

CALCULATIONS OF IMPACT CRATER SIZE VERSUS METEORITE VELOCITY.

J. B. Bryan, D. E. Burton, L. A. Lettis, Jr., L. K. Morris, and W. E. Johnson*, Earth Sciences Division, Lawrence Livermore Laboratory, Livermore, CA 94550.

Two-dimensional cratering calculations have been performed to study crater size at different impact velocities. The Eulerian SOIL code was used to model a cylindrical iron meteorite projectile with constant mass (1.67×10^8 kg) impacting at normal incidence onto a limestone target half-space. The present series of calculations was purely hydrodynamic (without shear strength) although strength was treated in a separate calculation. The calculational approach has been discussed in earlier work which included a simulation of the formation of Barringer Crater in Arizona (1-3).

Results for impacts with velocities ranging between 2 and 25 km/s are summarized in the table. Values for kinetic energy lie between 3.3×10^{14} and 5.2×10^{16} J (80 to 12,000 kilotons). Most variables in the table can be related using a power-law expression of the form $Y = AX^B$. However, one exception is the effective depth-of-burst EDOB which is used to relate impact and explosion craters. An extrapolation of a fit of velocity U and scaled effective depth-of-burst SEDOB for the higher velocity cases suggests a value nearly three times larger than the value $SEDOB = 11.6 \text{ m}/(\text{kt})^{1/3}$ for the 2 km/s case. The calculation indicates that for this low velocity impact the projectile essentially remains intact. In the higher velocity cases melting and vaporization are important processes. Oberbeck (4) obtained a similar value of $SEDOB = 10.6 \text{ m}/(\text{kt})^{1/3}$ ($EDOB = 6.2+2.0 \text{ mm}$ for $W = 8.7 \times 10^2 \text{ J}$) from cratering experiments in quartz sand for explosion and impacts at 2 km/s. Thomsen et al. (5) found a value of $SEDOB = 5.9 \text{ m}/(\text{kt})^{1/3}$ at a relatively early time in their calculation of an aluminum sphere impacting onto plasticene clay ($EDOB = 6.5 \text{ mm}$ for $W = 5.7 \times 10^3 \text{ J}$).

The apparent crater radius R_A increases with increasing kinetic energy W as $R_A \propto W^n$ where $n = 0.21$ for constant gravitational acceleration ($g = 9.8 \text{ m/s}^2$). This value is slightly greater than the exponent ($n = 0.181$) obtained by Gault and Wedekind (6) from laboratory experiments. Their value was obtained for aluminum spheres with fixed mass impacting on quartz sand targets with velocities between 1 and 8 km/s.

Calculations such as those summarized here are very useful in helping extend cratering data from the laboratory scale where impact velocities are usually less than about 8 km/s to the higher impact velocities (11 to 72 km/s) which are involved in the formation of large impact craters. Calculations can help monitor variables that are difficult to measure such as energy partitioning as a function of time as demonstrated by Hill and Johnson (7). Future cratering calculations are planned to address material strength and gravitational effects.

*The address for W. E. Johnson is Computer Code Consultants, 1680 Camino Redondo, Los Alamos, NM 87544.

IMPACT CRATER SIZE VS. METEORITE VELOCITY

Bryan, J. B. et al.

TABLE Crater dimensions are summarized for calculated craters formed for different velocity impacts.⁽¹⁾ Meteorite mass was fixed at 1.67×10^8 kg.

$\frac{U}{\text{(km/s)}}$	$\frac{W}{\text{(kt)}}$	$\frac{R_A}{\text{(m)}}$	$\frac{D_A}{\text{(m)}}$	$\frac{V_A}{\text{(m}^3\text{)}}$	$\frac{\alpha}{(-)}$	$\frac{\text{EDOB}^{(2)}}{\text{(m)}}$	$\frac{\text{SEDOB}}{\text{m/kt}^{1/3}}$
2	79.6	217	75.6	5.39×10^6	0.35	50	11.6
10	1,990	444	154	4.57×10^7	0.35	90	7.2
15	4,480	505	179	6.85×10^7	0.35	85	5.2
20	7,960	567	198	9.58×10^7	0.35	80	4.0
25	12,400	631	214	1.29×10^8	0.34	75	3.2

Notation:

U : Meteorite impact velocity

W : Kinetic energy of meteorite (1 kiloton = 4.186×10^{12} J) R_A : Apparent crater radius D_A : Apparent crater depth V_A : Apparent crater volume α : Ratio D_A/R_A

EDOB : Effective depth-of-burst

SEDOB: Scaled effective depth of burst

(1) Final crater dimensions were obtained at a time of 0.50 seconds using a ballistic extrapolation technique with slope stability adjustment to obtain a hyperbolic shaped crater.

(2) The effective depth-of-burst for these impact craters is estimated at a time 0.50 seconds by fitting a hemisphere to the expanding cavity (1,3).

IMPACT CRATER SIZE VS. METEORITE VELOCITY

Bryan, J. B. et al.

REFERENCES

1. Bryan, J. B., Burton, D. E., Cunningham, M. E., and Lettis, L. A. Jr., (1978) Proc. Lunar Planet. Sci. Conf. 9th, 3931-3964.
2. Bryan, J. B., Burton, D. E., Cunningham, M. E., and Lettis, L. A. Jr., (1978) Lunar and Planet. Sci. IX, 128-130.
3. Bryan, J. B., Burton, D. E., and Lettis, L. A. Jr., (1979) Lunar and Planet. Sci. X, 154-161.
4. Oberbeck, V. R. (1971), J. Geophys. Res. 76, 5732-5749.
5. Thomsen, J. M., Austin, M. G., Ruhl, S. F., Schultz, P. H., and Orphal, D. L. (1979) Proc. Lunar Planet. Sci. Conf. 10th, 2741-2756.
6. Gault, D. E., and Wedekind, J. A., (1977), Experimental Hypervelocity Impact into Quartz Sand-II, Effects of Gravitational Acceleration, Impact and Explosion Cratering, (Roddy, D. J., Pepin, R. O., and Merrill, R. B., eds.) p. 1231-1260, Pergamon Press, NY.
7. Hill, L. R., and Johnson, W. E. (1970) Energy Partitioning During Hypervelocity Impact on Rocks, Sandia Laboratories, Albuquerque, NM, Report SC-R-70-4402.

"Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48."