ESTIMATION OF SEISMIC EFFICIENCY OF IMPACTS OF COSMIC OBJECTS BY METHODS OF NUMERICAL ANALYSIS.

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Introduction: In recent years, laboratory studies of propagation of seismic waves induced by high-velocity impacts [1] have demonstrated an order of magnitude higher efficiency of converting the kinetic energy of projectiles to seismic energy, compared to the widely used value of 10^{-4} [2]. The aim of this work is to evaluate the seismic efficiency of crater-forming impacts of asteroids by numerical simulation of impacts and underground explosions and subsequent comparison of the amplitudes of shock waves generated by them, taking into account that the seismic efficiency of underground explosions is well known.

Methods: To assess the seismic efficiency of crater-forming impacts, we conducted a series of numerical experiments simulating an underground explosion and a vertical impact of a stone asteroid of radius r_0, consisting of dunite with a density ϱ=3.32 g/cm^3, having a velocity U = 20 km/s, and a kinetic energy $E_0 = 4/3\,\pi r_0^3 \varrho U^2/2$. The properties of a ground were modeled by the equation of state of quartz. The numerical simulations were performed by the method [3]. All distances, including the depth of explosion H, are compared with an asteroid diameter D_0.

We assumed that (1) the underground explosion of energy E_1 and the impact of energy E_2 generate identical seismic waves if they generate the same shock waves at distances of 30-300 D_0, (2) the relationship between E_1 and E_2 is not strongly dependent on the model of strength and can be approximately estimated from hydrodynamic simulations without considering strength, (3) the similarity of shock waves is determined from an approximate coincidence of dimensions of regions with a pressure $p > p^*$, where p^* is some given pressure.

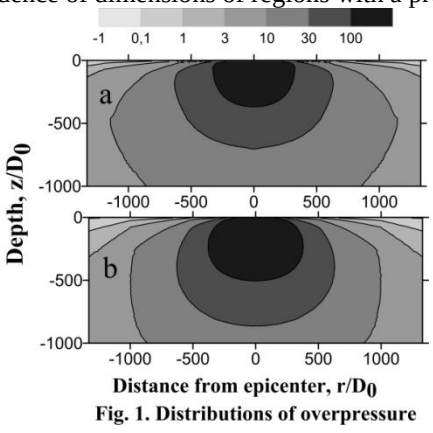

Fig. 1. Distributions of overpressure

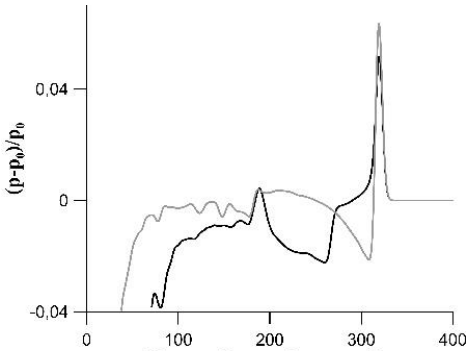

Fig.2. Pressure distribuiton.

Results: Figure 1 shows contours of overpressure p-p_0 in bars, where p_0 is the unperturbed pressure at the corresponding depth and p is the maximum pressure during the whole time of simulations at a given point. In this problem, the isolines of the overpressure can be interpreted as shock waves in the course of their propagation. Figure1a shows the results of simulations of an underground explosion with an energy E_0 at a depth $H = 40D_0$, and Fig. 1b shows the results of simulations of a vertical impact with an energy $5E_0$. We tried to select the initial impact energies so that the amplitudes of the shock waves at various distances along the horizontal were approximately the same.

Parameters of generated seismic waves can depend not only on the maximum amplitudes of the shock waves, but also on their profiles, in particular on the duration of a pressure pulse. According to Fig. 2, which shows the distribution of overpressure along a beam emerging from the point of impact at an angle of 45° (the black curve corresponds to the underground explosion at a depth of $40D_0$, and the gray curve corresponds to the impact), the first pressure peaks in the waves generated by the underground explosion and the impact coincide with an accuracy up to 5–10%, although the areas of unloading are slightly different. A series of 3D simulations of impacts at angles 45°, 30° and 15° showed that when evaluating the seismic effect of oblique impacts, it is sufficient to multiply the energy of a vertical impact by the sine of an angle.

Conclusions: Our numerical analysis shows that, to achieve the same seismic effect, it is necessary that the impact energy be 5 times greater than the energy of an underground explosion. Taking into account that the seismic efficiency of an underground explosion is $(1–3)\times10^{-2}$ [4], the seismic efficiency of an impact can be estimated by values $(2–6)\times10^{-3}$, which are close to the value 3.4×10^{-3}, determined in the laboratory experiments [1].

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References: [1] Güldemeister N. and Wünnemann K. (2017) *Icarus* 296:15-27. [2] Collins G. S. et al. (2005) *Meteoritics & Planetary Science* 40: 817–840. [3] Shuvalov V. V. (1999) *Shock Waves* 9:381-390. [4] Patton H. J. and Walter W. R. (1993) *Geophysical Research Letters* 20:277–280.