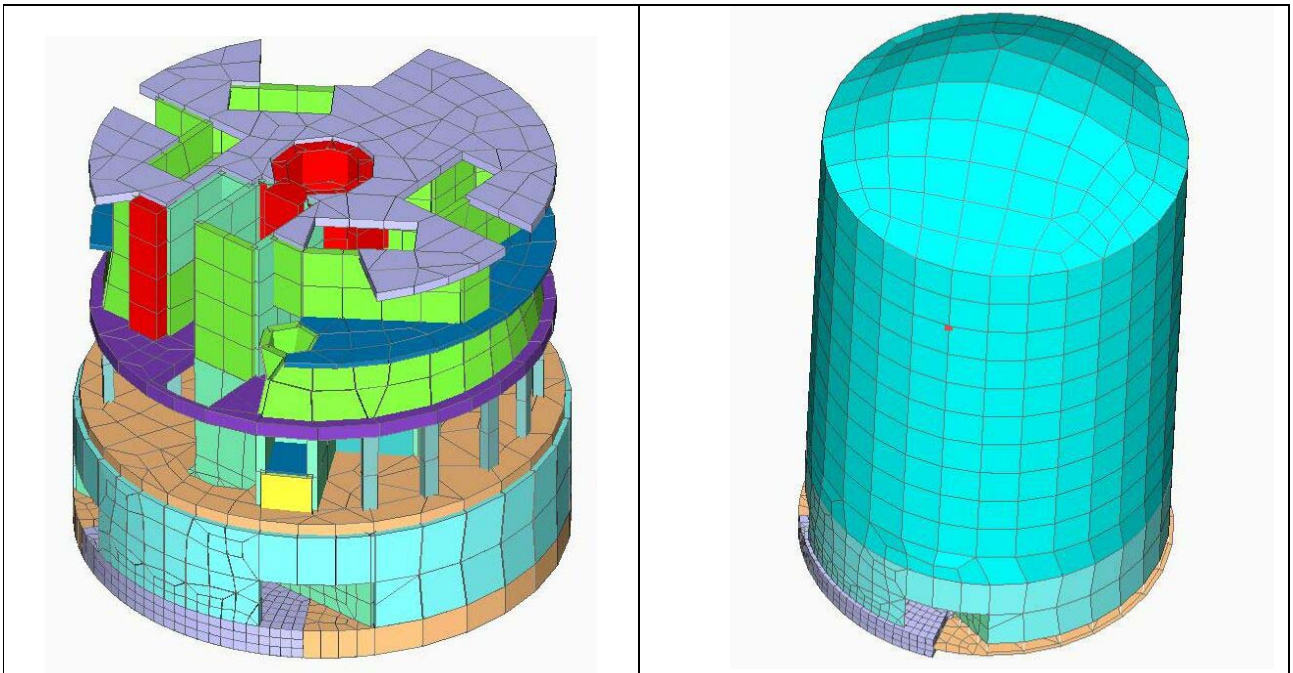


Fig. 4. RB foundation plate model (thickness, t=3.0 m).



RB Internal Structure	RB Finite Element Model General View

Fig. 5. RB Model

Bending Moment for the RB foundation plate was carried out for the two control sections located along corridor axe in middle area (Section 1) and nearby internal wall (Section 2).

Table 2. Maximal Linear Bending Moment in the RB Foundation Plate, kN*m/m

Container's location	Section 1	Section 2	Allowable (Capacity)
Angle	902	3847	11556
Horizontal	919	3918	11556
Vertical	872	3733	11556

On the Fig.6 is shown distribution of the normal stresses in the RB foundation plate when container TK-13 is dropped down in horizontal position.

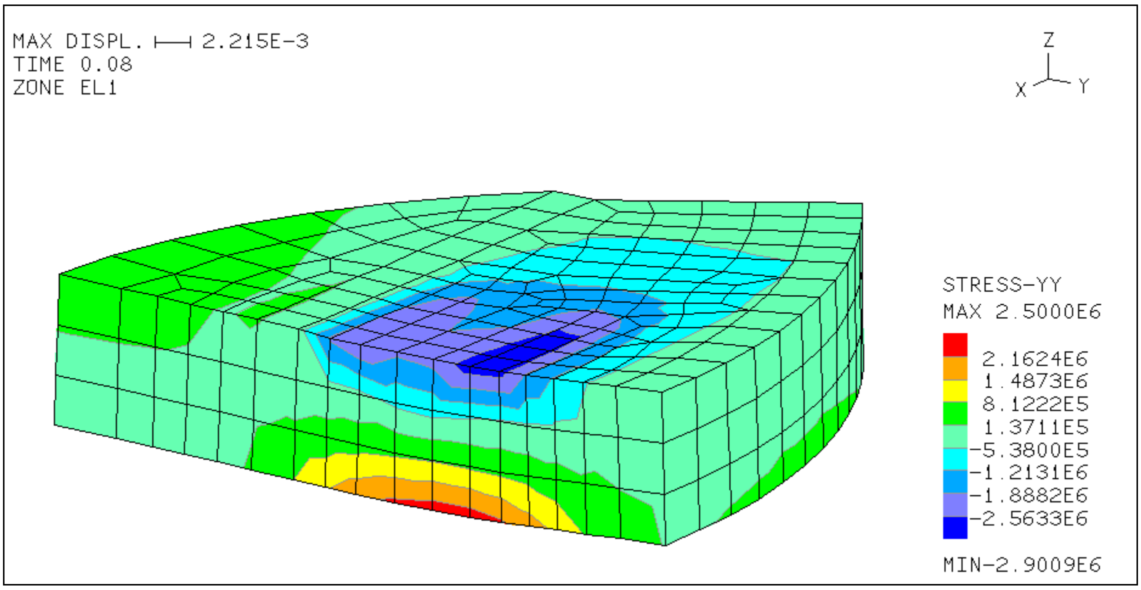


Fig. 6. Distribution of Normal Stresses in RB Foundation Plate under Dynamic Impact

On the Fig. 7 is presented comparison of the floor loads for the cases of dropping down TK-13 container from a height of 5.5 m without DP and the same container from a height of 38.05 m on the DP. Safety Factor for the G-load in the first case is equal to 145.7 < 197.0 (allowable).

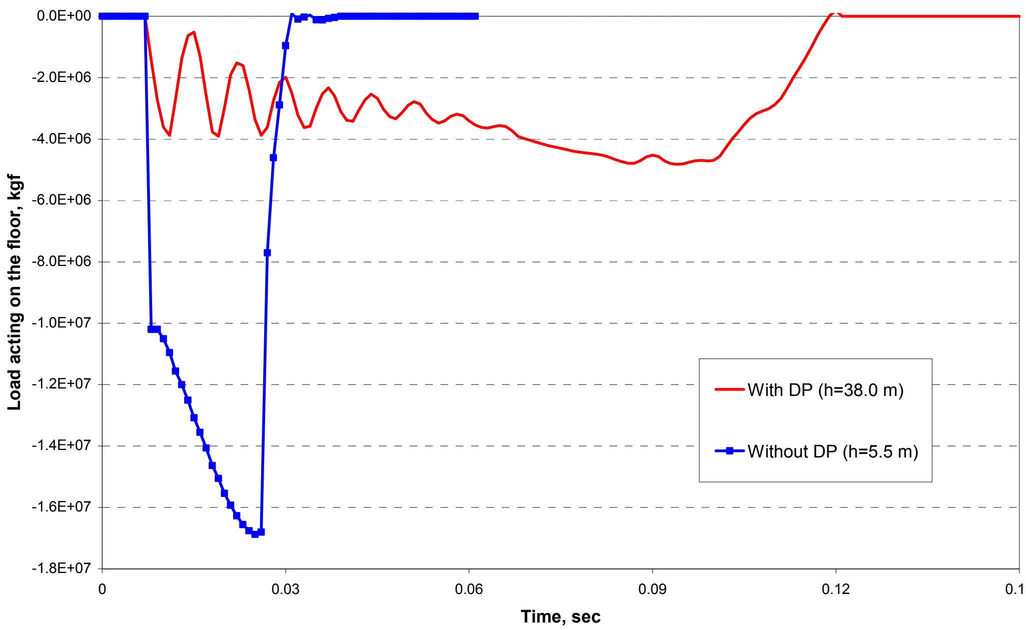


Fig. 7. Load Time History in Kg-Force on the Floor of Transportation Corridor

In accordance with DP Operation Technology and Manual the probability of container's dropping down from a height of 5.5 m just on the floor of transportation corridor is exist. In the presented work the RB acceleration spectra comparison analysis of containers dropping down from elevation +38.05 m on DP and from elevation 5.50 m without DP on the free floor of transportation corridor was fulfilled. In these analyses the damping in the system was assumed as 6÷8% critical damping [10].

On the Fig. 8 and 9 the comparison of obtained spectra on elevation +22.8 m (Elevation of Steam Generator Boxes) in different modes of container's dropping is shown. All spectra are for the 2% damping. It is obvious the dramatic positive influence of DP on full RB structure even for a such limited case with different initial heights.

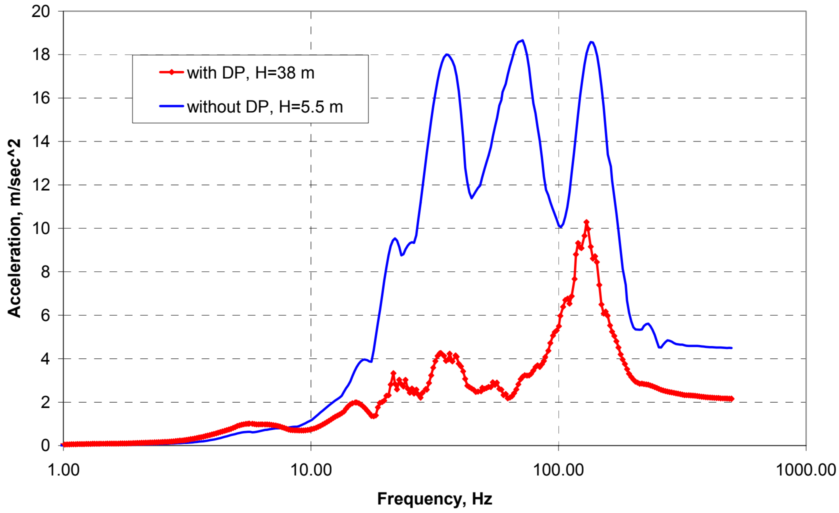


Fig. 8. Spectra Comparison for the Elevation +22.8 m, horizontal direction

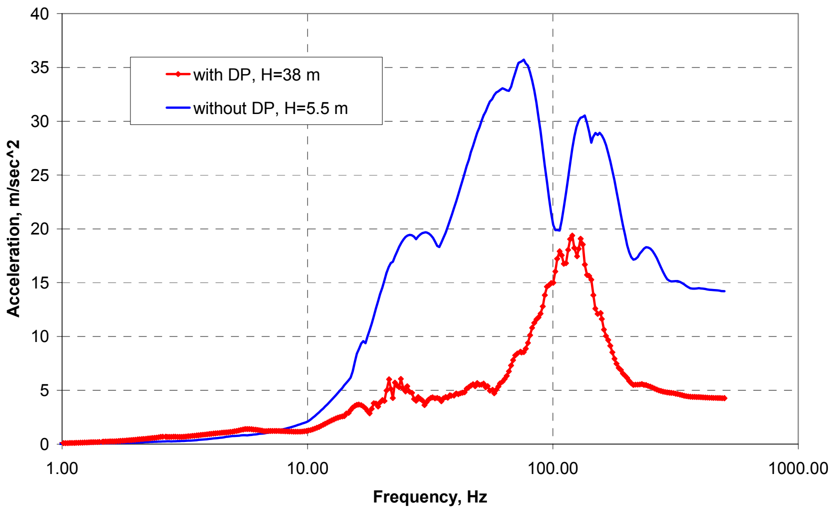


Fig. 9. Spectra Comparison for the Elevation +22.8 m, vertical direction

CONCLUSIONS

1. The Damping Platform (DP) was developed that provides operation radiation safety for the TK-10, TK-13 and CASTOR containers with spent fuel in transportation between elevations +38.05 m and 0.00 m in the shaft of the VVER-1000 Units of Kalinin and Novo-Voronez NPPs.
2. In-depth analysis has shown that using of DP dramatically decreases the probability of an accident with spent fuel containers in its transportation between elevations +38.05 and 0.00 meters. Safety Factor for the most severe case of Cask's dropping down from the maximal height is laying in the range of **1.22 – 3.34**.
3. The non-linear dynamic model of DP and Finite Element Model of Reactor Building were developed with consideration of the RB main structure properties and soil conditions. DP provides Safety Factor 3.0 for the RB foundation plate in the most severe analysis case for the maximal dropping height +38.05 m.
4. DP provides essential decreasing of RB Response Spectra in factor more than 3 and that way guaranteed safety of RB systems and equipment in case of the CASK transportation accident.
5. In general DP allows excluding catastrophic consequences for the containers with spent fuel and Rector Building in all transportation modes in the RB shaft even in case of dropping down from the maximal height of +38.05 m. DP is in operation at Kalinin NPP site (Fig .10).
6. Implementation of DPs could be recommended as an effective measure for providing safety in all Casks transportation cases on a relatively big height.

Fig. 10 DP assembled at Kalinin NPP

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