ERW transport container and mine roller – TIRAMISU project results

Marcin SZCZEPANIAK, Wiesław JASIŃSKI, Piotr KRYSIAK *

*In the paper will be presented results of digital simulation explosion explosive charges inside the constructed for TIRAMISU project platform for transporting mines and unexploded ordnance (End Residues of War - ERW) and under wheelset of mine fail resulting in the same project. Will be presented stresses in the structure of these devices and the total effect of impact forces generated during the explosion. In the second part of the work will be shown a filed trials blasting explosive charges under real objects and the results recorded exposure: mechanical stresses arising in the construction, propagation of the shock wave and propagation of fragments. At the end of the work will be presented the conclusions from the comparison of the outcome of simulation and real results in relation to changes in the design of the proposed construction of devices. Will be presented the final version of the trailer to transport the remains of war, as well as the final version of the mine roller with a remote-controlled tractor engaged by Pierre Trattori.*

## 1. SIMULATION OF THE EXPLOSION

In this paper, the Finite Element Method (FEM) is a fundamental method of analyzing the impact of the explosion. The study adopted the following system of the numerical options available in the LS-DYNA [1] system:

- explicit algorithm used to solve equations pertaining to structure dynamics in the nonlinear range,
- elastic-plastic material model,
- rigid material model,
- deformable coating elements of the SHELL type (type 2) [1],
- deformable solid elements of the SOLID type (type 1) [1]
- initial and boundary conditions considering the gravitation effect, large deformations and displacements.

The phenomena discussed in the paper are characterized by the following features:

- quickly changing in time (shot duration),
- great geometric nonlinearities (large deformations, displacements, contact) and signifficant physical nonlinearities (material nonlinearities),
- they require the small time increment $\Delta t$.

The following parameters of TNT were accepted:

- density: 1640 kg/m$^3$;
- detonation rate: 6930 m/s;
- Chapman-Jouget pressure (PCJ): 27 GPa.

### 1.1. Simulation of explosion inside the container

As a result of numerical calculations, maps of displacements, strains, stresses and graphs of selected physical parameters in respect to the time were obtained.

This is presented in the figure below:

Maps of total deformations of the container body for *t*=2ms presented in Fig. 1.

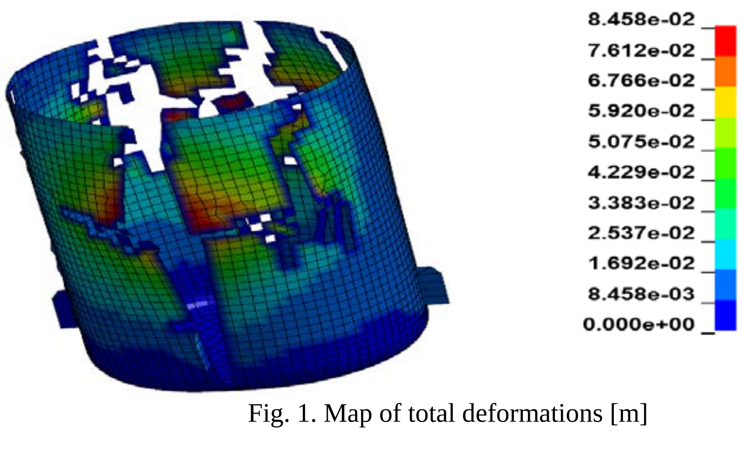


Fig. 1. Map of total deformations [m]

* Military Institute of Engineer Technology, Department for Mine Warfare and Engineer Technology, Wrocław

Structural elements absorbing the energy of explosion (wooden boards, rubber) are completely destroyed. The container skin is deformed and there is the possibility of breaking the structure (Fig. 1).

### 1.2. Simulation of the explosion under the mine roller

The numerical model was built basing on the CAD geometric model. Then, the model was divided into finite elements and the physical characteristics were given by defining the materials, thickness and connections between different parts of the mine roller. Consequently numerical model of the mine roller was developed.
The explosion of 1 kg TNT applied under the middle wheel set was assumed for the computer calculations. The results are presented (Fig. 2) in the form of distribution of reduced stresses acc. to Huber hypothesis. The results are expressed in MPa.

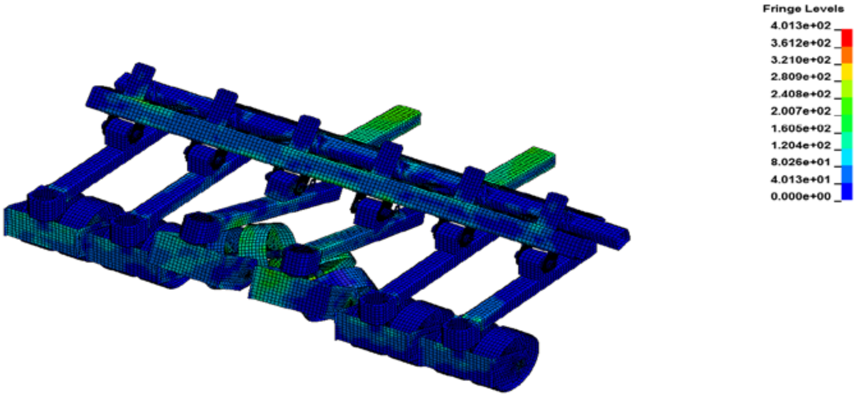


Fig. 2 Distribution of reduced stresses

It is possible that the roller which will be directly over the explosive charge can be completely destroyed. The whole mechanical construction of the mine roller will not be destroyed, because during the explosion the rocker arm together with the wheel set are to be thrown into the air (Fig. 2) and the energy is not transferred to the main part of construction. This phenomenon is confirms the design basis.
The damaged rocker arm should be replaced after the explosion. The mine clearance can continue.

## 2. EXPLOSION TESTS ON THE PROVING GROUND

The subject of the study were also the field tests of the container for transport and temporary storage of hazardous objects and the mine roller carried out on the proving ground. The subject is part of the TIRAMISU project.

### 2.1. Explosion tests inside the container carried out on the proving ground

The black foil placed on the ground and four control shields deployed around the container were used to assess the fragment scatter. The shield height was 3 m and its width was 2 m. The distance from the shields to the container axis was 6.5 m. The ICP 137A23 pressure sensors were used to measure the pulse and overpressure parameters at the front of the shock wave. The distance from the container axis to the first pressure sensor was 3.25 m, to the second sensor − 6.5 m and to the third sensor − 10 m.
The explosive charges used for testing included lethality enhancers. These charges were made of TNT pressed blocks weighing 75 g (11 elements) and a single 200 g block (1 piece). The lethality enhancers were steel balls (bearing balls) with the diameter of 6 mm. The total number of balls amounted to 2000. The 200 g TNT block has a body made of 2 mm steel sheet. The explosive charges were placed in the container and then armed with the “ERG” electrical detonators. Then they were connected to the measuring apparatus. The explosive charges were detonated by means of a TZK-100A electric blasting machine.

The effect of detonation of explosive charges is presented in Fig. 3. The container inspection was carried out after the trial and deformations of the container side surface in two areas were noted: larger, in the middle part and a minor one − of the container cover.


Fig. 3 Effect of detonation of explosive charges in the container
1-steel balls; 2-pressure sensor; 3-control shield

The inspection of the area covered with foil and of the control shields was carried out after the detonation. A dozen or so steel balls were found on the foil with a radius of 4.0 m from the container axis. Some wooden splinters of the damaged boards and of the cover of the cavity for explosive charges were present too. Not one steel ball had hit the control shields. The obtained results indicated that the substantial majority of balls remained in the container, only a few were ejected outside and fell around it. As a result of the impact of the high temperature of the post-explosion gasses, the wooden and rubber components inside the container had incinerated.
The experiment showed that the container was not damaged as a result of detonation of fragmentation explosive charges and that the explosion had no impact on the safety of its use. Tensile stresses of the side part of the container body, eye bolts and the frame of the container did not exceed the limit values for tensile strength. The probable cause of deformation of the container side surface in two places the impact of the 200 g block of TNT, which after detonation divided into two parts.
The maximum deformation values (Fig. 4) were 10÷11 mm and 4÷5 mm, respectively.
The courses of pulse and overpressure at the front of the shock wave registered by sensors.

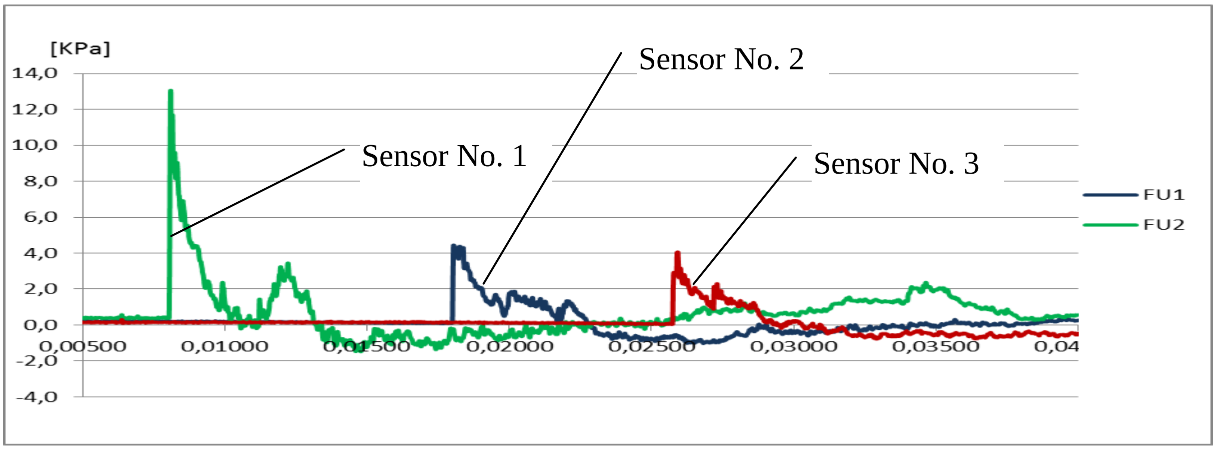


Fig. 4. The course of the pulse and overpressure at the front of the shock wave.

The peak values of the overpressure for the shock wave and reflected wave registered by separate sensors were as follows:
Sensor No. 1 – ΔP –max1 – 13.06 kPa; max2 – 3.45 kPa; (distance from the container axis – 3.25 m)
Sensor No. 2 – ΔP - max1 – 4.45 kPa; max2 – 1.74 kPa; (distance from the container axis – 6.5 m)
Sensor No. 3 - ΔP - max1 – 4.03 kPa; max2 – 2.14 kPa; (distance from the container axis – 10 m).
Area hazardous to human health and resulting from the impact of shock-wave (atmospheric pressure exceeding 0.1 standard atmosphere) measured from the centre of the explosion should equal:

a) from 0 to 6.5 m for a charge containing 2 kg of TNT,
b) from 6.5 m to 9.0 m for a charge containing 5 kg of TNT

according to the Ordnance of Ministers of Internal Affairs, National Defense, Finances and Justice (Journal of the Laws, No. 165, item 992 dated August 2$^{nd}$, 2011).
Thus it can be concluded that the **hazardous area for the tested container carrying fragmentation explosive charges up to 1 kg of TNT ranges from 0 m to maximum 4 m, which is well below the Ordnance regulation**.

## 2.2. Mine roller tests on the proving ground

The test stand consisted of the mine roller mounted on the auxiliary frame loaded with the weight of 26.7 kN. Sequences of the selected registered images during the trial of dynamic load caused by the detonation of 8 kg cast TNT in form of 400 g 20 blocks placed indirectly under the mine roller wheel are presented in Fig. 5.

Fig. 5 Images registered during trial by the high speed camera

The above images were registered by means of a high speed camera.
Only a wheel set on the rocker arm directly over the explosive charge was destroyed. The remaining rocker arms and elements were in good condition.
The trial result confirmed earlier calculations.

## 3. Conclusions

The methods of digital prototyping and simulation of explosive phenomena were described in the paper. These methods were verified by experiments on the proving ground.
Generally speaking, the design basics were met. The assumed construction of the mine roller with modular structure consisting of quickly replaced elements which would be damaged as a result of explosion proved effective. In particular, the mine clearing elements (wheel sets) were designed so as to be placed on movable bars (the so-called rocker arms) which move back during the explosion thus minimizing the effects of the destruction on the device. Both the digital simulations and the proving ground tests indicate that this concept is sound and solid.
During the design of the container to transport explosives, it has been assumed that the part of energy of explosion should be absorbed by the material filling the container inside to protect the container against disintegration. At the same time, the overpressure of the shock wave will be released vertically upward through the shutter structure of the upper container cover. The design of the shutter/grate should not allow significant ejections of the solids from the container. Basing on the tests carried out, it can be concluded that the design basics have been met.
The designed container should comply with the legal document connected with the impact of the shock wave. In this paper, it has been shown that the hazardous zone for the tested container has a radius of 4 m, what is not only acceptable but well below the legal requirement.
On completion of the work, the following observations were made:

- calculations of explosion under the mine roller and the explosion on the proving ground confirm the accuracy of calculations;
- the explosion of the container on the proving ground did not confirm the calculations – the damage to the container was minor, while according to the calculations it should have been great.

## Literature


1. LS-Dyna Theory Manual, Livermore Software Technology Corporation, Livermore, 2006.
2. LS-DYNA Keyword User’s Manual (Version 971).



**Acknowledgments**

The research leading to these information and results has received funding from the European Community's Seventh Framework Programme (FP7/2007 - 2013) under grant agreement n° 284747.