Physical Modelling of Mine Blast Impact on Armoured Vehicles

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Abstract. Studies related to the impact of a mine blast on armoured vehicles focus on aspects such as i) dynamic loads acting on the armoured vehicle at the moment of mine blast; ii) armoured vehicle response under the impact of a dynamic load; iii) dynamic loads acting on the crew and the assessment of potential human traumas. The paper presents similarity criteria for physical modelling of the mine blast under the armoured vehicle and the results of modelling of dynamic behaviour of vehicles. Similarity criteria, established as a result of the analysis of the governing parameters and similarity theory, are adequate to the processes of blast impact on the vehicle. Modelling experiments were conducted in the underground experimental base of the Mining Institute especially designed for the study of explosion processes. Physical modelling can be used for preliminary studies with the purpose of the evaluation of the protective level of armoured vehicles as well as for pre-testing experiments in accordance with STANAG 4569 requirements.

1. Introduction
Designing of explosion-resistant armoured vehicles and evaluating the protection level to blast mine threats requires a comprehensive study of blast impact processes. At present, such studies are conducted primarily by means of experimental or computer modelling, while the application of physical modelling methods is relatively rare although the latter has obvious advantages for certain types of tasks [1,2,3,4,5]. For example, the study of dynamic behaviour of vehicles during large-scale variation of dynamic loads, including near critical, through experimental or computer modelling is both difficult and expensive. The use of physical modelling potential in the design and testing of armoured vehicles is restricted due to the lack of the conditions of similarity between a model and a real-life prototype. Strict observance of the conditions of similarity between a model and its real-life prototype is essential for meeting the objective. According to the theory of modelling, the following characteristics are required and are sufficient for similarity: a) qualitative homogeneity; b) dimensionless combination of their governing parameters shall be equal.

The parameters governing the process of a blast impact of on an armoured vehicle depend on blast conditions and vehicle properties, as well as on the conditions of interaction between dynamic loads and a vehicle.
2. Similarity Criterion

2.1 Similarity Criteria for Explosions

Overpressure during mine blast under armoured vehicle equals overpressure in the model $P_N = P_M$, when

$$\frac{L_N}{E_N^{\frac{1}{2}}} = \frac{L_M}{E_M^{\frac{1}{2}}}$$

(1)

Where:

$L_N$ and $L_M$ are the distance from the centre of the charge to the underside of the chassis in the prototype and in the model, measured in m;

$E_N$ and $E_M$ - blast energy in the prototype and in the model, measured in J.

2.2. Similarity criteria of dynamic processes

Studies conducted by applying the provisions of the theory of dimensions and $\Pi$ theorem have allowed to establish criteria of similarity between a real-life prototype and a model, which is a dimensionless combination of governing parameters:

$$\frac{F_N^3 \times T_N^4 \times G_N}{E_N \times L_N^5 \times M_N \times I_N \times V_N} = \frac{F_M^3 \times T_M^4 \times G_M}{E_M \times L_M^5 \times M_M \times I_M \times V_M}$$

(2)

Where:

$F_N$ and $F_M$ - force in the prototype and in the model;

$T_N$ and $T_M$ - time in the prototype and in the model;

$G_N$ and $G_M$ - acceleration in the prototype and in the model;

$E_N$ and $E_M$ - modulus of elasticity in the prototype and in the model;

$L_N$ and $L_M$ - linear dimensions in the prototype and in the model;

$M_N$ and $M_M$ - mass in the prototype and in the model;

$I_N$ and $I_M$ - pressure impulse in the prototype and in the model;

$V_N$ and $V_M$, movement velocity in the prototype and in the model.

The following independent criteria were obtained for dimensionless combination of a real-life prototype and a model:

$$\frac{F_N}{E_N \times L_N^2} = \frac{F_M}{E_M \times L_M^2}$$

(3)

$$\frac{F_N \times T_N^2}{M_N \times L_N} = \frac{F_M \times T_M^2}{M_M \times L_M}$$

(4)

$$\frac{F_N \times T_N}{I_N \times L_N^3} = \frac{F_M \times T_M}{I_M \times L_M^3}$$

(5)

$$\frac{G_N \times T_N}{V_N} = \frac{G_M \times T_M}{V_M}$$

(6)
To the aforementioned criteria shall be added the criterion of equality of Poisson’s ratio of real-life prototype and model material:

\[ \nu_N = \nu_M \]  

(7)

The values of factors of similarity between a real-life prototype and a model are given in Table 1.

### Table 1. Factors of similarity between a real-life prototype and a model

| #  | Parameter                  | Dimensions | Scale factor |
|----|----------------------------|------------|--------------|
| 1  | Linear dimension           | [L]        | \( K_L = L_N / L_M \) |
| 2  | Mass                       | [M]        | \( K_M = M_N / M_M = K_L^2 \) |
| 3  | Time                       | [T]        | \( K_T = T_N / T_M = K_{0.5}^L \) |
| 4  | Pressure                   | [M] \[L^{-1}\] \[T^{-1}\] | 1 |
| 5  | Pressure pulse             | [M] \[L^{-1}\] \[T^{-1}\] | \( K_I = I_N / I_M = K_{0.5}^L \) |
| 6  | Force                      | [M] \[L\] \[T^{-2}\] | \( K_F = F_N / F_M = K_{2}^L \) |
| 7  | Velocity                   | [L] \[T^{-1}\] | \( K_V = V_N / V_M = K_{0.5}^L \) |
| 8  | Acceleration               | [L] \[T^{-2}\] | 1 |
| 9  | Linear displacement        | [L]        | \( K_X = X_N / X_M = K_L \) |
| 10 | Modulus of elasticity      | [M] \[L^{-1}\] \[T^{-2}\] | 1 |
| 11 | Poisson’s ratio            | -          | 1 |
| 12 | Strength                   | [M] \[L^{-1}\] \[T^{-2}\] | 1 |

#### 3. Physical Model of Armoured Vehicle

The scale factor of the physical model for linear dimension is \( K_L = 3 \). The model contains four support stands, a bottom plate, an upper plate and extra mass. The plate has the following dimensions: 1920 mm x 790 mm, thickness - 8 mm. It is made of steel. The compressive strength is 480 kg/mm². The distance between the floor and the bottom plate is regulated by means of hydraulic jacks and ranges between 10-60 cm with 5 cm intervals (Figure 1).

![Figure 1](image_url). 1 - support stand, 2 - bottom plate, 3 - extra mass, 4 - sensors, 5 – charge
The weight of the model encompasses 573 kg. To meet the similarity criteria, the model must weigh 900 kg. Therefore, evenly distributed steel blocks are placed in the front and back parts of the model. The total weight of the blocks is 327 kg.

4. Results and Discussions

4.1 Overpressure distribution on the vehicle bottom plate

Conditions of the experiments: the charge was placed on the floor, below the geometrical centre of the bottom plate. The charge weight in the model was 0.222 kg and the vertical distance from the charge to the plate was 16.6 cm. The floor was made of a 6 mm thick steel plate fixed into a concrete plate, the thickness of which is 50 cm. Overpressure was measured with PCB 102B sensors, acceleration with accelerometer PCB 350 B03 and velocity with velocimeter VBP-3. Data were recorded by means of Tektronix 420A oscilloscope. The layout of sensors on the bottom plate is presented in Figure 2.

![Figure 2. Layout of sensors on the bottom plate. S1-S9 – overpressure sensors, A – accelerometer, V1 and V2 – velocimeters](image)

According to oscillograms, the duration of overpressures in the models does not exceed 5-7 ms (Figure 3). In real conditions, overpressures last for 8-12 ms.

![Figure 3. Overpressure histories on the bottom plate (W= 0.222 kg, R= 16.6 cm)](image)
Figure 4 and 5 show the mean values of overpressures acting on the bottom plate in the transversal and longitudinal directions when the charge weight in the model was 0.222 kg, and the distance from the floor to the bottom plate was 0.166 m. In real conditions the distance is 0.498 m, and the weight charge is 6.0 kg.

![Figure 4](image)

**Figure 4.** Overpressure distribution in the direction of the transverse axis of the bottom plate. 1 - section 1-1; 2 - section 2-2

![Figure 5](image)

**Figure 5.** Overpressure distribution in the direction of longitudinal axis of the bottom plate. 1 - section 3-3; 2 - section 4-4

4.2 Vertical displacement, velocity and acceleration

In the conditions of the experiment, when the charge was located on the steel floor, the vehicle started moving after the detonation of 0.05 - 0.1 ms, while the entire duration of the movement is 30-40 ms (Figure 5, 6). Results of experiments are shown in Table 2.
Figure 6. Velocitygram of motions of the model. 1- forebody; 2- back part)

Figure 7. Accelerogram of motions of the model

Table 2. Kinematic characteristics of the motion

| Charge weight TNT, [kg] | Measurement place | Velocity, [m/s] | Displacement, [cm] | Acceleration, [g] |
|-------------------------|-------------------|----------------|-------------------|------------------|
| Model                   | Real              | Model         | Real             | Model            | Real            |
| 0.074 2.0               | Front side of the bottom plate | 13.33 | 23.0 | 1.73 | 5.19 | 5111 | 5111 |
|                         | Back side of the bottom plate | 6.0 | 10.39 | 1.2 | 3.6 | 3000 | 3000 |
|                         | Centre of the bottom plate | - | - | - | - | 3128 | 3128 |
| 0.185 5.0               | Front side of the bottom plate | 25.3 | 43.7 | 2.27 | 6.81 | 14055 | 14055 |
|                         | Back side of the bottom plate | 14.6 | 25.3 | 1.46 | 4.38 | 7330 | 7330 |
|                         | Centre of the bottom plate | - | - | - | - | 10168 | 10168 |
5. Conclusions
Similarity criteria, established as a result of the analysis of the governing parameters and similarity theory, are adequate to the processes of blast impact on the vehicle. Physical modelling can be used for preliminary studies with the purpose of evaluation of the protective level of armoured vehicles as well as for pre-testing experiments in accordance with STANAG 4569 requirements.

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