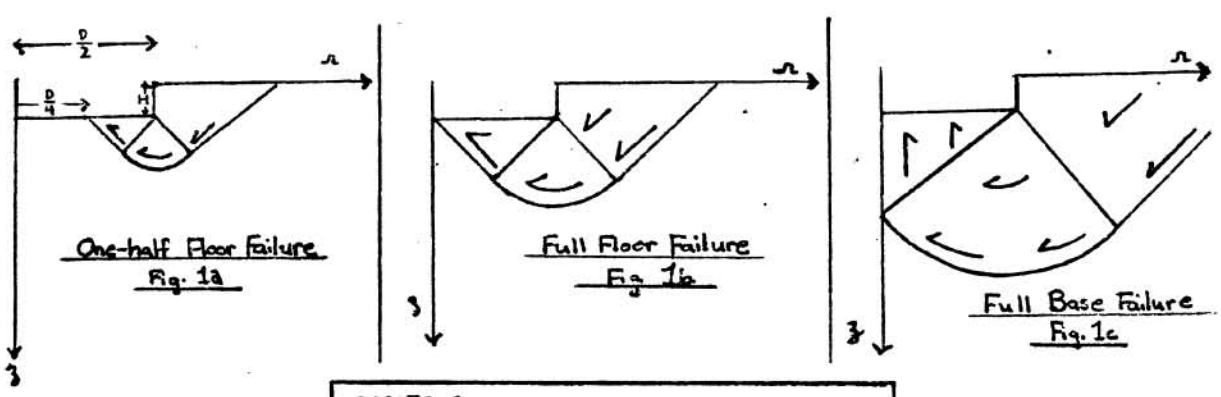
FURTHER INVESTIGATION INTO THE ROLE OF PLASTIC FAILURE IN CRATER MODIFICATION, William B. McKinnon and H. J. Melosh, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125

Examination of the depth/diameter relation for fresh lunar craters shows an abrupt trend toward lower values above approximately 15 km in diameter (1). This has been held indicative of gravitationally induced mechanical instability (2). A previous analysis considered the transient crater as failing in a perfectly plastic sense, i.e., possessing no internal friction (3). It was concluded that for collapse to occur the volume of rock containing the crater would have be be quite weak, with a cohension strength of less than 30 bars.

The present study is an expansion of the preceding one. Here the lunar surface material is considered to be parameterized by both a cohesion strength and an internal friction angle (Mohr-Coulomb plasticity). The results are in substantial agreement with the original work; that is, they require the rock to possess rather low strength. They also constrain the internal friction angle to be less than 2°. For the lunar surface to have these mechanical characteristics is puzzling, but such characteristics are essential if slumping is to occur.

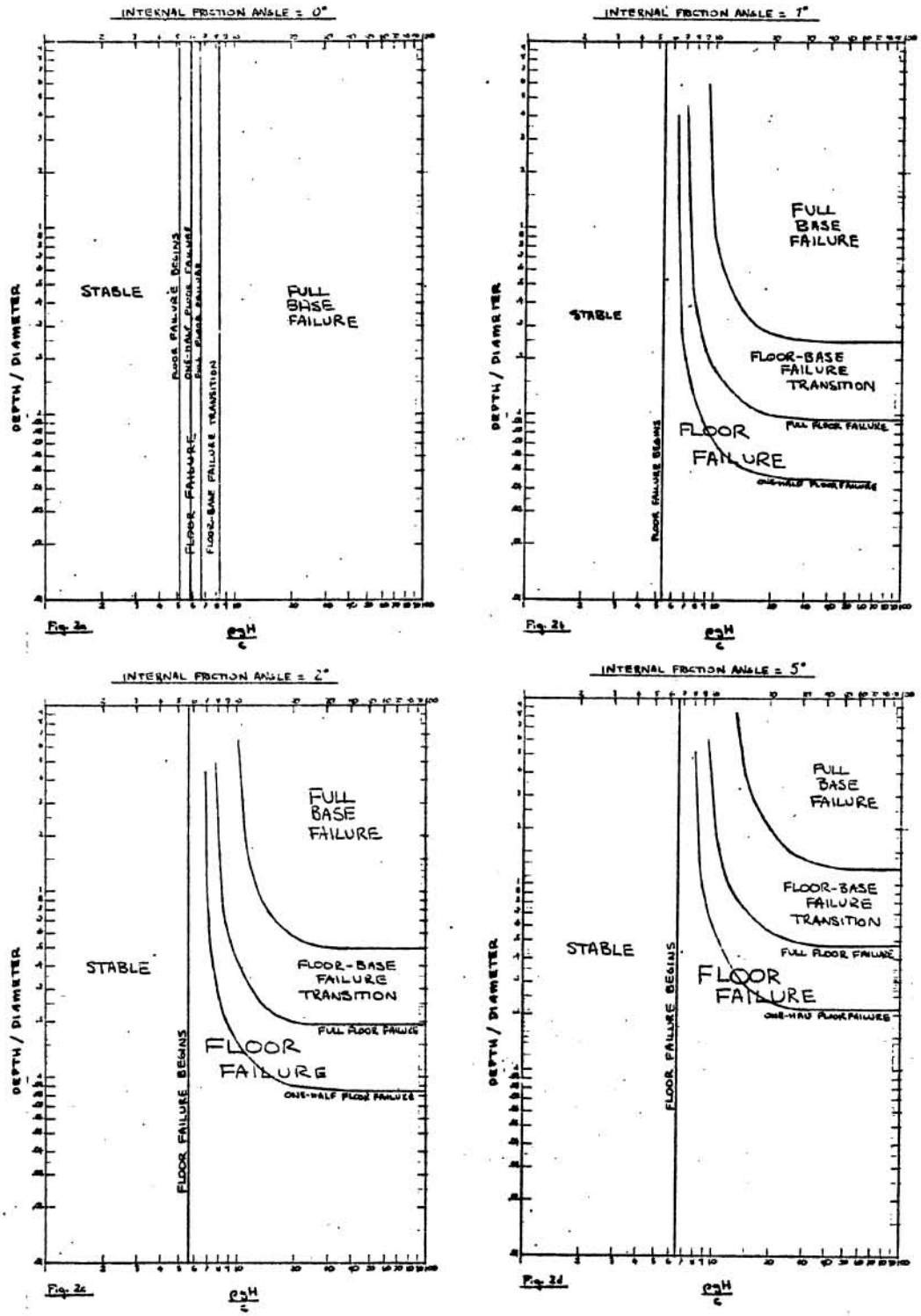
The theoretical crater models considered by us are rectangular in profile (i.e., cakepans) and axial symmetry is assumed throughout. The stability of these structures is examined utilizing the slip-line theory of plasticity (4). It is found that stability is determined by three factors: The depth/diameter ratio $H/D = \lambda$, the internal friction angle, and a dimensionless parameter $(\rho g H)/c$, where c is the cohension strength of the plastic substance. The degree of stability (or instability) manifests itself as the fraction of the crater floor that fails. A true bowl shaped crater would collapse via a combination of floor failure and slumping off the crater wall. Attendant structures such as central peaks or multiple mountain rings may



CRATER GEOMETRY AND FAILURE MODES

THE ROLE OF PLASTIC FAILURE IN CRATER MODIFICATION

McKinnon, W.B., et al.



CRATER FAILURE MODES AS FUNCTIONS OF DEPTH/DIAMETER RATIO, $\rho g H / c$ & INTERNAL FRICTION ANGLE (RECTANGULAR PROFILE)

THE ROLE OF PLASTIC FAILURE IN CRATER MODIFICATION

McKinnon, W.B., et al.

appear. However, the details of the collapse of the crater rim and the development of other structures will not be considered here.

The accompanying figures illustrate the results of the analysis. For a material possessing no internal friction, the depth/diameter ratio plays no role in determining the crater stability. For values of $(\rho gH)/c$ less than 5.1 no collapse will occur. Above this value increasingly larger amounts of the crater floor fail. When $(\rho gH)/c$ reaches 8.4, the entire floor of the crater rises as a unit as the rim slumps downward. This is termed full-base failure. Addition of even a small amount of internal friction drastically affects the crater stability. It is seen that for some values of λ certain modes of failure are forever out of reach no matter how weak the material is or how deep the original cavity.

This can be related to the moon in the following way. Fresh lunar craters with diameters under 15 km (rim to rim) have a depth/diameter ratio quite near .2. Larger craters all have depths between 3 and 5 km. Flat hummocky floors are characteristic of craters 30-100 km across (5). We believe that all transient craters start with $\lambda \cong .2$ but only those large enough to be unstable collapse. The flat hummocky floors of even larger craters are most probably due to a full-base failure mechanism. If the kink in the depth/diameter curve at 15 km is taken to be the limit of static stability, then for the case of zero internal friction a cohension strength of ~30 bars is implied. This value increases for increasing values of the internal friction angle. Yet when the internal friction angle is greater than 2° full-base failure for λ=.2 cannot occur.

Thus, the material encompassing a newly formed crater is shown to have low material strength and nearly zero internal friction. The fact that the surrounding rock is weak is plausible, considering the significant amount of plastic deformation that accompanies a hypervelocity impact. However, the near absence of internal friction is a stranger beast. In terrestrial situations, this can only be accomplished through a lubricating agent. An intriguing candidate would be melted rock itself, produced concomitant to the plastic deformation of excavation, as suggested by Dence (personal communication, 1977).

References

(1) Pike, R.J. (1974) Geophys. Res. Lett. 1, p. 291.
(2) Quaide, W.L., Gault, D.E., and Schmidt, R.A. (1965) Ann. N.Y. Acad. Sci. 123, p. 563.
(3) Melosh, H.J. (1977) in D. Roddy, Impact and Explosion Cratering Mechanics, Pergamon Press, in press.
(4) Cox, A.D., Eason, D., and Hopkins, H.G. (1961) Phil. Trans. Roy. Soc. London 254A, pp. 1-45.
(5) Howard, K.A. (1974) Proc. Lunar Sci. Conf. V, pp. 67-79.