

**BURIED EXPLOSION MODULE (BEM): A METHOD FOR  
DETERMINING THE FRAGMENT HAZARDS DUE TO DETONATION  
OF A BURIED MUNITION**

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**ABSTRACT**

During unexploded ordnance (UXO) remediation operations, ordnance may be found that is deemed unsafe to move. In this case, the ordnance must be destroyed in place. In order to protect the disposal personnel as well as the public, a withdrawal distance from the detonation is enforced. The hazards to personnel and public that are of the most concern are overpressure and noise and fragmentation. For most unexploded ordnance the fragmentation range is much larger than the inhabited building distance (IBD) for overpressure.

The Structural Branch of the U.S. Army Engineering and Support Center, Huntsville (USAESCH) has developed an analytical method to calculate public and operational personnel withdrawal distances for fragmentation of buried munitions. The method addresses cratering and soil ejecta effects as well as primary fragmentation from the munition.

The Structural Branch has developed software to simplify and standardize the calculations to determine the withdrawal distance due to fragmentation and soil ejecta due to the detonation of a buried munition. This software which is called the buried explosion module (BEM) has been incorporated in the Mapping Explosive Safety Hazards (MESH) software.

The theory used in the development of the BEM software will be discussed. The software will be outlined and an example presented.

**1.0 INTRODUCTION**

The U.S. Army Engineering and Support Center, Huntsville (USAESCH) has developed an analytical method to calculate public and operational personnel withdrawal distances for buried munition disposal. The buried explosion module (BEM) is a program designed to be used to calculate the residual velocity of fragments produced by a buried munition and the maximum ejecta radius of large soil chunks produced by the buried explosion. BEM is

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designed to be used in conjunction with the computer software TRAJ [1] to calculate the fragment trajectories.

The theory used in BEM is discussed. The input required for the software is detailed and two example problems are given.

The results from the BEM software are compared to the results obtained by applying the method by hand. USAESCH is involved in a test program to determine the thickness of sandbags necessary to defeat the primary fragments from a munition detonated on the ground surface. The results from the BEM software for mitigation of primary fragments by tamped earth are compared to the results of the sandbag tests completed to date.

## **1.1 BACKGROUND**

An analytical method to calculate public and operational personnel withdrawal distances for buried munition disposal has been proposed by Huntsville Center (HNC) to the Department of Defense Explosive Safety Board (DDESB). The method includes cratering calculations and calculations of the velocity of the fragment as it exits the soil using equations from DOE/TIC 11268 [2], and fragment trajectory calculations using TRAJ [1]. The maximum ejecta radii of large soil chunks produced by the cratering are calculated using Figure 5.20 in DOE/TIC 11268 [2].

In order to simplify and standardize the fragment calculations, new computer software (using this method) called BEM has been developed. This software is described in the following sections.

## **2.0 THEORY**

As a buried munition explodes fragments are produced which travel through soil before escaping to the air and presenting a hazard. The soil slows down the fragments and, in some cases, may stop the fragments completely. In most cases the explosion causes a crater. Soil from the crater is also thrown away from the center of the explosion becoming hazardous. However, if the munition is buried deeply enough a camouflet is formed instead and no soil is ejected from the site. The question becomes how much soil does the fragment have to penetrate before escaping and what is the density of this soil?

Preliminary calculations for a variety of munitions show that by a distance of one foot from the center of the explosion, the fragment velocity is approximately twice that of the soil particles. Which suggests that for at least a portion of the burial depth the fragment is travelling through undisturbed soil. However, it is not clear at this time for which portion of the burial depth this is true. Therefore, as a conservative estimate, all of the soil is assumed to have a density of one-half its undisturbed density for the purposes of calculating the drag coefficient on the fragment velocity.

## 2.1 FORMATION OF CRATER OR CAMOUFLET

Whenever a buried explosive charge is detonated, a cavity or void is formed within the soil. If the energy release is relatively close to the surface, the cavity or void vents to the atmosphere and a crater is formed. If the energy release is sufficiently deep below the surface a void, called a camouflet, is formed. Equations 5.19 and 5.20 from DOE/TIC 11268 [2] are used to determine whether a crater or a camouflet is formed.

$$X = 4.605 + \ln\left(\frac{W^{1/4}}{d}\right)$$
$$Y = [6.438 + 1.398(\ln(\frac{W^{1/3}}{d}))]\tanh^5[2.00 + 0.4343(\ln(\frac{W^{1/3}}{d}))]$$

where  $W$  = the explosive weight in pounds  
 $d$  = the depth of burial in feet.

If  $X$  is greater than  $Y$ , a camouflet will be formed. If  $X$  is less than  $Y$ , a crater will be formed.

## 2.2 FRAGMENT VELOCITY

The maximum fragment weight and initial velocity are calculated as described in Chapter 2 of TM 5-1300 [4] and detailed in HNC-ED-CS-S-98-1 [6]. Due to calculation restraints (division by the depth of burial), if the depth of burial is zero the software assumes a depth of burial of 0.1 ft. If the depth of burial is zero (surface burst) the fragment does not pass through any soil and the velocity of the fragment is the initial velocity. Otherwise, the fragment velocity as it exits the soil is calculated using equation 6.3 from DOE/TIC 11268 [2].

$$V_s = V_0 e^{-12k_v R}$$

where  $V_s$  = fragment velocity at a distance  $R$  from the center of detonation (ft/sec)  
 $V_0$  = initial (maximum) fragment velocity (ft/sec) (using the Mott-Gurney equation, equation 2-32 from TM5-1300)  
 $R$  = distance from the center of detonation (ft) = depth of burial  
 $k_v$  = velocity decay coefficient

$$k_v = (A/W_f)\gamma_0 C_D$$

where  $A/W_f$  = fragment form factor, the ratio of the presented area of the fragment (in<sup>2</sup>) to the fragment weight (lb). A standard fragment is assumed.  
 $\gamma_0$  = specific weight of the disturbed soil = ½ the specific weight of the undisturbed soil (lb/in<sup>3</sup>)

$C_D$  = drag coefficient (dimensionless) = 0.6 for  $V > 1100$  ft/sec for spinning chunky fragments

$V_s$  is used to calculate the fragment trajectories using TRAJ [1]. The line of sight angle from the depth of burial to the edge of the crater is calculated to determine the start angle for TRAJ. Using Equation 5.22a from DOE/TIC 11268 [2], the true crater radius is calculated.

$$R_T = 2.155 \cdot d \cdot \left( \frac{W^{1/3}}{d} \right)^{0.865}$$

Where  $R_T$  = the true crater radius (ft)

$d$  = the depth of burial (ft)

$W$  = 1.2 x TNT equivalent explosive weight (lb)

$$\text{Start Angle} = \tan^{-1} \left( \frac{d}{R_T} \right)$$

Using the fragment velocity as the fragment exits the soil, the fragment weight and the start angle, TRAJ [1] is used to calculate the maximum horizontal range of the fragment.

### 2.3 MAXIMUM EJECTA RADII

As the crater is formed, large chunks of soil are expelled and become potentially hazardous fragments. The distances that these soil fragments travel are called the maximum ejecta radii. These radii are shown in Figure 5.20 of DOE/TIC 11268 [2] (see Figure 1). The line shown in this figure has been specified by an equation and this equation has been included in BEM. Representing the values on the horizontal axis by the variable  $x$  and the values on the vertical axis by the variable  $y$ , the equation for the line becomes

$$y = 10^{(0.9 \log x + 1.11)}$$

$$x = \frac{W^{7/24}}{\rho^{7/24} c_p^{1/3} g^{1/8} d}$$

where  $W$  = explosive yield (lb) =  $1.7 \times 10^6 \times 1.2 \times$  TNT equivalent explosive weight (lb)

$\rho$  = soil mass density (lb-sec<sup>2</sup>/ft<sup>4</sup>)

$c_p$  = seismic velocity of the soil (ft/sec)

$g$  = gravitational constant (32.2 ft/sec<sup>2</sup>)

Figure 1 was developed from results of cratering experiments reported in AFWL-TR-74-351 [5]. The soil ejecta radii from Figure 1 are based on 2- inch diameter (or larger) soil chunks and the hazardous fragment areal density requirement (1 hazardous fragment/600 square feet). To be consistent with the primary fragment calculations, the maximum range of the soil ejecta should be used. Examination of the original soil ejecta data from AFWL-TR-74-351 [5] shows that the average ratio between the maximum soil ejecta range and the range of one hazardous ejecta per 600 square feet is 1.9. Therefore, the maximum ejecta radius  $R_{\max}$  is then

$$R_{\max} = 1.9(2 \cdot y \cdot d) = 3.8 \cdot y \cdot d$$

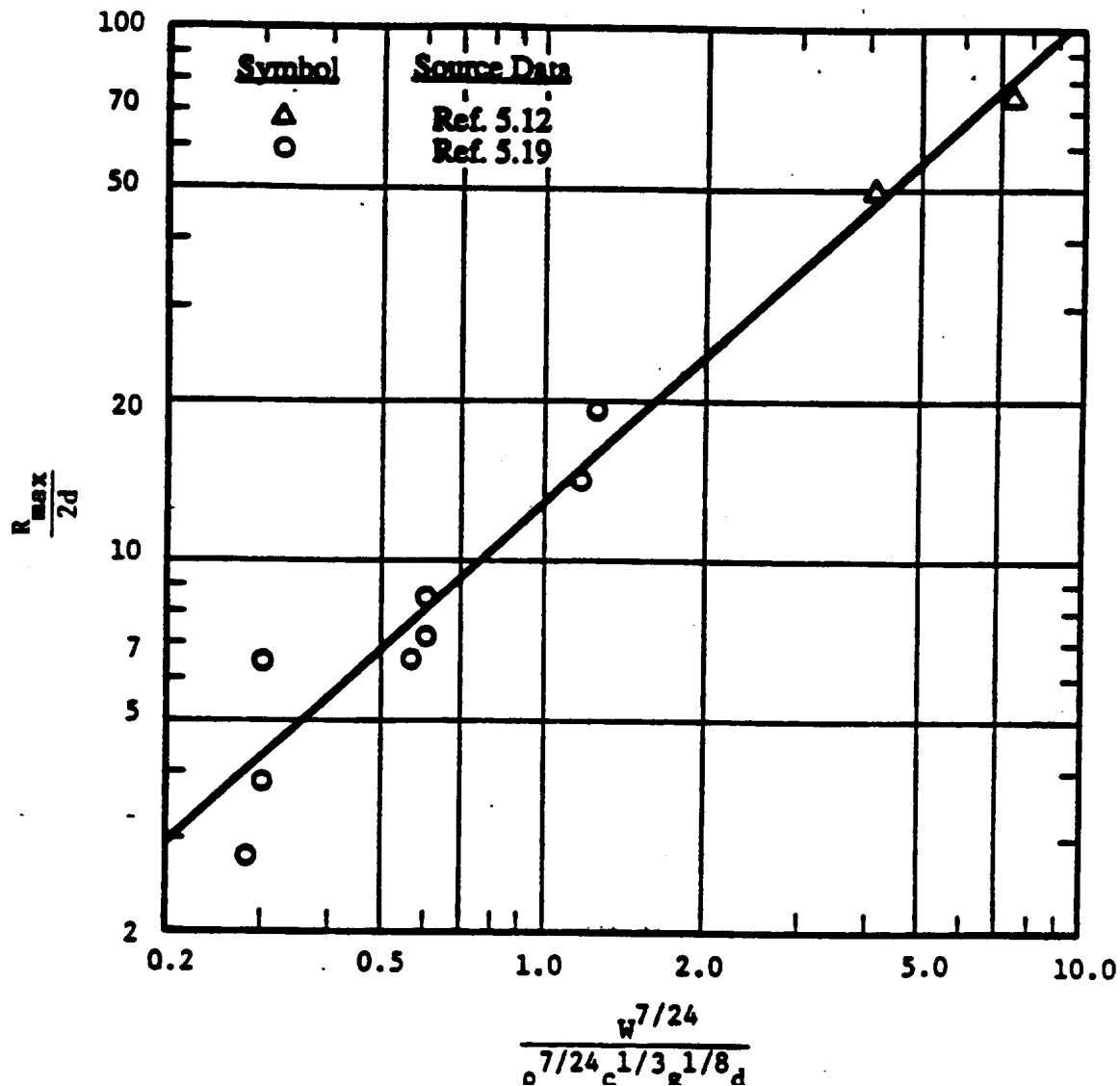


Figure 1 – Maximum Ejecta Radii for Large Soil Chunks [2]

Due to the nature of the equations used in BEM, the calculations will never result in a final fragment velocity and corresponding fragment range of zero. However, where a crater is formed a burial depth may be found where the fragment range will be less than the soil ejecta range. There is no added benefit to burying the munition any deeper until reaching the depth at which a camouflet is formed.

### **3.0 SOFTWARE DESCRIPTION**

#### **3.1 INPUT DATA**

The necessary values are input into BEM in an interactive mode. The user is prompted to input the following values.

- 1) A title identifying the problem.
- 2) The total net explosive weight (TNT equivalent) in lbs.
- 3) The depth of burial in feet.
- 4) The design fragment weight in lbs.
- 5) The initial fragment velocity in feet/sec.
- 6) The soil type chosen from a pre-defined list or
  - a) the specific weight of the soil in  $\text{lbs/in}^3$ ,
  - b) the mass density of the soil in  $\text{lb-sec}^2/\text{ft}^4$ ,
  - c) and the seismic velocity of soil in ft/sec.

Some commonly found munitions have been analyzed and the explosive weight, initial velocity and maximum fragment weights are shown in Table 1. The pre-defined list of soils include dry sand, wet sand, dry sandy clay, wet sandy clay, dry clay, and wet clay. Average soil properties are used for each of these soil types. Some typical soil data from TM 5-855-1 are shown in Table 2.

#### **3.2 OUTPUT FILE**

The results are written to a file called 'BEMOUT'. BEM does not include commands to view or print the results directly.

#### **3.3 SOFTWARE VALIDATION**

In order to validate the program, a sample problem was calculated by hand and using the software BEM. Write statements were inserted to print intermediate results. The results of the hand calculations and the BEM calculations are shown in Figures 2 and 3. For a burial depth of 6 ft, both sets of calculations yield a final fragment velocity of 101 ft/sec and a soil ejecta radius of 356 ft. For a burial depth of 8 ft, both sets of calculations show that a camouflet is formed and the final fragment velocity is 31 ft/sec.

**Table 1 – Munition Information**

| <b>Munition</b> | <b>Explosive Type</b> | <b>Explosive Weight (lb)</b> | <b>TNT Equivalent Explosive Weight (lb)</b> | <b>Critical Fragment Weight (lb)</b> | <b>Critical Fragment Velocity (fps)</b> |
|-----------------|-----------------------|------------------------------|---------------------------------------------|--------------------------------------|-----------------------------------------|
| 20 mm M56A4     | H761 (RDX)            | 0.0264                       | 0.0290                                      | 0.0006                               | 3183                                    |
| 25 mm M792      | HMX                   | 0.0959                       | 0.1199                                      | 0.0082                               | 4256                                    |
| 37 mm Mk II     | TNT                   | 0.5270                       | 0.5270                                      | 0.0295                               | 5758                                    |
| 40 mm MK2       | TNT                   | 0.1870                       | 0.1870                                      | 0.0331                               | 3605                                    |
| 60 mm M49A3     | Comp B                | 0.4200                       | 0.5376                                      | 0.0237                               | 5114                                    |
| 75 mm M48       | TNT                   | 1.4700                       | 1.4700                                      | 0.1530                               | 3471                                    |
| 81 mm M374      | Comp B                | 2.0900                       | 2.6752                                      | 0.0308                               | 6721                                    |
| 105 mm M1       | Comp B                | 5.0700                       | 6.4896                                      | 0.2057                               | 4055                                    |
| 155 mm M107     | Comp B                | 15.4480                      | 19.7734                                     | 0.6482                               | 3426                                    |
| 4.2 in M3A1     | TNT                   | 8.1700                       | 8.1700                                      | 0.0787                               | 6391                                    |
| 3 in Stokes     | TNT                   | 2.1000                       | 2.1000                                      | 0.0436                               | 6189                                    |
| 4 in Stokes     | TNT                   | 7.9200                       | 7.9200                                      | 0.0782                               | 6336                                    |
| 8 in M106       | Comp B                | 38.8000                      | 49.6640                                     | 1.693                                | 3091                                    |
| 4.7 in Mark 1   | TNT                   | 6.0700                       | 6.0700                                      | 0.5915                               | 3566                                    |

USAESCH has been running a test program to determine the thickness of sandbags needed to defeat fragments from a munition on the ground surface. A munition is placed on its side on the ground surface and sandbags are placed around all four sides and the top of the munition with a 6-inch standoff from the munition. The munition is detonated using a perforating shaped charge. Witness screens are used between sandbags to determine if fragments penetrate the sandbag layer and overpressure and noise measurements are taken at several distances from the center of the detonation. Sandbag throw is also measured. At the end of the test program, a full report of these results will be available.



**Table 2 – Soil Properties from Explosion Tests**

| <b>Soil Description</b>                                 | <b>Unit Wt<br/>(pcf)</b> | <b>Seismic<br/>Velocity<br/>(fps)</b> | <b>Mass<br/>Density<br/>(lb-<br/>sec<sup>2</sup>/ft<sup>4</sup>)</b> | <b>Specific<br/>Weight<br/>(pci)</b> |
|---------------------------------------------------------|--------------------------|---------------------------------------|----------------------------------------------------------------------|--------------------------------------|
| Dry desert alluvium and playa, partially cemented       | 97                       | 3150                                  | 3.0124                                                               | 0.0561                               |
| Loose, dry poorly graded sand                           | 90                       | 600                                   | 2.7950                                                               | 0.0521                               |
| Loose, wet, poorly graded sand with free-standing water | 116                      | 550                                   | 3.6025                                                               | 0.0671                               |
| Dense dry sand, poorly graded                           | 104                      | 1100                                  | 3.2298                                                               | 0.0602                               |
| Dense wet sand, poorly graded, with free-standing water | 124                      | 1000                                  | 3.8509                                                               | 0.0718                               |
| Very dense dry sand, relative density = 100%            | 109                      | 1600                                  | 3.3851                                                               | 0.0631                               |
| Silty-clay, wet                                         | 123                      | 800                                   | 3.8199                                                               | 0.0712                               |
| Moist loess, clayey sand                                | 122                      | 1000                                  | 3.7888                                                               | 0.0706                               |
| Wet sandy clay, above water table                       | 123                      | 1800                                  | 3.8199                                                               | 0.0712                               |
| Saturated sandy clay, below water table                 | 117                      | 5500                                  | 3.6335                                                               | 0.0677                               |
| Saturated stiff clay, saturated clay-shale              | 125                      | >5000                                 | 3.8820                                                               | 0.0723                               |

To date, sandbag tests have been completed on five munitions. The results from these tests are compared to the results from BEM in Table 3. The burial depths determined using BEM are approximately twice the required thickness of sandbags from the sandbag tests. Also, where a crater is formed, the soil ejecta range is greater than the sandbag throw. The sandbag tests are run with a standoff between the munition and the sandbag. Therefore, there is not full coupling between the explosive event and the sandbags whereas BEM assumes full coupling between the explosive event and the soil. In addition, the sandbags are larger than the soil ejecta considered in BEM so the drag is larger and the sandbags won't travel as far as the soil ejecta. Also, BEM will never result in a zero fragment velocity and fragment range.

The BEM software produces the same results as when the method is applied by hand. Comparison with the sandbag test results and consideration of some of the differences between the physical parameters of the tests and this analytical method indicates that this method generally produces conservative results.

**Table 3 – Primary Fragment Mitigation Using Earth Cover**

| Munition     | Sandbag Tests                              |                    | Tamped Earth Using BEM        |                     |                        |
|--------------|--------------------------------------------|--------------------|-------------------------------|---------------------|------------------------|
|              | Thickness Required to Defeat Fragment (ft) | Sandbag Throw (ft) | Thickness of Earth Cover (ft) | Fragment Range (ft) | Soil Ejecta Range (ft) |
| 155 mm M107  | 3                                          | 200                | 6                             | 247                 | 356                    |
| 4.2" M3A1    | 2                                          | 110                | 4                             | 83                  | 271                    |
| 105 mm M1    | 2                                          | 120                | 5                             | 84                  | N/A*                   |
| 81 mm M374A1 | 1.67                                       | 110                | 3                             | 70                  | 197                    |
| 60 mm M49A3  | 1                                          | 20                 | 2                             | 271                 | N/A*                   |

\*Note: Camouflet is formed

#### **4.0 REFERENCES**

1. "TRAJ--A Two Dimensional Trajectory Program for Personal Computers", Minutes of the Twenty-Fourth Explosives Safety Seminar, August 1990, pp. 1853-1879, Montanaro, P.E.
2. DOE/TIC-11268, A Manual for the Prediction of Blast and Fragment Loadings on Structures, February 1992.
3. Army TM 5-855-1, Fundamentals of Protective Design for Conventional Weapons, November 1986.
4. Army TM 5-1300, Structures to Resist the Effects of Accidental Explosions, November 1990.
5. "Near-Surface Cratering Experiments, Fort Polk, Louisiana", AFWL-TR-74-351, U.S. Army Engineers Waterways Experiment Station, November 1975.
6. "Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives", HNC-ED-CS-S-98-1, U.S. Army Engineering and Support Center, Huntsville, January 1998.

## Figure 2 - Sample Problem Hand Calculations

Given: 155 mm M107

Explosive weight = 15.4 lbs Comp B x 1.28 = 19.71 lbs TNT equivalent

Design fragment weight = 0.6482 lbs

Initial fragment velocity = 3426 fps

Dry Sand

Mass density of soil = 3.1367 lb-sec<sup>2</sup>/ft<sup>4</sup>

Seismic velocity of soil = 1100 fps

Specific weight of soil = .0585 pci

Depth of burial = 6 ft

Calculations:

Is a crater or a camouflet formed?

$$X = 4.605 + \ln((1.2(19.71)^{.25})/6) = 3.60$$

$$Y = [6.438 + 1.398 \ln((1.2(19.71)^{.5})/8)] \tanh^5[2.00 + 0.4343 \ln((1.2(19.71)^{.5})/8)] = 3.82$$

$X < Y$  Therefore a crater is formed

$$d = \text{diameter of fragment} = (W_f/0.186)^{1/3} = 1.516 \text{ in}$$

$$A = \text{presented area of fragment} = \pi d^2/4 = 1.805 \text{ in}^2$$

$$k_v = \left(\frac{A}{W_f}\right) \cdot \left(\frac{\gamma_0}{2}\right) \cdot C_D = 0.0489$$

$$V_s = V_0 e^{-12k_v R} = 101 \text{ fps}$$

Soil Ejecta

$$x = \frac{(1.2 \cdot 19.71 \cdot 1.7 \times 10^6)^{7/24}}{3.1367^{7/24} \cdot 1100^{1/3} \cdot 32.2^{1/8} \cdot 6} = 1.24$$

$$y = 10^{(0.9 \log(1.24) + 1.11)} = 15.61$$

$$R_{\max} = 3.8 \text{ DOB } y = 356 \text{ ft}$$

Given: 155 mm M107

Depth of burial = 8 ft

Calculations:

$$X = 3.32$$

$$Y = 3.20$$

$X > Y$  Therefore a camouflet is formed.

$$V_s = 31 \text{ fps}$$

### Figure 3 - Sample Problem Results from BEM (File BEMOUT)

#### BURIED EXPLOSION MODULE (BEM)

155 MM M107 AT 6 FT

Total net explosive weight, lbs = 19.71  
Initial fragment velocity, fps = 3426.  
Fragment weight, lbs = .6482  
Depth of burial, ft = 6.00  
Specific weight of soil, pci = .0585  
Mass density of soil, lb-sec<sup>2</sup>/ft<sup>4</sup> = 3.1367  
Seismic velocity of soil, fps = 1100.0000

A CRATER IS FORMED

True crater radius, ft = 20.43  
Final fragment velocity, fps = 101.  
Start angle for trajectory, deg = 16  
Maximum soil ejecta radius, ft = 355.9230

#### BURIED EXPLOSION MODULE (BEM)

155 MM M107 AT 8 FT

Total net explosive weight, lbs = 19.71  
Initial fragment velocity, fps = 3426.  
Fragment weight, lbs = .6482  
Depth of burial, ft = 8.00  
Specific weight of soil, pci = .0585

A CAMOUFLET IS FORMED

Camouflet radius, ft = 3.10  
Final fragment velocity, fps = 31.