A MATERIAL STRENGTH MODEL FOR APPARENT CRATER VOLUME*

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For restricted classes of soil types, such as a rate independent Mohr-Coulomb material, it can be shown that to simulate large scale cratering phenomena with laboratory scale experiments, the gravity field strength must be increased with the reciprocal of the linear geometric scale reduction factor. This follows from similarity requirements relating the subscale crater formation to the full scale prototype in identical soils. The sufficiency of this requirement has been demonstrated experimentally for various types of soils including Ottawa sand, desert alluvium, and modeling clay. These results validate the use of a centrifuge to model large scale events in a given material. That is, there is no additional modeling requirement on the material itself and both the subscale model experiment and the full scale prototype can be and in fact must be performed in the identical soil type.

Material strength effects are now examined using a Mohr-Coulomb failure theory for soils. A dimensionless strength-size-gravity parameter:

\[ \bar{\pi}_2 = (k + \tan \varphi) \pi_2 + \frac{c}{\rho Q_e} \]

with

\[ \pi_2 = \frac{g}{Q_e} \left( \frac{W}{\delta} \right)^{1/3} \]

gravity-scaled size

and

- \( \rho \) soil density
- \( c \) soil cohesion
- \( \varphi \) soil angle of internal friction
- \( W \) mass of explosive
- \( \delta \) explosive mass density
- \( Q_e \) explosive energy density
- \( g \) acceleration of gravity
- \( k \) empirically determined constant

*Work performed for Defense Nuclear Agency under contract no. DNA001-78-C-0149.
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Holsapple, K.A. and Schmidt, R. M.

is generated from this analysis. The experimental results for the cratering efficiency:

$$\pi_1 = V \cdot \frac{\rho}{W}$$

where V is the crater apparent volume, fall on a single curve described by

$$\pi_1 = 0.174 \cdot \pi_2^{-0.472}$$

for all material tested, with k = 0.1.

Based upon this result the figure shows a schematic depicting the cratering behavior for a given material as scaled size is increased. The predicted response is a curve with two straight line asymptotes. The "cohesion dominated" regime to the left leads to cube root scaling. This is often referred to as the "strength" dominated regime which is not a correct terminology unless the friction angle is zero. For finite friction angle the strength contribution due to increased lithostatic pressure begins to dominate the cohesion component at a transition size based upon soil properties. Above this transition, the cratering efficiency decreases with increasing scaled size in a manner that is usually attributed solely to potential energy of formation.

The model is consistent with experimental results where cohesive materials with small friction angles exhibit greater cratering efficiency than non-cohesive granular soils and where soils having approximately the same friction angle have indistinguishable response above the transition size. It shows qualitative consistency with idealized impact cratering calculations using a Mohr-Coulomb model with a maximum stress cut-off. Furthermore, a correlation between impact and explosive cratering shown previously for quartz sands together with preliminary centrifuge results for impact in modeling clay indicate that this strength model is valid for impact cratering also.

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\[ \log \pi_1 = \log \left[ \frac{\rho}{\Delta \theta} \right], \quad \text{GRAVITY-SCALED SIZE} \]

\[ \log \pi_2 = \log \left[ \frac{g}{g_0} \left( \frac{W}{W_0} \right)^{1/3} \right], \quad \text{GRAVITY-SCALED SIZE} \]


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