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# Analytical and experimental method for testing the protective frame of the building machine

*The research results presented in the paper contribute the safety and protection of the building machine operator. The comparative analysis of experimental results and the results obtained by the finite element method (FEM) shows high compatibility. Therefore, protective frames of building or agricultural machines can be tested without destruction in a simple and cheap manner.*

***Keywords:*** *protective frame, experimental testing, finite element method, comparative analysis.*

## 1. INTRODUCTION

Free flow of goods is only possible by adopting the technical regulations which dictate the conditions for product safety and which demand development of experimental and analytical methods for testing and checking the operator's protection. The activities have aimed at the manufacture of a product which should satisfy the customer. One of the most important activities for satisfying the building machine buyer is the operator's safety and protection (Figure 1).

When designing the building machines, it is very important to consider the interactions existing in a complex dynamic system operator-machine-environment.

If any of these relations within the above mentioned system are incompatible, the system will fail as a whole, which in some cases can endanger the operator's safety.

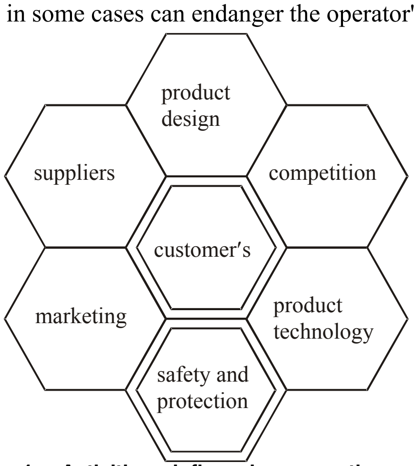


**Figure 1. Activities influencing on the customer's satisfaction**

The information the operator gets from the environment and machine results from the ground configuration, vibrations and subsystem noise, deviation from wanted path, resistance at the steering system, etc.

Roughness of the ground has the biggest influence on the machine stability. The methodology presenting the machine as an assembly of various subsystems is the most appropriate for studying the relations within the system operator-machine-environment (Figure 2).

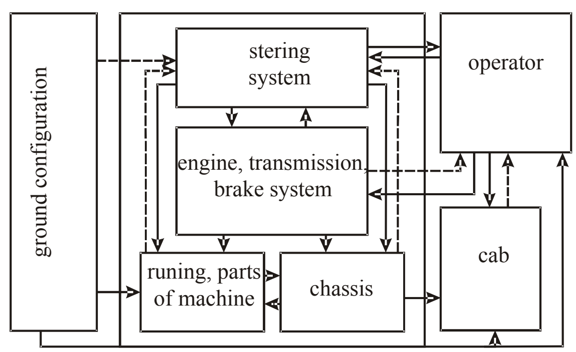


**Figure 2.**

The operator makes a decision which is important not only for his safety and protection but for the safety and protection of the machine and environment as well.

## 2. EXPERIMENTAL METHOD FOR TESTING THE OPERATOR'S SAFETY

The working speeds of machines are relatively low and their structures are robust, so they are rarely damaged and the operators are rarely hurt in direct crashes or when the machine hits the barrier.

In fact, the accident only happens when the machine rolls over. If there is not protective frame capable of holding the load when the machine rolls over, the cab is totally destroyed and the operator is unlikely to stay alive. The machine itself is almost undamaged.

Most regulations relating to protective frames of building and agricultural machines were adopted in the 1970s. International standards regarding protective

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frames were set out later. These standards include:

- roll-over protective structures
- fall-over protective structures
- deflection limiting volume

The research work done in the laboratories are static-type and include side loads of top protective frame, where side force $F_b$ and absorbed energy should not exceed the values defined by diagrams defined in Figures 3 and 4, respectively.

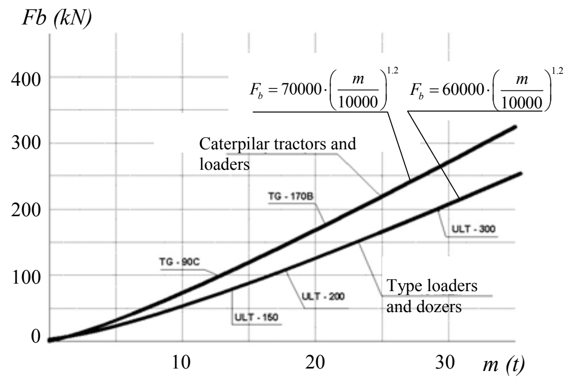


**Figure 3. Activities influencing on the customer's satisfaction**

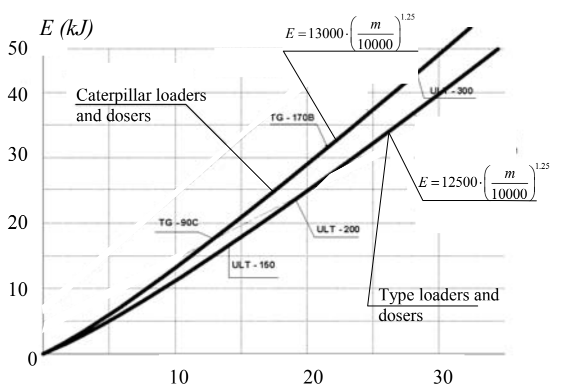


**Figure 4. Dependence between absorbed energy E(kJ) and machine weight [2]**

Testing is done by hydrocylinder, and side force is recorded in every 15÷20mm proportional to hydraulic pressure in the cylinder.

Laboratory plant used for testing the protective frame of the cab, situated in "14. oktobar" Krusevac, is shown in Figure 5.

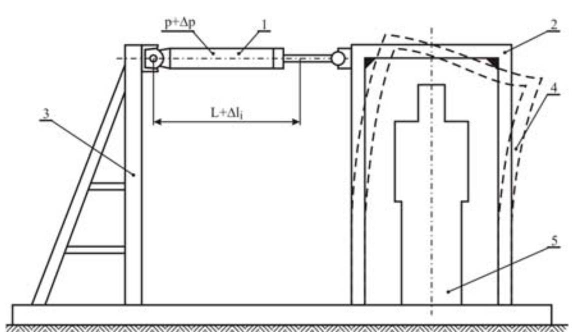


**Figure 5. Laboratory plant used for static testing of protective frames**

Figure 5 shows:

1- hydrocylinder used in order to obtain side force
2 - protective frame before force action
3 - structure of testboard
4 - deformed protective frame
5 - operator's protective zone

Instrumentation used for recording deflection ΔL and side force $F_b$ is shown in Figure 6.

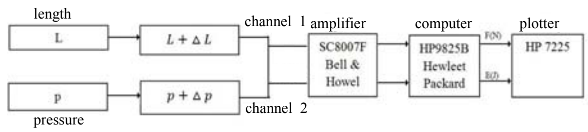


**Figure 6. Instrumentation**

Testing is stopped:

- when defined minimal deformation energy is achieved, if minimal side force has been previously (or simultaneously) achieved;
- when defined side force is achieved, if defined energy has been previously achieved;
- when any protective frame element penetrates the protective zone.

### 2.1 Results obtained by laboratory testing the protective frame of vibration roller KVV-12B

Protective frame of combined vibration roller, whose weight is 12500kg, is made of steel pipes having the box-like cross section whose dimensions are 100x100x4mm. Similar frame is built into loaders made by the company named "14. oktobar", Krusevac. Geometrical characteristics of the frame having four columns at the combined vibration roller KVV-12B are shown in Figure 7.

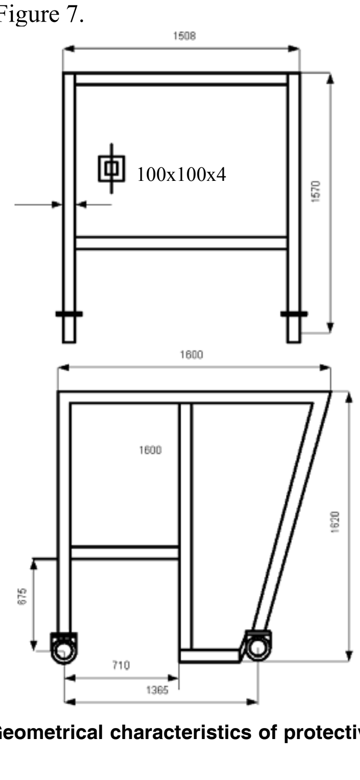


**Figure 7. Geometrical characteristics of protective frame of KVV-12B**

Horizontal side force received by the frame is:

$$F_b = 70000 \cdot \left(\frac{m}{10000}\right)^{1.2} = 70000 \cdot \left(\frac{12500}{10000}\right)^{1.2} = 91494\,N$$

Absorbed energy is

$$E = 13000 \cdot \left(\frac{m}{10000}\right)^{1.25} = 13000 \cdot \left(\frac{12500}{10000}\right)^{1.25} = 17182\,J$$

Absorbed energy of protective frame is identified in the lab by the following expression:

$$E = \frac{F_1 \cdot \Delta l_1}{2} + \sum_{i=2}^{n} \frac{F_i + F_{i-1}}{2} \cdot \left(\Delta l_i - \Delta l_{i-1}\right)$$

Its value must be higher than standard value but operator's protective zone must not be damaged.

Deflections of top protective frame *Δl* and absorbed energy are shown in figures 8 and 9, respectively.

**Table 1.**

| No | Force $F_b$ (kN) | Deflection $\Delta l$ (mm) | Apsorbed energy $E_1$ (J) | |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | |
| 2 | 20 | 20 | 240 | 240 |
| 3 | 35 | 30 | 330 | 570 |
| 4 | 40 | 40 | 450 | 1020 |
| 5 | 44 | 50 | 504 | 1524 |
| 6 | 48 | 70 | 1104 | 2628 |
| 7 | 50 | 80 | 588 | 3216 |
| 8 | 52 | 100 | 1224 | 4440 |
| 9 | 53 | 110 | 630 | 5070 |
| 10 | 53,4 | 120 | 652 | 5722 |
| 11 | 53,5 | 140 | 1309,50 | 7031.5 |
| 12 | 53,6 | 160 | 1285,20 | 8316,70 |
| 13 | 53,7 | 180 | 1287,60 | 9604,30 |
| 14 | 54 | 200 | 1292,40 | 10896,70 |
| 15 | 54,1 | 210 | 662 | 11558,70 |
| 16 | 54,2 | 230 | 1326,65 | 12885,35 |
| 17 | 54,5 | 250 | 1304,40 | 14189,75 |
| 18 | 54,6 | 270 | 1309,50 | 15499,25 |
| 19 | 54,7 | 290 | 1311,60 | 16810,85 |
| 20 | 55 | 300 | 658,20 | 17469,05 |

**Figure 8. Measured values $F_b$ - $\Delta l$**

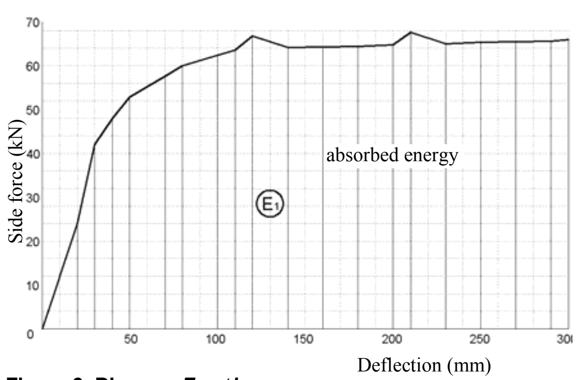


**Figure 9. Diagram $F_b$ - $\Delta l$**

## 3. PROTECTIVE FRAMES ANALYZED BY FINITE ELEMENT METHOD

The model presented in Figure 7 has been analyzed. The model consists of 49248 elements and 49236 nodes. Limitations at the support point have been modelled as cylindrical joint.

The calculations of defined loads have been done by finite element method in the PAKS program which is at the same level as the known software used for structure analysis such as NASTRAN, ANSYS, ABAQUS, ADINA, etc. [5]

Figures 10 and 11 show deflections when the force acts in X and Y directions, while Figures 12 and 13 show stresses.

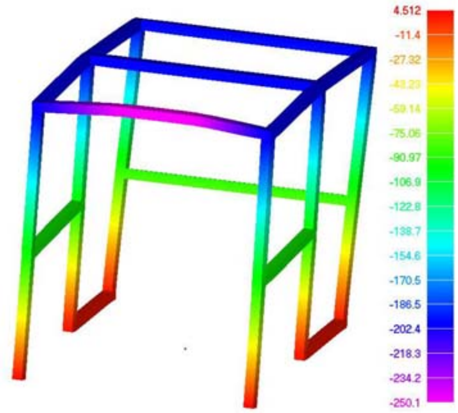


**Figure 10. Deflections when the force acts in X direction**

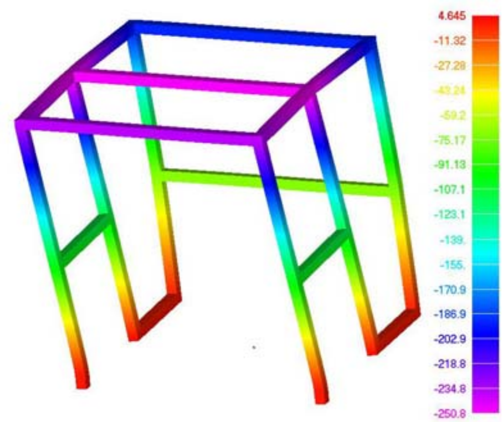


**Figure 11. Deflections when the force acts in Y direction**

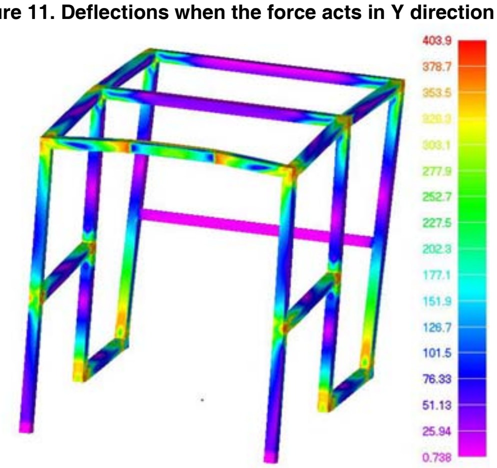


**Figure 12. Stresses when the force acts in X direction**

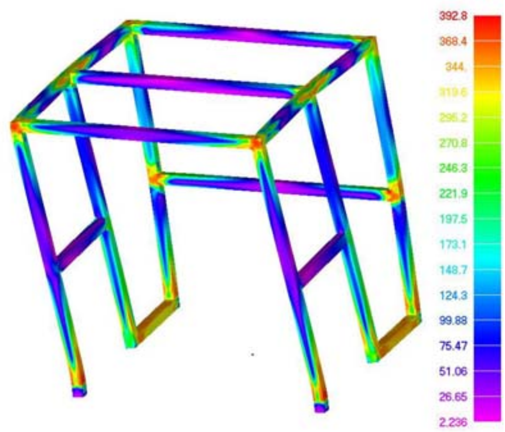

**Figure 13. Stresses when the force acts in Y direction**

## 4. CONCLUSION

Comparative analysis of experimental results of protective frames, made of steel box-like profiles 100x100x4mm, and results obtained by finite element method using the software package PAKS shows:

- the same character of deflection line caused by side force acting in horizontal plane
- high compatibility between theoretical and experimental results relating to absorbed energies (Figure 14)

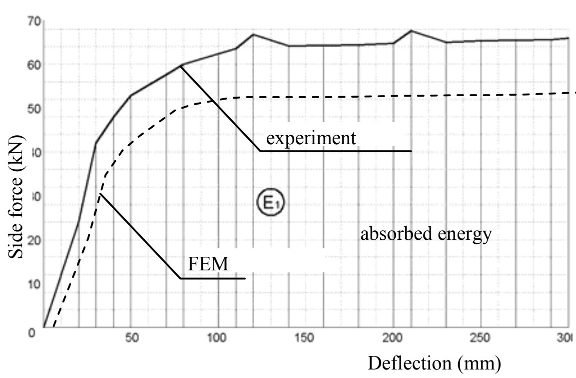


**Figure 14. Comparative results of absorbed energy obtained by experiments and by FEM**

- if side forces are multiplied by coefficient K=1.20, the experimental results and results obtained by finite element method are the same.

Correction coefficient K depends on the elements which make the frame more rigid. Thus the real structure corresponds to the modelled structure, which results in faster and cheaper testing of the protective frames.

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