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# About Mechanical Shock Energy Dissipation by Deformation and Friction, with Applications to Increase Performance of Protective Structures

*Increasing the capacity of the mechanical shock's energy dissipation is the main objective in design of protective structures. Article brings to the forefront the idea of increasing the amount of energy dissipated by simultaneously deformation and friction of the structural elements. In this context, some experimental results are presented and some aspects of finite element modeling of the behavior of such systems. At the end of the article are drawn some conclusions on the implementation of such systems in protective structures*

***Keywords**: Shock energy, deformation, friction, protective structures*

## 1. Introduction

One of the most important performance requirements imposed on mobile machinery's cabins is their ability to prevent crushing the human operator if the vehicle rollover or if falling objects. In such situations, strength structure of cabin is subject to shock loads.

It follows that the protective role of such structures is directly related to their ability to dissipate impact energy of the shock loads.

In field of the earth-moving machinery, the protective structures, depending on their functional role, are classified into two categories:

- *Roll-over protective structure* (ROPS) – system of structural members whose primary purpose is to reduce the possibility of a seat-belted operator being crushed should the machine roll-over;
- *Falling-object protective structure* (FOPS) – system of structural members arranged in such a way as to provide operators with reasonable protection from falling objects (e.g. trees, rocks, small concrete blocks, tools).

A protective structure may be only ROPS, or only FOPS, or simultaneously ROPS and FOPS.

Level of protection offered by these structures the human operator is imposed by rules and standards and depends on the machinery type, the nature of the operations and it's mass. Following these regulations, one of the main design goals is to find constructive solutions to leading to structures with increased capacity to dissipate impact energy.

Generally, after the collision with the ground (in the event of rollover) or with falling objects, protective structures have permanent deformations due to exceeding yield limit of the structural members material. In case of a protective structure, subjected to a mechanical shock by its collision with an object, it is found that impact energy is dissipated in post-impact elastic oscillations and plastic deformations both in structure and object and in possible post-impact rebound of the object.

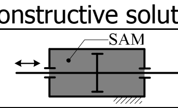
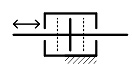
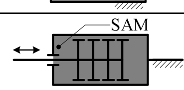
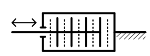
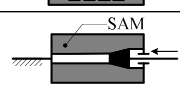
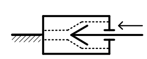
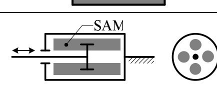
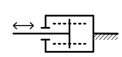
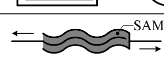
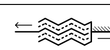
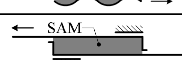
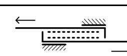
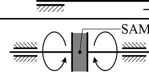
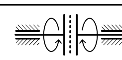
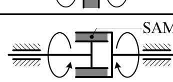
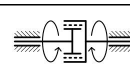
Analyzing the system consisting of structure and object that strikes in terms of shock energy dissipation capacity, appears the idea of using other ways to dissipate energy shock. One of these ways is the friction.

In this context, occurs the idea of finding constructive solutions for protective structures that contain sub-assemblies with high capacity to dissipate impact energy in simultaneously deformation and friction of the structural elements.

Therefore, the structural elements of these sub-assemblies must be made of materials with low stiffness, allowing significant deformations. Such materials, herein referred to as SAM (shock absorber materials), are polystyrene and rubber.

In Table 1 are given some in principle constructive solutions for some such sub-assemblies with good dissipative capability and symbols proposed for them.

**Table 1.** Constructive solutions of dissipative sub-assemblies

| No. | Constructive solution | Proposed Symbols |
|---|---|---|
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |
| 4 |  |  |
| 5 |  |  |
| 6 |  |  |
| 7 |  |  |
| 8 |  |  |

## 2. Experimental tests

The experimental tests were focused on investigation of the energy impact dissipation capability for the 3rd constructive solution presented in Table 1.

The motivation of choosing this constructive solution was simplicity of its adaptation as a sub-assembly of a protective structure (ROPS or FOPS).

The goal of the experimental study was to compare two constructive solutions (more precisely, their geometric shape) for the dissipative elements manufactured from SAM.

For experimental tests were manufactured two experimental devices with constructive solution shown in Figure 1a. Also, in Figure 1 is suggested the experimental procedure used (Figure 1a), and geometric shape of the structural elements that have been tested (figure 1b).

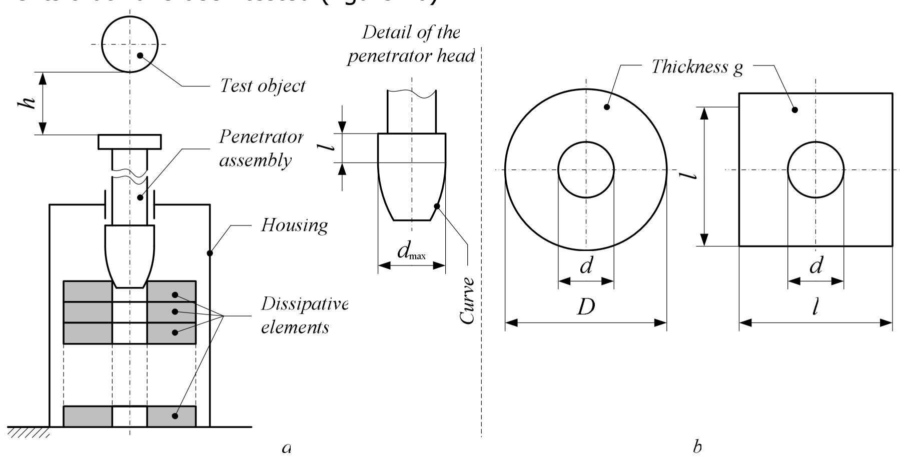



**Figure 1.** Experimental tests

a – Experimental device and experimental procedure; b – Shape of the tested dissipative elements

The experimental study was performed for extruded polystyrene and for rubber. In this context, had been used extruded polystyrene Xpan Styropan and rubber with ~60 0Sh A hardness.

During experimental tests, the shock was created by hitting a penetrator assembly with a test object with known mass, in free fall from a height known.

The penetrator assembly slides into a guide fixed on housing where are the dissipative elements manufactured of SAM.

During experimental tests, following the two geometric shapes adopted for dissipative elements, were used two housings: housing from round pipe and housing from square pipe. This is because the idea of practical use of such a system is to be used as housing the round or square pipes of which are made the structural members of the protective structure. Also, into research, for each material and geometric shape, for the penetrator head were used two head generating curves and two maximum diameters.

In Figure 2 are presented the experimental devices and dissipative elements used in experimental tests.

**Figure 2.** Experimental devices and dissipative elements

In order to obtain relevant experimental results, it is necessary that the fraction of the energy of impact which is dissipated by friction in the guide be negligible compared to the energy dissipated by deformation of the elements made of SAM and by friction between them and penetrator head. In this context, into guide was provided lubrication.

Below are given the conditions that were complied in experimental tests.

- For all dissipative elements: $D = 114\,mm$, $d = 50\,mm$, $L = 114\,mm$;
- For the dissipative elements manufactured from polystyrene: $g = 30\,mm$;
- For the dissipative elements manufactured from rubber: $g \in \{11, 20\}\,mm$;
- The mass of the test object: $m = 4.12\,kg$;
- Height of free fall of the test object: $h \in \{0.746, 4,333\}\,m$, which corresponds for the domain $E \in [30.14, 175.04]\,J$ of the impact energies;
- The maximum diameter of the penetrator head: $d_{\max} \in \{51, 52, 55\}\,mm$.

During experiments were recorded following aspects:

- The penetration depth of the penetration assembly: $\Delta\,[mm]$;
- If secondary collisions occur between the test subject and the penetrator assembly;
- If cracks occur in dissipative elements.

All experimental results and all remarks related to above mentioned aspects were embedded in a database for later their use.

The research showed a better capability to dissipate impact energy of the circular dissipative elements. Also, the research showed a better adaptability to shock for polystyrene in relation to rubber.

Experimental tests were conducted under a research project which studied ways to increase the capability to dissipate the shocks of the protective structures embedded into earth-moving machinery cabin [1].

### 3. Some aspects of numerical modeling the behavior of dissipative systems with elements made of SAM

It is obvious that the experimental study of dissipative systems of the type used in experimental tests or of the types presented in Table 1, involves the manufacture a lot of constructive versions. Also, the recording process of the relevant physical quantities produced into the very short during of the shock requires sophisticated laboratory equipment. Therefore, the experimental study can become very expensive.

Given the considerable enlargement of the current range of problems addressed by the finite element method, appears as a viable approach to study such systems using the MES technique (Mechanical Event Simulation).

To study such systems using numerical simulation of their behavior is necessary to take into account a series of recommendations, of which the most important are:

- It is recommended rigid finite elements for meshes related with the housing and all model parts that that are associated with the penetrator assembly. This is because the deformations of these parts are negligible compared to deformations of the dissipative elements.
- It is recommended to use Mooney-Rivlin material model for dissipative rubber elements and a foam material model for polystyrene elements.
- To obtain numerical results characterized by acceptable accuracy, it is necessary to calibrate the material models based on experimental tests.

The experimental study briefly presented in previous section was used for validation of the numerical simulation of the behavior of such systems. In this context we aimed to validate the material models used in pre-processing of finite element models and also, we aimed to validate the friction coefficients adopted in numerical modeling.

### 4. Conclusions and recommendation

Embedding in protective structures of sub-assemblies that contain dissipative elements made of SAM must take into account the following aspects:

- The global geometric shape of protective structure;
- The location of the dissipative sub-assembly must take into account the structural composition of the protective structure;

- Interposition between the dissipative subassembly and the rest of the protective structure a system that provides entry into service of the dissipative system only when the impact energy exceeds the level required. Thus, the dissipative role will begin only when are produced the shocks that are considered to be dangerous for the human operator integrity. Such a system could use elements with controlled shearing, or could use elements made of materials with non-Newtonian rheological behavior.

Future research will be focused on validation of the modeling assumptions used in behavior simulation of the dissipative elements manufactured from polystyrene and rubber.

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