SEISMIC IMPACT SHAKING: HOW IMPORTANT FOR SMALL LUNAR CRATER DEGRADATION?

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Introduction: The small lunar crater degradation results in an equilibrium areal crater density. It is important to study mechanisms of crater aging [1]. One of these mechanisms is the surface seismic shaking due to impacts [2]. The current project goal is to study seismic action around an impact site. The qualitative task is to check a possibility that variations in the local seismic structure could affect the apparently place-to-place variable small crater degradation rates [3, 4].

Numerical modeling: The project task starts with a numerical modeling of seismic waves generated by an impact in uniform and layered targets. We use the SALEB hydrocode in the Eulerian mode [5] with an intention in a close future to couple the near zone Eulerian model with a far-field Largrangian mesh like it was done earlier [6]. The strength model assumes totally damaged materials with a dry friction. Tillotson's EOS describes proxy materials for the reconnaissance stage: "sand" (ρ= 1.76 g cm-^{3} ,A= 4 GPa, B= 0.1 GPa), "tuff " (ρ= 1.97 g cm-^{3} ,A= 10 GPa, B= 10 GPa) and "hard rock" (ρ= 2.7 g cm-^{3} ,A= 53 GPa, B= 53 GPa).

Unexpected problem: For the "hard rock" test the model produces a standard mix of longitudinal and Rayleigh waves (Fig.1). Maximal velocities and accelerations in the numerical scheme are seen in Rayleigh waves.

In the uniform no-cohesion dry friction target of all three tested materials for an expected crater diameter of ~100 m we observe an extensive near-surface zone of zero pressure behind the leading stress wave (Fig. 2), and spall-like motion of tracers ended at ~10 R_{crater} distance. The low velocity impacts (1 kms^{-1}) modeled for a secondary impact studies enhance the effect. Only models with 30 to 100 times larger linear scale (40 km of regular mesh vs. 400 m) suppress the "spallation" due to high lithostatic pressure at a constant gravity.

Layered targets. We modeled a few layered configurations; the will investigated so far is the tree-layer model of 10 m of "sand" (regolith) and 50 m of "tuff" (megaregolith) over the "hard rock" basement (to enhance the deep wave overrun effect).

Fig. 3 demonstrates three time frames of wave's propagation presented as the pressure field. The "spallation" is constrained within upper two "weak" layers. The extension of the "spalled" zone is about 6 to 7 expected rim crater radii.

Discussion and Perspectives: We observe in the model that layered targets (typical for upper lunar crust) enhance the near-surface spallation. While absolute vertical velocities are modest, the spalled material has acceleration 2 to 10 times larger the lunar gravity in the model (Fig.4), and possibly larger at the real Moon. This shaking seems to be able to result in a short period of downslope material motion in small craters around the new impact.

We suppose to estimate in a future the shaking mechanism efficiency in comparison with other degradation mechanisms, listed earlier in [9].

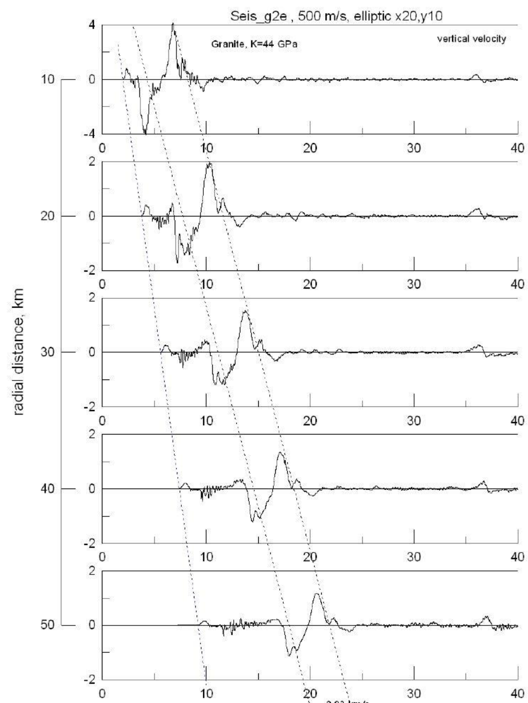


Fig. 1. A classic wave surface pattern in a hard rock target for a low velocity (0.5 kms^{-1}, D_{proj} ~ 3 km) impact. The model reproduces the longitudinal and Raleigh wave (5.5 and 2.9 kms^{-1} correspondingly). Time is in seconds.

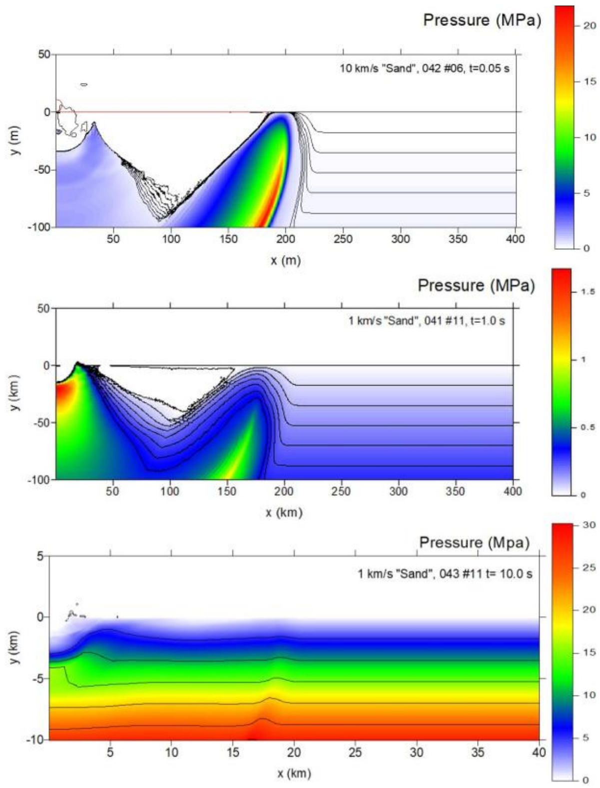
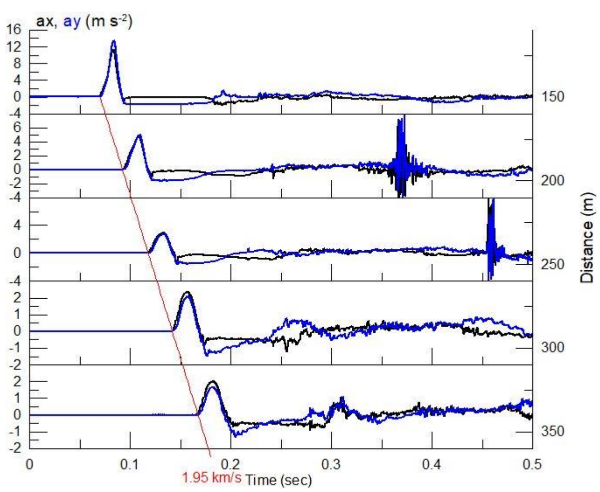


Fig. 2. "Spallation" near-surface zone in modeling of 10 kms^{-1} (top panel) and 1 kms^{-1} (middle and bottom panels) impacts into an uniform soft ("sand") target. Only the large natural lithostatic pressure (bottom panel, projectile diameter 1 km) suppresses the origin of zero-pressure ("spalled") zone behind the shock wave sliding along the free surface.



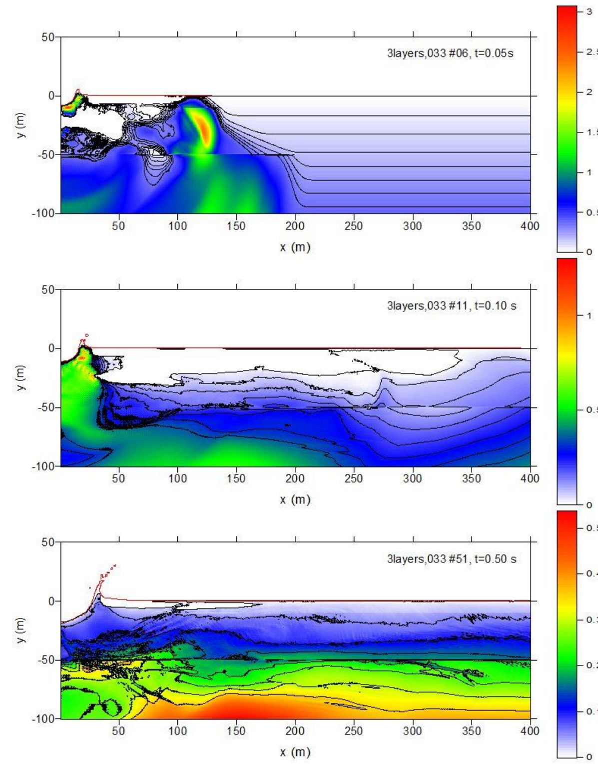


Fig. 3. Three time frames for the 1 kms^{-1} impact (D_{proj}=10 m, lunar gravity) into 3-layers target: 10 m "sand", and 50 m "tuff" over a hard rock basement. Zero pressure ("spalled") near surface zone reaches ~8 crater radii.

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References: [1] Richardson J. E. (2009) *Icarus,. 204*, 697-715. [2] Richardson J. E. et al. (2005) *Icarus, 179*, 325-349. [3] Mahanti P. et al. (2018) *Icarus, 299*, 475-501. [4] Ivanov B. A. (2018) *Solar System Research, 52(1)*, 1-25. [5] Ivanov B. A. and H. J. Melosh (2013) *JGR-Planets, 118*, 1545-1557. [6] Head, J.N. et al. (2002) *Science, 298*, 1752-1756.

Fig. 4 (left). Modeled accelerations recorded with 5 Lagrangian tracers at distances from 150 m to 350 m, placed at a depth of 0.75 m (cell dy=0.5 m). The first wave propagates at ~1.95 km s^{-1}, the longitudinal velocity speed in "tuff". Acceleration bursts at distances 200 and 250 m probably reflects a kind of Raleigh wave, clearly seen in another model runs.