

SIMULATION TECHNOLOGIES AT FOPS DESIGN PHASE FOR “AMKODOR” MACHINES: APPLICATION EXPERIENCE

Summary

The capability for operator protection in case of falling objects accidents is one of the most important criteria for cabin evaluation. For this reason, machines are equipped with falling-object protective structures (FOPS). There is a number of standards defining FOPS requirements depending on the machine class and mass. Engineer's primary task at FOPS design phase is to develop such a structure that will meet the safety requirements. The results of cooperation of «AMKODOR» holding and The United Institute of Informatics Problems of the National Academy of Sciences of Belarus (UIIP NASB) on special machines FOPS design are presented in the current paper.

Key words: cabin evaluation, operator protection, accidents, simulation technologies

1. Introduction

The construction machines are used on building areas, forests, careers. That can involve the risk of an incident, for instance, falling objects of different sizes' mass.

FOPS is intended to assure operators of reasonable protection from localized impact penetration. FOPS is the structure used to protect the operator. That is realized by one element (fig. 1) as well as the integrated elements of the driver cab (fig. 2).



Source: own work

Fig. 1. A separate protective structure of FOPS



Source: own work

Fig. 2. Integrated elements of FOPS

2. Problem description

The international standard provides performance criteria for FOPS. These criteria at the laboratory tests for measuring the structural characteristics are specified. Designing is the very important stage of the machine creation because the design error requires to carrying out the repeated laboratory tests, but it costs much money. The implementation of an analytical calculation is very difficult, as compared with the numerical computing. In addition, it saves the time.

The advanced solutions in the designing as well as the computing are performed. At the same time, the behavior of FOPS under different conditions of loading are predicted.

The world experience indicates that the stress-strain state FOPS under impact stress and dynamic load successfully are computed, but very often it is in need of more computational resources. The up-to-date equipment and software enables to create the solid model and the computation models to perform the computer-aided engineering. That makes for constructive final parameters to be supposed before to accept a final design solution.

3. Requirements

The type of international standard depends on a class and size of machine, and gives performance requirements in a representative test. ISO 3449, ISO 10262 [6, 8] is intended for use on the road and earth-moving machines, ISO 8083 - for forestry machinery [9], OECD Code 10 - for agricultural machinery [1]. It is applicable to both FOPS supplied as an integral part of the machine and those supplied separately for attachment to the machine.

All standards based on the concept of safety deflection limiting volume under the typical specified impacts. This object is possessed of a potential energy as a function of the height versus the falling mass. The potential energy is determined on the assumption of the machine working conditions. The impact number depends on the design parameters FOPS. An impact cabin place is selected as the most dangerous. The deflection limiting volume (DLV), the clearance zone (CZ) base on the anthropometric operator's data in accordance with ISO 3164 [7], OECD Code 3 [2], OECD Code 4 [3], OECD Code 6 [4], OECD Code 7 [5]. The structural members and the falling mass do not have to penetrate in the specified area (DLV, CZ).

Table 1. The standard's requirements

Standard	Protection level	falling typical mass	Clearance zone
ISO 3449 [8]	Level I: E=1365 J (a shock resistance from the small falling mass) Level II: E=11600 J (a shock resistance from the big falling mass)	For level I: the round object (spherical surface contact) For level II: the round object (cylindrical surface contact)	DLV in accordance with ISO 3164
ISO 10262 [6]	Level I: E=1365 J (m<6000 kg) Level II E=11600 J (m?6000 kg)	For level I: the round object (spherical surface contact) For level II: the round object (cylindrical surface contact)	DLV in accordance with ISO 3164
ISO 8083 [9]	E=11600 J (self-propelled machine and portable loader) E=5800 J (another self-propelled machines and portable loaders)	the round object (cylindrical surface contact)	DLV in accordance with ISO 3164. For the reverser sitting sum DLV
OECD Code 10 [1]	E=1365 J	the round object (cylindrical surface contact)	CZ for the tractor equipped ROPS in accordance with OECD Code 3, 4, 6 and 7 DLV in accordance with ISO 3164. For the reverser sitting sum DLV

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FOPS must be installed on the machine frame as on the existed object. The whole frame is not necessarily to be mounted but the applied part have to correspond to the real object. The support vertical cabin stiffness and the real object stiffness have to be identical. The parts of the cabin element that is not bearing (a window, a removable board and etc.) have to be disassembled. The FOPS shall completely cover and overlap the vertical projection of the DLV. The DLV shall not be entered by any part of the protective structure under the first or subsequent impact of the test object. Should the test object penetrate the FOPS, the FOPS shall be considered to have failed the test.

A comparative analysis of the standard's requirements (table 1) based on the design of FOPS are produced.

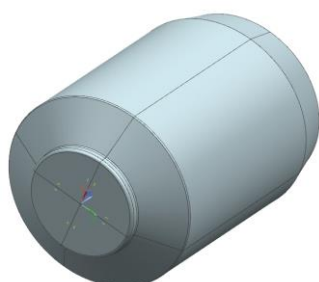
4. FOPS development for wheel loader AMKODOR

The main objective is the testing of the AMKODOR's road-making machine according to requirements of standard ISO 3449 Level II [8].

In the first step, the typical computing impact model (fig. 3) of the round falling object with the specified potential energy (cylindrical surface contact) is designed.

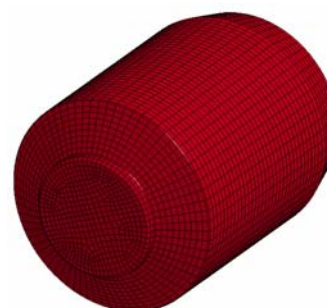
The solid typical round object reasoning from requirements of standard ISO 3449 [8] as well as the physical model has been done.

The finite element model (FEM) including to 8 nodes hex elements (size 10 mm) have been performed. The FEM with the high-quality mesh on the contact surface has been obtained. The final FEM round falling object is shown in the fig. 4



Source: own work

Fig. 3. The solid typical round falling object



Source: own work

Fig. 4. The final FEM round falling object

The typical computing impact model of the round falling object in LS-PREPOST [11] is defined. The round falling object material is modelled as a rigid body model. Thereafter, the material is deformed plastically according to a linear relation between true stress vs true strain. The automatic surface contact between the falling mass and a structure of the cab is performed. The impact energy is calculated in compliance with a relation between the rigid body object velocity at the moment of the collision and the element of FOPS. The gravitational acceleration is set in order to define the trajectory of the rigid falling object after the contact with the FOPS.

In the second step is required to accomplish the numerical model of the prototype FOPS.

The solid model FOPS is generated with the solid cabin. An early experience was an indication that only the top cabin part for the design's estimate need to be simulated. Cause: the rigid falling object hits and deforms this part. A decrease in the pillar length will further improve the cabin stiffness in one's turn, increase loading impact on FOPS. The solid model FOPS is divided into the three fragments for conveniences. The control points are marked on the fragments in order to measure off the strain values. The final solid FOPS is shown in the fig. 5.

The finite element model of FOPS including 4 nodes tetra elements (sizes 10 mm) has been performed. The FEM with the high-quality mesh on the contact surface has been obtained. The finite element model of FOPS is shown in the fig. 6.

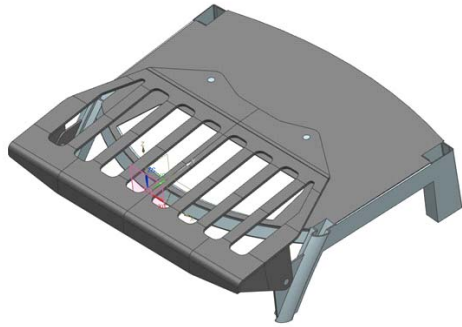


Fig. 5. The final solid FOPS

Source: own work



Fig. 6. The finite element model of FOPS

Source: own work

The numerical model FOPS with the specified parameters in LS-DYNA is performed. This information applies to the execution of the model computation. It is important to obtain damping coefficient of the oscillation due to the impact loading.

In the third step, the final simulated model of FOPS is carried out.

The simulated model described above in the second step requires to accomplish the integration to the typical computing impact object referred to the first step. In that way the final simulated model of FOPS is generated. The typical computing impact object is disposed as near as possible at the top part FOPS relative to a vertical axis. The point of the impact loading corresponds to standard's requirements ISO 3449 [8].

The final simulated model of FOPS for the numerical computational is shown in the fig. 7.



Fig. 7. Final simulating model

Source: own work

In the fourth step, the simulation test of the design of FOPS is defined.

On account of the complication of the current task related to a nonlinear dynamic analysis the rigid falling object

and the simulated model of FOPS in the explicit [10] calculations has been solved. The assigned tasks in the cluster SKIF-UIIP placed in UIIP NASB [12] have been solved.

At the fifth step, the simulation results analysis, the stress-strain estimate of the FOPS design, the typical penetration of the falling object and FOPS element in DLV is calculated.

The simulation results of FOPS is shown in the fig. 8-11.

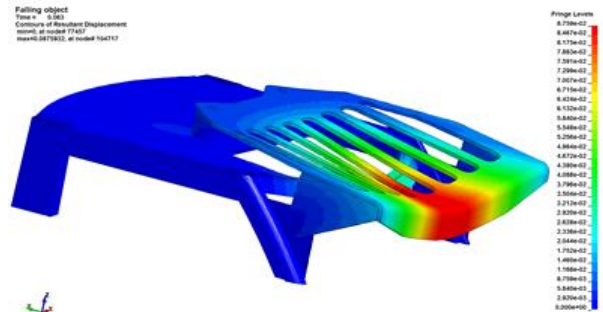


Fig. 8. FOPS strain after the impact

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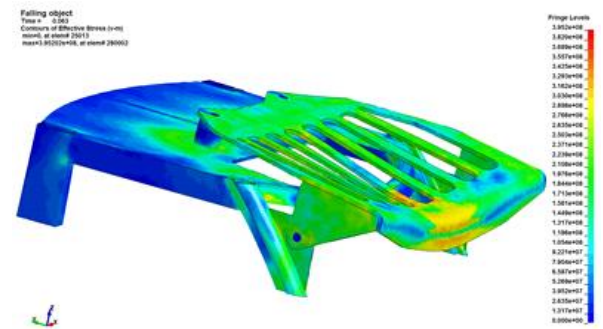


Fig. 9. FOPS von Mises stress after the impact

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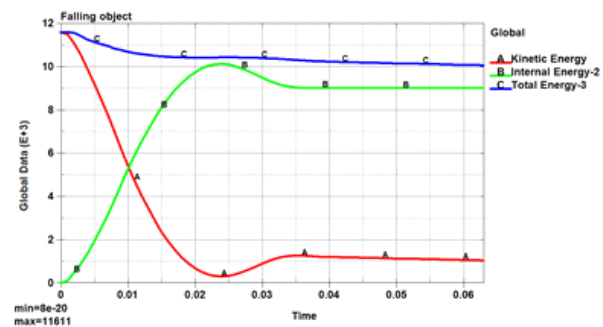


Fig. 10. Kinetic and adsorbed energy vs time graph

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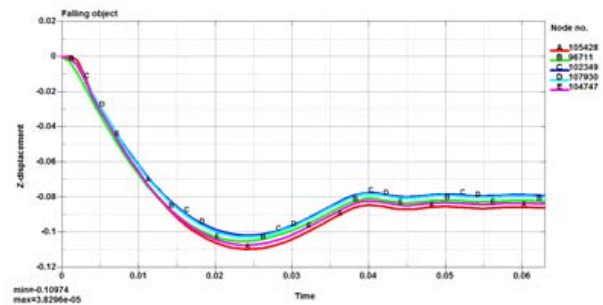
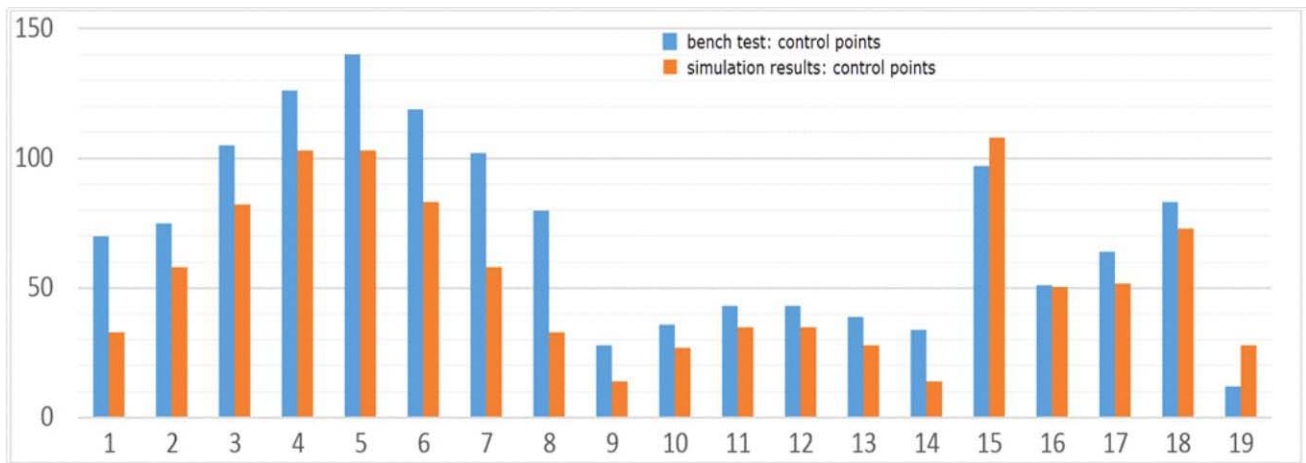


Fig. 11. The control point displacement of FOPS vs time graph

Source: own work



Source: own work

Fig. 12. Control point displacements chart

If the simulation tests do not undergo according to standard ISO 3449 [8] requirements, it is necessary to come to the step 2 and fulfill the new calculation of FOPS.

5. Results comparison

The simulations have in general shown good compliance with the corresponding tests. The control point displacements along to Z axis have been checked (fig. 12).

The united chart with the test control point displacements as well as the simulation control point displacements is displayed.

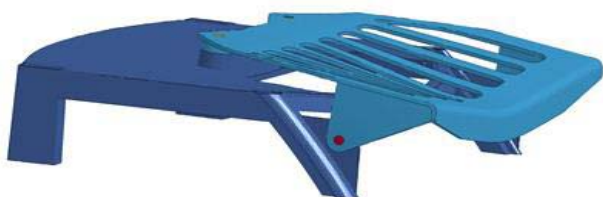
Test and simulation results AMKODOR's machine (AMKODOR 320CE) as well residual strain are shown in fig. 13-14.

The simulation results is quite accurate as compared with the bench tests. It gives rise to use that technology in the following design of FOPS.



Source: own work

Fig. 13. Test results AMKODOR's machine (AMKODOR 320CE)



Source: own work

Fig. 14. Simulation results AMKODOR's machine (AMKODOR 320CE)

6. Conclusion

The proposed technology in JSC «AMKODOR» – Holding Managing Company has been adopted. The shown technique allows to manufacture the different machines and can be used for the definition of the design behavior under the dynamic load accurate within 90%. The described technology provides to fulfill requirements in accordance with ISO 3449, ISO 8083 [8, 9].

The given numerical technology enables to reduce both a period of design of FOPS and cut down costs of FOPS tests.

7. References

- [1] Code 10 OECD standard code for the official testing of falling object protective structures on agricultural and forestry tractors.
- [2] Code 3 OECD standard code for the official testing of protective structures on agricultural and forestry tractors (dynamic test).
- [3] Code 4 OECD standard code for the official testing of protective structures on agricultural and forestry tractors (static test).
- [4] Code 6 OECD standard code for the official testing of front mounted roll-over protective structures on narrow-track wheeled agricultural and forestry tractors.
- [5] Code 7 OECD standard code for the official testing of rear mounted roll-over protective structure on narrow-track wheeled agricultural and forestry tractors.
- [6] ISO 10262:1998 Earth-moving machinery – Hydraulic excavators – Laboratory tests and performance requirements for operator protective guards.
- [7] ISO 3164:2013 Earth-moving machinery – Laboratory evaluations of protective structures – Specifications for deflection-limiting volume.
- [8] ISO 3449:2005 Earth-moving machinery – Falling-object protective structures – Laboratory tests and performance requirements.
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- [12] United Institute of Informatics Problems: <http://uiip.bas-net.by>.