research report

HIGH EXPLOSIVE CRATER STUDIES: TUFF

Byron F. Murphey, 5112

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ABSTRACT

Spherical charges of TNT, each weighing 256 pounds, were exploded at various depths in tuff to determine apparent crater dimensions in a soft rock. No craters were obtained for depths of burst equal to or greater than 13.3 feet. It was deduced that rock fragments were sufficiently large that charges of greater magnitude should be employed for crater experiments intended as models of nuclear explosions.
ACKNOWLEDGMENTS

These experiments at Nevada Test Site were carried out by the Sandia Corporation Field Test organization under the direction of H. R. MacDougall. E. S. Ames arranged the air shock pressure measurements. W. G. Foy was responsible for photography. Crater surveys were conducted by Holmes and Narver survey crews.
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HIGH-EXPLOSIVE CRATER STUDIES: TUFF

Introduction

During April 1959, thirteen 256-pound spherical charges of TNT were exploded in tuff at Nevada Test Site at depths ranging from 6.35 feet to 22.5 feet. The purpose of the series was to provide reference high-explosive crater data for comparison to results from nuclear explosives and for comparison to a similar series of explosions in desert alluvium.\(^1\)

It was expected that the greater shear strength of tuff compared to desert alluvium would result in failure to crater at shallower burst depths. When reference is made to previous explosion testing in rock, the crater description is nearly always a description of the true crater.\(^2\) That is, crater dimensions are given for the crater which remains after all rubble has been removed. In the experiments described here, interest is in the apparent crater. Consequently, true craters have not been excavated (except for one case). Comparisons given below are between apparent crater dimensions.

The Experiments

Tamping of the high explosive consisted of sand to a few inches above the charge and of high early strength concrete which filled the charge hole to the surface. The concrete was allowed to cure for three days. Compressive strengths of the concrete were tested at greater than 3000 psi. Compressive strength of the tuff had been previously measured to be in the range from 2800 to 7900 psi. High-speed photography indicated that the concrete served the purpose of stemming, in that upward motion of concrete was not much different than upward motion of adjacent rock.

A clearly defined result of the experiment is that no crater was obtained when the depth of burst was 13.3 feet or greater. The mounds of rubble remaining after each of the 13-foot depth-of-burst shots are
illustrated in Figure 1. These mounds are about 6 feet high. The maximum height which the rock reached before falling back was 20 feet.

Figure 1. Rock mounds remaining following shots 3 and 8. Depths of burst are 13.4 and 13.3 feet, respectively.
A summary of apparent crater dimensions is given in Table I.

**TABLE I**

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>DOB (ft)</th>
<th>Radius (ft)</th>
<th>Depth (ft)</th>
<th>Volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.37</td>
<td>15</td>
<td>2.36</td>
<td>4.9</td>
</tr>
<tr>
<td>2</td>
<td>9.62</td>
<td>13.9</td>
<td>2.18</td>
<td>4.2</td>
</tr>
<tr>
<td>6</td>
<td>6.92</td>
<td>11.7</td>
<td>1.84</td>
<td>4.3</td>
</tr>
<tr>
<td>7</td>
<td>10.37</td>
<td>6.9</td>
<td>1.08</td>
<td>2.3</td>
</tr>
<tr>
<td>11</td>
<td>9.32</td>
<td>11.6</td>
<td>1.82</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Hole numbers 3, 4, 5, 8, 9, 10, 12, and 13 at depths of burst of 13.25 feet and greater did not result in craters but did result in mounds. Apparent mound dimensions are given in Table II.

**TABLE II**

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>DOB (ft)</th>
<th>Mound radius (ft)</th>
<th>Mound height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(λ)</td>
<td>(λ)</td>
<td>(λ)</td>
</tr>
<tr>
<td>3</td>
<td>13.37</td>
<td>37.9</td>
<td>5.78</td>
</tr>
<tr>
<td>4</td>
<td>16.62</td>
<td>37.4</td>
<td>5.9</td>
</tr>
<tr>
<td>5</td>
<td>18.72</td>
<td>33.9</td>
<td>5.3</td>
</tr>
<tr>
<td>8</td>
<td>13.27</td>
<td>35.6</td>
<td>5.6</td>
</tr>
<tr>
<td>9</td>
<td>15.82</td>
<td>37</td>
<td>5.8</td>
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<td>10</td>
<td>18.82</td>
<td>34</td>
<td>5.3</td>
</tr>
<tr>
<td>12</td>
<td>15.92</td>
<td>35.3</td>
<td>5.6</td>
</tr>
<tr>
<td>13</td>
<td>22.62</td>
<td>29.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Survey data from which these dimensions were obtained are given in Figures A-1 through A-14 in Appendix A in the form of contour maps and
and profiles. No explosions were conducted for shallower depths of burst. The data of Table I are plotted in Figure 2.

![Figure 2. Crater radius and depth versus depth of burst for 256-pound TNT charges in tuff.]

Motion pictures of the vicinity of surface zero were taken to provide measurement of surface displacement versus time. Examples of the data are illustrated in Figure 3 for depths of burst from 7 to 19 feet. The drop in initial surface particle velocities (differentiated displacements) from a depth of burst of 9.3 feet to a depth of burst of 13.4 feet is from 80 feet per second to 32 feet per second. Sample frames from motion picture studies of these two shots are illustrated in Figure 4.

The particle size of the material in the mounds shown in Figure 1 is large enough that it was decided to determine cavity size on one of the deeper explosions (hole number 10). The methods used were (1) to pump the cavity full of colored grout (weak sand-cement mix) and (2) to core-drill the grouted cavity at ten locations in order to estimate the extent of the grout-filled cavity. Since 9-3/4 cubic yards of grout were pumped into the cavity, the radius corresponding to a spherical cavity was 4 feet. A value of 4.6 feet was deduced from the core samples. The cavity diameter was therefore 8 or 9 feet, which was small enough that the blocks of tuff would be unlikely to topple into the cavity. This is a significant point since, in modeling nuclear explosions, nonscaling features such as particle
Figure 3. NTS tuff crater data.
Figure 4. Motion picture studies of shots 11 and 3. Depths of burst are 9.32 and 13.4 feet, respectively.
size can obscure the application of small-scale experiments to those of large scale. It is deduced that in tuff somewhat larger explosions (e.g., 40,000 pounds of TNT) might give a small crater for a depth of burial of \( \text{DOB/W}^{1/3} = 2 \).

This very point is relevant in comparing these data with the nuclear explosion Neptune (115 tons burst at a depth of 110 feet), which seems to give an anomalously large crater when compared with TNT explosions in tuff but agrees with desert alluvium crater data.

A partial explanation may lie in the fact that Neptune was burst under a 30-degree slope. Figure 5, taken from Morris and Schneiderban, is a plot of surface displacement versus time for Neptune. The average particle velocity is about 40 feet per second. The surface had moved 11 feet at 0.35 seconds when the motion was obscured by gas venting. If cube-root scaling is applied to the Neptune event (\( \text{DOB/W}^{1/3} = 1.8 \)), the corresponding depth for a 256-pound charge would be 11.5 feet. This depth is intermediate between shots 11 and 3 of the present series. It would be expected that particle motion of the ground surface above the Neptune shot would lie between the motions observed for shots 3 and 11 which are plotted in Figure 3. Because the particle size is relatively 10 times smaller, a crater would be expected for the Neptune event. In fact, a very large crater was obtained.

Two possible causes for this are: (1) further particle acceleration by late gas venting on Neptune, and (2) the influence of the 30-degree slope to allow the fallback material to slide downhill.

Figure 6 shows a frame from a 256-pound shot in hole number 3 in tuff. Clearly, shot number 3 does not eject material in the manner of Neptune. The lower frame is tilted 30 degrees to give some impression of the likelihood of the material sliding out to form a crater, but no conclusive statements can be made. However, some caution should be used with respect to application of crater data from Neptune, since a true crater rather than an apparent crater may be represented.

Some measurements of air shock pressure versus time were made near the explosions to show to what extent blast suppression was similar to observations made previously for 256-pound TNT bursts in desert alluvium. Data
Figure 5. Earth motion versus time, Shot Neptune.
Figure 6. Frame from time of near maximum excursion for a 256-pound burst in tuff. Lower photo is same frame but tilted 30 degrees. Depth of burst is $2.1 \text{ ft}/W^{1/3}$.

obtained from buried explosions in tuff are compared in Figure 7 with data from explosions in desert alluvium. It is known that long distance air blast is much less suppressed.
Figure 7. Peak pressure at 25.5 feet versus depth of burst.
REFERENCES


APPENDIX A

Contour maps and profiles are presented in Figures A-1 through A-13. Figure A-14 is a map of hole number 6 after excavation to determine the true crater profile. Colored grout columns were placed prior to the shots to aid in true crater determination. However, only hole 6 was excavated. The other craters have been preserved and can, if desirable, be excavated at some time in the future.
Figure A-4

LEGEND
- POST-BUILT
- POST-BUILT SURFACE WELLS

REFERENCE PLANS
HE CONTAINMENT TEST HOLES: PLAN & DETAILS

AS-BUILT

BY

HOLLIES & NARVER, INC.
ENGINEERS-CONSTRUCTORS

ENGINEERS-CONTRACTORS

HOLMES & NARVER, INC.
Figure A-6
NOTE: Due to earth fallout only visible fissures shown.

Figure A-8
Figure A-9

AS-BUILT

HOLMES & NARVER, INC.
ENGINEERS-CONSTRUCTORS

CONTURVES HOLE 9

AREA 9

NTA
JS-041400052
Figure A-11

LEGEND

--- = PRE-MACT
--- = POST-SHAFT

REFERENCE CHART
HE CONTAINMENT TEST HOLE PLAN & DETAILS JSD-94/0808-01
Figure A-12
Figure A-14

EXCAVATION CONTOURS HOLE #6
SCALE 1:50

LEGEND:
PRE-SHOT
EXCAVATION

REFERENCE DRAW:
UL COMPARTMENT TEST HOLES PLAN & DETAILS 10-OCT-69-10
UL COMPARTMENT TEST HOLES CONTOURS & PROFILES 10-OCT-69-28

AS BUILT
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