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CRATERING CAPABILITIES OF LOW-YIELD NUCLEAR WEAPONS

by

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A review of past cratering experiments, both from high explosives and nuclear explosives, was conducted and the data gathered were analyzed in order to develop a generalized empirical method for predicting crater dimensions when only qualitative information on the media cratered is available. The methods developed enable crater predictions to be made in homogeneous and layered media within the stated orders of scatter.

It is believed that the probability of a given crater falling within the predicted values is in the range of 0.8.

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PREFACE

This investigation was conducted by the U. S. Army Engineer Waterways Experiment Station (WES), Structures Laboratory (SL), during FY 1981.

This report was prepared by Mr. John N. Strange, SL. Mr. Bryant Mather was Chief, SL.

COL Nelson P. Conover, CE, was Commander and Director of WES during the conduct of this study. Mr. Fred R. Brown was Technical Director.

CONTENTS

Conversion Factors, Metric (SI) to Inch-Pound and Non-SI to Metric (SI) Units of Measurement

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
Metric (SI) to Inch-Pound		
Celsius degrees or Kelvins	9/5	Fahrenheit degrees*
cubic metres	35.31466	cubic feet
kilograms	2.204622	pounds (mass)
metres	3.280839	feet
Non-SI to Metric (SI)		
kiloton (TNT equivalent)	4.184	terajoules
megabar	100000.00	megapascals
megaton (TNT equivalent)	4.184	petajoules
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
tons (TNT equivalent)	4.184	gigajoules

* To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following formula: $F = 9/5(C) + 32$. To obtain Fahrenheit readings from Kelvin (K) readings, use: $F = 9/5(K - 273.15) + 32$.

CRATERING CAPABILITIES OF LOW-YIELD NUCLEAR WEAPONS

Background

1. The extensive use of explosives in quarrying, mining, and massive excavation projects; in demolition operations; and in wartime operations; has necessitated a generally continuous study of the effects of explosions. These studies, conducted both by private industry and various government groups, have given rise to the expenditures of literally hundreds of millions of dollars in an effort to systematically document and more accurately define the phenomenology and effects of explosions. In practically all such studies, major emphasis has usually been given to the task of defining the mechanical effects, i.e., those effects that are capable of doing vast amounts of work.

2. Until 1945, and the advent of the atomic age, man was seldom concerned with single source detonations that involved quantities of explosives greater than a few tons or, in isolated cases, greater than a few tens-of-tons of TNT or equivalent amounts of other explosives (equivalent from the standpoint of crater production). Only in exceedingly rare cases did explosions occur that involved yields in the range of hundreds-of-tons of TNT equivalent, and then they were generally the result of accidental explosions.

3. Even when such detonations did occur, very little scientifically credible information was ever gathered due mainly to unknowns relative to the actual charge size and weight, whether or not complete, high-order detonation was achieved, the position of the charge relative to the ground surface, and in some cases, the exact composition of the explosive itself. Furthermore, because of the spontaneity of the blast, no measuring devices were ever in place to quantitatively record the explosion's effects.

4. Then, in 1945 the advent of atomic energy changed the yield picture drastically. Atomic weaponry upgraded by many orders of magnitude the range of explosion yields that must be considered in an overall

and comprehensive evaluation of high-yield explosion effects.

5. Since 1946, the various effects of nuclear weapons have been studied intensively and much has been learned, particularly as regards weapons in the so-called low- and intermediate-yield ranges In recent years, the nuclear weapons effects community has divided the nuclear yield spectrum into three caterogies: low, intermediate, and high. The low-yield range includes from fractional kiloton yields to about 10 kt,* the intermediate range includes from just over 10 kt to just under a megaton, and high-yield weapons are generally taken as those that equal or exceed 1 MT.

Scope

6. A general treatise on the cratering effects of explosions, regardless of yield, is much beyond the intended scope of this paper. Certain factors, important to the general phenomemology of the cratering process, exert different levels of influence as weapon yields continually increase. For example, cratering processes are significantly influenced by gravitational effects in the high-yield domain but not in the low-yield domain. This paper was prepared specifically to detail the cratering effects of low-yield detonations. Concern relative to the cratering capabilities of low-yield nuclear weapons arises principally from the possible employment of low-yield weapons in a tactical war environment where such weapons might well be used in a demolition role to form barriers or obstacles to mobility, or to attack underground hardened facilities.

Data Base

7. Development of theoretical or empirical solutions to the cratering problem requires an appropriate data base. Theoretical

* A table of factors for converting metric (SI) units of measurement to inch-pound units and non-SI units to metric (SI) units is presented on page 3. Notations and Abbreviations are listed in Appendix A.

efforts must have relevant data in order to calibrate or quantify end results. For an empirical solution to be meaningful (statistically significant), a data base of considerable size is required. Although the United States has conducted literally hundreds of nuclear tests, most of them have had zero points (centers of detonation) that were considerably above the ground surface or were at containment depths of burst and thus were not cratering-type shots. Data compiled by Strange et al. (1961), Rooke et al., and McAneny, indicate that only about a dozen nuclear events have had shot geometries where the nuclear source (zero point) was placed below the ground surface at depths equal to or shallower than $50Y^{0.3}$ metres, where Y specifies the explosion yield in kilotons. Both Ricketts and Werth have reported on craters resulting from several Russian shots. Even so, there is a very small nuclear data base for generalizing an empirical solution to the nuclear cratering problem.

8. There is still another shortcoming to the nuclear data base as regards cratering: most of the subsurface nuclear cratering shots were accomplished in either desert alluvium or in rock, either of sedimentary or igneous origin. To further restrict the general utility of the data, all shots were in relatively dry materials except for a few shots that were accomplished at the Pacific Proving Grounds. Thus, the bulk of the current data base has little or no direct relevance to areas where layered geologies of sands, clays, silts, and mixtures thereof dominate, where moisture contents are high, or where a water table or rock layer lies within a few metres or a few tens-of-metres of the ground surface.

9. Over the years, the cratering data base for high explosives (HE) has expanded significantly, particularly since the Nuclear Test Ban Treaty was approved in 1963. HE charge weights have ranged from fractions of an ounce (about 1 gram) in microscaled tests up to hundreds of tons of TNT equivalent (hundreds of thousands of kilograms). Shots have been fired in almost every kind of geology that nature provides, yet there are relatively few instances in which data are available from well-planned test programs wherein explosions of constant yield were accomplished at different depths of burst in a variety of media.

10. While there are literally thousands of HE cratering events from which to garner data, most of the shots involved less than a thousand pounds of explosive (less than a few hundred kilograms). While these shots are invaluable for developing crater-scaling criteria for charges weighing less than a few thousand pounds, their value when used to infer crater size from explosions having yields 5 or 6 orders of magnitude greater than that may be questionable.

11. Because of the limited amount of nuclear cratering data, it has been necessary to use HE cratering data, either from TNT or TNT-equivalent sources, to expand the very limited nuclear data base. Over the past 15 years, the Department of Defense, primarily through the Defense Nuclear Agency, has conducted a large number of large-scale HE events; however, a major portion of these have had shot geometries such that the charge masses (generally spheres) were sitting surface tangent to the ground or hemispheres that rested directly on the ground surface. Such tests, though important in studying airblast and direct and air-induced ground shock, were not traditionally regarded as cratering events, though they did add to the cratering data base for bursts near the surface.

12. In order to compare HE and nuclear explosive (NE) experiments directly, it was necessary to determine what HE yield would provide the same global kinetic energy field as a given nuclear yield. Calculations by Thomsen and by Blake (1973, 1974a, and 1974b) have shown that the kinetic energy field generated by 500 tons of HE is roughly equivalent to that from a 1-kt nuclear source, provided the depth of burial ranges from approximately $5Y^{0.3}$ to $30Y^{0.3}$ metres. Using this equivalence, the HE data base for yields equal to or larger than 1000 pounds (TNT equivalent) was transformed to equivalent NE yields and used along with the nuclear data base to generate an expanded pseudo-nuclear cratering data base. To predict nuclear cratering in nonarid environments, HE cratering data in varied geologies were transformed to nuclear equivalent yields and the HE results were then used to infer nuclear results in those materials. In other words, the HE and NE data for the soils and rocks of the Nevada Test Site were normalized. Then the HE data for

the nonarid soil environments were also normalized in the same manner and used to develop the NE cratering capability curves for relevant nonarid geologies.

Cratering Mechanics

13. Figures 1-3 depict a time history of the cratering process. If a near point-source of energy is assumed, which is usually the case for a nuclear source, then within a few nanoseconds after detonation, the source becomes a spherical plasma approximately a metre in radius. Its temperature is on the order of several millions of Kelvins and its pressure level is in the range of 100 Mbar (about 1.5×10^9 psi). Underground, the expansion of this high-energy source emits a shock wave which expands spherically until it reaches the ground surface, at which time the shock is reflected as a rarefaction (tension) wave (time t_4, Figure 1) which acts to overcome whatever tensile strength the soil/rock material(s) might have. A portion of the incident shock energy is transmitted through the ground surface, producing airblast and causing surface particles to spall at a velocity roughly twice that

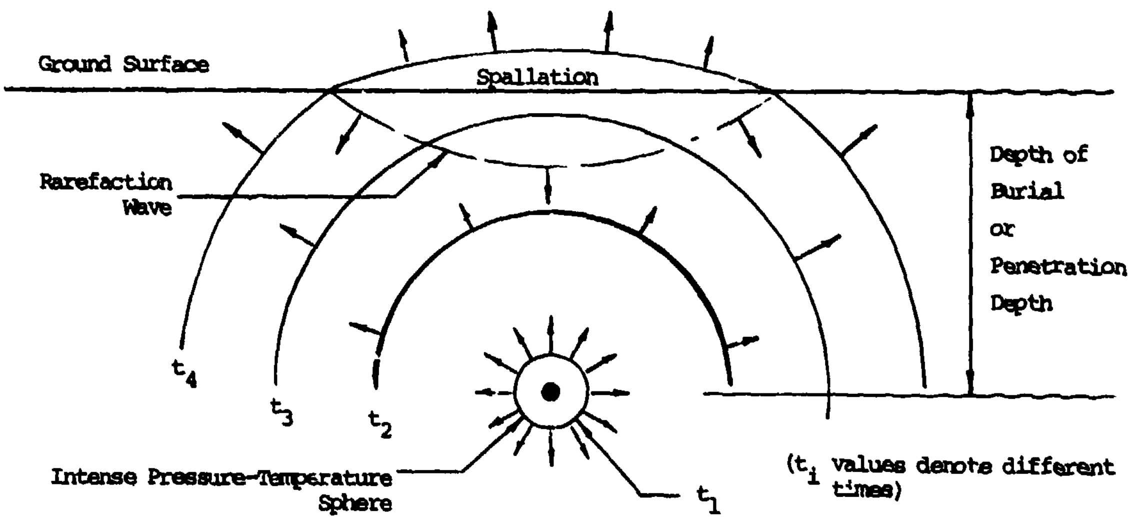


Figure 1. Early-time phenomena associated with underground bursts

which exists immediately behind the incident shock front. The particle velocity immediately behind the incident shock is given by

$$V_p = \sigma(\rho c)^{-1}$$

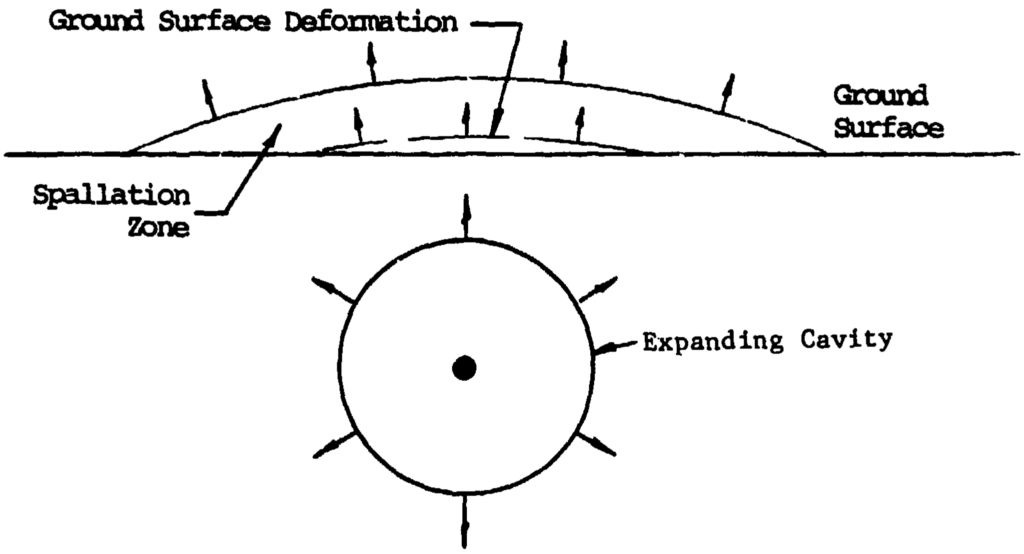
where

σ = the value of the peak stress induced into the parent material by the shock

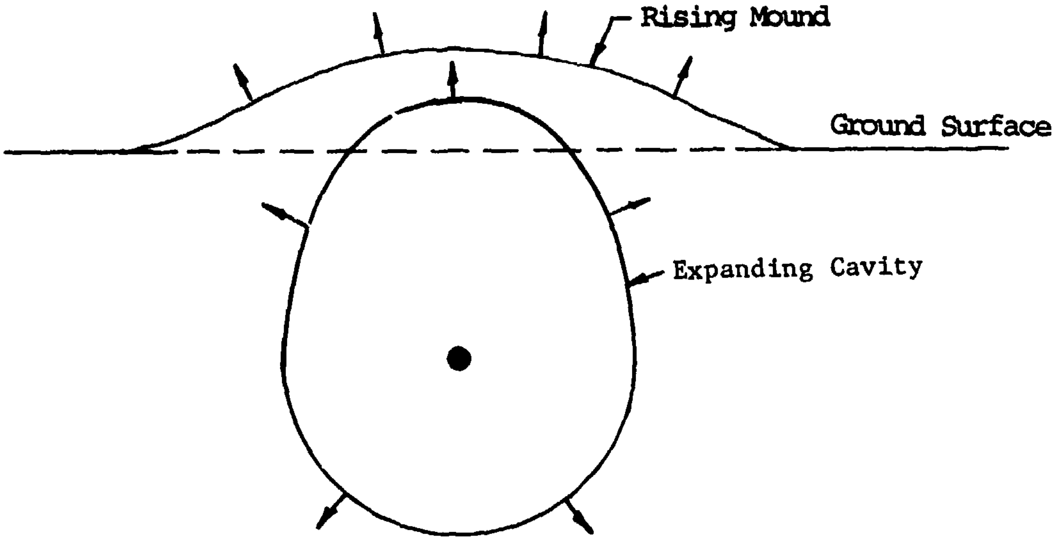
ρ = the material density

c = the sonic or compressional wave velocity of the material

14. Meanwhile, the high-pressure gas cavity continues to grow by virtue of material being vaporized in the early stages, and by material compaction and mass motion in later stages (Figure 2). By the time of venting (Figure 2d), the depth of the true crater is, for all practical purposes, fully determined. Nearly all particles that will be dissociated from the parent soil mass along the cavity profile are now airborne; their final at-rest locations are now almost solely determined by ballistic trajectory mechanics. Much of the airborne material, particularly that which was immediately above the zero point, falls back into the true crater making it shallower. In many instances, the side slopes near the rim of the crater are too steep to remain stable and their failure sluffs additional material into the true crater, making it still shallower and increasing its width. After all motions/displacements have ceased and the dust settles, there remains the apparent crater (Figure 3). It is this "residual" crater that interests those who would use explosively-produced craters for certain civil applications, such as the excavation of canals. It is also this crater along with the true crater that is of interest to military planners who visualize how such excavations in battlefield scenarios might influence tactical maneuvers or damage underground protective structures.

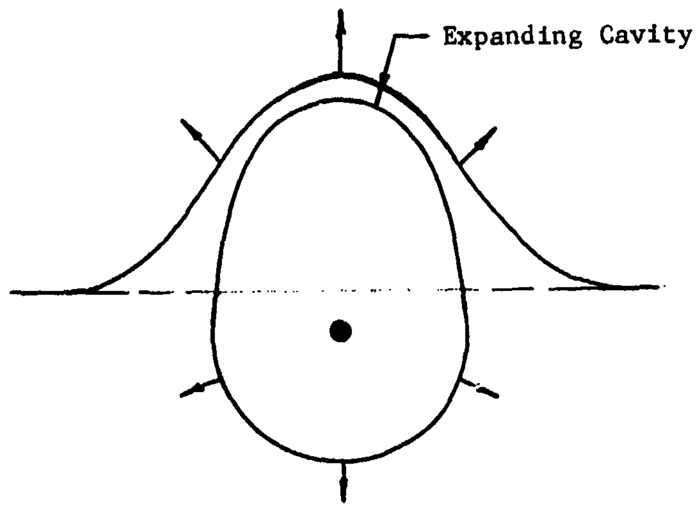


a. Schematically depicted situation at time t_5

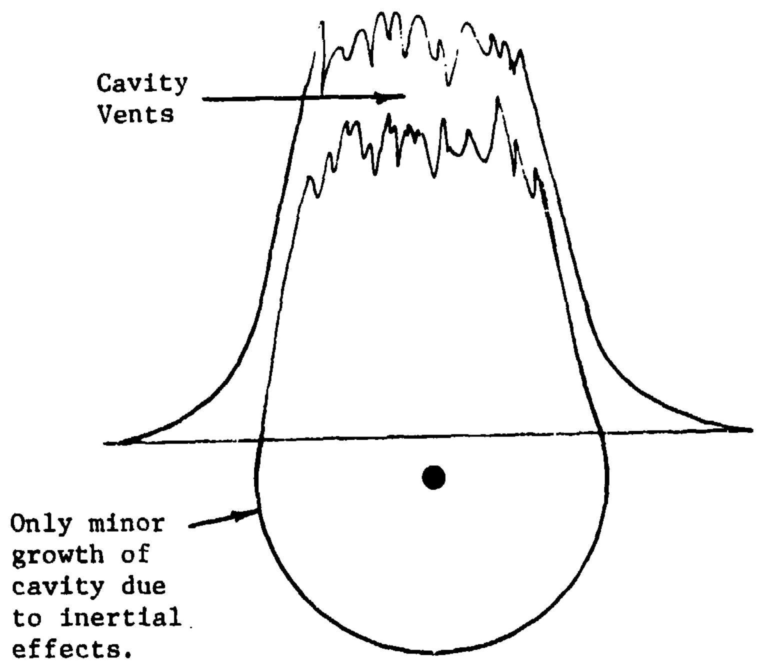


b. Schematically depicted situation at time t_6

Figure 2. Time history of crater formation (Continued)



c. Schematically depicted situation at time t_7



d. Schematically depicted situation at time t_8

Figure 2. (Concluded)

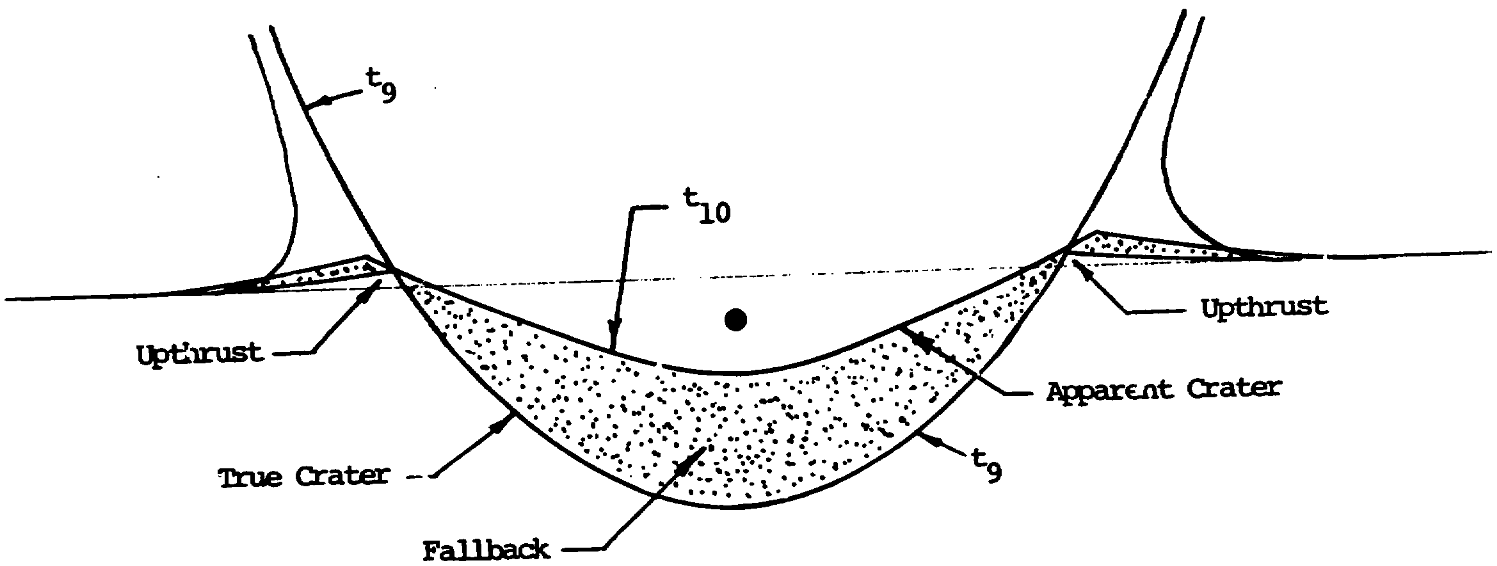


Figure 3. Delineation of the true and apparent craters

Variables That Affect Crater Size

15. The size and shape of an explosively produced crater depend upon the quantity and type of explosive used, the physical characteristics of the medium being cratered, and the method of charge placement and its position above, at, or below the ground surface. These general variables are broken down further as follows:

a. Properties of the explosive
   (1) Charge weight
   (2) Charge shape
   (3) Casting density (high explosives only)
   (4) Energy density
   (5) Detonation velocity
   (6) Yield-to-mass ratio (nuclear source only)
   (7) Burn and gas-generation characteristics

b. Properties of the medium being cratered
   (1) Density
   (2) Strength characteristics (dynamic)
      (a) Compressive
      (b) Shear
      (c) Tensile
   (3) Porosity
   (4) Degree of saturation
   (5) Void ratio
   (6) Other unspecified soil properties

c. Charge position
   (1) Aboveground regime
   (2) Air-ground interface ($Z = 0$)
   (3) Below-ground regime

16. This listing of the variables that affect cratering is reasonably complete, even if a rigorous solution to the cratering problem were contemplated. Unfortunately, on any given cratering experiment, few of the variables listed are quantitatively known. Certainly in a real war environment, it is highly unlikely that the exact charge

position, with respect to the ground surface, would be known, unless the device was preemplaced as in a demolition charge. Also, there would likely be little or no quantitative data available for describing the stratigraphy or physical properties of the medium. In all probability, the soil type and a rough estimate of the soil moisture content is all the information that might be available. Thus, pragmatically, the cratering problem reduces to:

$$r, d, h, \text{ and } V = f(Y, Z, S)$$

where

- r = the apparent crater radius
- d = the apparent crater depth
- h = the apparent crater lip height
- V = the apparent crater volume
- Y = the yield of the explosion
- Z = the known or estimated position of the charge with respect to the ground surface
- S = a qualitative descriptor of the medium being cratered.

The available information on the soil might well consist of nothing more than terms like: a strongly cohesive soil (e.g., dry-to-moist clay), a weakly cohesive soil (e.g., sandy clayey silt), a noncohesive material (e.g., dry sand), hard rock (e.g., granite), or soft rock (e.g., weathered shale). By virtue of geologic maps or other sources of information, only a crude estimate of the stratigraphy at point X, the intended ground zero, would be possible.

Predicting the Crater Size

Nonlayered geologies

17. As stated earlier, the range of yields that is considered appropriate for the low-yield domain does not exceed 10 kt; thus, the crater prediction methodology developed hereafter pertains only to yields in the range of fractional kiloton devices up to 10 kt. For

the low-yield domain, there is no need in this report to consider possible changes in the scaling exponents nor changes in the crater shape that normally occur as explosion yeilds increase beyond the high-yield level ($Y > 1$ MT). These changes which occur for high yields are generally attributable to gravitational and other physical effects such as degree of saturation, layering, etc. The basic prediction methods developed herein were derived from the available subsurface nuclear cratering shots and from high-yield HE experiments (the minimum HE yield considered was 1000 pounds). The TNT-equivalent HE yields were converted to equivalent NE yields by multiplying the HE yield (in pounds) by a factor of 10^{-6} i.e., 40,000 lb of TNT was considered the cratering equivalent of 0.04 kt, or 80,000 lb NE. As stated earlier (paragraph 12), this conversion is based on the calculational code work of Thomsen and of Blake (1973, 1974a, and 1974b) and applies to shot geometries where the actual depth of burial ranges from $5Y^{0.3}$ to $50Y^{0.3}$ metres. The calculational results have been verified by HE experiments.

18. The actual crater dimensions of each shot, both from nuclear and HE nuclear-equivalent results, were normalized by the 0.3 power scaling law. This scaling procedure was used because it appears to minimize the scatter of all experimental data and has for some years now been commonly used in preparing cratering capability curves the latter being a plot of a particular scaled crater dimension ($d' = d/Y^{0.3}$) versus scaled depth of burst ($Z' = Z/Y^{0.3}$) (Glasstone and Dolan). This reasoning assumes that the power law that best collapses the data scatter is the power law that the experiments most nearly obey.

19. The cratering capability curves so derived are presented in Figures 4 and 5 and define d' and r' as functions of Z'. The uppermost and lowermost curves in each plot mark the approximate upper and lower limits of the overall data spread, irrespective of the soil type. The total spread is then divided into eight, more or less equally spaced bands or zones, which are then keyed to specific soil and rock types as shown in the following table.

Zones of Influence for Various Geologic Media

General Description	Data Scatter Zones for Figures 4 and 5 Depth	Radius
Hard rock, e.g., granite and basalt	1,2, and 3	1 and 2
Soft rock and dry cohesive soils	2,3, and 4	2,3, and 4
Dry sandy soils, e.g., desert alluvium	3,4, and 5	4 and 5
Moist sand and frozen ground	3,4, and 5	4,5, and 6
Moist soils	4,5, and 6	5 and 6
Clayey silt		
Sandy silt		
Sedimentary rocks (weathered and saturated)	5,6, and 7	5 and 6
Moist cohesive soils	5,6, and 7	5,6, and 7
Silty clay		
Loess		
Sand clay, sandy silty clay		
Wet sand and ice	5,6, and 7	6 and 7
Wet soils	5,6, and 7	5,6, and 7
Clayey silt		
Sandy silt		
Wet cohesive soils	6,7, and 8	6,7, and 8

While there is some overlapping among the zones due to experimental scatter, the zones identified in the Table describe the dominant trends in cratering for the various media and their use should provide a reasonably good prediction of crater size, assuming the media's physical properties do not change significantly with depth, at least not within the range of depths of interest.

20. To predict the crater size for a nonlayered soil environment, the reader should follow the step-by-step procedure listed below:

a. Calculate the value of Z' . It is assumed that Z and Y are known, or are selectable.

b. Enter Figures 4 and 5 with the appropriate abscissa value and read off the curves appropriate values of d' and r' (see Table for appropriate zoning selections).

c. Transform d' and r' values to the actual crater depth and radius by multiplying the scaled values by $Y^{0.3}$.

21. An estimate of h can be made from the predicted depth. Routinely, for granular soils, h is about 0.2 of the predicted

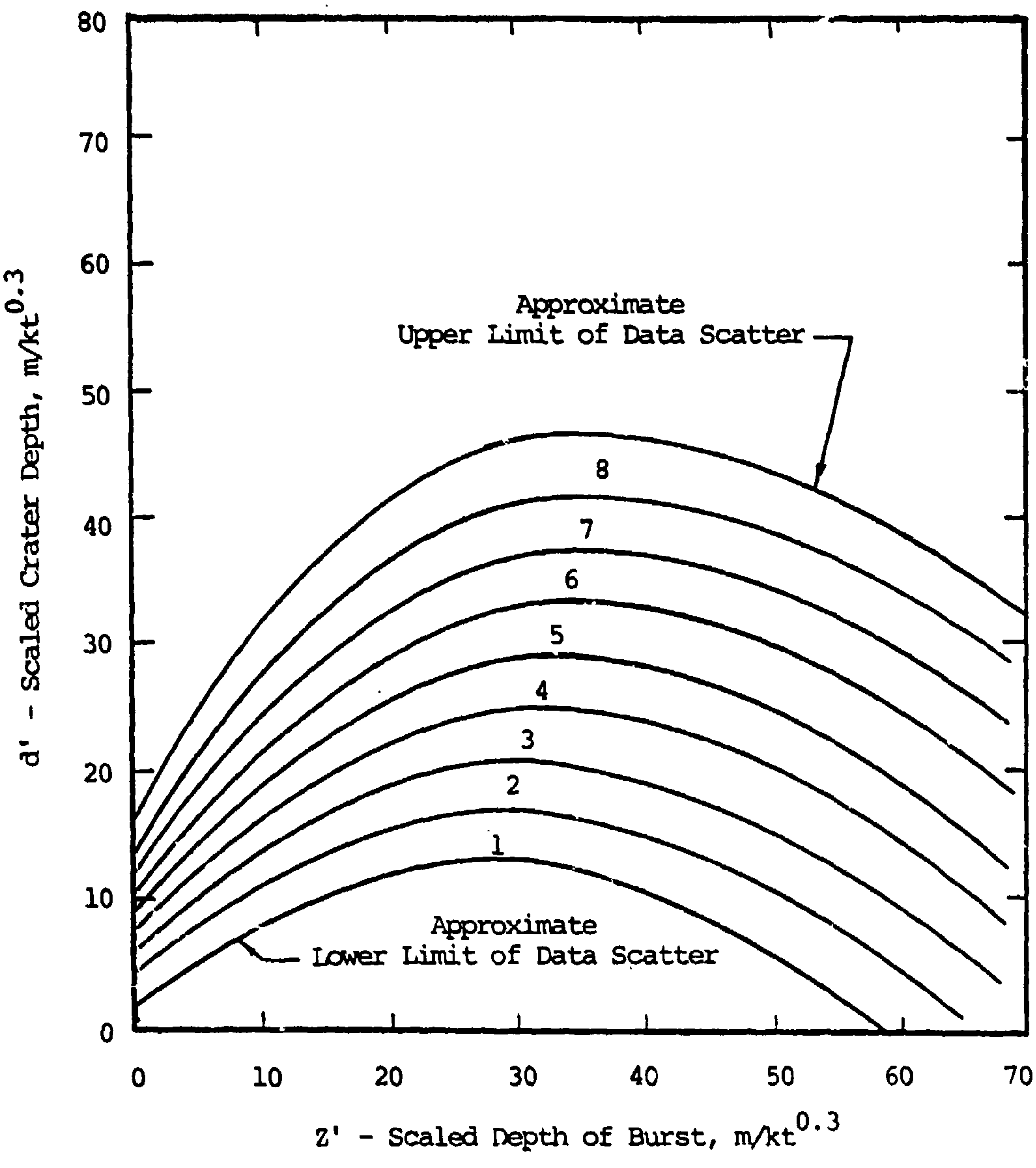


Figure 4. Range in variation of scaled crater depth as a function of scaled depth of burst. Numbered zones delineate various types of soil and rock

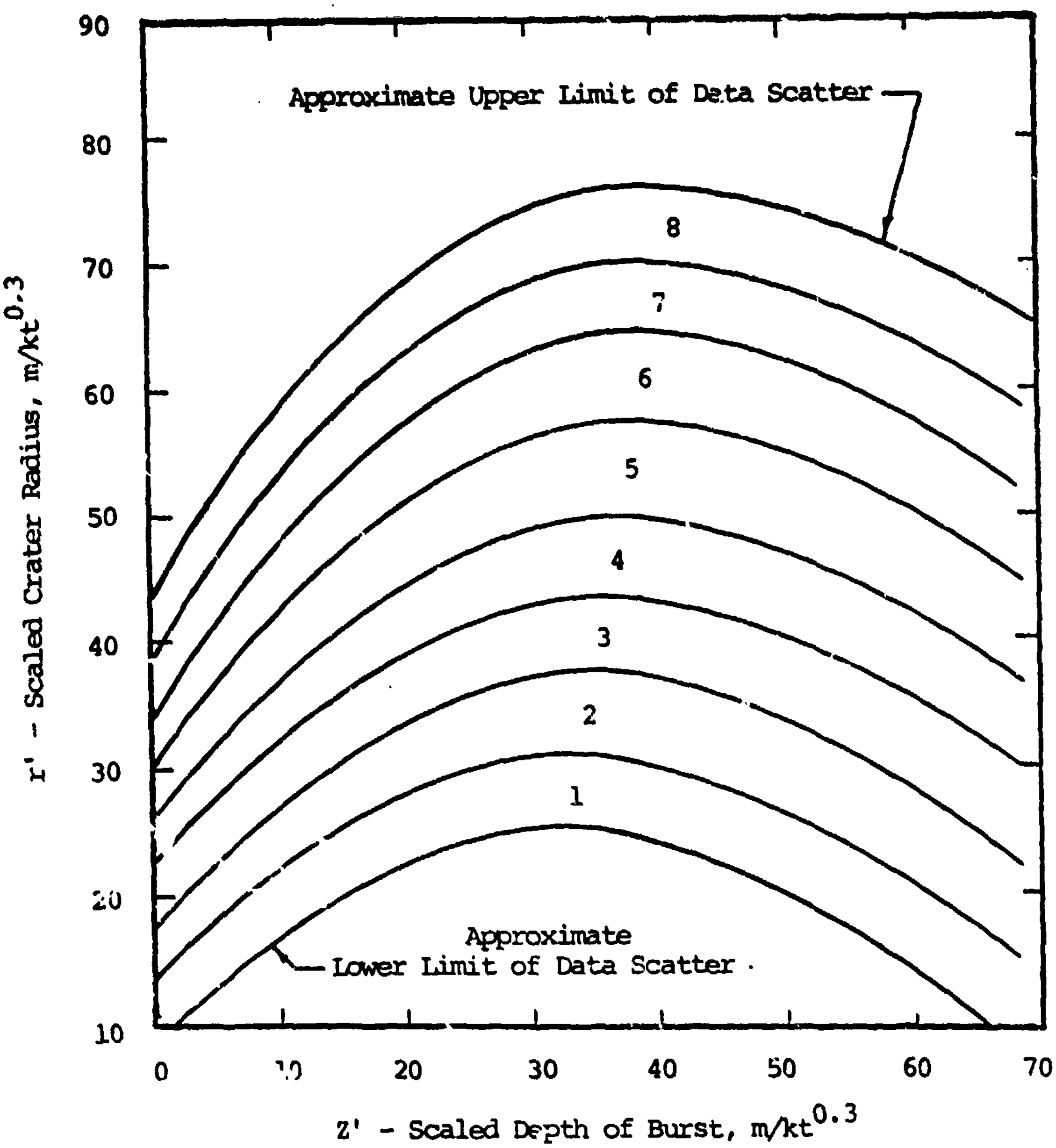


Figure 5. Range in variation of scaled crater radius as a function of scaled depth of burst. Numbered zones delineate various types of soil ard rock

crater depth; for cohesive soils, it is about 0.3 of the apparent crater depth. An estimate of the crater volume, V can be made from the equation:

$$V = 0.45\pi r^2 d$$

Layered geologies

22. Generally, WES experience, gathered from a number of cratering tests (Strange, et al, 1958; Davis; and Carnes shows that if no significant change in material properties occurs with depth over an interval equal to about 1.5 times the predicted apparent crater depth for that medium, then whatever layering lies below that depth will have no significant effect on the formation of the crater. Abrupt changes that occur at shallower and shallower depths will affect crater formation more and more drastically. In the context of this paper, abrupt changes are defined, for example, by a few metres of soil overlying a very thick layer of rock or by a very thick layer of a given type soil that has a definite water table occurring at a relatively shallow depth below the ground surface. Further, it is thus assumed that layering that involves mere changes in soil types (e.g., sandy silt to clayey silt to silty clays,) and slight changes in moisture content will not produce a significant effect on the cratering process.

23. In most instances, at least for cratering purposes and for yields of 10 kt or less, layered media can be treated as a two-layered system, i.e., soils overlying hardpan or rock, or soils in which there exists a clearly defined water table.

24. Soil-Rock Layered System. In a soil-rock layered system, the empirically derived method for predicting apparent crater dimensions as described herein is based on limited data (Strange, et al; 1958) and consequently may undergo significant changes as additional data become available. In the meantime, the prediction technique described below, is recommended for the case where a dry-to-moist soil overlies a competent rock and where the zero point of the explosion is essentially at

the ground surface, i.e., no penetration of the weapon was assumed for this study. Figure 6 shows a schematic of the two-layer system under consideration and defines the crater nomenclature. Data from layered cratering experiments in soils other than those classified under the broad "dry-to-moist" term are inadequate to properly quantify a prediction techniuqe.

25. Figures 7 and 8 show the variation in scaled apparent crater depth and radius as the proximity of the underlying soil-rock interface changes. In Figure 7, four domains of scaled overburden depth are particularly significant. For values of D'_o less than about 10, the crater action penetrates the underlying rock layers and obviously, when $D'_o = 0$, the cratering action takes place altogether in the rock layer. For the case when $D'_o = 0$, the apparent crater depth for a 1 kt surface burst on competent rock is predicted to be between 3 and 4 metres. When D'_o has values such that $9 < D'_o < 12$, the apparent crater does not penetrate the rock layer; its depth generally equals the overburden depth. For values of $12 < D'_o < 30$, the apparent crater depth experiences some enhancement due to the presence of the rock layer, enhancement which is generally attributed to shock reflection off the rock layer. Finally, for values of D'_o greater than about 30, the cratering actions are not influenced at all by the underlying rock layers.

26. In Figure 8, the apparent crater radius for a 1 kt surface burst is predicted to be about 12 metres. Over the range of scaled overburden depths from approximately 2 to 30, the apparent crater radius experiences enhancement due to the combined effects of shock reflection and shear motions along the interface. When $D'_o > 30$, the radius producing cratering mechanisms are unaffected by the underlying interface.

27. An example of how Figures 7 and 8 are used is presented below:

> Example: Assume a 5-kt weapon detonates on the ground surface and that the soil media consists of a dry-to-moist soil that is 20 metres deep. The soil overlies a massive rock formation of significant but undetermined depth. Predict the apparent crater depth and radius. First, calculate

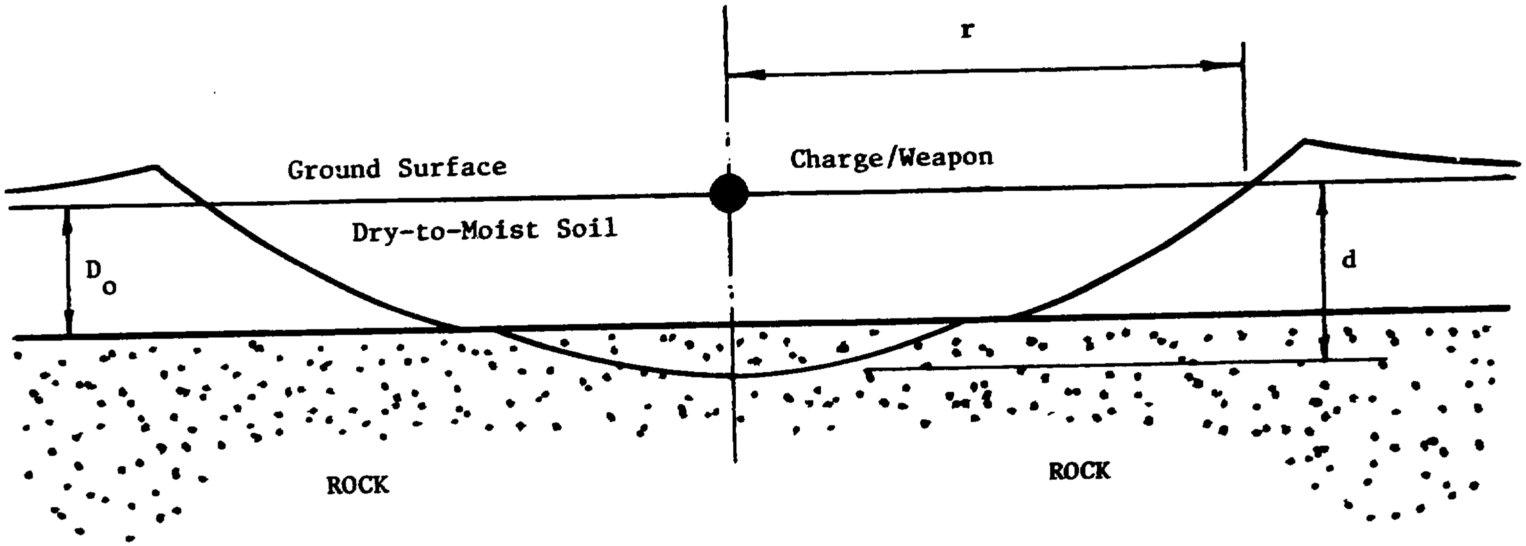


Figure 6. Definition of the crater nomenclature and schematic representation of the two-layer system

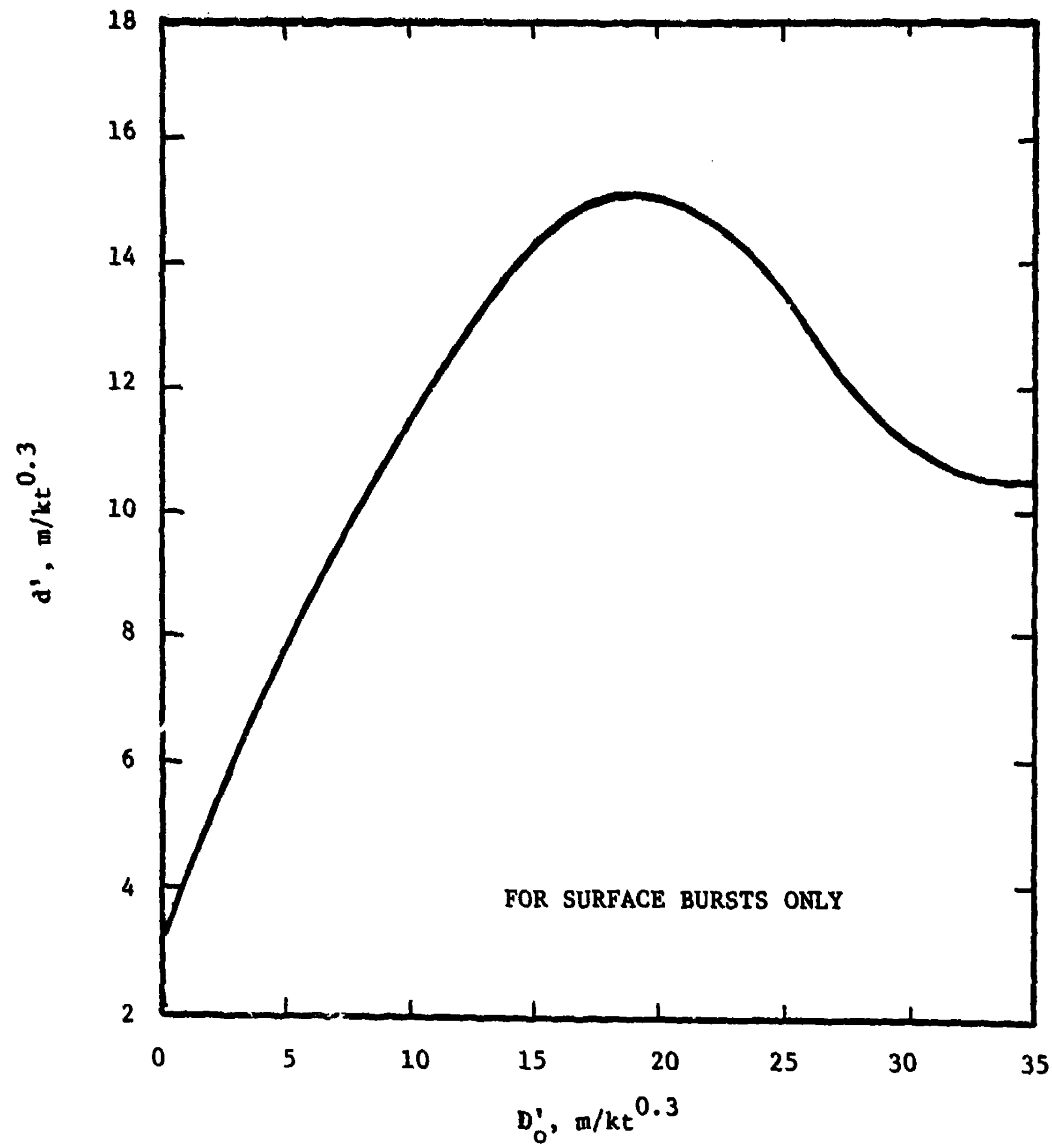


Figure 7. Manner in which the scaled apparent crater depth varies as the proximity of an underlying rock layer changes

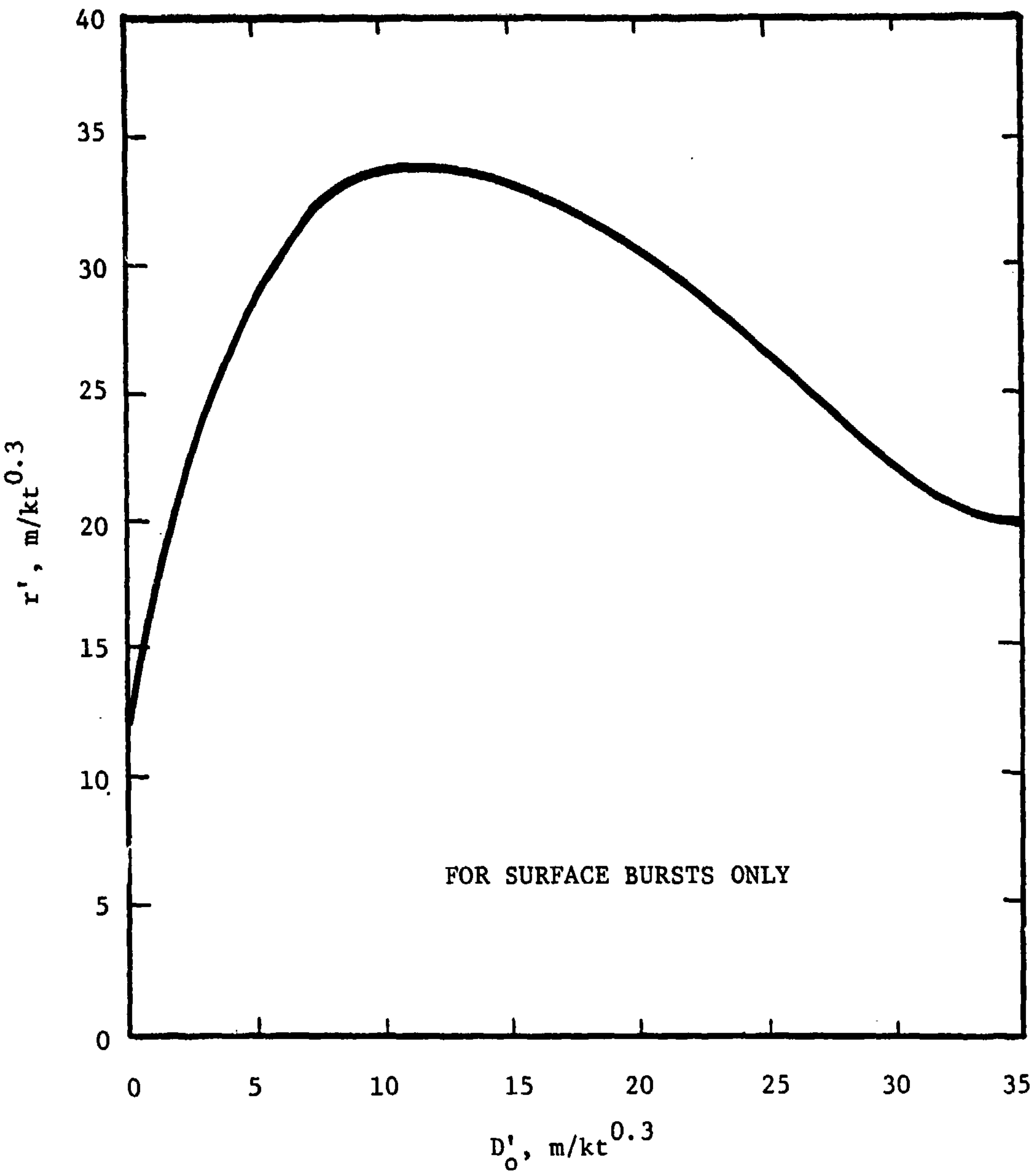


Figure 8. Manner in which the scaled apparent crater radius varies as the proximity of an underlying rock layer changes

$$D'_o = \frac{D_o}{Y^{0.3}} = \frac{20}{5^{0.3}} = \frac{20}{1.62} = 12.3$$

Enter Figures 7 and 8 with D'_o values of 12.3 and read off values for d' and r'. For

$$D'_o = 12.3$$

$$d' = 11.8$$

and

$$r' = 34$$

From the relationship,

$$d' = \frac{d}{Y^{0.3}}$$

$$d = d'Y^{0.3}$$

and

$$d = 11.8\ (1.62)$$

$$d = 19 \text{ metres}$$

Similarly,

$$r' = \frac{r}{Y^{0.3}}$$

$$r = r'Y^{0.3}$$

and

$$r = 34\ (1.62)$$

$$r = 55 \text{ metres}$$

For this case, the apparent crater depth is roughly equal to the overburden depth and the crater's aspect ratio (r/d) is 2.9.

28. Soil-Water Table Layered System. Because of a paucity of data for reasonably large yields of even HE results, only generalized rules-of-thumb are currently possible for a soil-water table layering. These generalizations are summarized below:

a. Experiments by Carnes, have shown that crater size and shape are only slightly affected by the presence of a water table if the scaled water table depth equals or is slightly greater than the scaled apparent crater depth predicted for the parent media exclusive of the water table's presence.

b. For surface explosions, Davis concluded that an underlying water table will have no effect on crater formation if the water table is at a depth greater than $10Y^{0.3}$ metres.

c. In nearly saturated media, particularly granular materials where the void ratios are relatively high, slumping (slope failure) of the crater walls is to be expected. For the crater sizes envisioned for yields up to 10 kt, the slumping action will likely reduce the crater depth by as much as a half and increase the crater radius by as much as a fourth.

d. Where the media is saturated, liquefaction in the less dense, fine grained sands (granular materials) is likely to occur. Such action will significantly alter the crater shape; typically the depth might well be reduced by like 80 percent and the radius might well be increased by 50 to 75 percent.

Conclusions

29. The crater prediction methods presented should provide reasonably good estimates of apparent crater depth and radius in a variety of cratered materials, and with the empirically determined constants of proportionality, reasonable estimates of lip height and crater volume as well. However, the search for data from which to document more confidently the problem of predicting cratering in layered media revealed a serious lack of data. Additional tests in the tens or hundreds of tons of HE in well defined two-layered systems are sorely needed in order to develop a larger (larger in number) and broader (different layering geologies) data base.

30. Obviously, there are geological scenarios involving layered media that are not adequately treated here, but the absence of a data base for other than the dry-to-moist soil over rock layering prevents all efforts save speculation. Even so, logical modifications of the methods presented can aid in making gross estimates of crater size for undocumented scenarios.

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APPENDIX A

ABBREVIATIONS AND NOTATIONS

Abbreviations

Abbreviations	
HE	High explosive (usually expressed as TNT equivalent)
kt	Kilotons
MT	Megaton
NE	Nuclear explosive
TNT	The explosive, trinitrotoluene

Notations

Notations	
c	Sonic velocity of in situ material, m/sec
d	Apparent crater depth, m
d'	$d/Y^{0.3}$, $m/kt^{0.3}$
D_o	Overburden depth, m
D'_o	$D_o/Y^{0.3}$, $m/kt^{0.3}$
h	Height of apparent crater lip, m
r	Apparent crater radius, m
r'	$r/Y^{0.3}$, $m/kt^{0.3}$
S	A qualitative descriptor of the medium cratered
V	Volume of the apparent crater, m^3
V_p	Particle velocity, m/sec
Y	Explosion yield, kilotons
Z	Charge depth of submergence, m
Z'	$Z/Y^{0.3}$, $m/kt^{0.3}$
ρ	Density of cratered medium
σ	Peak stress induced into the parent median by the shock

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

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