INTRODUCTION
The important evaluation criterion of the mobile working machines is the safety of the machine operator. The initial safety standards were established for the machines used in civil engineering industry and ground shaping industry. The machines operating in the above mentioned areas are now sorted into the category of middle range machines. At the present time the frequent use of smaller scale and bigger scale machines in the various industry areas is common. Momentarily the evaluation criteria were unified for all machine types. The certification requirements are settled by following regulation and standards: 86/296/EEC, ISO 3449:1992 – Falling objects Protective Structure (FOPS) testing and ISO 3471 – Roll-Over Protective Structure (ROPS) testing. The fulfilling of defined requirements by regulation and standards are the basic condition for certificating of reliability of safety frame of the mobile working machine.

Fig.1  Wheel front loader

Fig.2  Front loader driven by the wheel slip

REQUIREMENTS
The safety frames of the mobile working machines for the groundwork machines have to ensure the operator safety during the machine operation even in the difficult and extremely heavy working conditions. The working space of the machine operator is evaluated in the term of ability to protect the operator in the situation of rolling-over of the machine and in the situation when the object is falling to the safety frame of the mobile working machine. To declare the conformity with the regulations and standards requirements the laboratory measurements are provided on actual structure prepared for launch to the market. The laboratory measurements of the structure can be considered as the final stage of the design process, because after proving of safety frame reliability the mobile working machine can be operated from the operator’s safety point of view. The requirements of minimum endurance during the tests are given by the existing regulation and standards and vary according the machine type and
the machine weight. Table 1 presents the requirements for selected group of the machines – front loaders.

Tab. 1a Basic requirement for sorting of machines

<table>
<thead>
<tr>
<th>Machine mass ( m ) (kg)</th>
<th>Lateral load ( F ) (N)</th>
<th>Lateral energy ( E ) (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 700 &lt; m \leq 1000 )</td>
<td>6.m</td>
<td></td>
</tr>
<tr>
<td>( 10000 &lt; m \leq 128600 )</td>
<td>60000( \frac{m}{10000} )^{1.2}</td>
<td>125000( \frac{m}{10000} )^{1.23}</td>
</tr>
<tr>
<td>( m &gt; 128600 )</td>
<td>10.m</td>
<td>2.09.m</td>
</tr>
</tbody>
</table>

Tab. 1b Basic requirement for sorting of machines

<table>
<thead>
<tr>
<th>Machine mass ( m ) (kg)</th>
<th>Upper load ( F ) (N)</th>
<th>Front load ( F ) (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 700 &lt; m \leq 1000 )</td>
<td>19.61.m</td>
<td>4.8.m</td>
</tr>
<tr>
<td>( 10000 &lt; m \leq 128600 )</td>
<td>56000( \frac{m}{10000} )^{1.7}</td>
<td>8.m</td>
</tr>
<tr>
<td>( m &gt; 128600 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the reliability of safety frame testing according the FOPS test for the first category the spherical steel or cast iron object is used. Standardized object for the falling object protective structure test can not exceed the diameter of 250mm and weight of 45 kg. After finishing of the falling object protective structure test can not be present permanent deformations on the testing object. The energy of the falling testing object has to be 1365J. Testing object for the second category of mobile working machines can be spherical or cylinder shape with the maximum diameter of 400mm. The energy of the falling testing object for second category has to be 11600J. Falling testing object contact area must be flat circle with the diameter of 200 mm.

ROPS test is simulating the roll-over of the mobile working machine by the use of quasistatical load according the following sequence:
- side load – where horizontal load is applied to the upper part of the safety structure,
- vertical load – where vertical load is applied to the given place of the safety structure in the same plain as the side load,
- lateral load – where the horizontal load is applied in the lateral direction of the safety structure.

The above mentioned loads have to be carried out by the safety structure without jeopardizing the safety space of the machine operator.
MEASURING

The deformation has to increase such way, that the load to the safety structure can be considered to be static. It means that the velocity of the deformation at the position of acting load can not exceed 5mm.s⁻¹. The computation method for the absorbed energy of the safety structure is given by integration of elementary loading forces and measured length lₙ of displacement of the point where load is acting.

\[ E = \frac{E₁}{2} \left( l₁ - \frac{E₁}{2} \right)^2 + \frac{E₂}{2} \left( l₂ - \frac{E₂}{2} \right)^2 + \ldots + \frac{Eₙ}{2} \left( lₙ - \frac{Eₙ}{2} \right)^2 \] \[ \text{[J]} \quad (1) \]

It is required, that the safety structure after reaching required accumulated energy has to reach also the required or even greater force.

DESIGN

It is important to realize, that to fulfill the requirement of absorbed energy in the safety structure is often necessary significantly increase the loading force or to sustain on the load with the aim to achieve deformation in the area of skid limit of the material [1]. The situation, where the requirement to increase the loading force occurred during the testing of the safety structure is presented at the fig. After reaching of the load given by the regulation and standard the accumulated energy in the safety structure reached only 25% of required level. During the increasing of the loading force to fulfill the condition of the accumulated energy in the safety structure the structure after significant deformation in the area of anchoring points was broken in the anchoring points. Such result of the test usually leads to the reinforcing of the weak points of the structure. The result of such solution is the increase of the mass of the structure and in the final stage to extremely and uselessly rigid structure. Ideal solution is such rigidity of the structure, which can guarantee the required load and accumulated energy at the same time.
CONCLUSION

The philosophy of the above mentioned tests given by existing regulation and standards is assuming following action during machine accident:
- impact or not impact of the safety structure of the machine by falling object
- roll-over of the machine in difficult terrain conditions to the side
- following roll-over of the machine to the roof (upper side of the safety frame),
- acting of frontal or back force to the safety structure of the machine due to the inertial forces increasing from the operation speed of the machine.

Such scenario of the accident of the mobile working machine seems to be most reliable.

During the tests is often seen the machines where the primal risk is in roll-over of the machine to the front or to the back. In such cases there is the greatest risk of jeopardizing of operator from the lateral forces. In such situation the condition of accumulated energy according existing and valid regulation and standards is problematic to reach.

Other area to solve is the problematic of exceeding rigidity of the safety structure of the mobile working machine. For example the achieving of three times bigger lateral force as it is required by regulation for the safety structure is necessary for achieving of required energy absorbed in the structure. It has direct influence to the magnitude of the deformation. During the accident such rigidity of the structure causes the bigger deceleration, which can be dangerous for the operator. The more rigid the safety structure is the bigger deceleration can be watched.

The goal of the paper is also to create the discussion between testing authorities, users and producers of the mobile working machines about the sufficiency of the evaluation of the reliability of safety of operator from the point of primal roll-over of the machine to the front side or to the back side view, and from the point of exceeding rigidity of the safety structures of the mobile working machines.

Acknowledgements

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REFERENCES