STRESS-STRAIN STUDY OF A POWERED ROOF SUPPORT SECTION USING NUMERIC SIMULATION

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Abstract: The processes and technologies for supporting the roof of underground mining works have advanced during the years, thus fundamental changes resulted in both the roof control and the exploitation from economic and technical points of view. The support of the underground excavation roof is carried out by two methods, namely using individual supports, usually metal beams and props, or hydraulic powered supports/shields, the latter representing the most up-to-date technology. The paper presents a virtual model of a powered roof support section made in SOLIDWORKS. For its components a mechanical analysis was performed through the static simulation of the pressure of the roof on the support beam.

Key words: simulation, finite element, powered roof support, force, load, stress-strain.

1. THE DYNAMIC MODELLING OF THE ROCK-SUPPORT SYSTEM (INTERACTION)

The interaction phenomena between the support and the surrounding rocks are particularly complex, with a multitude of factors influencing the description of the phenomena, such as:

- the constructive, geometric, functional and rigidity characteristics of the support;
- the technological processes that take place in the coal face, in particular the removal/assembly, respectively the detensioning/advance of the props or adjacent shields and the increase of the unsupported roof after the use of shearer loaders or explosives;
- the type, physical-mechanical characteristics and stratigraphic structure of

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the upper roof strata;

- physical-mechanical characteristics of the coal layer and of the rocks in the floor.

The measurable parameters at the level of the individual supporting element (prop or shield section), which change their value over time as a result of the interaction process, are the pressure in the hydraulic props and the closing movement of the prop or support section.

The interdependencies between the factors that determine the processes of rock displacement and the appearance of forces as a result of the disruption of the natural balance due to the excavation, can be considered as convergence of the roof, which can be determined for a specific case and expressed analytically.

Thus, for the mean speed of convergence of the roof in the face (the arithmetic mean of the convergences measured at each leg), an euquation of the following form can be proposed:

$$v_k(c,p,n,v_{k0},P_{\max}) = v_{k0} \cdot e^{\frac{c \cdot p \cdot n}{P_{\max} - n \cdot p}} \tag{2}$$

where:

c empirical constant;

p is the instantaneous value of the pressure of the hydraulic agent in the support leg;

n is the roof support resisntance coefficient, defined as the ratio between the average specific support resistance P of the face powered support and the pressure p in the leg;

v_{k0} is the hypothetical convergence speed of the unsupported roof;

$P_{\max}$ the hypothetical value of the specific load bearing capacity where speed of convergence is cancelled.

Considering the convergence of the roof during one cycle, it is distributed between the powered support sliding movement and the contact deformation of the rocks in the roof in contact with the canopy and in the bedding in contact with the base of the support:

$$\Delta h = \Delta h_1 + \Delta h_2 \tag{2}$$

where:

Δh - the roof convergence;

Δh_1 - the support sliding movement;

Δh_2 - este deformaţia de contact a rocilor înconjurătoare.

The convergece Δh, during a time interval Δt, can be expressed based on the convergence speed v_k:

$$\Delta h = v_k \cdot \Delta t \tag{3}$$

The sliding movement of the support also has two components: the elastic sliding, Δh_e and the sliding due to non-tightness, Δh_s, expressed as:

$$\Delta h_e = \frac{\Delta p}{K_e} \tag{4}$$

and

$$\Delta h_s = v_s \cdot \Delta t = \frac{p}{K_{er}} \cdot \Delta t \tag{5}$$

where:

K_e - the equivalent elastic constant of the support;

K_{er} - the hermeticity coefficient of the hydraulic equipment of the support, if we accept for the sliding speed corresponding to the leakage loss flow, the expression:

$$v_s = \frac{\Delta h_s}{\Delta t} = \frac{p}{K_{er}} \tag{6}$$

By changing the values of the coefficient K_{er}, the state of the discharge valve can also be expressed as:

$$K_{er} = \begin{cases} K_{er\max}, & \text{dacă} \quad p < p_{\max} \quad \text{şi} \quad \dfrac{\mathrm{d}p}{\mathrm{d}t} > 0 \\ K_{er\min}, & \text{dacă} \quad p_{\min} < p < p_{\max} \quad \text{şi} \quad \dfrac{\mathrm{d}p}{\mathrm{d}t} < 0 \end{cases} \tag{7}$$

For the contact deformation, a non-linear formula can be considered as:

$$\Delta h_2 = n \cdot \Delta p \cdot \frac{P_l - n \cdot p}{P_l \cdot K_{rP_l}} \tag{8}$$

where:

K_r - the equivalent settlement coefficient of the roof and bedding rocks;

P_l - is the load bearing capacity at which the settlement becomes negligible (compaction limit).

By replacing in relations and explaining $\Delta p / \Delta t$, the finalform is obtained as:

$$\frac{\Delta p}{\Delta t} = \frac{v_k - v_s}{\dfrac{1}{K_e} + \dfrac{P_e - n \cdot p}{K_r' \cdot P_e}} \tag{9}$$

Where the notation $K_r' = Kr / n$ is made.

After further substitutions and passing to the limit, we obtain a differential equation of the form:

$$\frac{dp}{dt}=\frac{v_{k0}\cdot e^{\frac{c\cdot p\cdot n}{P_{\max}\cdot n\cdot p}}-\frac{p}{K_{er}}}{\frac{1}{K_e}+\frac{P_l-n\cdot p}{K_r^{'}\cdot P_l}} \tag{10}$$

The influence of the increase of the unsupported roof surface can be simulated using the variation of parameters for the constant n.

Its value represents the ratio between the pressure in the leg and the specific load bearing capacity, which in turn represents the ratio between the total load bearing of the roof and the roof surface corresponding to one leg. So, the sudden increase of the unsupported roof surface during the passage of the shearer loader in front of the support, or dislocation using explosives, can be simulated by the sudden reduction of the value of *n*, using for this purpose the Heaviside function *H*(*t)*, expressed as:

$$n(t)=n_0+(n_1-n_0)\cdot H\cdot(t-t_0) \tag{11}$$

where:

n_0 - is the value of *n* corresponding to the initial roof surface;
n_1 - the value of *n* corresponding to the increased roof surface;
t_0 – the time corresponding to the passage of the shearer in front of the support.

2. THE VIRTUAL MODEL OF THE POWERED ROOF SUPPORT

As shown in the abstract the stress-strain analysis for a powered roof support was conducted in SOLIDWORKS.

First, a 1:1 scale model of the SMA-2 type powered support was built.

This type of powered support is manufactured in Romania and it is mainly used in the underground hard coal mines from the Jiu Valley.

The model is an assembly (Figure 1) of several parts created separately:

- Two bases;
- Two long and two short linkages of the lemniscate mechanism;
- Caving shield;
- Canopy;
- Two long hydraulic legs;
- One short hydraulic cylinder.

Fig.1. Model of the powered roof support

2.1. The floor base model of the powered roof support

Figure 2 shows the dimentions of one of the bases of the powered support model.

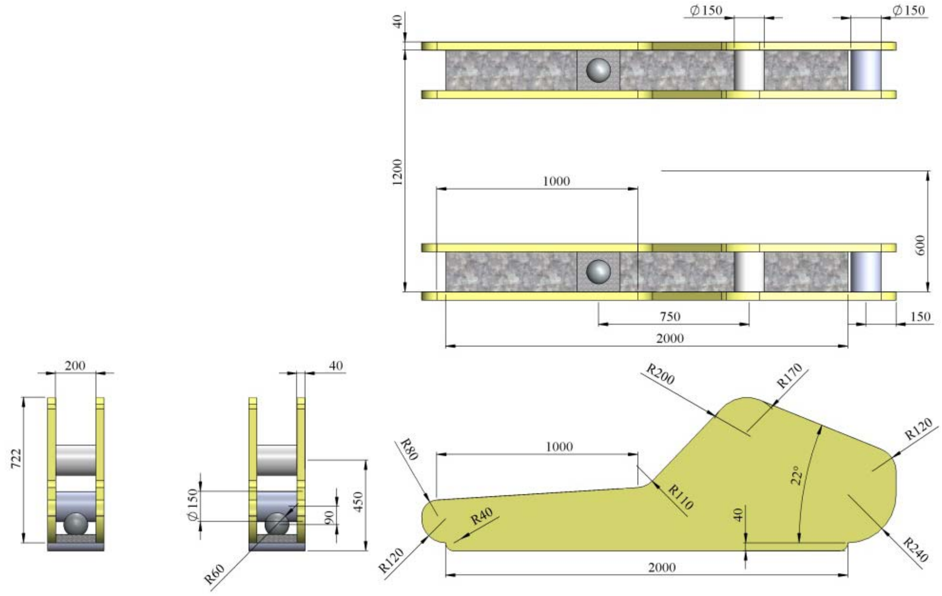
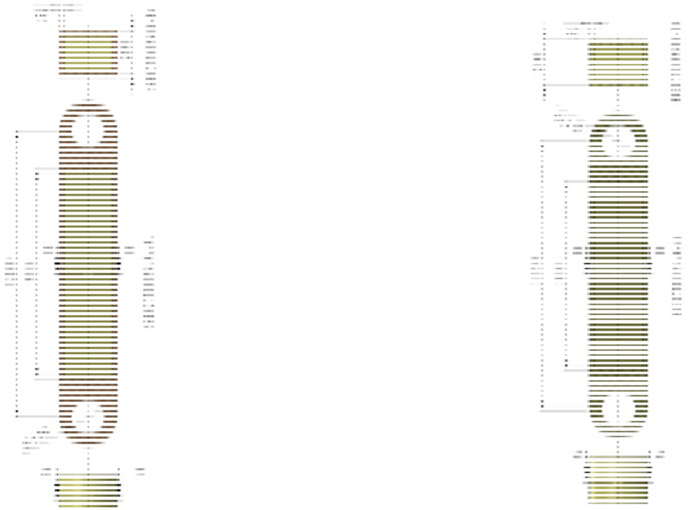


Fig.2. The floor base model of the powered roof support

2.2. The lemniscate linkages model

Figures 3a and 3b present the long and short linkages of the lemniscate mechanism and their dimensions.



a b

Fig.3. The linkages (long and short) of the lemniscate mechanism

2.3. The model of the powered roof support shield

Figure 4 presents the dimensions and model of the shield of the powered roof support.

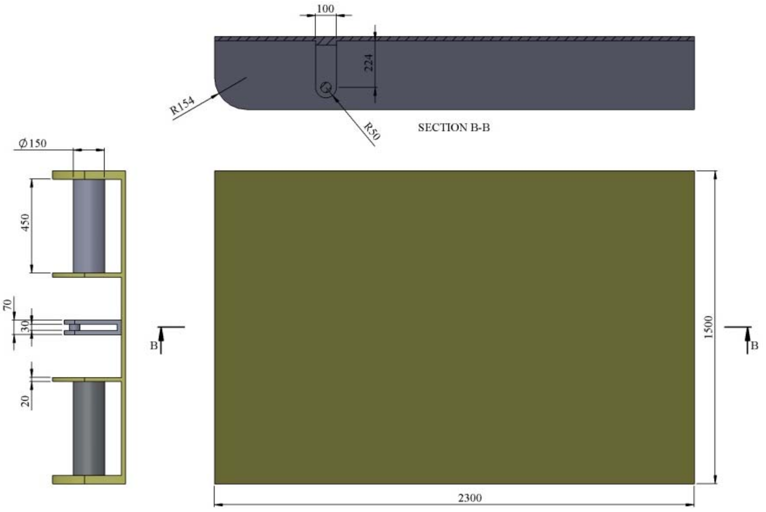


Fig.4. Scutul susţinerii mecanizate

2.4. The model of the canopy

Figure 5 shows the dimensions and model of the powered roof support canopy.

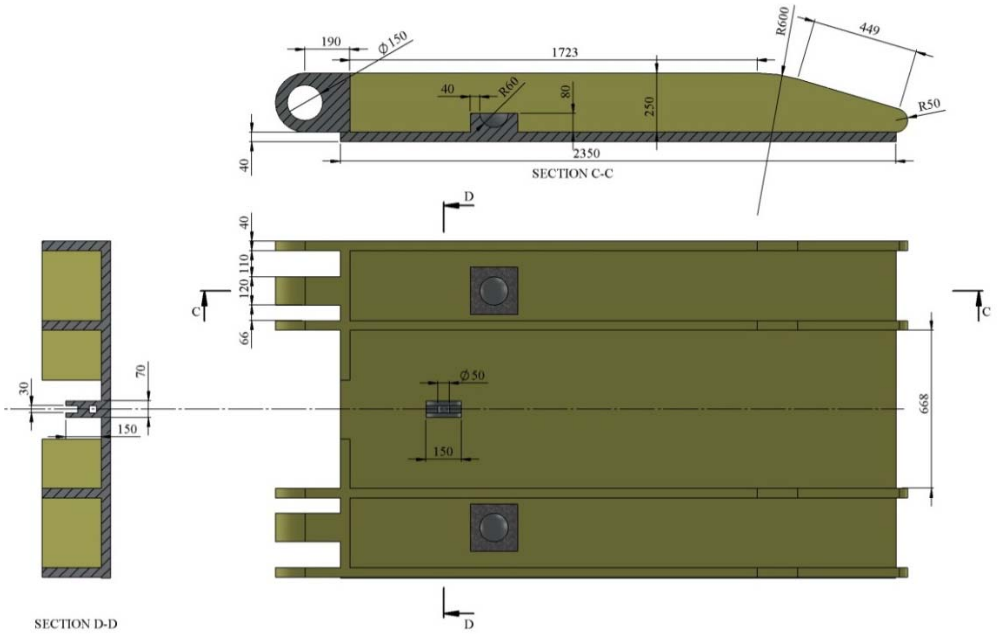


Fig.5. Canopy model

2.5. Long hydraulic leg model

The long hydraulic leg model model is shown in figure 6. This is used in pair to link the base of the powered support to the canopy.

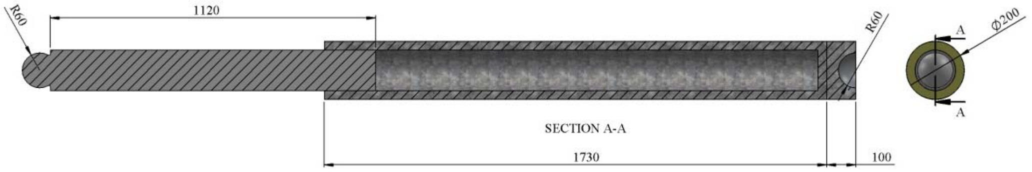


Fig.6. Long hydraulic leg model

2.6. Model of the short hydraulic cylinder

Figure 7 shows the model of the short hydraulic cylinder linking the base and the shield.

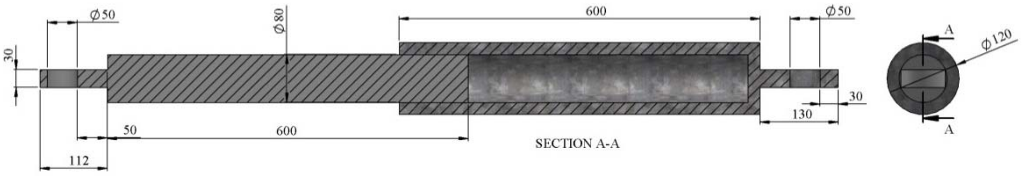


Fig.7. Short hydraulic cylinder model

3. MECHANICAL ANALYSIS BY STATIC SIMULATION OF THE ROOF PRESSURE

The pressure of the face roof was simulated by a force distributed on the surface of the canopy, as can be seen in figure 8. This force has the variation equation:

$$F(x,y,z) = 2 \cdot F_{\max} \cdot x \tag{12}$$

where $F_{\max}$=800.000 N.

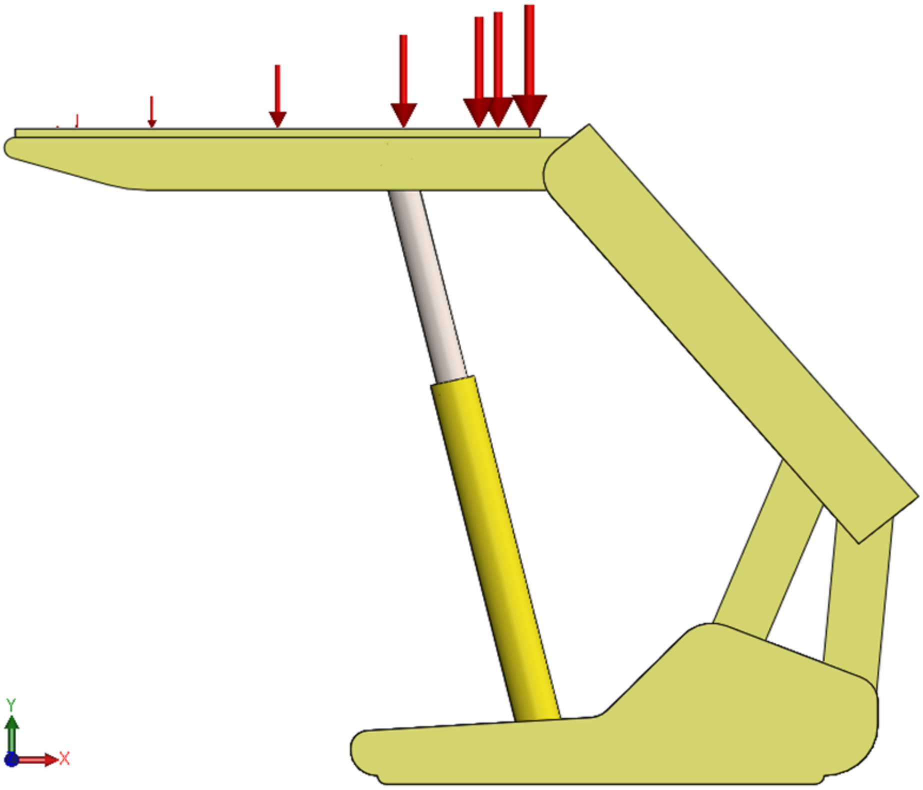


Fig.8. The force distributed on the canopy

First, the finite element mesh was generated as shown in figure 9.

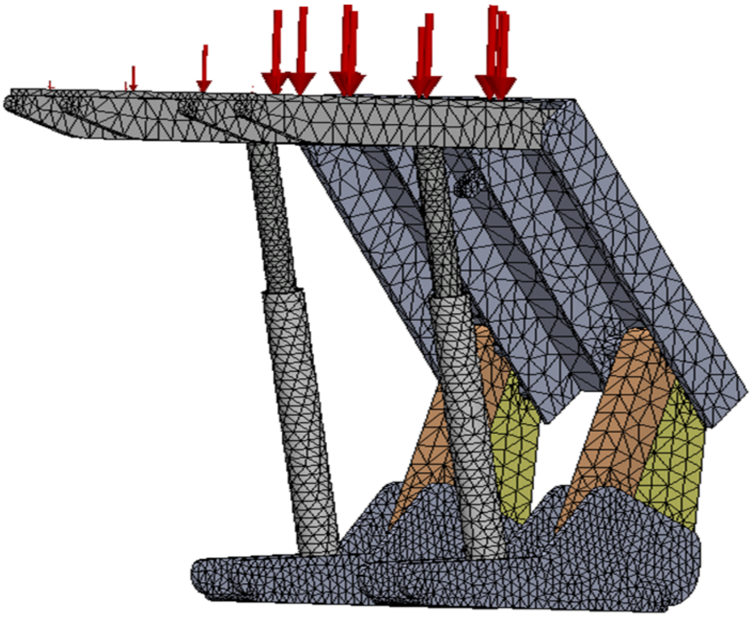


Fig.9. The finite element mesh

After running the simulation, the von Mises stress was determined as can be seen in figure 10.

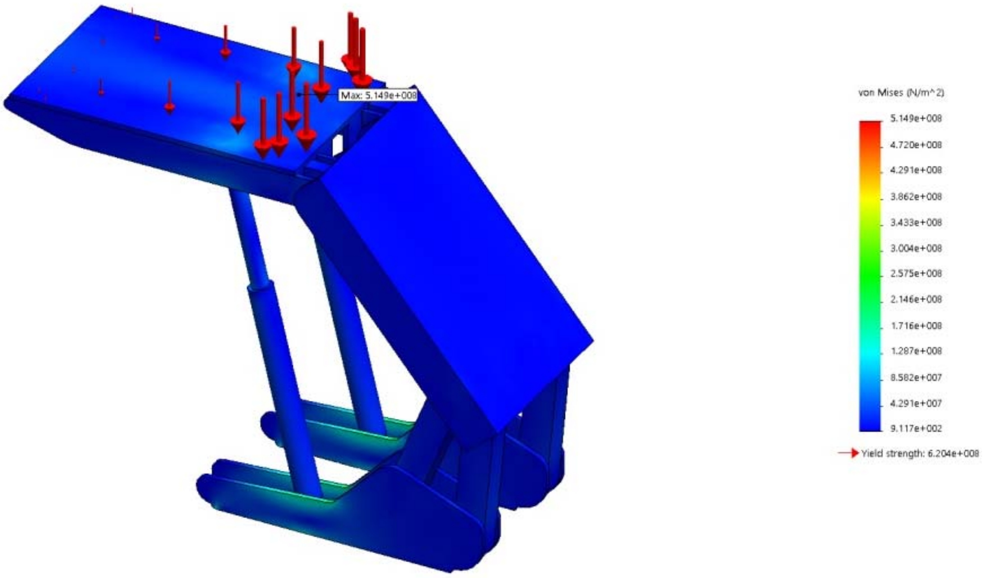


Fig.10. The von Mises stress

To better highlight the place where the von Mises stress is maximum, in figure 11 we used the option *Plot Tools* → *Section Clipping* to display the results.

The point of maximum is positioned in the upper area of the long hydraulic leg. It is observed that the maximum value of the von Mises stress 5.149x10^8 N/m^2 does not exceed the yield stress value of the material 6.204x10^8 N/m^2.

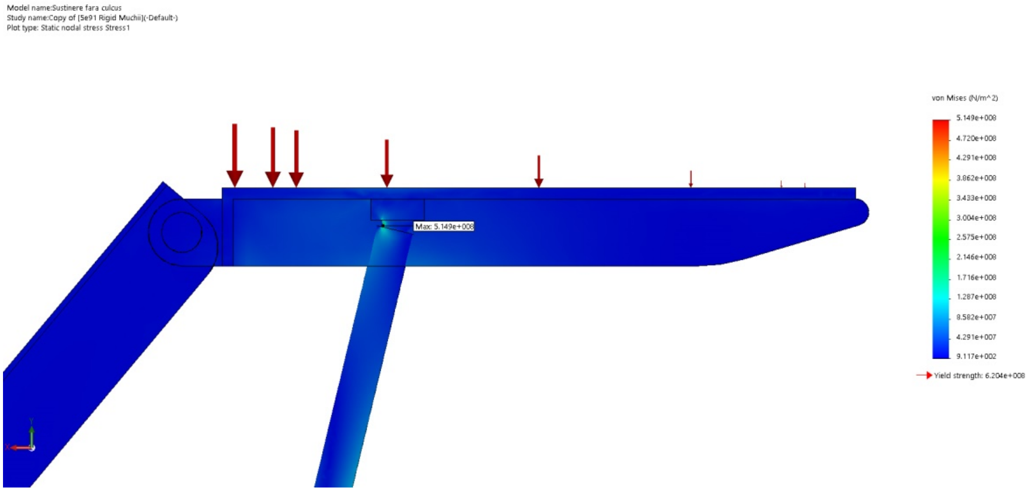


Fig.11. The von Mises stress in side view

In figure 12, we have presented the total deformation that the powered support undergoes under the pressure of the face roof. Figures 13, 14 and 15 show the deformation of the powered support on the directions X, Y and Z.

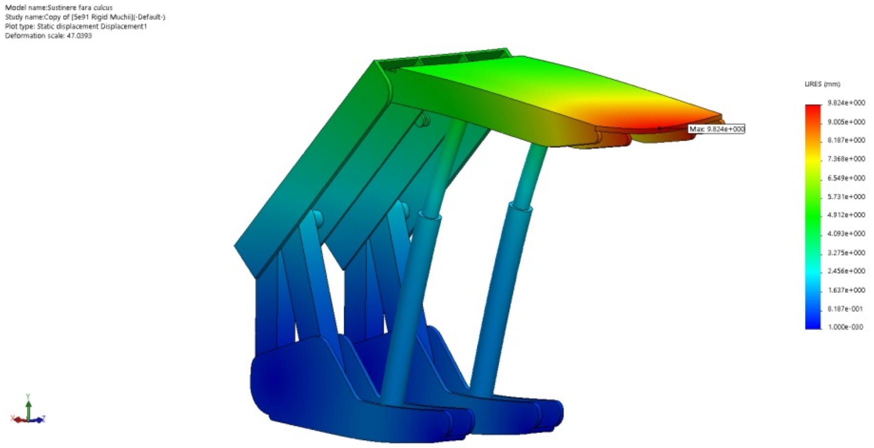


Fig.12. The total deformation of the powered roof support

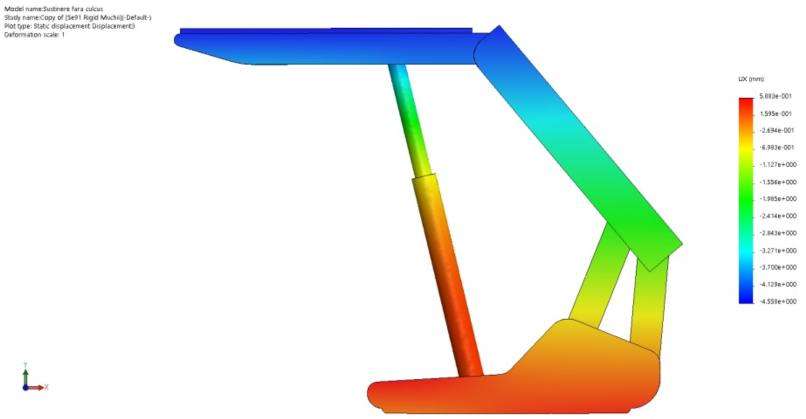


Fig.13. Deformation of the powered support on direction X

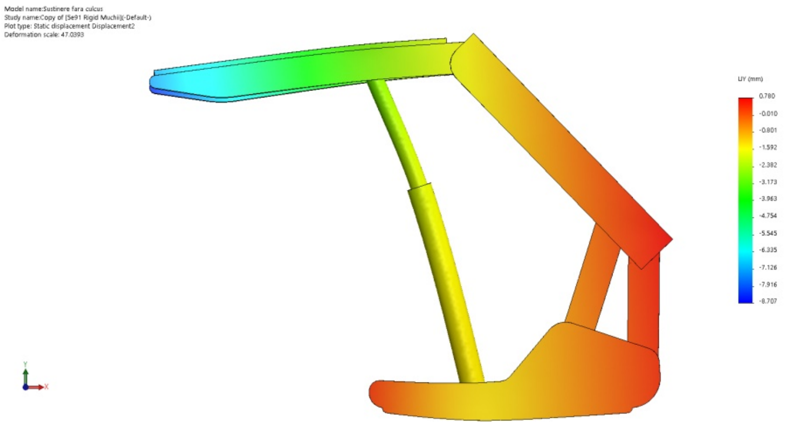


Fig.14. Deformation of the powered support on direction Y

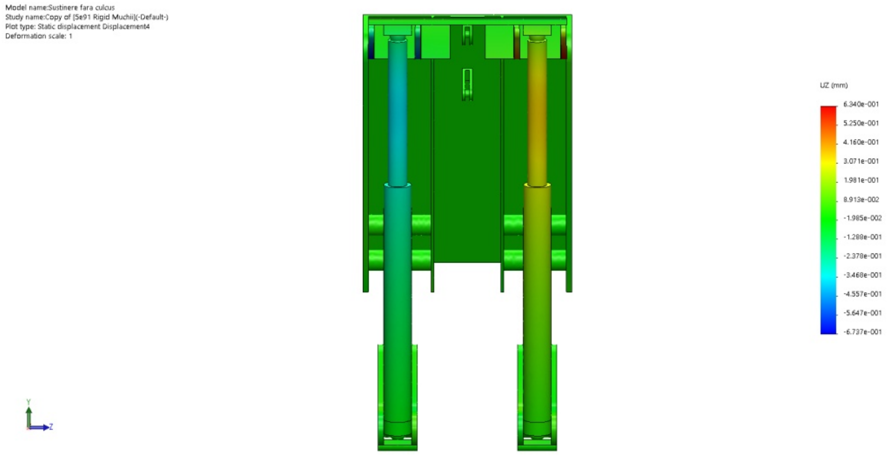


Fig.15. Deformation of the powered support on direction Z

CONCLUSIONS

There are still a lot of things to improve regarding the design and manufacture phases of powered supports, especially from the point of view of their durability and adaptability to the wide diversity of the conditions in which they must work.

In this regard, the classical methods, based on experimental data collected from the mine of from the laboratory testing, as well as on theoretical models and assumptions, often lead to oversizing or incompatibilities, that are discovered only after the powered supports are put into production or exploitation.

For these reasons, it is necessary to implement flexible and easily adaptable modeling and simulation methods and techniques to be used for the design and interactive analysis of these products, using virtual prototypes. Thus, the presented model can easily be used using other static or dynamic loads. This approach to powered supports with the help of virtual models represents a valuable tool for design and verification purposes.

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