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NUMERICAL ANALYSIS OF THE INFLUENCE OF THE DEFLECTOR STIFFNESS AND GEOMETRY ON ITS EFFECTIVENESS

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Abstract

The aim of the paper is to present the results of numerical analyses of designed classical system for measuring impact of the pressure wave originating from the detonation of explosive charge. In the paper, authors present classical ballistic pendulum in the form of the 1-meter length, HEB220, double T beam, which was suspended on the four parallel steel cables. On the front part of the pendulum, steel deflector was attached, whose aim was to disperse the energy. A few variants of used deflector were prepared, differing in the deflector geometry and thickness of the used material. In the next step, presented system was loaded with use of pressure wave, originating from detonation of 50 grams explosive charge. In order to properly describe the detonation process ConWep method was used. In this method, on the basis of preset geometric and mass parameters, together with TNT equivalent, the pressure pulse is determined. A three dimensional model of classical ballistic pendulum was prepared in MSC Patran software and numerical analyses were performed using LS-Dyna software. As the result of numerical analyses, the maximum deflection of the pendulum was determined for each case. Based on obtained results the influence of deflector geometry and stiffness on energy absorbing was identified and presented in the form of graphs.

Keywords: *ballistic pendulum, dynamics, finite element method, ConWep*

1. Introduction

One of the most serious threats to soldiers involved in stabilization missions are improvised explosive devices (IED). Over the years researchers sought to develop as most effective ways to protect against these types of threats as possible. One of these developed protection methods is use of deflectors, which specially selected shape, and material from which they are made will allow for effective dispersion of energy originating from the detonation of explosive charge. One of the most important parameters characterizing the deflectors is the amount of energy that they are able to dissipate or absorb.

In order to determine the ability of the deflectors to dissipate energy the ballistic pendulums are often used. Such pendulum consists of a relatively large mass M suspended on the long arm (Fig. 1, 2). In the front part of the mass tested dissipating or absorbing energy structure is mounted.

The operation principle of classical ballistic pendulum is based on the use of the law of conservation of momentum:

$$mU = (M + m)V, \tag{1}$$

where:

m – weight of the projectile,
U – velocity of the projectile before the impact,
M – shield mass,
V – horizontal velocity of the missile – shield system.

Knowledge of the projectile impacting into pendulum mass “m”, mass of the pendulum “M” and his displacement, allows determining the momentum of the projectile before striking the shield, its velocity and kinetic energy.

Fig. 1. Example of ballistic pendulum [1]

In situations when ballistic pendulum is used to evaluate the effectiveness of the energy dispersing structures, pendulum is initially loaded without any protective structures and in the next step the same system but with mounted energy dissipating structure/element is loaded. The resulting difference in the deflection of the pendulum is proportional to the energy dissipated by the tested object.

The article presents results of the numerical analyses of the deflectors mounted on the ballistic pendulum made of HEB220 H-beam suspended on four parallel steel ropes. In front of the pendulum, steel plate is located, to which mounting of different energy absorbing structures and deflectors is possible. Tested objects are attached to steel plate by using 200 mm length screws, which are providing the required distance between tested deflector and front steel plate of the pendulum. In the rear part of the pendulum the next steel plate is placed, which enables correct fitting of the counterweight (Fig. 2.).

2. Numerical model of ballistic pendulum

Presented in the article system for deflector effectiveness research consist of the six main parts (Fig. 2.):
- ballistic pendulum in the form of HEB220 H-beam,
- two mounting plates,
- V-shaped steel deflector,
- four steel ropes,
- counterweight.

Mechanical properties of the steel deflectors were described using a simplified Johnson-Cook type material [2]. This model correctly reproduces the behaviour of the described material during dynamic interaction with high strain rates and strains. Transition into plastic state depends on the product of a function depended on the strain and strain rate. The influence of the strain rate on the material behaviour is identical as in the classical Johnson-Cook model. The simplified model does not take into account thermal effects [3]:

$$\sigma_{flow} = [A + B(\varepsilon^{p})^{n}]\left(1 + C ln \dot{\varepsilon}^{p^{*}}\right), \quad (2)$$

where:
A, B, C, n, m - material constants,
$\dot{\varepsilon}$ - strain rate.

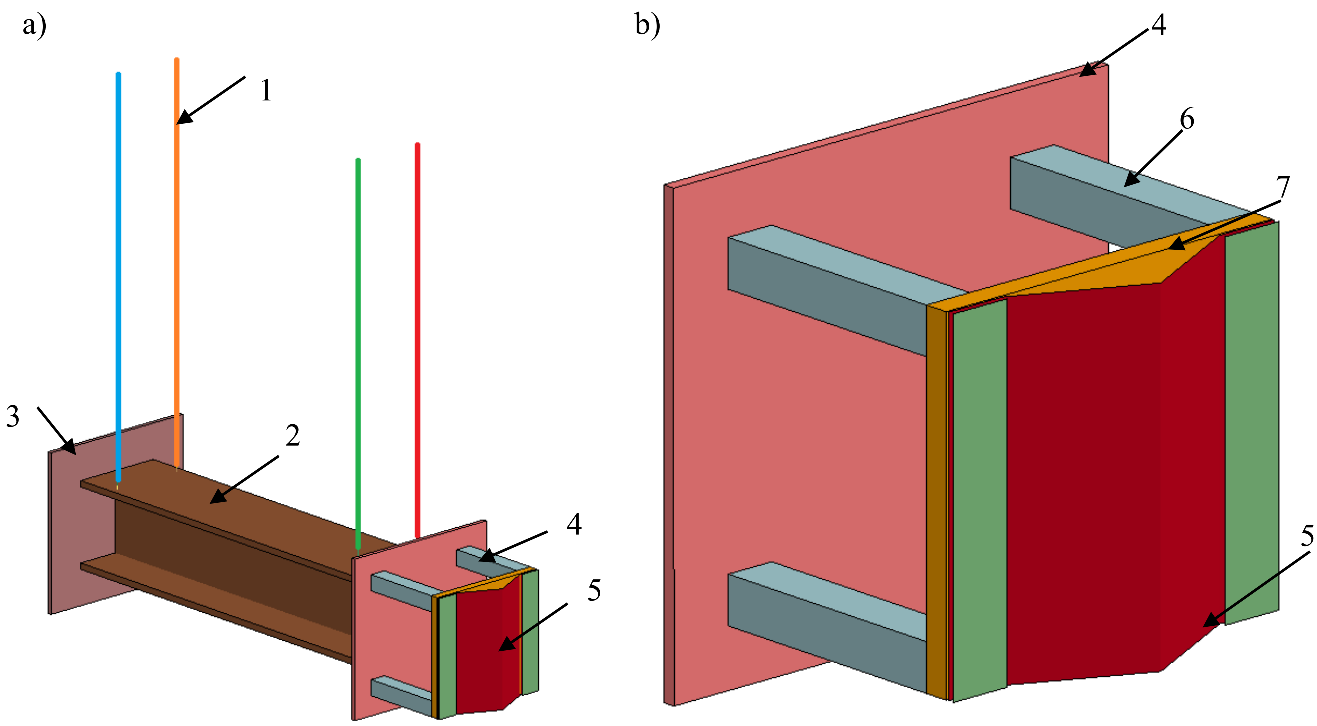

Fig. 2. a) Ballistic pendulum, b) front part of the pendulum: 1 -steel ropes; 2 -pendulum; 3 - counterweight; 4 - front plate; 5 - deflector; 6 - spacers; 7 - mounting plate

In order to correctly model, the behaviour of the ropes material model CABLE DISCRETE BEAM was used. To be able to use this model it is necessary to use "discrete beam/cable" finite element formulation. In this material model, force is generated by rope only during stretching [2]:

$$F = \max(F_{+} + K\Delta L, 0.), \quad (3)$$

where ΔL is change in length:

$$\Delta L = L_C - (L_P - O), \quad (4)$$

where:

L_C – current length,

L_P – initial length,

O – offset.

Stiffness K is defined as:

$$K = \frac{E * A}{(L_P - O)}, \quad (5)$$

where:

E – Young modulus,

A – cross section area.

In order to model the dynamic load of the system originating from detonation of the explosive charge the Conwep scheme was used. This method was developed by Kingery and Bulmash [4]. It is applicable in spherical explosions in the air or semi spherical when explosive is placed on solid support. This method was initially implemented into Conwep software developed by the United States Army and then became part of the LS-Dyna solver (*LOAD_BLAST keyword) [5].

The change in pressure in the time is described by the following formula:

$$P(t) = P_{S0}\left[1 - \frac{t - T_a}{T_0}\right]\exp\left[\frac{-A(t - T_a)}{T_0}\right], \quad (6)$$

where:

P(t) – pressure in the *t* moment (kPa),

P_{S0} – peak pressure (kPa),

A – rate of decay (dimensionless),

T_0 – the duration of the positive phase (msec).

This equation is called the Friedlander equation [4].

If you choose Conwep, method for modelling the explosion phenomenon it is necessary to provide the following values:

- mass of the explosive – related to the mass of TNT by TNT equivalent,
- coordinates of the detonation point,
- delay after which the detonation occur in relation to the start of calculations,
- system of units,
- type of explosion:
  - in the air,
  - on the ground [6].

Material constants used in the calculations are presented in the Tab. 1.

Tab. 1. J-C material constants [7]

Parameter	Description	Unit	Value
ρ	Density	g/cm^3	7.89
E	Young modulus	MPa	210000
v	Poisson coefficient	-	0.3
A	Material constant	MPa	365
B	Material constant	MPa	510
n	Material constant	-	0.9
C	Material constant	-	0.0936
ε_f	Plastic strain at the failure	-	0.3

3. Numerical analyses

Three variants of geometric shape of the steel V-shaped deflector were analysed by the authors. Considered geometric shapes of the deflectors are presented in Fig. 3. In addition, each of this deflector has been made in two variations, differing the thickness of the material from which they were made – 1 mm and 4 mm. In each of the variants, system was loaded with detonation wave origination from explosion of 50 g TNT. Summary of the variants under consideration is shown in Tab. 2.

Tab. 2. Summary of considered variants

	Variant 1	Variant 2	Explosive mass
Deflector 1	1 mm	4 mm	50 g
Deflector 2	1 mm	4 mm	50 g
Deflector 3	1 mm	4 mm	50 g

In each considered case, explosive material was placed at the distance of 200 mm from the tested deflector.

Figures 4-6 shows a comparison chart of the ballistic pendulum displacement for deflectors made from 1 mm and 4 mm thick material respectively. Fig. 7 and 8 shows the ballistic pendulum displacement for all three variants of geometric shape and material thickness.

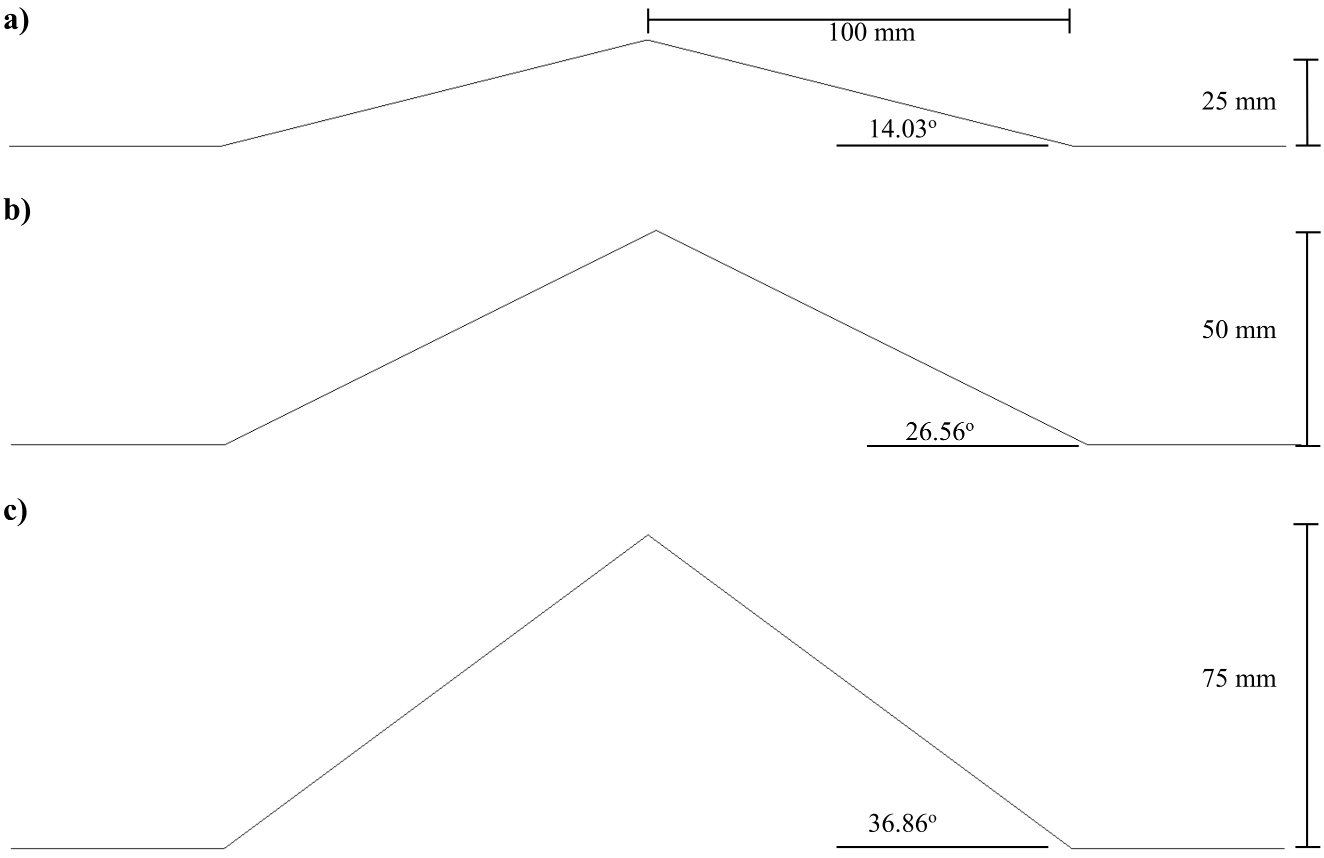

Fig. 3. Geometric shapes of tested deflectors a) deflector 1; b) deflector 2; c) deflector

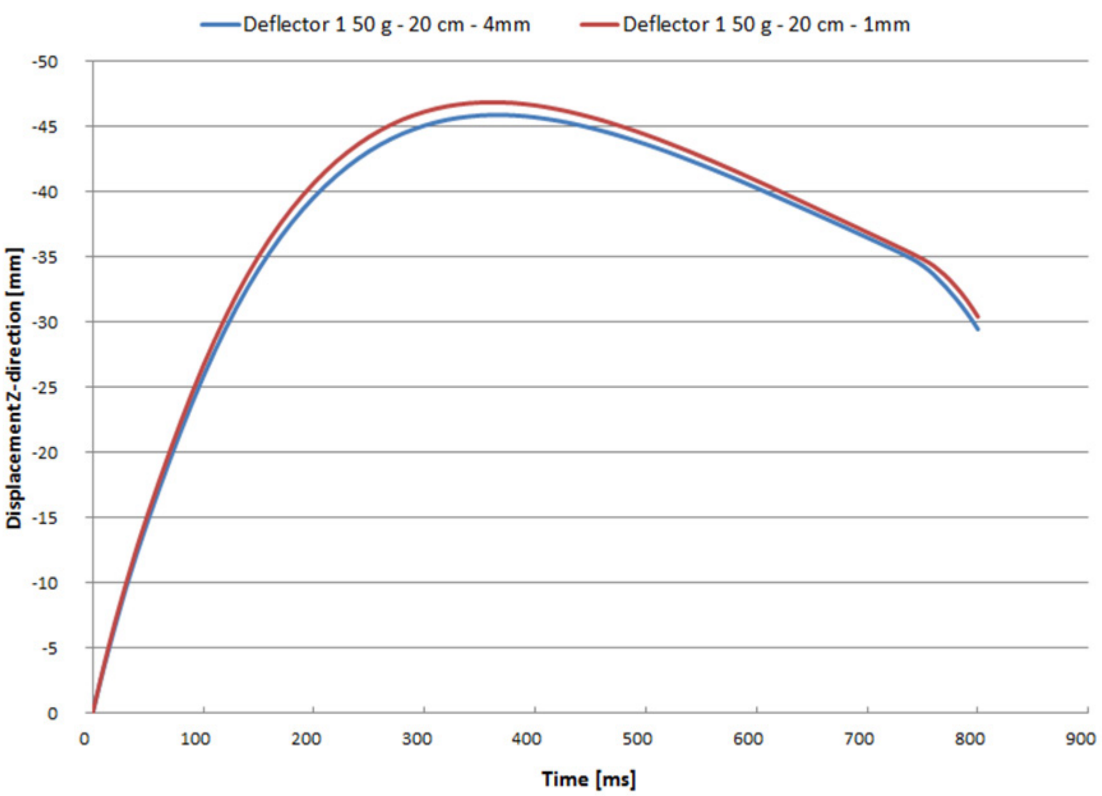

Fig. 4. Ballistic pendulum displacement with mounted deflector 1

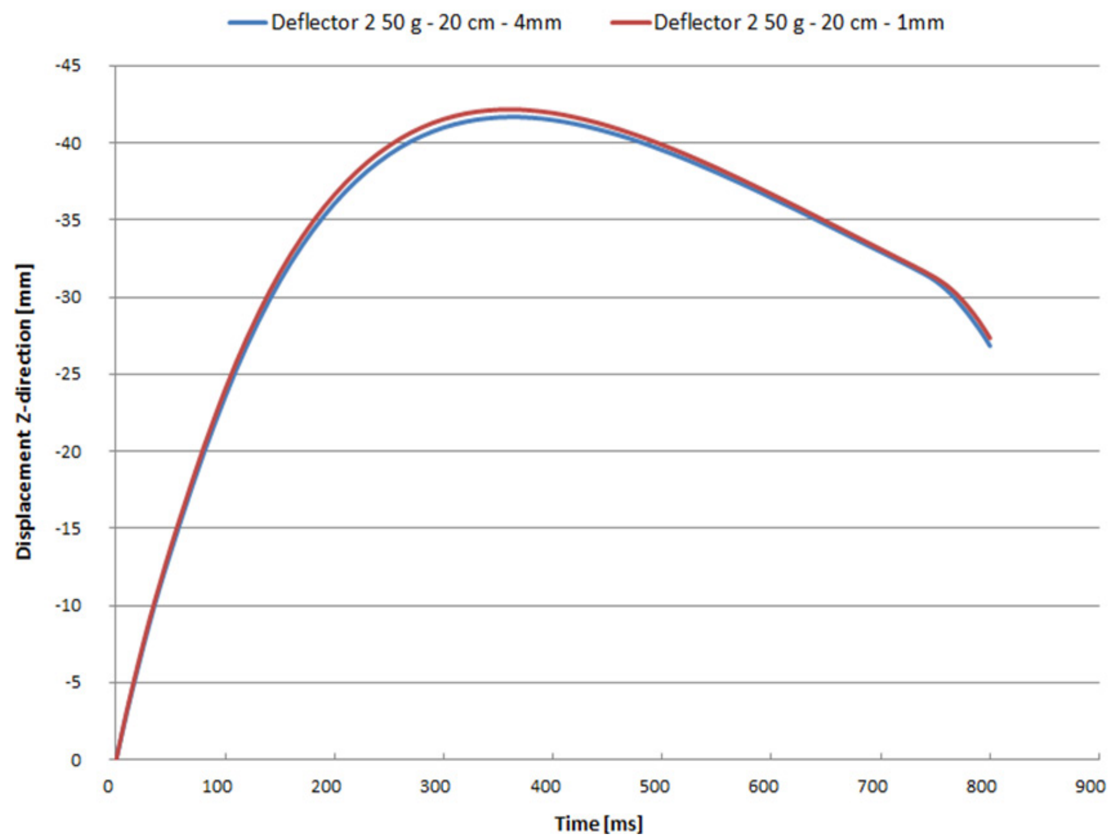

Fig. 5. Ballistic pendulum displacement with mounted deflector 2

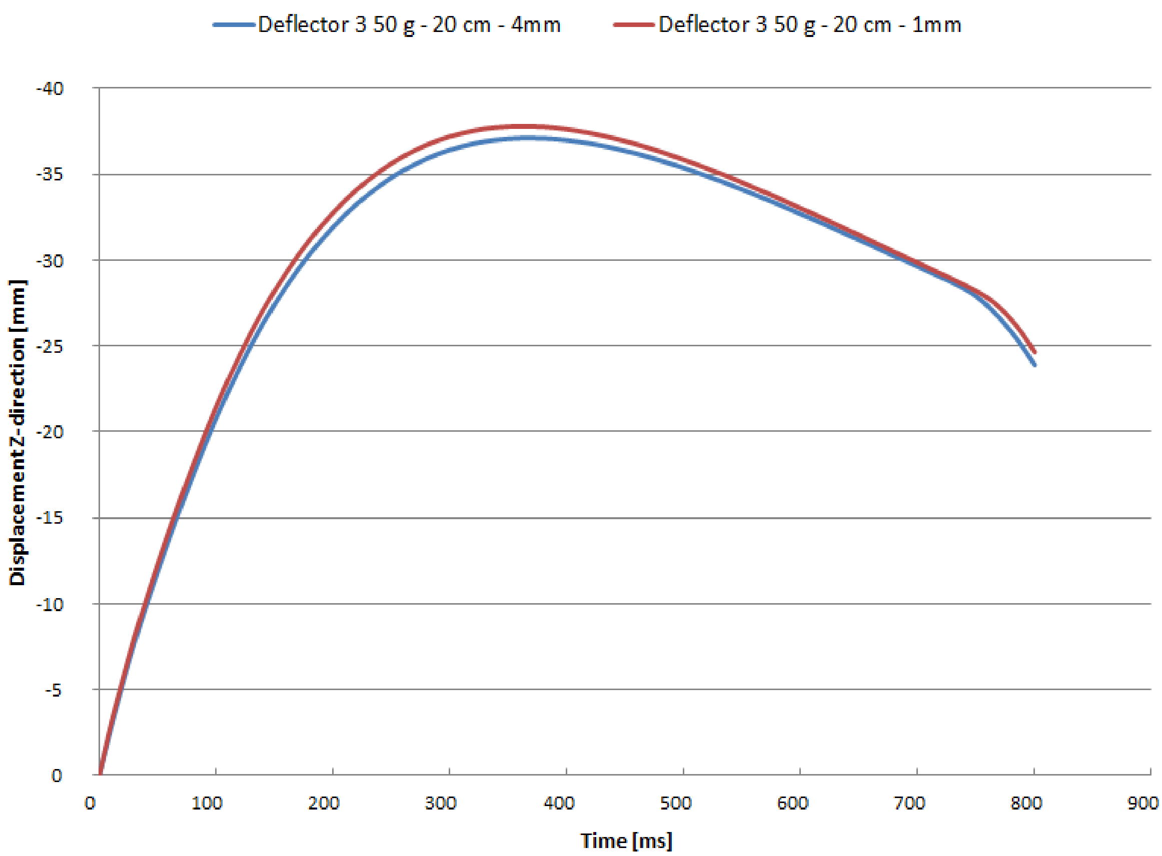

Fig. 6. Ballistic pendulum displacement with mounted deflector 3

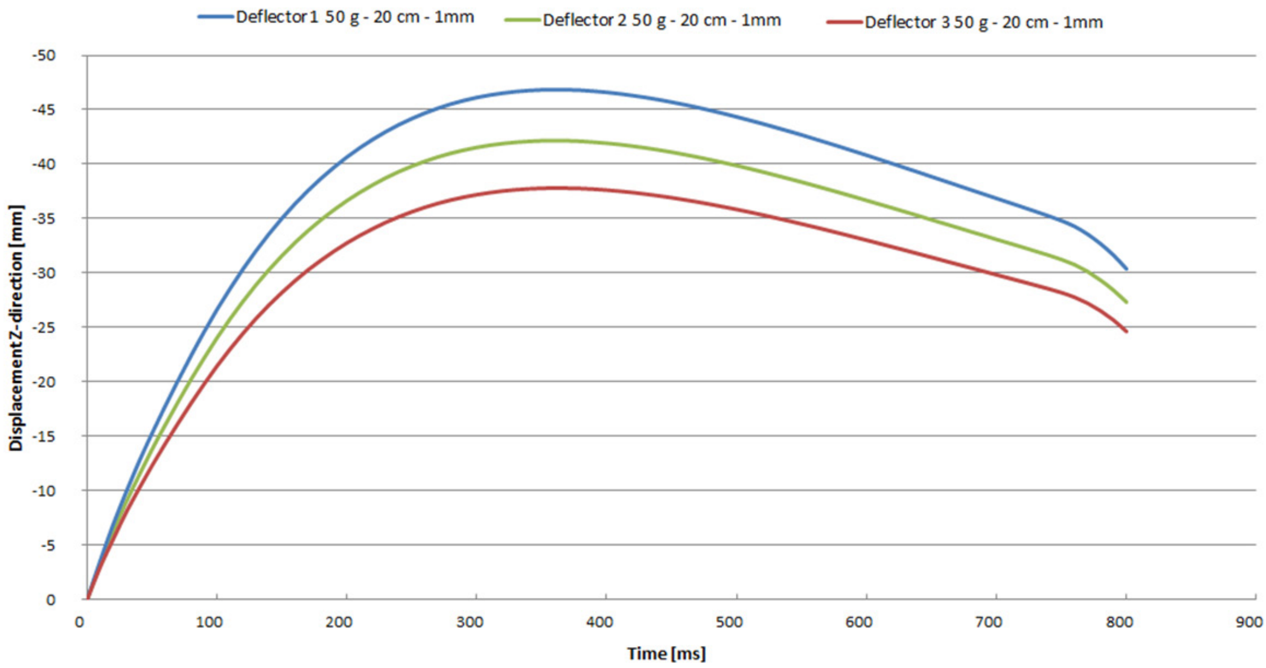

Fig. 7. Ballistic pendulum displacement with deflectors made of 1 mm thick material

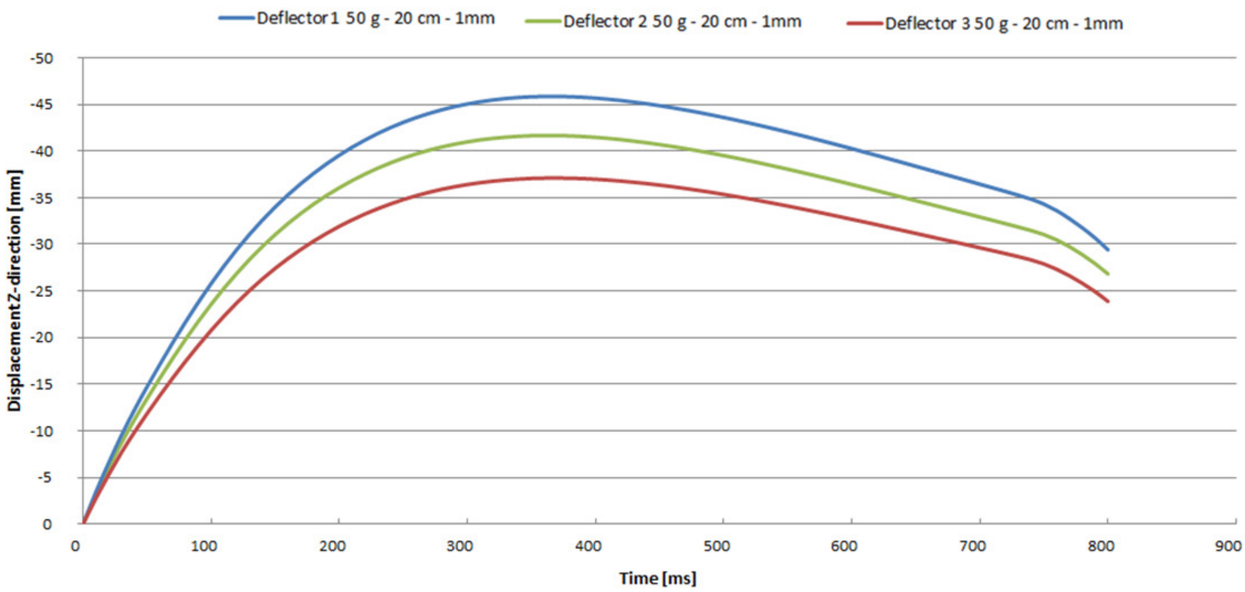

Fig. 8. Ballistic pendulum displacement with deflectors made of 4 mm thick material

On the above graphs, we can see that the thickness of the material from which the deflectors were made has little effect on the obtained values of pendulum displacement. For variant number 1 maximal pendulum displacement for 4 mm thick material was 41.7 mm and for 1 mm thick material – 42.2 mm. For variant number 2 these values are respectively 45.9 mm and 46.8 mm, and for variant number 3-37.1 mm and 37.8 mm. In the worst case, the difference between thickness variants does not exceed 1%. No clear difference between those variants is probably caused by the use of only 50 g explosive material for generating the pressure wave. With such small explosive charge for both 1 mm and 4 mm, thick deflector there is virtually no deformation.

However, the geometrical shape of the deflector has great influence on the obtained maximal displacement of the ballistic pendulum. For deflector number 1 the displacement was 41.7 mm, for deflector number 2 – 45.9 mm and for deflector number 3 – 37.1 mm. The difference between the highest and the lowest obtained value was approximately 20%. A displacement of the ballistic pendulum without any deflector reached 71.5, almost 100% more than for the deflector number 3.

4. Summary

The performed numerical analyses can be concluded that the steel V-shaped deflectors are good solutions aimed at the effective dispersion of energy originating from detonation of explosive charge. Maximal displacement of ballistic pendulum without any deflector was 71.5 mm while with mounted deflector number 3 it was only 37.1 mm.

In case when dynamic load of the pendulum comes from detonation of only 50 g of the explosive charge, thickness of used material is irrelevant. Performed analyses shows that for 1 mm and 4 mm material thickness difference was at the level of 1%. We can assume that with the increase in mass of the explosive charge this difference will gradually increase. However, confirmation of this assumption requires additional study.

Geometric shape of the deflector has a significant impact on its ability to dissipate energy from the detonation of explosives. The more the deflector is “flat” its ability to dissipate the energy decrease. The best results were obtained for deflector wherein the distance from the base to the outermost edge was 75 mm.

Acknowledgement

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