26th International Conference
ENGINEERING MECHANICS 2020
Brno, Czech Republic, November 24 – 25, 2020

VIRTUAL ROPS TESTING ON SUSPENDED AGRICULTURAL TRACTOR

Rekem J.[*], Prokop A.[**], Zajac R.[***], Rehak K.[****]

Abstract: *This paper is devoted to the agricultural tractor's rollover protective structure. The ROPS Code 4 testing procedure for small-sized suspended tractor has to be performed by technical experiment, but numerical simulation can significantly affect the number of testing. For that reason, the whole procedure is simulated by using finite element method software Ansys. A complex simulation contains models of rubber silent blocks and spring-damper suspension units. The protective structure is accepted for laboratory tests and ways of optimization or possible critical regions are proposed. Based on the results, presented approach has good correlation with technical experiment, thus can be used as powerful tool in the development phase.*

Keywords: Agricultural tractor, Rolling over protective structure, ROPS, Virtual ROPS, Cabin.

1. Introduction

Agricultural tractors operate commonly on uneven terrain, where the risk of overturning cannot be neglected. Cabin frame is considered as the rollover protective structure (ROPS) and to reduce fatalities, the Organization for Economic Co-operation and Development (OECD) established standards to harmonize the protective structure testing. To avoid repetition of expensive laboratory tests during the designing process, virtual ROPS testing models using finite element method are being used (Hailoua Blanco et al., 2016). Moreover, an extensive research was done in order to completely replace the laboratory testing by the simulations (Clark, 2005), which has not happened yet.

Laboratory tests of the studied tractor follow the OECD Code 4, which imposes these load steps and requirements (see Fig. 2):

1. Longitudinal loading with a prescribed absorbed energy;
2. Rear crushing with a prescribed reaction force;
3. Side loading with a prescribed absorbed energy;
4. Front crushing with a prescribed reaction force.

2. Methods

Simulations were carried out on a newly designed cabin suspension. At the front, the cabin is mounted on silent blocks and at the rear, the spring-damper units are used. The testing procedure is equivalent for unsuspended and suspended cabin frame. In case of an unsuspended cabin that lies on four silent blocks, all four consoles are loaded similarly. On the other hand, the spring-damper units allow a significantly larger movement of the cabin, which implies larger forces induced on the front consoles. When investigating the strength of the protective structure, suspension elements and their connection to the cabin frame must be properly modelled.

[*] Ing. Jakub Rekem: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 61669, Brno; CZ, jakub.rekem@vutbr.cz

[**] Ing. Aleš Prokop, PhD.: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 61669, Brno; CZ, ales.prokop@vutbr.cz

[***] Ing. Roman Zajac: Institute of Automotive Engineering, Brno University of Technology; Technicka 2896/2; 61669, Brno; CZ, roman.zajac@vutbr.cz

[****] Ing. Kamil Řehák, PhD.: Institute of Automotive Engineering, Brno University of Technology; Technicka 2896/2; 61669, Brno; CZ, kamil.rehak@vutbr.cz

doi: 10.21495/5896-3-436

As the cabin frame is welded from tubular steel, surface representation was prepared using the SpaceClaim software. Surface bodies were tied together at the mesh level with Ansys functionality Mesh Connections. By means of this, a lot of computationally expensive contact regions could be eliminated.

The front axially oriented silent blocks are modelled without using a non-linear rubber material model. Some of the approaches (Drapal et al., 2016) use an axisymmetry model for simplification of the solution, but in this case it is represented by full geometry Elastic deformation of the rubber element is described with Ansys Virtual Springs, which are connected to a dummy part. The shape of this dummy part models a plastic deformation of the silent block washers, see Fig. 1. The spring-damper units at the rear side of the cabin frame are modelled as virtual springs with a stress-strain characteristic obtained from the technical documentation.

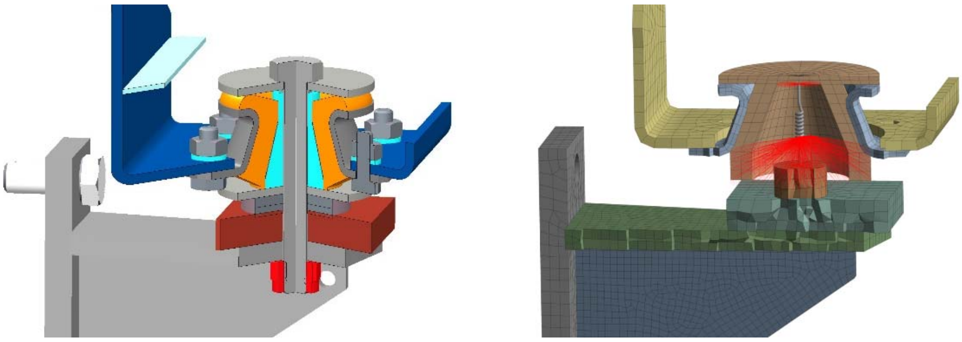

Fig. 1: Section of the axially oriented rubber silent block used in the front (left) and its simulation model (right).

All the consoles that hold the suspension elements were preserved as volume bodies with Shared Topology. Since these were the main area of investigation, consoles were meshed precisely. Bilinear material model was applied to all steel parts of the structure. Plastic deformation is always presented in these structures so that they can absorb the kinetic energy of rollover.

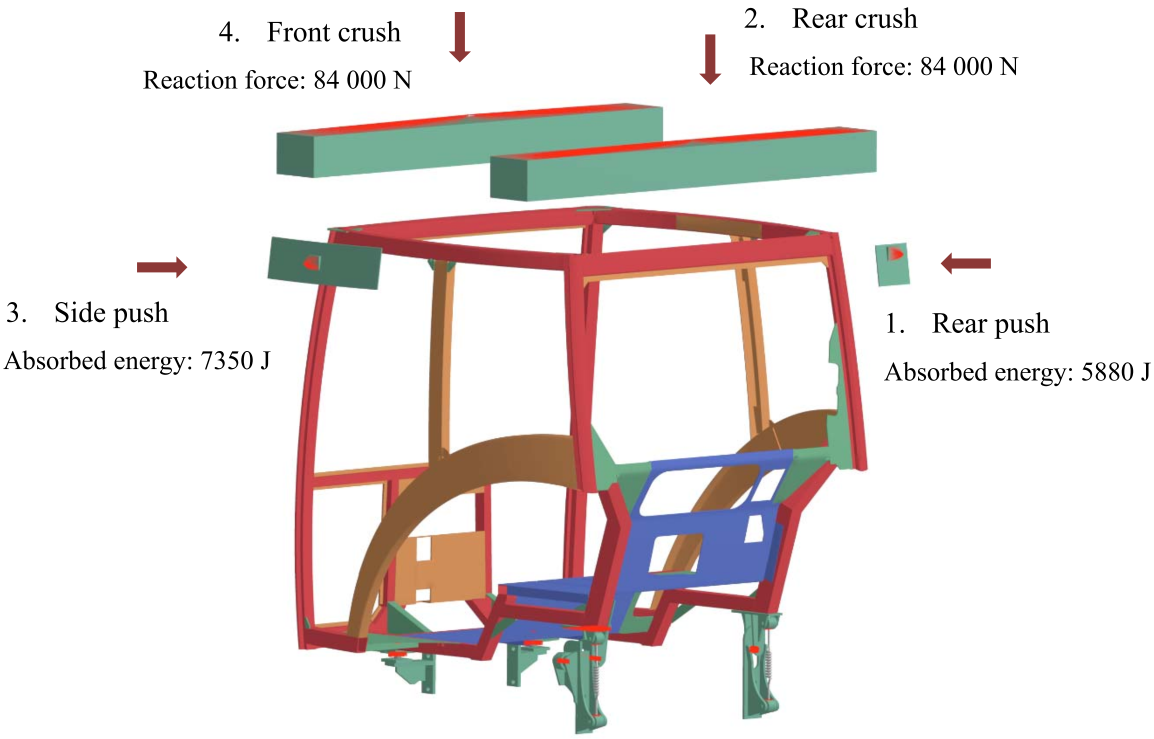

Fig. 2: Geometry used for the simulation. Different colours are assigned to different materials. Pushers with procedure rank number and corresponding requirement are shown. Also, red areas where constraints by means of Remote Points were applied can be seen.

During laboratory tests, the reaction force and displacement of the hydraulic piston are measured and controlled by closed loop algorithm, based on Field Programmable Gate Array—FPGA, which enables fast processing (Kucera et al., 2019). The absorbed energy is calculated as a displacement of the hydraulic piston multiplied by the reaction force. In the simulation, the displacement is prescribed in a series of the load steps and when the absorbed energy requirement is met, the loading is slowly retracted (see Fig. 3).

This means that the procedure cannot be simulated at once yet can continue after the load step is validated. Additionally, the deformed cabin frame from one load step is input for the following one. As noted in (Blanco, 2016), for these purposes the functionality for restarting the simulation is necessary.

Hydraulic pistons deform the cabin frame by means of pushers which distribute the pressure on the cabin frame uniformly. Ball coupling between these parts is modelled in Ansys with Remote Points set to Coupling setting. Given that during the simulation the cabin frame lies on virtual springs with no damping, between consecutive load steps the frame has to be fixed to assure convergence. The pushers were constrained in contact initialization phases.

3. Results

Tested cabin frame was already approved with different suspension design. The consoles of suspension were approved after minor design modification. The structure was able to absorb required energy in the first (see Fig. 3) and in the third (see Fig. 4) load step and reached prescribed reaction force in other two load steps. Moreover, none of the cabin frame parts did enter the driver clearance zone, which is also the ROPS procedure requirement. The equivalent total strain was the criterion for evaluating the likelihood of structural fractionation.

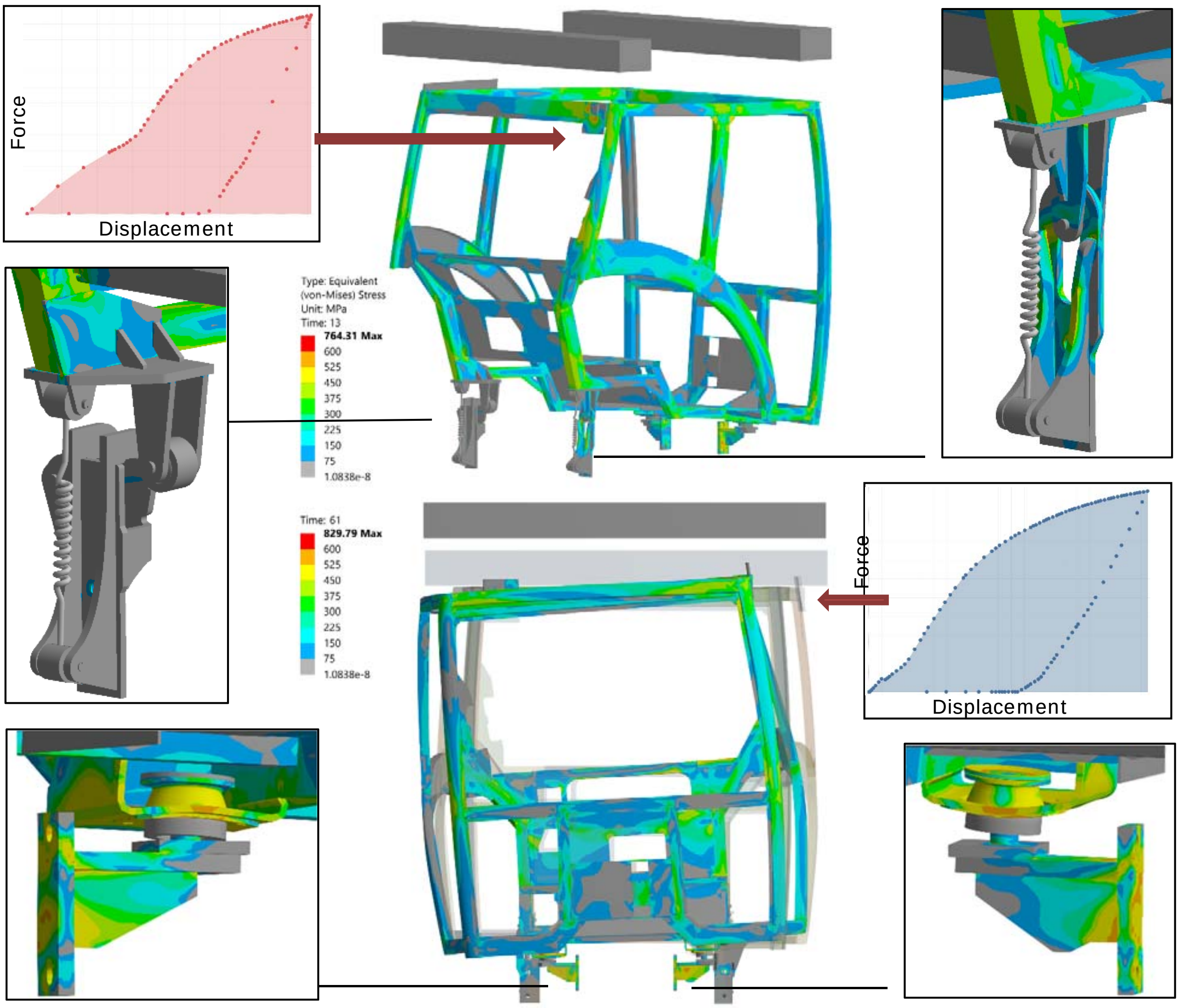

Fig. 3: Equivalent stress in the cabin frame during the rear and side pushing with recorded absorbed energy diagram. Detailed views of the front and rear consoles.

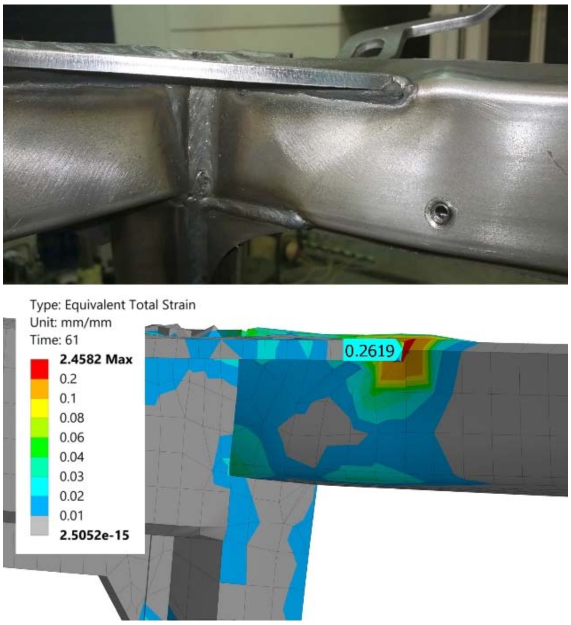

Fig. 4: Equivalent total strain exceeded 26 % in one of the top corners of the cabin frame. The simulation result is confronted with experimental testing of the frame.

The deformed shape of the cabin frame matched the shape of experimental results, where the whole design is very similar. However, the suspension design, which was investigated by using a computational approach, was not tested experimentally yet.

4. Conclusion

Despite the fact that the validation of the model is still a topic for further work, the model confirmed to be a useful tool for the design process and revealed a couple of regions relevant for optimization (see Fig. 5). The simulation showed that horizontal loadings in the first and the third load step have a significantly higher impact on the structure than two crushing load steps, where nearly no new plastic deformation of the structure was introduced. Therefore, in early design stage simulations skipping the two crushing loads can save CPU time reasonably.

It is also possible to use the spring-damper suspension unit as a structural part since they are constructed for much higher tensile force than is presented in working conditions. More specifically, the highest tensile force reached in the simulations was around 10 kN, whereas the suspension units must withstand tensile force 30 kN. Thus, the rest of the structure can be less robust which could have a positive effect on production cost.

Acknowledgement

The research leading to these results has received funding from the project Specific research on BUT FSI-S-20-6267 and project TN01000026 granted by Technology Agency of the Czech Republic. The authors gratefully acknowledge this support.

References

Clark, B. (2005) Behaviour of Roll Over Protective Structures subjected to Static and Dynamic Loading Conditions. The School of Civil Engineering, Queensland University of Technology. Faculty of Built Environment & Engineering.

Drápal,L., J. Vopařil (2016) Shape Design of a Piston Ring. Transport Means 2016 – Proceedings of the 20th International Scientific Conference, Kaunas: Kaunas University of Technology, pp. 767-771.

Hailoua Blanco, D, Martin, C and Ortalda, A. (2016) Virtual ROPS and FOPS Testing on Agricultural Tractors According to OECD Standard Code 4 and 10, 14th International LS-DYNA Users Conference, EnginSoft S.p.A.

Kučera, P., V. Píštěk (2019) Prototyping a System for Truck Differential Lock Control. SENSORS, vol. 19, no. 16, p. 1-18. ISSN: 1424-8220.

OECD Standard Code for the official testing of protective structures on agricultural and forestry tractors. Code 04. February 2018.