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NUMERICAL ANALYSES OF THE V-SHAPED DEFLECTOR EFFECTIVENESS

Robert Panowicz, Marcin Konarzewski, Michał Trypolin

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 683-98-49, fax. +48 22 683-93-55
e-mail: robert.panowicz@wat.edu.pl, marcin.konarzewski@wat.edu.pl

Abstract

One of the most effective ways to protect mobile objects from the effects of the pressure wave originating from the detonation of a landmine or an explosive charge is to use a special design of the bottom of the protected vehicle. Such structure, called the deflector, in most cases has the shape of the V letter. Article presents the study of effectiveness of the V-shaped deflector. Authors prepared numerical model of a ballistic pendulum consisting of the 1 meter long HEB220 H-beam, suspended using four parallel steel ropes. In the front part of the beam, deflector was mounted. The test component was loaded with pressure wave coming from the detonation of an explosive charge. The article presents an analysis of the ability of the deflector to disperse and/or absorption of energy, depending on the type of the used explosive material and its mass. Studies have been done on the basis of numerical analysis performed with use of the finite element method with explicit integration over time scheme, implemented in the LS-Dyna software. For generation of the pressure wave originating from the detonation of explosive charge ConWep algorithm was used. It uses the predefined by the user geometric and mass parameters, and TNT equivalent to the generation of a pressure pulses.

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

1. Introduction

The one of the most popular and simplest ways to evaluate effectiveness of the energy absorbing structures such as deflectors is to use a ballistic pendulum. In its simplest form ballistic pendulum, consist of the large mass suspended on the long arm. Is operation principle 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.

One of the most effective structures to disperse energy from detonation of the explosive material is V-shaped steel deflectors. Such objects can not only absorb energy but also deflect a pressure wave outwards [2]. Schematic illustrating the principle of action of the deflector is shown in the Fig. 1.

Authors prepared the classical ballistic pendulum made from 1-meter long double-T beam HEB220. The beam is suspended on four parallel steel ropes. On the front part of the pendulum, there is steel plate, which allows us to mount a variety of energy dissipating structures. The structures are mounted by 200 millimetres long spacers. Such numerical model allow for wide range of analyses. In the previous works, authors researched an effectiveness of selected aluminium foams for energy absorption [5] and influence of V-shaped deflector geometry and stiffness [6].

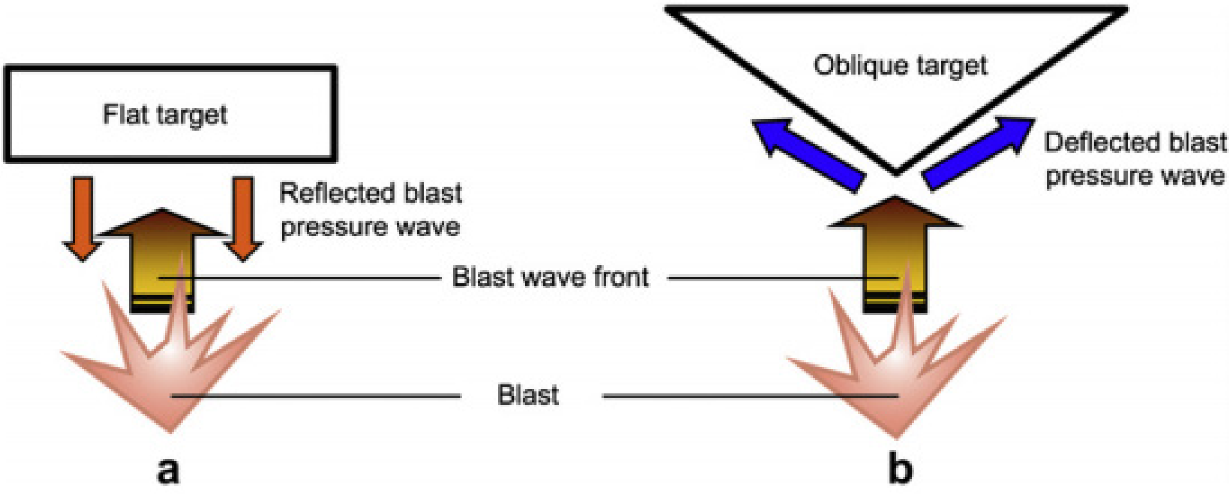

Fig. 1. Schematic of blast wave deflection by flat and V-shaped deflector [2]

The article presents results of the numerical analyses of the steel, V-shaped deflector mounted on the ballistic pendulum. Authors researched the ability to disperse the energy originating from detonation of several different explosive materials. In every case, generation of pressure wave was performed by using the Conwep algorithm.

2. Numerical model of ballistic pendulum

Presented in the article ballistic pendulum is made from 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.

The research was conducted with the use of finite element method.

Mechanical properties of the steel deflector were described using simplified Johnson-Cook material model (J-C) [3]. The only difference between simplified and full model, is that simplified does not take into account influence of thermal effects on the material properties [7]. The influence of strain rate is in both models identical.

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

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

Material constants used during the numerical analyses are presented in the Tab. 1. Geometric shape of the deflector is shown in the Fig. 3.

To generate a dynamic load from detonation process of an explosive charge the ConWep algorithm was used. This scheme was originally developed by Kingery and Bulmash [6], is applicable for spherical explosions in the air, and for semi spherical for cases when explosive is placed on solid support. Currently this algorithm is a part of LS-Dyna solver [8].

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

$$P(t) = P_{S0}\left[1 - \frac{t-T_a}{T_0}\right]\exp\left[\frac{-A(t-T_a)}{T_0}\right], \tag{3}$$

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 [ms].

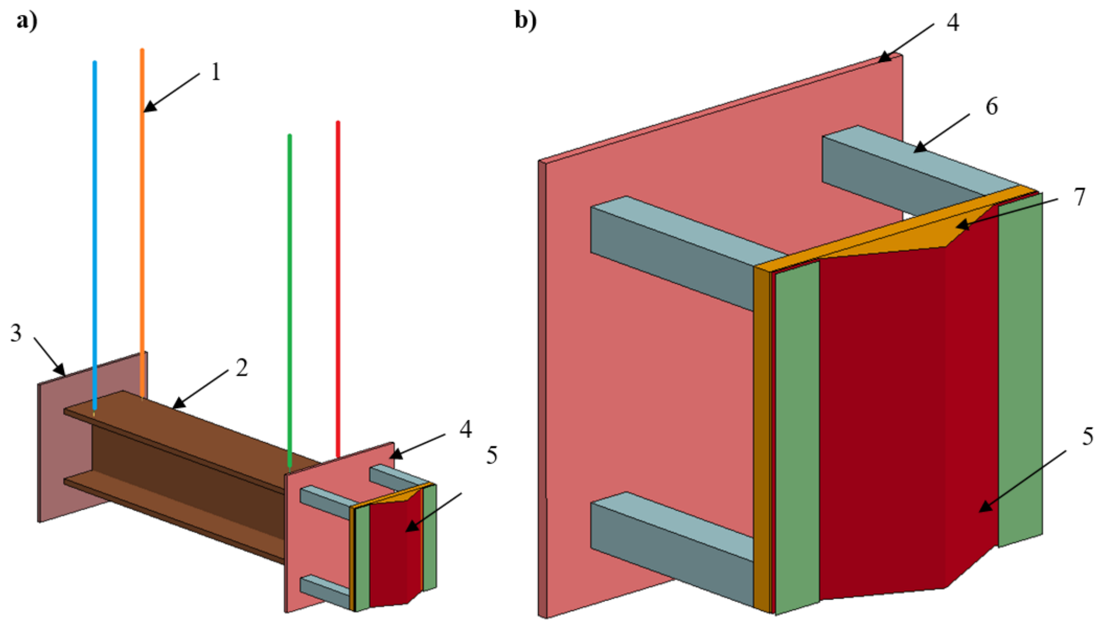

Fig. 2. Ballistic pendulum (a), front part of the pendulum (b), 1 –steel ropes, 2 –double-T beam, 3 – counterweight, 4 – front plate, 5 – deflector; 6 –spacers; 7 –mounting plate

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

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

In order to correctly model, the behaviour of the steel 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 [3]:

$$F = \max(F_{+} + K\Delta L, 0.), \tag{4}$$

where $\Delta L$is change in length:

$$\Delta L = L_C - (L_P - O), \tag{5}$$

where:
L_C – current length,

L_P – initial length,
O – offset.

Stiffness K is defined as:

$$K = \frac{E*A}{(L_P - O)}, \tag{6}$$

where:
E –Young modulus,
A –cross section area.

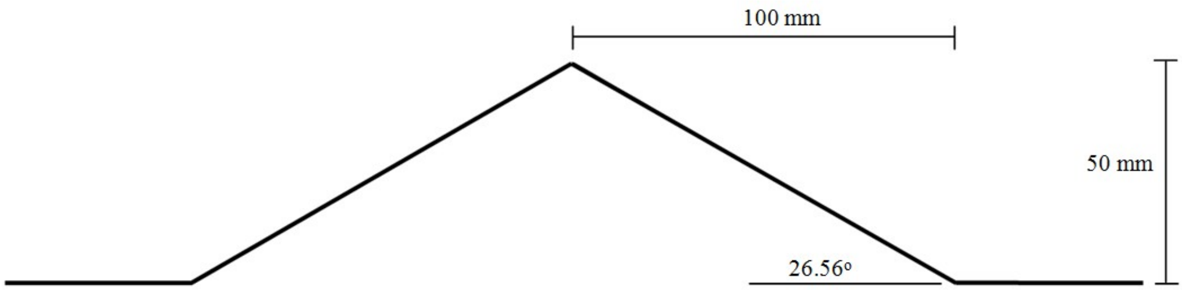

Fig. 3. Geometric shape of tested deflector

3. Results of numerical analyses

One geometric shape of deflector was analysed by the authors (Fig. 3). The entire system was loaded with pressure wave originating from detonation of several different explosive materials of different masses. The authors decided to research capabilities of deflector to disperse and/or absorb the energy from such explosives as octogen (HMX), composition B, semtex and penthrite (PETN). Each material was prepared in two mass variants: 50 g and 100 g. In every case, the distance between the deflector mounting plate and explosive material was constant and equal to 250 millimetres. Summary of the analysed variants is presented in the Tab. 2.

Tab. Summary of considered variants

	Explosive mass – variant 1	**Explosive mass – variant 2**
Composition B	50 g	100 g
Octogen (HMX)	50 g	100 g
Penthrite (PETN)	50 g	100 g
Semtex	50 g	100 g

In order to model different explosive charges with the ConWep algorithm it is necessary to relate mass of given explosive to the mass of TNT with use of the TNT equivalent. TNT equivalents used by the authors are presented in the Tab. 3.

Tab. 3. TNT equivalents of selected explosive materials

	Mass [g]	**TNT Equivalent**	**Equivalent in the TNT mass [g]**
Composition B	50	1.191	59.55
Composition B	100	1.191	119.1
Octogen(HMX)	50	1.447	72.33
Octogen (HMX)	100	1.447	144.7
Penthrite (PETN)	50	1.121	56.05
Penthrite (PETN)	100	1.121	112.1

Semtex	50	1.286	64.3
Semtex	100	1.286	128.6

As the measured parameter, the maximum displacement of the centre of the pendulum was chosen. Obtained results in the form of graphs are presented in Fig. 4 and 5.

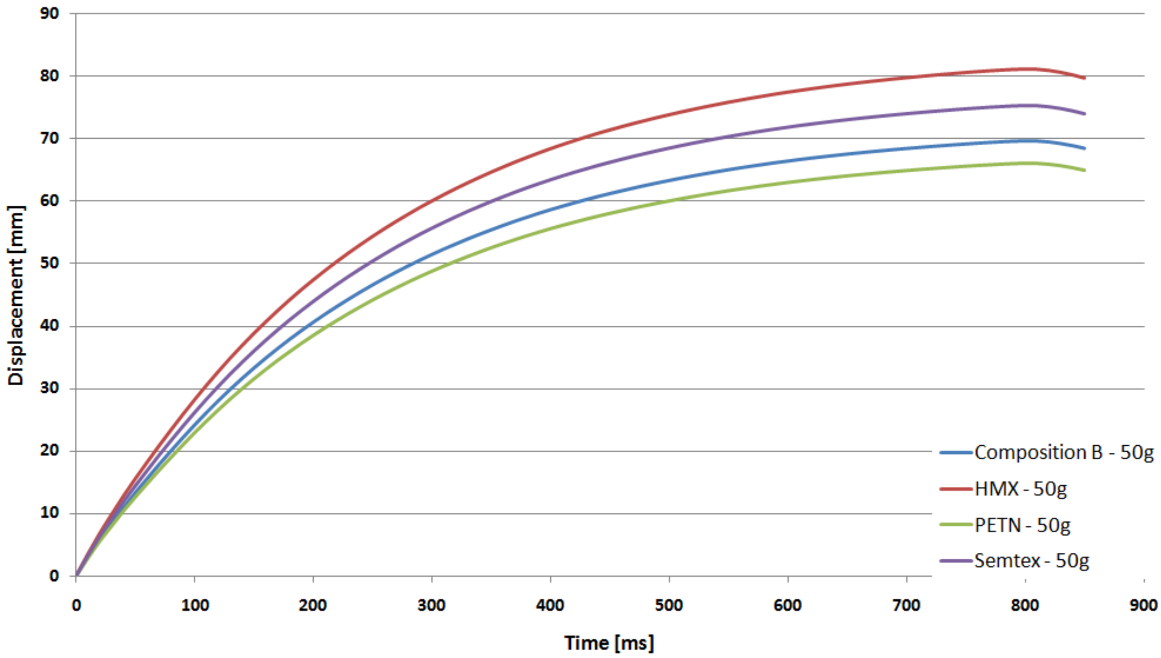

Fig. 4. Time-displacement graph for 50 g explosive materials

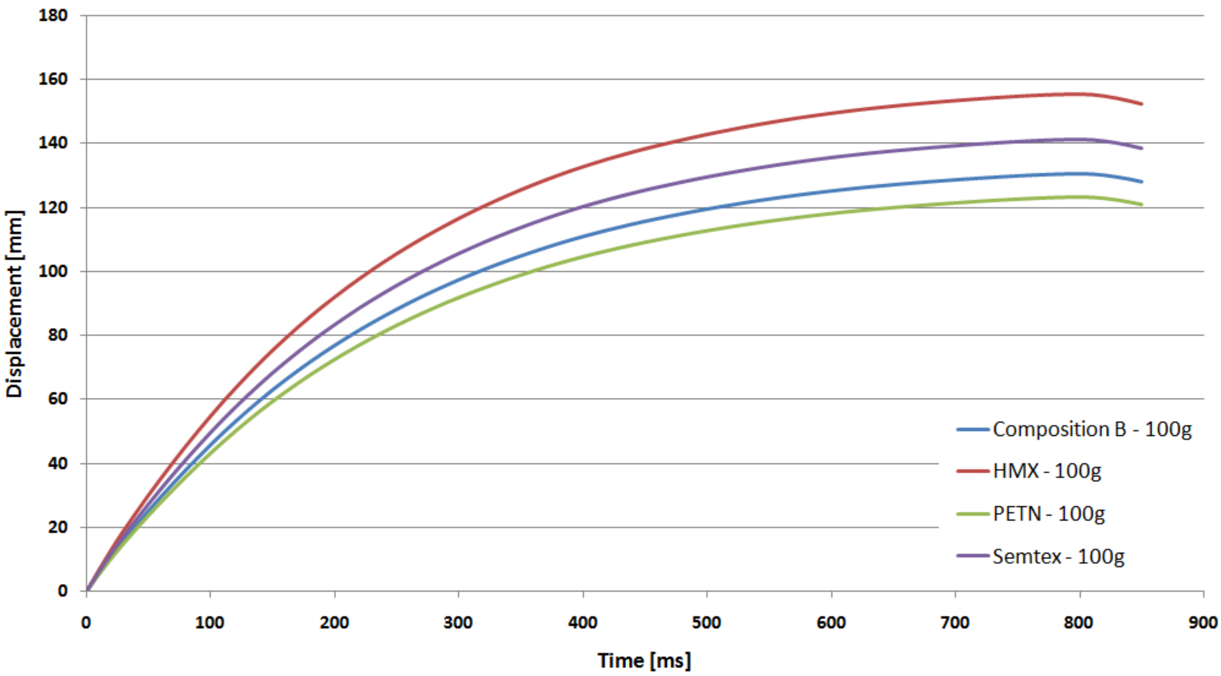

Fig. 5. Time-displacement graph for 100 g explosive materials

From the results of the numerical analyses, we can observe that in every case the obtained displacement of the pendulum was largest for the HMX explosive. It is due the fact, that HMX, because of its parameters (such as detonation speed, Chapman-Jouguet pressure), has the largest value of the TNT equivalent, from the selected explosive materials. The difference between the highest value (from HMX explosive) and the lowest (PETN) for the 50 g variant is equal to the 19% and is insignificantly higher for the 100 g variant where is equal to 20%.

The values of the pendulum displacement for every variant are presented in the Tab. 4.

Tab. 4. Maximum displacement of the ballistic pendulum

	Mass [g]	Pendulum displacement [mm]
Composition B	50	69.6
Composition B	100	130.5
Octogen (HMX)	50	81.8
Octogen (HMX)	100	155.5
Penthrite (PETN)	50	66.1
Penthrite (PETN)	100	123.4
Semtex	50	75.3
Semtex	100	141.5

4. Summary

Article presents numerical analyses of a V-shaped deflector mounted on ballistic pendulum. The system was loaded by a pressure wave originating from detonation of the selected explosive materials using Conwep algorithm. Authors measured maximum displacement of the pendulum. The highest values were obtained for the HMX explosive. Maximum displacement of pendulum was obtained for HMX explosive charge.

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