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ABOUT THE PARAMETRIC MODELLING OF THE PROTECTIVE STRUCTURE INCLUDED IN A TRACTOR CABIN IN ORDER TO STUDY ITS PROTECTIVE CAPABILITY USING THE FINITE ELEMENT METHOD

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ABSTRACT

The objective of the paper is the highlighting of the main aspects that are considered in parametric modelling of the protective structures included in a tractor cabin in order to study its protective capability, using finite element method. In the first part of the paper are presented, briefly, the main reference documents governing the mechanical protection of the human operator working on an agricultural tractor or forestry tractor. Also, it is presented the algorithm used in optimization process of the protective structures using CAD and FEA platforms. Next, it is presented a parametric analysis of the protective structure included in a tractor cabin, in order to determine the main geometric parameters characterizing such structures. These geometrical parameters are used in a case study where the geometry for a protective structure was generated using a CAD platform. In the final part of the article conclusions are presented.

KEYWORDS: Protective structures, tractor cabin, parametric modelling

1. Preliminary

One of the most important performance criteria that must satisfy the cabins of the agricultural and forestry tractors is to ensure mechanical protection of the human operator during accomplishment of the technological operations for which the machine was designed. In this context, the strength structure of the tractor cabin must be a structure which must have capability to ensure mechanical protection in case of the tractor rollover or/and in case when the cabin is stricken by falling objects.

Due to the great importance to ensure mechanical protection of the human operator working on agricultural or forestry tractors, this is an area governed by rules and standards and manufacturers of the above mentioned tractors are bound to meet the regulations contained in these documents.

In accordance with international standards, in this area are used the following concepts:

- **Roll Over Protective Structure** (ROPS) - a structure designed to be attached to, or form part of, mobile plant for the purpose of reducing the possibility of an operator, when also wearing a seatbelt, from being injured, should the plant roll over.
- **Falling Object Protective Structure** (FOPS) - a structure designed to be attached to, or form part of, mobile plant for the purpose of reducing the possibility that an operator seated beneath the structure in the driving position from being harmed should the FOPS receive a blow from a falling object.
- **Deflection-limiting volume** (DLV) – orthogonal approximation of a large, seated, male operator, wearing normal clothing and a hard hat. The specifications for the geometric shape and DLV dimensions are contained in ISO 3164 standard.

The first Standard Code for the official testing of agricultural tractors was approved on the 21st of April 1959, by the Council of the OEEC (Organisation for European Economic Cooperation) which became the OECD (Organisation for Economic Cooperation and Development). This Code has since been extended to cover forestry tractors and other features of performance, safety and noise.

The current OECD Codes governing tractors testing are the following:

- **Code 2**: the performance of tractors;
- **Code 3**: the strength of protective structures for standard tractors (Dynamic Test);
- **Code 4**: the strength of protective structures for standard tractors (Static Test);
- **Code 5**: noise measurement at the driver's position(s);
- **Code 6**: the strength of the front-mounted roll-over protective structures on narrow-track wheeled agricultural and forestry tractors;
- **Code 7**: the strength of the rear-mounted roll-over protective structures on narrow-track wheeled agricultural and forestry tractors;
- **Code 8**: the strength of protective structures on track laying tractors;
- **Code 9**: the strength of protective structures for telehandlers;
- **Code 10**: the strength of falling object protective structures for agricultural and forestry tractors.

In addition to the reference documents above mentioned, are available the following general standards:

- **ISO 26322**: Tractors safety;
- **ISO 5700**: Testing of ROPS structures;
- **ISO 27850**: Testing of FOPS structures;
- **EN ISO 12100**: Safety of machinery. General principles for design. Risk assessment and risk reduction;
- **EN ISO 4254-1**: Agricultural machinery safety. General requirements;
- **EN ISO 4254-x**: Safety for a particular agricultural machine (parts 5 to 14).

In recent years, finite element method has become a powerful design tool that allows the generation of models of reality affected by a small number of simplifying assumptions. Referring strictly to the ROPS/FOPS protective structures, finite element method has created the basis to obtain results with high accuracy, allowing adoption in the design process of near-optimal technical solutions. In this context, the study of a protective structure's behaviour using finite element method is based on its geometry, which constitutes support of mesh generating on FEA platform.

2. Optimization algorithm of the protective structures

The performance requirements imposed by standards and regulations governing the protective structures included in the cabin of the agricultural and forestry tractors, and the imperative of minimizing the costs, require, undoubtedly, the optimization of these structures.

Basically, optimization of protective structures requires analysis of several constructive variants and choosing the best one based on criteria of optimization aiming at maximizing or/and minimizing certain objective functions. In figure 1 is presented the optimization algorithm of the protective structures.

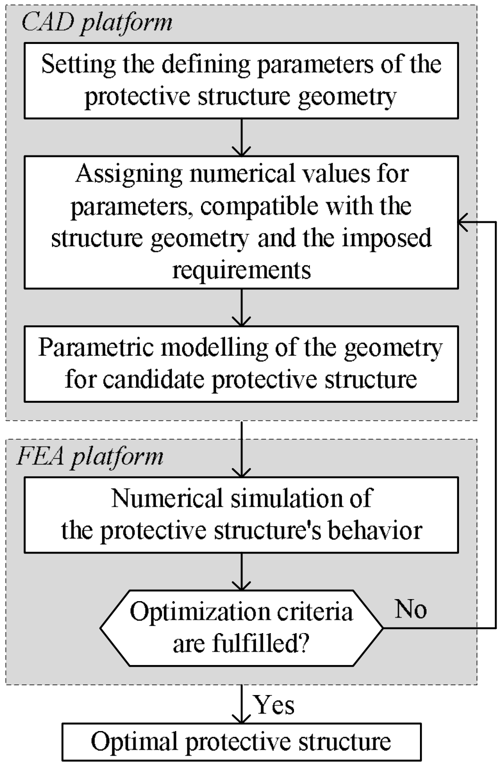


Fig. 1 – Optimization algorithm of the protective structures

From Figure 1 we can see that the optimization process of a protective structure is, in fact, an iterative process whose duration depends mainly on the time duration of the creation of candidate structure geometry on CAD platform and by the time duration of solving finite element model on FEA platform. If time of solving finite element model depends mainly on the hardware performance of computer, the time duration of the creation of candidate structure geometry depends largely on the user of CAD platform and his approach of this problem. Based on the above considerations, it follows that the parametric modelling of geometry of the protective structures is a preferable alternative to classical modelling of these geometries, because it is possible, by considerably shorten the time, to generate the geometry of the candidate protective structures.

3. Parametric analysis of the protective structures geometry

The protective structures used in the production of the cabins of the agricultural and forestry tractors have a great variety. These structures can be characterized on the basis of several criteria, among which the most important are:

- Overall geometry of the protective structure;
- Structural composition of the protective structure;
- Geometric shape and sizes of the cabin windscreens;
- Method of attachment of the cab on the tractor chassis;

The overall geometry of the protective structures can be classified into one of the two categories:

- **Polyhedral overall geometry -** internal volume of the cabin is a polyhedral volume. The members of the protective structure are straight, and the structure has no fillets in transition area from a structural member to the adjacent members.
- **Curve overall geometry -** internal volume of the cabin is a volume with straight and curve edges. At least two members of the protective structure are curved and the structure has fillets in transition areas from a structural member to the adjacent members.

Generally, the overall geometry of the protective structures has symmetry with respect to a longitudinal plan which is parallel with forward direction of the tractor and perpendicular to the fictive horizontal plane of the soil. Cabin width is perpendicular to its plane of symmetry. In the process of the modelling of the protective structure geometry it is advisable to use this symmetry. Consequently, it is necessary to create only that part of the geometry (profile of the cabin) which is contained in the plane parallel to the plane of symmetry of the protective structure and structural members connecting the symmetric parts of the geometry. In Figures 2, 3 and 4 are presented some profiles for cabins with polyhedral overall geometry and with curved overall geometry and their defining parameters of the geometry. It shall be noted that the profiles presented in Figures 2, 3 and 4 are not the only profiles used by existing producers of the earthmoving machinery. They were presented because, after some research, they are more commonly used. In addition, in Figures 2, 3 and 4 FDT means Forward Direction of the Tractor.

The structural composition of the protective structure concerns the geometric shape and sizes of structural members. Typically, protective structures included in tractor cabins are made with the form of spatial frames with rigid nodes. Generally, the bars from which are manufactured these frames are made of round or rectangular pipes. In geometrical terms, the bars contribute to the protective structure geometry with geometric shape of their longitudinal axis, with their length and with shape and geometric dimensions of the cross section.

The cabin surfaces without windscreen are covered with steel plates welded on bars of the protective structure. In general, the thickness of the steel plates (another geometric parameter involved into geometric modelling) is at most equal to the thickness of the wall pipe used for bars of the protective structure.

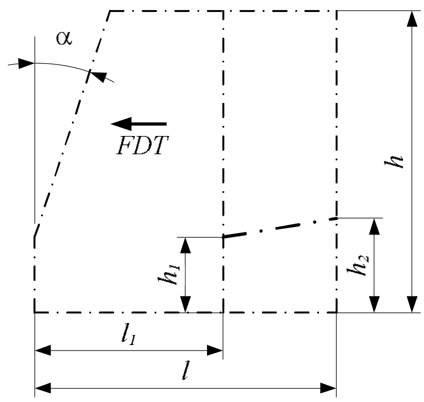


Fig. 2 – The profile of a cabin with polyhedral overall geometry

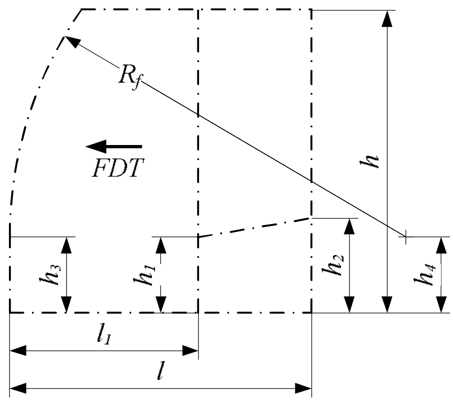


Fig. 3 – The profile of a cabin with curve overall geometry (only the front of the cabin is curved)

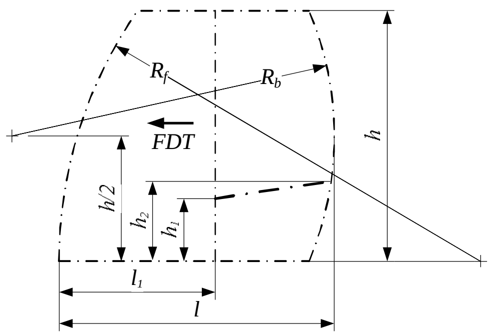


Fig. 4 – The profile of a cabin with curve overall geometry (both front side and back side of the cabin are curved)

The geometric shape and dimensions of the cabin windscreens is governed, mainly, by providing for human operator a suitable visual field in working area of the tractor. The overall dimensions of the cabin influence the surface of the windscreens. The geometric shape of the windscreens and their sizes affect the cabin interior volume and costs of their fabrication technology. Currently, the major manufacturers of agricultural and forestry tractors prefer to manufacture cabins with front and rear windscreens with a curved convex shape and with flat lateral windscreens.

Method of attachment of the cab to the tractor chassis affects the geometry of the protective structure in fixing areas. Currently, is preferred the rigid fixation of the protective structures on the tractor chassis. However, the use of elastic supports between the protective structure and the tractor chassis can have a decisive influence on the dissipation of the impact energy occurring in shock loadings produced in case of the tractor roll over or in case a falling object strikes the cabin.

Generally speaking, geometric modelling of an object using a CAD platform aims at one of the following objectives:

- Obtaining *of the manufacturing documentation.* In this case, it is necessary the unchanged reproduction of the body geometry.
- *Analysis of body behaviour under the action of functional loads, using the finite element method.* In this case is not strictly necessary the unchanged reproduction of the body geometry. Basically, there is a geometric modelling adapted to finite element analysis objectives. In this regard it will renounce to modelling of the geometric elements which do not have a decisive influence on distribution and size of the stresses which are produced due to applied loads. In other words, there will be a geometric simplification without affecting the required level of the accuracy for results obtained from solving the numerical models which are associated with the finite element models.

In the case of the protective structures included in tractor cabins, it is advisable not to create the geometries associated with insignificant stress concentration, some clamping elements of the structure of the chassis of the machine, even some structural members with insignificant role in the strength of the protective structure, etc.

Therefore, it results a simplification of the finite element model, this simplification causing a shortening of the time required to solve the numerical model associated with the finite element model. Also, a simplified geometric model allows, in meshing stage, to refine the mesh in areas of interest, in this case, in areas where the impact occurs. Thus it is possible to obtain finite element models with a reasonable number of finite elements, allowing obtaining results with a good precision level.

Note that the use of finite element method to solve problems where loads are dynamically applied is leading to long duration to solving the numerical model associated with the finite element model. For this reason it is advisable any simplification of the finite element model without significantly affecting the accuracy of results.

In addition, in order to simulate the conditions imposed to the tractor cabins, in the geometric modelling stage, it is advisable to include modelling of the DLV and modelling of the standardized impact object, placed near the point of impact at a calculated distance.

After importing of the geometry on FEA platform, DLV can be included or not in finite element model. DLV has only meant to highlight any impermissible deformation of the structure caused to the shock loading of the structure, in accordance with the requirements imposed by the reference documentation.

To summarize, the main geometrical parameters to be taken into account in the modelling of the geometry of the protective structures in order to analyze their behaviour using finite element method, are:

- cabin length;
- cabin height;
- cabin width;
- diameter of the round pipes used in the manufacture of structural members (if such pipes are used);
- the dimensions, in cross section, of the rectangular pipes used in the manufacture of structural members (if such pipes are used);
- the wall thickness of the pipes used in the manufacture of structural members;
- the radii of circle arcs which materialize longitudinal axis of curved structural members;
- the radii of the fillets used in the structure nodes;
- the thickness of the plates used in manufacturing of the cabin.

4. Case study

The case study is focused on the protective structure of a single-post tractor cabin. In a first stage, the protective structure of the existing cabin was analyzed as FOPS structure for the first level of acceptance (this level of acceptance is defined in EN ISO 3449). We mention that for this level of acceptance, it is necessary not to occur any penetration of DLV when the protective structure of the cabin supports a shock in vertical direction, shock which has the energy of impact of 1360 J.

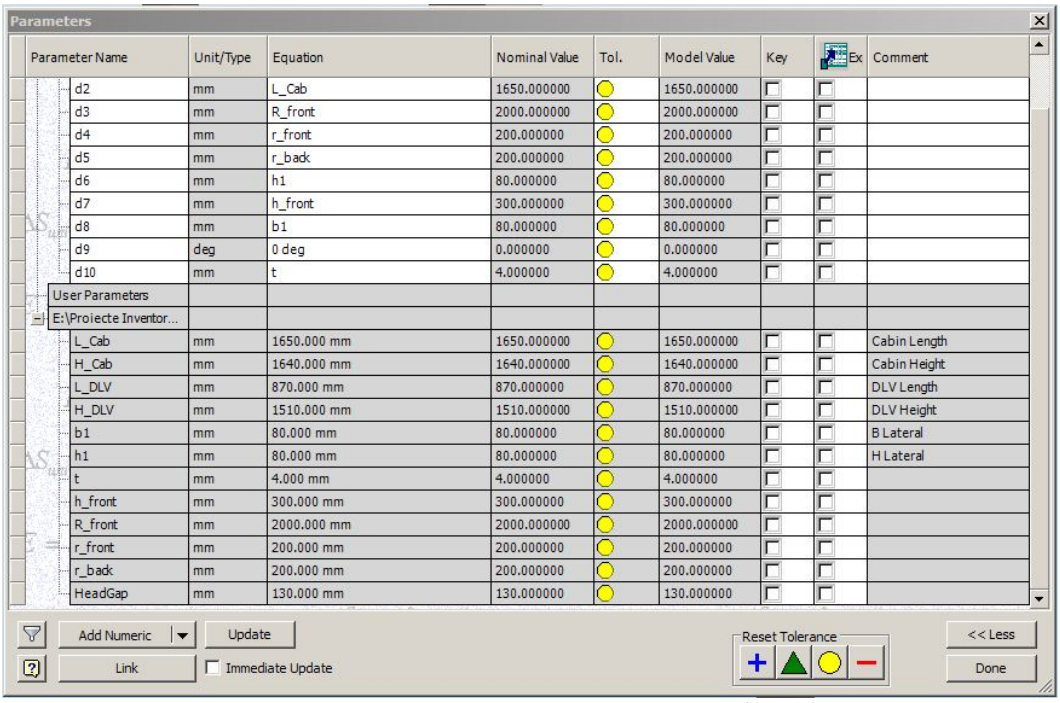
The analysis in this sense of protective structure using finite element method showed that the structure does not meet the acceptance level required. As a result, it was imposed the problem to change geometry of the structure, its sizes (within imposed limits) and the component of the structure so that the new protective structure meets the first level of acceptance.

In these conditions, because the study required the analysis of several protective structures, their parametric modelling of geometry has been a perfectly viable alternative.

Modelling of protective structure geometry was done in accordance with the principles modelling exposed in the previous paragraph. Therefore, in the geometric model of protective structure were maintained only those structural members which have a significant role in dissipating impact energy corresponding to the first level of acceptance FOPS. Also were created the geometry of DLV and the geometry of the impact object in accordance with ISO 3164, respectively EN ISO 3449.

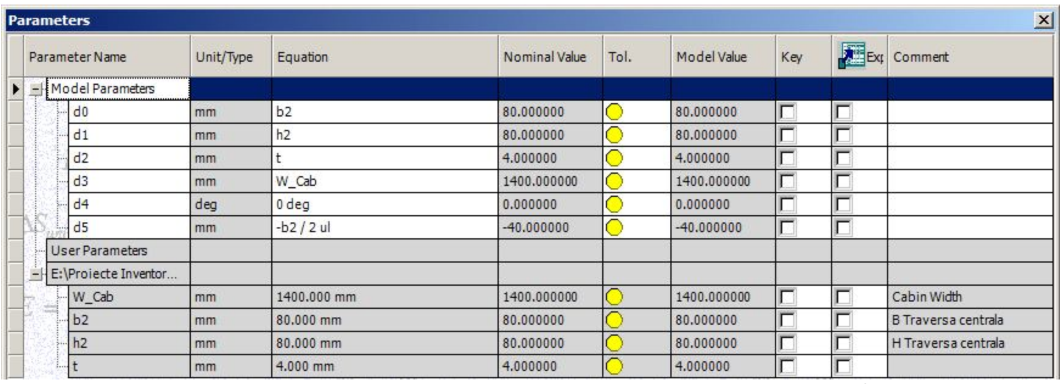
After creating each version of geometry, the geometry was imported into the FEA platform in the STEP format. On the FEA platform was performed a simulation of the shock produced by the impact object and were formulated observations and conclusions on the analyzed structure.

In Figures 5 and 6 are shown screen captures made on CAD platform where one can see the parameters which were used in modelling the protective structures geometry.


Parameters

Parameter Name	Unit/Type	Equation	Nominal Value	Tol.	Model Value	Key	Ex	Comment
d2	mm	L_Cab	1650.000000		1650.000000			
d3	mm	R_front	2000.000000		2000.000000			
d4	mm	r_front	200.000000		200.000000			
d5	mm	r_back	200.000000		200.000000			
d6	mm	h1	80.000000		80.000000			
d7	mm	h_front	300.000000		300.000000			
d8	mm	b1	80.000000		80.000000			
d9	deg	0 deg	0.000000		0.000000			
d10	mm	t	4.000000		4.000000			
User Parameters								
E:\Proiecte Inventor...								
L_Cab	mm	1650.000 mm	1650.000000		1650.000000			Cabin Length
H_Cab	mm	1640.000 mm	1640.000000		1640.000000			Cabin Height
L_DLV	mm	870.000 mm	870.000000		870.000000			DLV Length
H_DLV	mm	1510.000 mm	1510.000000		1510.000000			DLV Height
b1	mm	80.000 mm	80.000000		80.000000			B Lateral
h1	mm	80.000 mm	80.000000		80.000000			H Lateral
t	mm	4.000 mm	4.000000		4.000000			
h_front	mm	300.000 mm	300.000000		300.000000			
R_front	mm	2000.000 mm	2000.000000		2000.000000			
r_front	mm	200.000 mm	200.000000		200.000000			
r_back	mm	200.000 mm	200.000000		200.000000			
HeadGap	mm	130.000 mm	130.000000		130.000000			

Fig. 5 – Parameters used in modelling the structural members from cabin lateral sides


Parameters

Parameter Name	Unit/Type	Equation	Nominal Value	Tol.	Model Value	Key	Exp	Comment
Model Parameters								
d0	mm	b2	80.000000		80.000000			
d1	mm	h2	80.000000		80.000000			
d2	mm	t	4.000000		4.000000			
d3	mm	W_Cab	1400.000000		1400.000000			
d4	deg	0 deg	0.000000		0.000000			
d5	mm	-b2 / 2 ul	-40.000000		-40.000000			
User Parameters								
E:\Proiecte Inventor...								
W_Cab	mm	1400.000 mm	1400.000000		1400.000000			Cabin Width
b2	mm	80.000 mm	80.000000		80.000000			B Traversa centrala
h2	mm	80.000 mm	80.000000		80.000000			H Traversa centrala
t	mm	4.000 mm	4.000000		4.000000			

Fig. 6 – Parameters used in modelling the structural transverse members of the structure

It is mentioned that parameters that can be seen in Figures 5 and 6 correspond to the protective structure that meets the required acceptance.

In Figure 7 is shown on a screen capture made on CAD platform where you can see the final version of the protective structure, DLV and the testing object before importing their assembly into the FEA platform.

In addition, it should be noted that although the initial protective structure has a polyhedral overall geometry, was adopted as a basis for parameterized modelling a curve overall geometry. This is due to the requirement to avoid (if possible) creating too many areas of the protective structure in which concentrations of stress occur.

After importing each geometric model into FEA platform, was performed a mechanical event simulation, the event being the impact between the standardized testing object and the protective structure.

After analyzing the obtained results, were generated conclusions targeting changes in geometric model of protective structure, changes which were made on the platform CAD, by changing the values of the geometry parameters. This process was continued until the objectives of the optimization were achieved (see diagram in Figure 1).

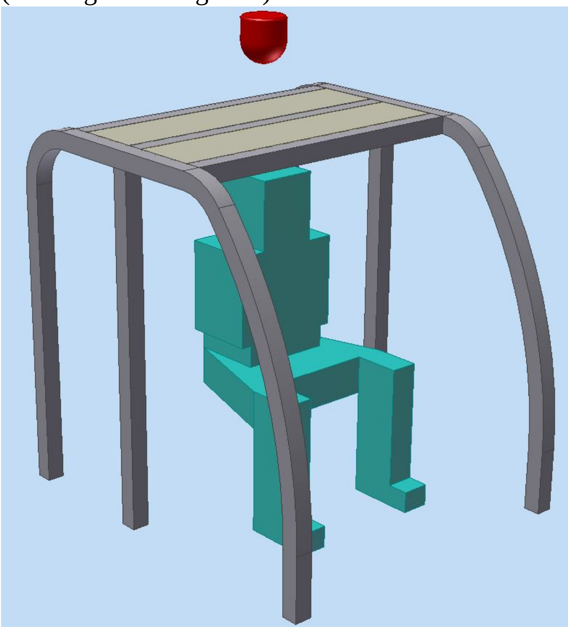


Fig. 7 – Final version of the protective structure

5. Conclusions

Parametric modelling of the geometry of bodies, a common tool into current CAD platforms, is a very powerful method of modelling, and, compared to traditional modelling, has undeniable advantages.

In the case of the strength structures optimization, the parametric modelling of their geometries is the best way to get simple and efficient versions of the same geometry, by changing the parameters considered in the optimization.

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