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RESEARCH ON THE SCALING LAWS OF GRANITE UNDER HYPERVELOCITY IMPACT

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INTRODUCTION

The establishment of reasonable and reliable scaling laws is the prerequisite for the study of asteroid impact in scaling method. By using scaling laws, the results of the tests and simulations in the laboratory can be used to simulate the real asteroids impact events under specific conditions accurately. CARDC presented four kinds of scaling laws about the asteroid hypervelocity impact, which were validated in the methods of tests and simulations. In order to simulate the real condition, the steel ball was selected as projectile to simulate the iron asteroid. Meanwhile, as the most widely distributed geotechnical material on the earth, the granite was selected as target material.

SCALING LAWS

Scaling Laws For the Crater Depth

$$\frac{d}{a} = f\left\{\frac{\delta}{\rho}, \frac{Y_t}{\rho U^2}, \frac{\sigma_f}{\rho U^2}, \frac{C_p}{U}, \frac{C_t}{U}\right\}$$ Size scaling

$$d\left(\frac{E}{Y_t}\right)^{-\frac{1}{3}} = f\left\{\frac{Y_t}{\sigma_f}, \frac{\delta C_t^2}{Y_t}, \frac{C_p}{C_t}\right\}$$ Kinetic energy scaling

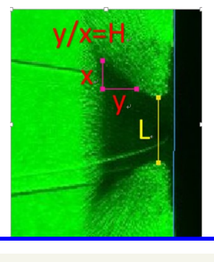
$$d\left(\frac{PC_t}{Y_t}\right)^{-\frac{1}{3}} = f\left\{\frac{Y_t}{\sigma_f}, \frac{\delta C_t^2}{Y_t}, \frac{C_p}{C_t}\right\}$$ Momentum scaling

d-crater depth
a-diameter of the projectile
ρ-density of the steel
δ-density of the granite
U-impact velocity
Y_t-yield strength of the granite
σ_f-breaking strength of the granite
C_p-sound speed of the steel
C_t-sound speed of the granite

Scaling Laws for the Scale of Debris Clouds

$$\frac{L}{a} = f\left\{\frac{\delta}{\rho}, \frac{Y_t}{\rho U^2}, \frac{C_t}{U}, \frac{t}{a/U}\right\}$$

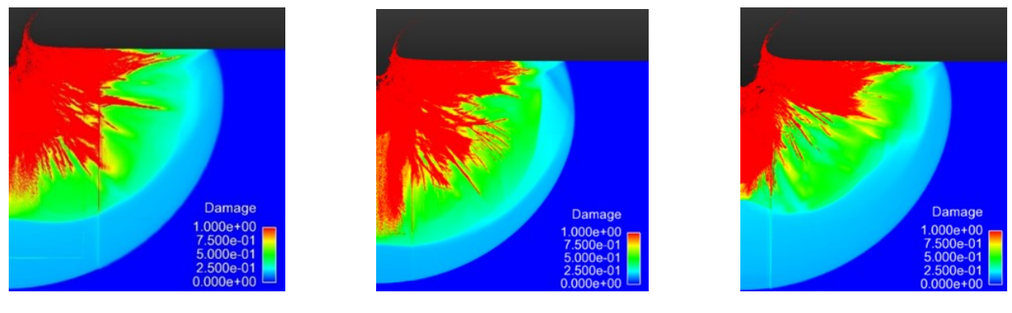
$$H = f\left\{\frac{\delta}{\rho}, \frac{Y_t}{\rho U^2}, \frac{C_t}{U}, \frac{t}{a/U}\right\}$$



L-the characteristic size of the debris clouds
H-the slope of the edge of the debris clouds

PRELIMINARY SIMULATION

- 2D
- SPH simulated method
- HJC model for granite
- Diameters of the projectiles: 5mm, 10mm, 20mm
- Velocities of the projectiles: 2.5km/s, 4.0km/s



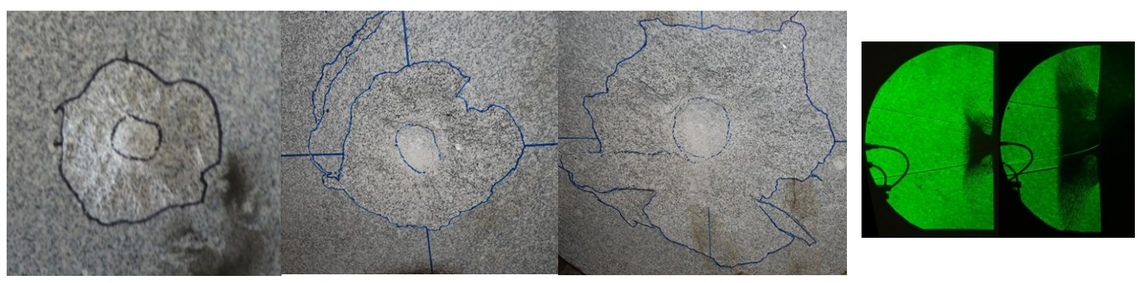
Preliminary simulated results suggested that when the projectiles impacted the targets in the different size but the same velocity, the crater depth increased with the increasing of the diameter, which satisfied the size scaling.

TESTS AND FURTHER SIMULATIONS

Parameters and Results of the Tests

- Ballistic range of CARDC
- 16mm and 37mm two-stage light gas gun
- Multiple sequences laser shadow graphs

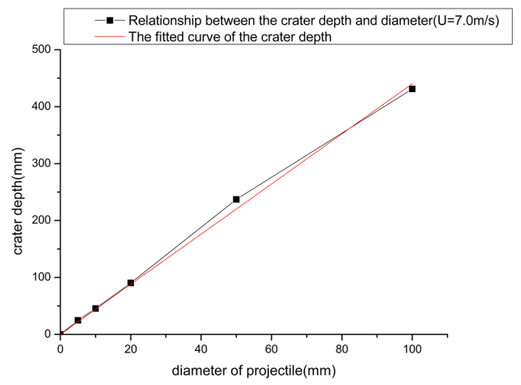
Diameter - a（mm）	Impact velocity-U (km/s)	Kinetic energy of projectile-E (J)	Momentum of projectile-P （kg•m/s）	Crater depth-d (mm)
5.0	2.64	1793	1.36	17.53
10.0	2.43	12151	10.00	31.81
20.0	2.30	87084	75.72	66.74
5.0	3.88	3872	2.00	21.31
10.0	3.81	29870	15.68	40.67
20.0	3.80	237710	125.11	110.00



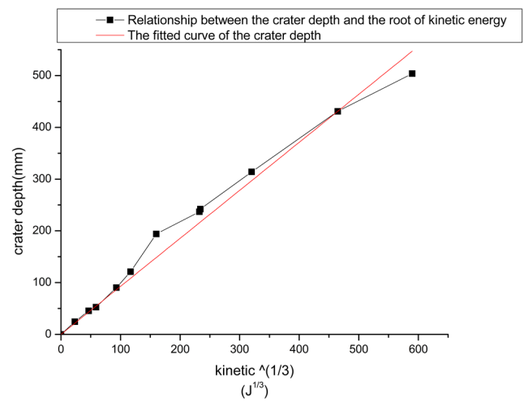
The results of tests meet the simulated results well. Besides, it also suggested that the scaling laws for the crater depth can be reasonable but for the debris clouds may not applicable.

Further Simulations and Results

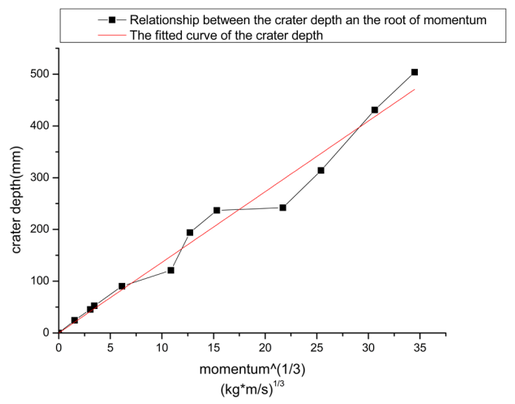
- The same method with the preliminary simulation
- Diameters range from 5mm to 100mm
- Velocities range from 2.5km/s to 10.0km/s



Size scaling



Kinetic energy scaling



Momentum scaling

The crater depth varied linearly with the changing of the independent variable as the scaling laws predicted. With the increasing of the projectile's kinetic energy, the scaling laws for the crater depth are still tenable.

CONCLUSIONS

1.Dimensionless parameters relating to strength and sound speed of the material are the most important parameters to determine the size of impact crater.
2.The results of the tests shows that the crater depth of the granite satisfies the scaling laws, but the characteristic scale for the debris clouds can not meet the scaling laws.
3.The simulated results are in good agreement with the results of the tests, so the numerical method can be used to do further simulations.
4.For the impact velocities between 2.5km/s to 10.0km/s and the impact projectile sizes between 5mm to 100mm, the depth for crater of granite meets the scaling laws well. Therefore, the impact damage characteristics of small-sized projectiles can be studied to simulate the impact conditions with large-sized projectiles.

REFERENCES

[1]. Holsapple K A. The Scaling of Impact Process in Planetary Sciences. Annual Review of Earth and Planetary, 1993, 21: 333-373.
[2]. Holsapple K A. The Scaling of Impact Phenomena. International Journal of Impact Engineering, 1987, 5: 343-355.
[3]. Michael H Poelchau, Thomas K. Scaling Impact Cratering Experiments in Porous Sandstones. Meteoritics&Planetary, 2013, 48(1): 8-22.
[4]. Schill W, Wasem J V, Owen J M. Modeling and simulation of cratering and ejecta production during high velocity impacts. Journal of Dynamic Behavior of Materials, 2017.
[5]. Kong X, Qin F, Hao W, et al. Numerical predictions of cratering and scabbing in concrete slabs subjected to projectile impact using a modified version of HJC material model. International Journal of Impact Engineering, 2016, 95: 61-71.