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NUMERICALLY MODELING OF EXPLOSIVE LOADING PROCESSES OF SNOW

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Abstract. Snow is modeled using S.S. Grigoryan's plastic compressible medium with nonlinear equations of state different for loading and unloading also capable of shear deformation. The adequacy of equation of state in the pressure range from tens to some hundreds megapascals is verified using comparison of one-dimensional plane problem's numerical solution of snow pack impact loading and available experimental data. The numerical solution's results of spherical explosion of blasting charge in snow are presented. Time-history dependences of radial and tangential stresses into the points located on the different distances from charge are analyzed. The analysis results are compared with data of experimental investigations.

1. Introduction

Research of processes of behaviour of packs of a snow under action of shock and explosive loadings actually from the point of view of carrying out of civil work, development of a transport infrastructure during winter time, an estimation of parameters of an avalanche formation, interaction of a snow with various barrier and elements of designs. Now the small amount of the works containing results of experimental researches [1-5] on dynamic loading of snow is known. Also there are not enough the works, devoted numerical modelling of impact loading of snow environments [6, 7]. Results of experiments show, that the snow shows nonlinear properties, various for stages loading and unloading. Below processes of snow's loading by a flat wave and spherical blasting charge with use of model of S.S.Grigoryan [8] are investigated. The numerical solution of problems is received using of S.K.Godunov's modified method [9] and variational-difference method, which are realized in software «Dynamika-1» [10].

2. Snow equation of state

For the description of compression of a snow approximation of a shock adiabatic curve in the form of Rankin- Hugoniot [6] up to density ρ = 0.82 g/cm^3 was used:

$$p=\rho_0 c_0^2\varepsilon/(1-s\varepsilon)^2,\ \varepsilon=1-\rho_0/\rho, \qquad (1)$$

where p – pressure, ε – volumetric deformation, ρ_0 – initial density.

Relations (1) assume linear dependence of speed of shock wave D and speed of particles of environment u: - $D=c_0+su$, where c_0 и s – material constants, which values for a snow are experimentally certain in [6] - c_0 = 54 m/s, s = 1.86 (Fig. 1a). For ρ > 0.82 g/cm^3 equation of state was continued nonlinear up to ρ = 0.9 g/cm^3, and linear up to ρ =5 g/cm^3, p = 10^5 MPa (Fig. 1b). Irreversibility of volumetric deformation of environment is supposed.

Sound speed for unloading C_p = 230 m/s. For $\rho \geq \rho_g$ =0.6 g/cm^3 is supposed that environment behaves as a nonlinear liquid (reversible).

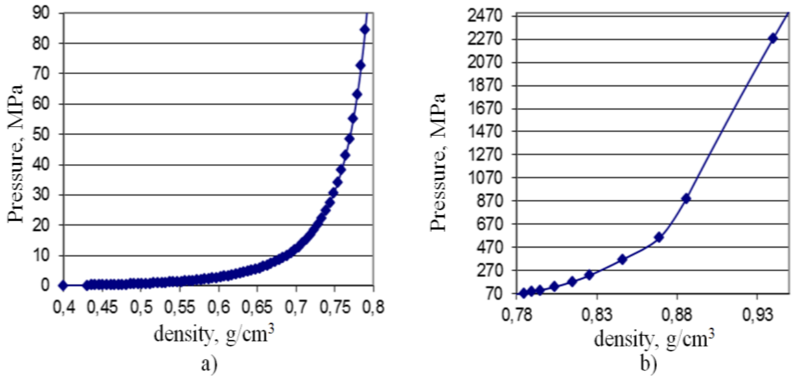

Fig. 1. Shock adiabat of snow.

Yield strength - pressure dependence in a snow was accepted in the form of a two-unit broken line

$$\sigma_T(p) = \begin{cases} Y(p) = Y_0 + \mu p, & p_e < p < P_{pl}, \\ Y_{pl}, & p \geq P_{pl}, \end{cases} \quad (2)$$

where μ - internal friction factor, Y_0 - coupling, Y_{pl}, P_{pl} – parameters of ultimate strength. Shear modulus was accepted equal G=20 MPa; constants in relation (2): Y_0=0.01 MPa, μ = 0.25, P_{pl} = 100 MPa, Y_{pl} = 25 MPa, ρ_0 = 0.4 g/cm^3.

3. Plane compression wave

For verification of the equation of state (1) - (2) comparison of the numerical solution of an one-dimensional flat problem about shock loading of semi-infinite snow environment with results of experiment [3] which scheme is specified on Fig. 2. At point 1 (x=0) time history dependence of pressure was applied (Fig. 3). As a result of experiment were measured time history dependences of stress at sencors (2-4) located along a line of action of shock loading on distances x = 0.013, 0.027, 0.037 m from place of impact.

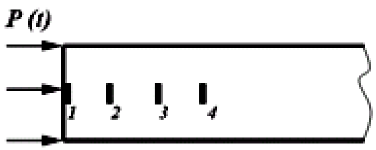

Fig. 2. Loading of snow solid by plane wave, 1-4 - position of sensors.

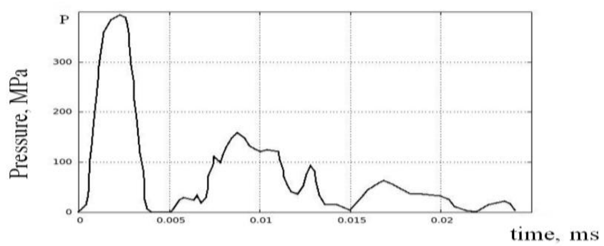

Fig. 3. The pressure dependence of time at point 1 (x = 0).

Figure 4 shows curves of time history dependences of stress, are obtained using analysis results (continuous lines) and experimentally (markers), corresponding indications of sencors 2-4.

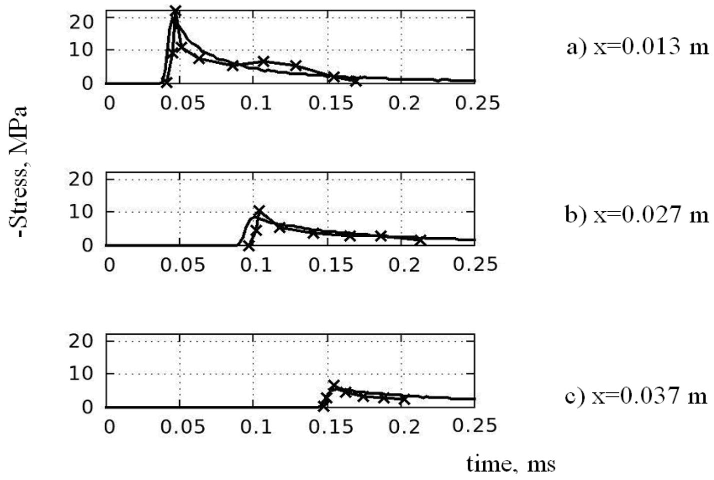

Fig. 4. The stress dependence of time at points 2-4.

Conformity of experimental and numerical results testifies to adequacy of used model of dynamic compression of a snow.

4. Spherical explosion in a snow pack

The one-dimensional problem about spherical explosion of blasting charge in a snow, modeling of a condition of experiments of G.M. Lyakhov [5] is considered. At [5] results of experimental researches of spherical blast waves in a snow of natural addition at ρ_0 = 0.27 g/cm^3 and artificial condensed at ρ_0 =0.4 g/cm^3 are resulted. Waves were created at blast explosion with density of blasting charge ρ_{BC} = 1.5 g/cm^3, mass 0.02 kg and radius r_{BC} = 1,47 cm, with the detonation characteristics close to trotyl. Maximal radial σ_r and tangential σ_θ stresses were measured on distances r ≥ 0.15 from charge.

Numerical solution is obtained for range 0 < r < 2 m, covered with mesh of 2000 cells. The coupling wave processes in a cavity filled by gas products of explosion, and in an environment with allocation of moving border of a cavity during the solution of the problem were described. Initial parameter's distributions in products of a detonation are taken from [11]. At Fig. 5 numerical radial a) and tangential b) stresses at points r=0,35 m, r=0,30 m, r=0,25 m, noted by 1, 2, 3 accordingly are presented.

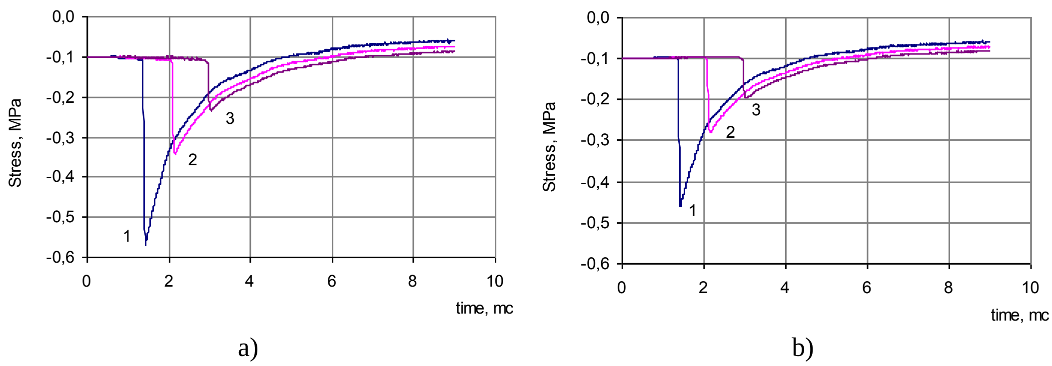

Fig. 5. The stress dependence of time at the selected points.

Numerical results in comparison with experimental data are shown at Fig. 6. Here digit 1 designates the bold curve approximating experimental data [5] for radial stresses, digits 2, 3 – curves, which obtained numerically for σ_r and σ_θ accordingly. Experimental points for stresses σ_θ are not resulted here owing to their wide scatter. It is possible to note good conformity of peak values of stresses in the chosen points. At [5] experimental value of radius

$r_к$ of camouflet cavities after the termination of expansion in a snow is resulted $r_к/r_{BC}$ =17. At carrying out of numerical researches it is obtained - $r_к/r_{BC}$ =16.3

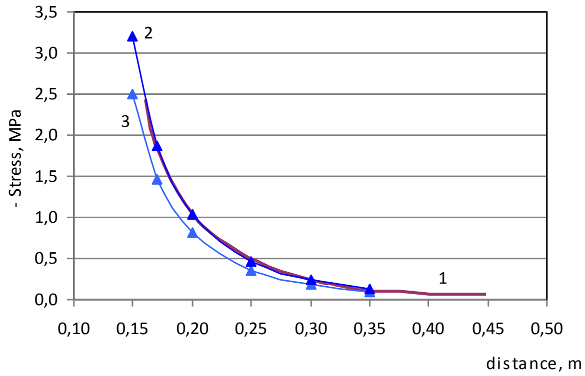

Fig. 6. The maximum tension depending on the distance; calculation and experiment.

5. Conclusion

The wide-range equation of state for the description of snow's dynamic дeformation is constructed. One-dimensional nonlinear problems about distribution of a plane wave and spherical explosion of blasting charge in a snow pack are solved. Conformity of experimental and numerical results testifies to adequacy of used model of dynamic behaviour of a snow and an opportunity of its application for the solution of applied problems.

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References

[1] C.W. Young, *Penetration Equations. Contractor report. SAND97-2426.* (Applied Research Associates, Inc., 1997).

[2] J.B. Johnson, D.J. Solie, J.B. Brown, E.S. Gaffney // *Journal of Applied Physics* **73(10)** (1993) 4852.

[3] J.B. Johnson, J.A. Brown, E.S. Gaffney, G.L. BIaisdell, D.J. Solie, In: *USA CRREL Rep.* (1992), p. 91-12.

[4] Yu.N. Buharev, V.P. Gandurin, A.E. Korablev, V.A. Morovov, M.I. Haymovich, In: *Applied problems of strength and plasticity. Analysis and optimization of structures* (Nizhni Novgorod University, 1991), Vol. **48**, p. 99.

[5] G.M. Lyakhov, V.I. Salitskaya, A.M. Averchenko, S.D. Zakharov, L.G. Bahrushina // *Combustion, Explosion, and Shock Waves* **25(4)** (1989) 124.

[6] D.A. Miller, R.G. Tichota, E.E. Adams // *Cold Regions Science and Technology* **69(2-3)** (2011) 156.

[7] E.G. Glazova, A.V. Kochetkov, S.V. Krylov, E.Yu. Poverennov // *Problems of Strength and Plasticity* **76** (2014) 235.

[8] S.S. Grigoryan // *Journal of Applied Mathematics and Mechanics* **24(6)** (1960) 1057.

[9] M.H. Abuzyarov, V.G. Bazhenov, V.L. Kotov, A.V. Kochetkov, S.V. Krylov, V.R. Feldgun // *Computational Mathematics and Mathematical Physics* **40(6)** (2000) 900.

[10] S.A. Afanasyev, V.G. Bazhenov, A.V. Kochetkov, V.R. Feldgun, In: *Applied problems of strength and plasticity. Automation of scientific strength research* (Gorky University, 1986), p. 21.

[11] F.A. Baum, L.L. Orlenko, K.P. Stanyukovich, *Physics of Explosion* (Nauka, M. 1975).