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Research of the mine imitator interaction with deformable soil and its practical realisation

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1. Introduction

The mine imitator‘s facilities are designed for artillery specialists training. The simulator consists of a housing the external surface of which in fact reconstructs contour of the mine with a barrel and charge installed inside. With the purpose to imitate blast of the mine the simulator the charge of which is filled with smoke gunpowder is fired at the necessary distance and then when falling and hitting the soil it is initiated thus imitating the blast. The simulator has four parts which consist of the mine imitator, the shell and the charges with the corresponding amount of gunpowder, what ensures semi-natural field firing at the distances scaled by the factor of 1/10 with respect to the natural ones. When the mine imitator hits the soil surface the detonator is initiated thus imitating the blast and "smoke cloud" appearance [1].

The simulator should ensure reliable performance of the mine imitator using it at different conditions of soil surfaces. This is predefined by sufficient displacement of the detonator's stud with respect to the capsule during interaction process of the detonator's cap and the soil. Mathematical model of the interaction of the simulator and the soil and the results obtained are presented in the following sections [2].

In the problem analysed two aspects can be distinguished – displacement of the free falling shell structure and its deformation at the interaction with the mass (body), which has characteristic elastic – dissipative properties as in analysed in literature [3, 4]. But the analysed case is distinctive by the fact that the process under analysis evolves at the same time and parameters and characteristics of certain dynamical system are evaluated.

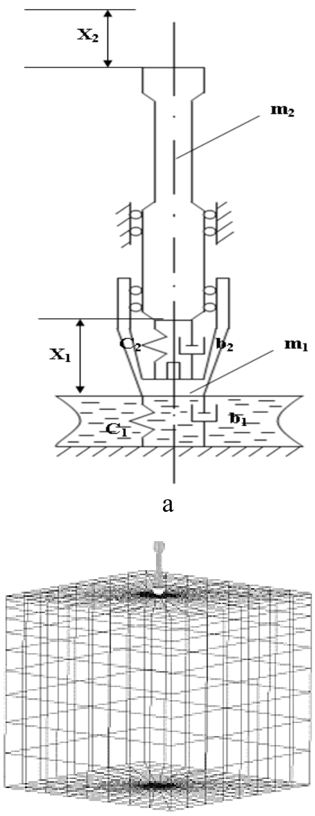
Strength characteristics of the soil due to dynamic effects strongly depend on microstructure of the soil, the size and distribution of its grains. Humidity level of the soil has a certain effect on initiation of the imitator. Pores in between the grains can be filled with air or water.

A mathematical model of the interaction of the mortar mine imitator and the soil is presented in the paper. Simulation of the mine‘s imitator penetration into the soil is performed using MATLAB software. FEM simulation of the penetration is also performed by LS-DYNA FEM code. The penetration characteristics obtained by the simulation both using MATLAB and LS-DYNA has similar tendencies.

2. Dynamical model of the interaction of mortar mine‘s imitator and the soil

Dynamical model of the interaction of the mortar mine‘s imitator and the soil is constructed with the purpose to determine penetration rate of the imitator, its penetration depth and displacement of the stud of the detonator's cap towards capsule-detonator. These three main parameters are described by two differential equations of motion.

Dynamical model of the interaction of the mortar mine‘s imitator and the soil is presented in Fig. 1.



a

b

Fig. 1 Dynamical model of the interaction of the mortar mine‘s imitator and the soil (a) and finite element model generated by LS-DYNA code (b)

Equations of motion

$$m_1\ddot{x}_1 + (b_1 + b_2)\dot{x}_1 + (c_1 + c_2)x_1 - b_2\dot{x}_2 - c_2x_2 = 0$$

$$m_2\ddot{x}_2 + b_2\dot{x}_2 + c_2x_2 - b_2\dot{x}_1 - c_2x_1 = 0$$

where m_2 is mass of the body of the mine imitator; m_1 is mass of the cap of the mine imitator; c_1, b_1 are stiffness and damping coefficients of the soil for which elasticity and damping properties are characteristic; c_2, b_2 are stiffness and damping coefficients of the cap.

From the presented above model in the form of differential equations of motion it can be concluded that depending on the parameter values motion of the system can be of two types – nonperiodic or oscillatory with decaying amplitude.

Stiffness and damping coefficients of the soil for which elasticity and damping properties are characteristic and the cap in the lumped parameter model presented above are selected as presented in Table.

Table

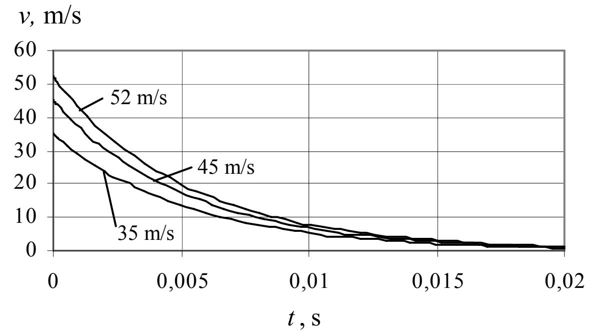
Stiffness and damping coefficients

	c_1	c_2
Stiffness coefficient	10 N/m	57 N/m
	b_1	b_2
Damping coefficient	2.5 Ns/m	5 Ns/m

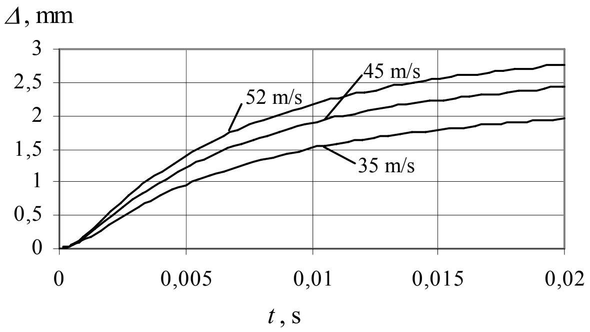
Also the two main parameters are selected as follows: the mass of mine imitator's cap m_1 = 0.005 kg and the mass of mine imitator's body m_2 = 0.25 kg.

3. Results of the theoretical research

The dependences of penetration rate of the mine imitator, displacement of the stud of the detonator's cap towards capsule-detonator and penetration depth of the mine imitator into the soil on time obtained by the simulation using MATLAB 6 [5] and LS-DYNA [6] are shown in Figs. 2 and 3.



a

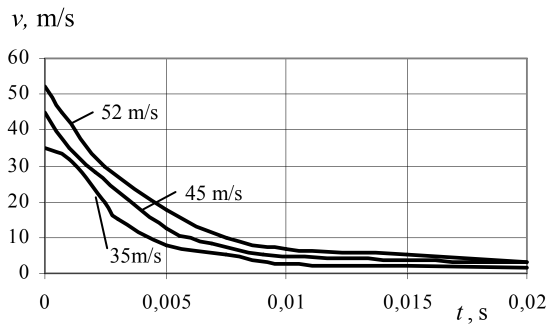


b

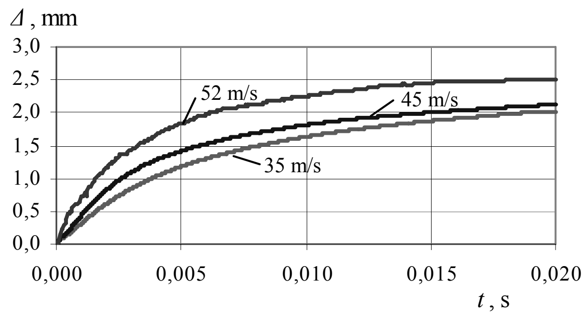
Fig. 2 Dependences of penetration rate of the mine imitator (a), displacement of the stud of the detonator's cap towards capsule-detonator (b) on time obtained by the simulation using MATLAB 6

The dependences of penetration rate of the mine imitator and displacement of the stud of the detonator's cap towards capsule-detonator are shown in Fig. 3, a and b at different imitator's initial speeds - v = 35, 45, 52 m/s.

The penetration rate after the imitator hits the soil starts to decay. Simultaneously after hitting the soil by the imitator the displacement of the stud of the detonator's cap Δ grows with time until it reaches capsule-detonator. For initiation of the detonator the displacement of the stud towards capsule-detonator should be not less than 2.5 mm. The obtained results show that the detonator will be initiated at the hitting speed of v = 52 m/s.



a



b

Fig. 3 Dependences of penetration rate of the mine imitator (a), displacement of the stud of the detonator's cap towards capsule-detonator (b) on time obtained by the simulation using LS-DYNA

The most important indicators of the penetration of the mine imitator into the soil are penetration rate of the mine imitator and composition of the soil. The more porous is the soil the greater penetration depth will be reached. Penetration depth of the mine imitator into the soil (the soil – sand) in dependence on penetration rate is shown in Figs. 4 and 5.

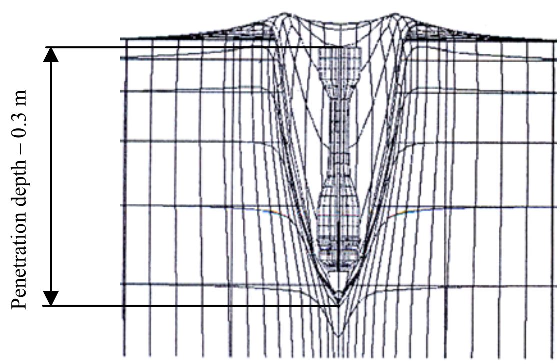
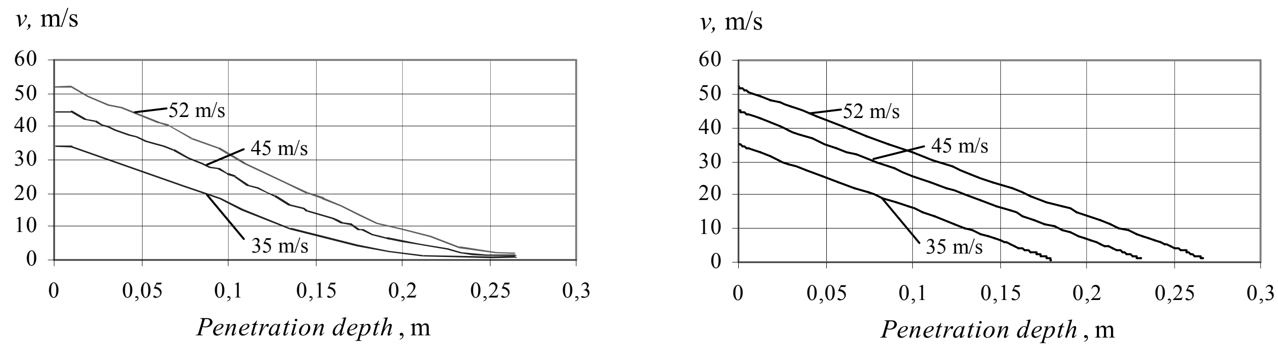


Fig. 4 The example of the resulting penetration into the soil at the velocity of the mine imitator v = 35 m/s



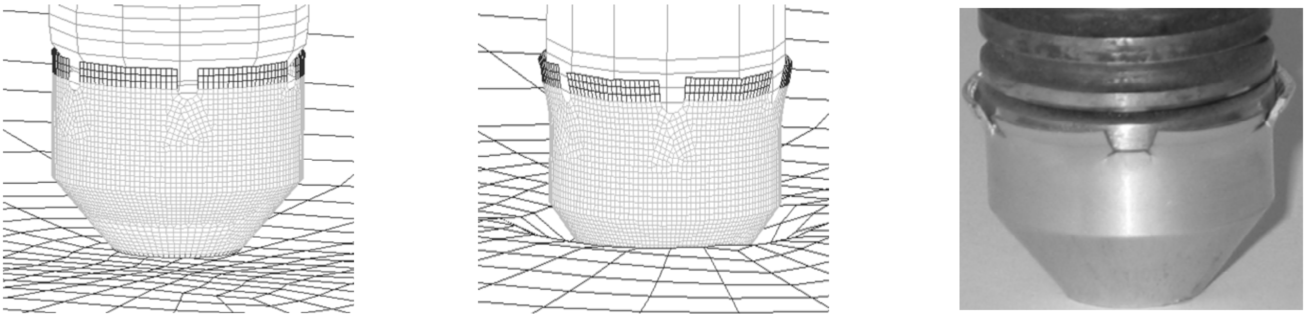
a b

Fig. 5 Penetration depth of the mine imitator into the soil (the soil-sand) dependence from initial velocity (35, 45, 52 m/s): a – simulation using the programme MATLAB 6; b – simulation using the programme LS-DYNA

Comparison of the simulation results obtained using MATLAB 6 software and LS-DYNA FEM code indicate that the displacement of the stud of the detonator's cap towards capsule-detonator and the penetration rate of the mine imitator coincide with sufficient level.

The contact force acting the cap reaches the maximum value at the beginning of the penetration into the soil material. The FE simulations shows that in case of soft sand soil and impact velocity $v = 35$ m/s, the reliability of mine imitator is on the limit to initiate explosion. It is obtained, that the cap deforms just in first 20 mm of penetration. This also seen from the cap deformations presented in Fig. 6, b comparing to the initial form Fig. 6, a. Residual impact energy (about 99% at $v = 35$ m/s) is absorbed only by deformations of the soil material.

Comparing the structural behaviours of mine imitator was estimated that the deformations of the caps in all analyzed velocities were similar. In all cases cap deforms similarly and differs just final penetration depth of the soil.



a b c

Fig. 6 Resulting deformations of detonator's cap a – initial form; b – $v = 35$ m/s 20 mm depth of penetration; c – picture of deformed detonator cap from experiments at polygon

4. Experimental field tests and practical realisation

The trainer is used at different soil surface conditions and should ensure the reliable performance of the mine imitator. This is predefined by sufficient displacement of the detonator's stud with respect to the capsule during interaction process of the detonator's cap and the soil. The methodics of experimental interaction research of detonator's cap of the mine imitator and non deformable or deformable surface, test rig structure and results of the performed experiments are presented in this section.

Experimental field tests of the developed training facilities were performed. For this purpose a batch of 100 test imitators was manufactured. Imitators of the batch were tested simulating all firing charges and all firing angles – 45°, 60°, 80°. There were at all no non performance cases during the tests.

For test simulation cap views of the mine imitator after initiation when firing with initial speed $v = 45$ m/s at 45°, 60°, 80 firing angles are shown in Fig. 7. The 60 mm and 120 mm mortar training equipment was created on the basis of obtained theoretical and experimental research results (Fig. 8).

This equipment was successfully implemented in practice for training of solders and combat units.

a b c

Fig. 7 Experiment field test views of the mine imitator after firing with initial speed $v = 45$ m/s: a – 45°; b – 60°; c – 80°angles

a b c

Fig. 8 60 mm and 120 mm mortar training equipment: a – 60 mm sabots; b – 120 mm sabots; c – mine imitators with charges

5. Conclusions

1. Dynamical and mathematical models of the interaction of the mortar mine‘s imitator and the soil are developed, FEM model is generated by LS-DYNA code, the characteristics of penetration rate and depth of the imitator into the soil, the displacement of the stud of the detonator’s cap towards capsule-detonator are determined.

2. Comparison of the simulation results obtained using MATLAB 6 software and LS-DYNA FEM code indicate the sufficient level of their agreement.

3. The created semi natural mortar shooting equipment in successfully implement in practice.

Acknowledgements

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A. Fedaravičius, S. Kilikevičius, A. Survila, P. Šaulys, V. Lendraitis

MINOSVAIDŽIO MINOS IMITATORIAUS IR BESIDEFORMUOJANČIO PAVIRŠIAUS SĄVEIKOS TYRIMAS IR PRAKTINIS PRITAIKYMAS

R e z i u m ė

Darbe nagrinėjami minos imitatoriaus sąveikos su grunto paviršiumi procesai. Naudojant programą LS-DYNA, nustatyta minos imitatoriaus sąveikos su gruntu, esant 35, 45 ir 52 m/s kritimo greičiams, pobūdis ir kompiuterinės charakteristikos. Sudarytas minos imitatoriaus sąveikos su gruntu dinaminis modelis. Kompiuterinis sąveikos modeliavimas atliktas programine įranga MATLAB 6. Gauti rezultatai palyginti su baigtinių elementų metodo programine įranga LS-DYNA gautais rezultatais. Tyrimo rezultatai sėkmingai pritaikyti praktikoje.

A. Fedaravičius, S. Kilikevičius, A. Survila, P. Šaulys, V. Lendraitis

RESEARCH OF THE MINE IMITATOR INTERACTION WITH DEFORMABLE SOIL AND ITS PRACTICAL REALIZATION

S u m m a r y

The interaction processes of mine imitator and the soil surface are analysed in the research. With the application of LS-DYNA FEM code the interaction characteristics and parameters of the mine imitator and the soil were determined for the velocity values of 35, 45, and 52 m/s. Dynamical model of the interaction of the mine imitator and the soil was developed. Computer simulation of the interaction was performed using MATLAB 6 software and the results obtained were compared with the results of simulation obtained using LS-DYNA FEM code. The obtained results were successfully applied in practice.

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