**US Army Corps**
**of Engineers**
Engineering and Support
Center, Huntsville

# OPEN BURN/OPEN DETONATION (OB/OD) MUNITIONS RESPONSE SITE (MRS) BOUNDARIES BASED ON KICK OUT DISTANCES

**CEHNC-EDS-O-12-03**

**MARCH 2012**

MARCH 2012

Prepared by

Michelle Crull, PhD, PE

Shannon Ward

Department of the Army

U.S. Army Engineering & Support Center, Huntsville

ATTN: CEHNC-EDS-O

P.O. Box 1600

Huntsville, AL 35807-4301

Telephone: Commercial 256-895-1770

Approved by: Rick Owens 3-6-12

Rick Owens DATE

Branch Chief, Operations Branch

# EXECUTIVE SUMMARY

Historically the Archive Search Reports (ASR) assigned a 4000 ft radius around all Open Burn/Open Detonation (OB/OD) grounds as the boundary for the Munitions Response Site (MRS) Boundary. This 4000 ft was based on the 1999 (or earlier) DoD 6055.9 STD distance for intentional detonations of fragmenting explosive materials with a diameter of 5 inches or greater.

It is important to understand this the 4000 ft distance was specified in the DoD 6055.9 STD to protect non-essential personnel from the primary fragments due to the detonation of a munition 5 inches or larger in diameter. It was not intended to use to estimate the possible kick out distance from an open detonation of multiple items.

At the time that these historical ASR were written, the idea of footprint reduction had not come into being. So, while it is true that kick outs do not travel any further than the maximum primary fragment distance, kick outs actually travel much less distance than the maximum primary fragment distances.

The Project Delivery Team must determine a reasonable Maximum Credible Event for the OB/OD ground based on historical information. Useful historical information might include location of OB/OD ground with respect to buildings and transportation routes that existed when the OB/OD ground was in use as well as the mission of the installation at the time to determine what munitions were likely to have been destroyed at the OB/OD ground. Any information on items that might have been recovered in the area since closure of the OB/OD ground may also be useful.

The Buried Explosion Module (BEM) [TP 16, 2009] can be used to calculate the maximum soil ejecta distance for a given Maximum Credible Event (MCE). Comparison of the maximum soil ejecta distances with the maximum kick out distances from the stack tests show that the maximum soil ejecta distance is not always conservative. Therefore, the maximum soil ejecta distance must be multiplied by 1.3 to ensure that a maximum kick out distance based on this method is conservative when compared with the stack test data. This method requires some expertise in the use of the BEM but a list of pre-calculated values has been supplied in Appendix A.

The use of the Hazardous Fragment Distance (HFD) for an analogous munition can be used to estimate the kick out distance for MCE no larger than 1306 lbs. If an analogous munition is selected from the DDESB TP 16 Fragmentation Database [18 Oct 2011] then comparison with the stack test data shows that use of the HFD is not always conservative. Therefore, the HFD from the analogous munition must be multiplied by 1.25 to ensure that a maximum kick out distance based on this method is conservative when compared with the stack test data.

Using the Generic Equation Calculator v1 (GEQ v1) [TP 16, 2009] with a given MCE to calculate a HFD results in a HFD that is conservative when compared with the maximum kick out distance from the stack tests. This method has the same maximum MCE limit of 1306 lbs as the other HFD method but does not require a multiplier. This method may also be easier to use than the other HFD method.



ED_001691B_00002460

If the MCE is less than 1306 lbs then the easiest method to estimate the maximum kick out distance is to use the largest HFD calculated by the GEQ [TP 16, 2009] for the given MCE. For any MCE, the maximum kick out distance may be estimated using the BEM [TP 16, 2009]. This method is fully described, including all assumed input values, in Section 4.1. Table A-1 lists the estimated kick out distances for given MCE based on this method.



ED_001691B_00002460

## TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... ii
TABLE OF CONTENTS ..... iv
LIST OF FIGURES ..... v
LIST OF TABLES ..... v
1.0 INTRODUCTION ..... 1
2.0 SUMMARY OF STACK TESTING ..... 2
3.0 PROPOSED METHODOLOGIES FOR DETERMINING KICK OUT DISTANCES ..... 3
3.1 ESTIMATION OF KICK OUT DISTANCE USING THE BURIED EXPLOSION MODULE (BEM) ..... 3
3.1.1 DETERMINATION OF SOIL EJECTA DISTANCE ..... 4
3.1.2 EVALUATION OF USE OF BURIED EXPLOSION MODULE TO ESTIMATE MAXIMUM KICK OUT DISTANCE ..... 4
3.1.3 SUMMARY OF METHODOLOGY USING THE BURIED EXPLOSION MODULE TO ESTIMATE MAXIMUM KICK OUT DISTANCE ..... 5
3.2 ESTIMATION OF KICK OUT DISTANCE USING HAZARDOUS FRAGMENT DISTANCE FOR ANALOGOUS MUNITIONS ..... 6
3.2.1 DETERMINATION OF HAZARDOUS FRAGMENT DISTANCE FOR ANALOGOUS MUNITIONS ..... 6
3.2.2 EVALUATION OF USE OF HAZARDOUS FRAGMENT DISTANCE OF ANALOGOUS MUNITION TO ESTIMATE MAXIMUM KICK OUT DISTANCE ..... 7
3.2.3 SUMMARY OF METHODOLOGY USING THE HAZARDOUS FRAGMENT DISTANCE OF ANALOGOUS MUNITION TO ESTIMATE MAXIMUM KICK OUT DISTANCE ..... 8
3.3 ESTIMATION OF KICK OUT DISTANCE USING HAZARDOUS FRAGMENT DISTANCE VIA THE GENERIC EQUATION CALCULATOR ..... 8
3.3.1 DETERMINATION OF HAZARDOUS FRAGMENT DISTANCE USING THE GENERIC EQUATION CALCULATOR ..... 8
3.3.2 SUMMARY OF METHODOLOGY USING THE HAZARDOUS FRAGMENT DISTANCE VIA THE GENERIC EQUATION CALCULATOR ..... 8
3.3.3 SUMMARY OF METHODOLOGY USING THE HAZARDOUS FRAGMENT DISTANCE VIA THE GEQ ..... 9
4.0 CONCLUSIONS FROM COMPARISON OF STACK TEST DATA WITH PROPOSED METHODS ..... 9
5.0 RECOMMENDATIONS ..... 10
6.0 REFERENCES ..... 10
APPENDIX A ..... 1



ED_001691B_00002460

## LIST OF FIGURES

Figure A-1 – Estimated Kick Out Distance Using 1.3 x Maximum Soil Ejecta Distance ..... A3

## LIST OF TABLES

Table 2-1- Fragment Recovery Data..... 3
Table 3-1 – Maximum Soil Ejecta Distances ..... 4
Table 3-2 – BEM Method Comparison ..... 5
Table 3-3 – Hazardous Fragment Distances for Analogous Munitions..... 6
Table 3-4 – Hazardous Fragment Distances for Analogous Munitions Method Comparison..... 7
Table 3-5 – Hazardous Fragment Distances via the GEQ ..... 9
Table A-1: Kick Out Distances Based on 1.3 x Maximum Soil Ejecta Distances ..... A2



ED_001691B_00002460

## 1.0 INTRODUCTION

Historically, the Archive Search Reports (ASR) assigned a 4000 ft radius around all Open Burn/Open Detonation (OB/OD) grounds as the boundary for the Munitions Response Site (MRS) Boundary. This 4000 ft was based on the 1999 (or earlier) DoD 6055.9 STD distance for intentional detonations of fragmenting explosive materials with a diameter of 5 inches or greater.

> *C5.5.4.* ***Ranges Used for Destruction of Ammunition, Demonstrations, and Explosive Ordnance Disposal (EOD)***
>
> *C5.5.4.1. The minimum separation distances between ranges (where explosives demolition, demonstrations, and EOD explosives operations are conducted) and non-essential personnel are determined by application of the criteria given below. If the minimum separation distance requirements for previously approved DDESB sitings or those prescribed in this section cannot be met, then personnel shall be provided with protection as specified in subsection C4.3.2., Chapter 4.*
>
> *C5.5.4.1.1. Distance (Feet) = 328 $W^{1/3}$, but not less than 1250 feet, for non-fragmenting explosive materials. If known, maximum debris throw ranges, with an applicable safety factor, may be used to replace the 1250 feet minimum range.*
>
> *C5.5.4.1.2. Distance (Feet) = 328 $W^{1/3}$, but not less than 2500 feet, for fragmenting explosive materials. For bombs and projectiles with caliber 5 inches or greater use a minimum distance of 4000 feet. The maximum fragment throw range (including the interaction effects for stacks of items or single items, whichever applies), with an appropriate safety factor, may be used to replace the 2500 feet or 4000 feet minimum ranges. Items should be sited so that lugs and/or strongbacks and nose and/or tail plate sections are oriented away from personnel locations.* [DoD 6055.9 STD, Ammunition and Explosives Safety Standards, July 1999]

It is important to understand this the 4000 ft distance was specified in the DoD 6055.9 STD to protect non-essential personnel from the primary fragments due to the detonation of a munition 5 inches or larger in diameter. It was not intended to use to estimate the possible kick out distance from an open detonation of multiple items.

At the time that these historical ASR were written, the idea of footprint reduction had not come into being. So, while it is true that kick outs do not travel any further than the maximum primary fragment distance, kick outs actually travel much less distance than the maximum primary fragment distances.

This paper describes methodologies for estimating kick out distances and compares these methodologies to results from stack tests. These methods are detailed and conclusions and recommendations for their use are given. Additionally a table of values for one method for Project Delivery Teams (PDTs) to use for specific projects is provided.



ED_001691B_00002460

## 2.0 SUMMARY OF STACK TESTING

In order to evaluate the proposed methodologies for determining kick outs, previous data was gathered from stack testing. This data was analyzed and used for comparison against kick out distances calculated using each of the proposed methodologies as well as for developing the appropriate safety factors to apply to methodologies.

A series of 12 tests were conducted on stacks of 105mm artillery cartridges and 81mm mortar cartridges. These tests were bonfire tests whose original purpose was for hazard classification standards. However, because the items tested were Hazard Division 1.2 (HD 1.2) items in their packaged configurations these tests resulted in kick outs. Although in these tests the munitions were in stacks 30 inches above the surface, the resulting kick outs and the data collection (location of intact warheads) make these tests suitable for use in developing a method for determining kick out distances from OB/OD sites.

Each of the tests conducted were on a flat, dried lake bed at the Naval Air Warfare Center, China Lake, CA. The area surrounding the test site was cleared of virtually all vegetation out to a range of approximately 1300 ft. Beyond 1300 ft the vegetation consisted of clusters of desert grasses and brush. In order to facilitate recovery of the test item debris, the cleared region was marked with a $10^{o}$ x 200 ft grid. Debris recovered inside the 200 ft range was not retained for analyses because of the large numbers of debris pieces found. Instead each piece of debris was given a segregated name (i.e., intact warheads, warhead pieces, or other debris). The posttest searches were limited to a range of 2000 ft or less. On-site observations and review of the video records indicated that few, if any, fragments impacted at ranges greater than 2000 ft. Additionally, the likelihood of finding any fragment outside the 2000 ft region was considered low because of vegetation [Houchins, et al, 1999]. Table 2-1 shows the recovery data for intact warheads from these 12 tests.

Typical reactions of the stacks of munitions during these tests consisted of item reactions within 10 to 15 minutes after complete engulfment of the stack by the fire underneath. These initial reactions were heard as small pops and/or seen as regions of intense burning within the stack. The relatively mild initial reactions were followed some time later by a series of much more violent reactions (explosions) that occurred intermittently throughout the remainder of the test, intermingled with additional mild reactions. Typically the fire would continue to burn at full intensity only until the first few explosions had occurred. The fire would then begin to die out slowly due to scattering of the stack by each successive explosion. Usually the fire was reduced to broadly scattered smoldering debris in less than one hour. However, in most of the tests, one or more explosions were observed after the fire appeared to be out [Houchins, et al, 1999].

Test 9 exhibited a different response. The fire buildup and onset of initial mild reactions were similar to that observed in other tests. However, approximately 26 minutes after the fire was lit, an extremely large explosion occurred that completely destroyed the stack and effectively cleared the test pad. No other reactions were observed after that time. A total of 102 warhead bodies were recovered essentially intact after the test, suggesting that 78 warheads were involved in the explosion [Houchins, et al, 1999].



ED_001691B_00002460

Test 11 was conducted primarily to verify the hazard classification of 81mm mortar cartridges when stored in metal boxes. The posttest recovery and characterization of debris from this test was very limited and, thus, the results were not used in subsequent analyses of fragment hazards [Houchins, et al, 1999].

Therefore, tests 9 and 11 will not be used in the development of the method to determine kick out distances.

**Table 2-1- Fragment Recovery Data**

| Test Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Rounds | 30 | 30 | 30 | 240 | 240 | 864 | 96 | 180 | 180 | 128 | 15 | 720 |
| Type of Rounds | 105mm M1 (TNT Filled) | 105mm M1 (TNT Filled) | 105mm M1 (TNT Filled) | 105mm M1 (TNT Filled) | 105mm M1 (TNT Filled) | 105mm M1 (TNT Filled) | 105mm M1 (Comp B Filled) | 81mm M374A2 (Comp B Filled) | 81mm M374A2 (Comp B Filled) | 105mm M1 (Comp B Filled) | 81mm M374A2 (Comp B Filled) | 81mm M374A2 (Comp B Filled) |
| Range Intervals (ft) | Number of Intact Warheads Recovered | | | | | | | | | | | |
| 200-400 | 1 | 0 | 1 | 6 | 6 | 37 | 0 | 0 | 31 | 0 | 0 | 16 |
| 400-600 | 0 | 0 | 2 | 3 | 1 | 9 | 0 | 1 | 18 | 2 | 0 | 7 |
| 600-800 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 1 | 15 | 1 | 0 | 1 |
| 800-1000 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 15 | 0 | 1 | 1 |
| 1000-1200 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 |
| 1200-1300 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 1300-1400 | 0 | 0 | 0 | 0 | 0 | 1* | 0* | 0 | 1* | 0* | Not Searched | 0 |
| 1400-1600 | 0 | 0 | 0 | 0 | 0 | 0* | 0* | Not Searched | 1* | 0* | Not Searched | 0 |
| 1600-1800 | 0 | 0 | 0 | 0 | 0 | 0* | 0* | Not Searched | 0* | 0* | Not Searched | 0 |
| 1800-2000 | 0 | 0 | 0 | 0 | 0 | 0* | 0* | Not Searched | 0* | 0* | Not Searched | 0 |

Note: *Due to presence of vegetation beyond the 1300 ft range, recovery was accomplished by thoroughly searching only selected azimuthal sectors. Total azimuthal region searched in tests number 6, 7, 9 and 10 were 130°, 90°, 180° and 220°, respectively.

## 3.0 PROPOSED METHODOLOGIES FOR DETERMINING KICK OUT DISTANCES

### 3.1 ESTIMATION OF KICK OUT DISTANCE USING THE BURIED EXPLOSION MODULE (BEM)

The Buried Explosion Module (BEM) [TP 16, 2009] calculates the maximum soil ejecta distance for a variety of soil types. The soil ejecta distance was developed from results of cratering experiments and the ejecta radii were based on 2 inch diameter or larger soil chunks (this equates to soil chunks weighing approximately 0.3 lbs or more).

Primary fragments result from the break-up of a case in contact with the explosives. Kick outs are munitions that were involved in a detonation (either intentional or unintentional) of multiple munitions that were thrown (or kicked out) from the initial detonation point and did not detonate. Such munitions kicked out from an open (or buried) detonation of multiple munitions will not



ED_001691B_00002460

have velocities approaching those of primary fragments. These kick outs are more analogous to soil ejecta than to primary fragments.

### 3.1.1 DETERMINATION OF SOIL EJECTA DISTANCE

The furthest soil ejecta distance will always occur assuming a detonation at a depth approaching the depth at which a camouflet is formed in wet clay soil. Table 3-1 shows the worst case soil ejecta distance for various maximum credible events (MCE) calculated using the BEM. The MCE shown in Table 3-1 were chosen to correspond to the total net explosive weights (NEW) tested as previously described in Section 2.0.

**Table 3-1 – Maximum Soil Ejecta Distances**

| Total Tested NEW (lbs) | Maximum Soil Ejecta Distance (ft) |
|---|---|
| 33 | 296 |
| 233 | 539 |
| 390 | 629 |
| 746 | 766 |
| 995 | 837 |
| 1560 | 1011 |
| 1866 | 1011 |
| 6716 | 1494 |

### 3.1.2 EVALUATION OF USE OF BURIED EXPLOSION MODULE TO ESTIMATE MAXIMUM KICK OUT DISTANCE

The maximum soil ejecta distance shown in Table 3-1 was calculated using the total tested NEW buried in wet clay at a depth just slightly less than the depth required to form a camouflet rather than a crater. The soil type and burial depth assumed results in the maximum soil ejecta distance for that NEW.

Table 3-2 presents a comparison of the values calculated using the BEM to the test data. Since the data from the tests was collected and reported as being within a distance range rather than a specific distance, to be conservative in evaluating these methods, it will be assumed that the maximum warhead recovery distance (i.e. maximum kick out distance) corresponds to the upper end of the reported range. Therefore the maximum kick out distance shown in Table 3-2 is a conservative assumption of the maximum warhead recovery range from the stack tests.

Based on the previously stated assumptions, the safety factor using the maximum soil ejecta to estimate the maximum kick out distance varies from 0.79 to 1.49 with a mean safety factor of 1.12 and a standard deviation of 0.24. If we multiply the maximum soil ejecta distance by 1.3 to estimate the maximum kick out distance the safety factor varies from 1.02 to 1.94 with a mean safety factor of 1.46 and a standard deviation of 0.32. Since this always results in a positive



ED_001691B_00002460

safety factor the 1.3 multiplier is recommended for use and will be used throughout the remainder of this document.

**Table 3-2 – BEM Method Comparison**

| Test No. | Maximum Kick Out Distance (ft) | Total Tested NEW (lbs) | Maximum Soil Ejecta Distance (ft) | Safety Factor Using Max. Soil Ejecta Distance | Maximum Soil Ejecta Distance (ft) x 1.3 | SF Using Max. Soil Ejecta Distance x 1.3 |
|---|---|---|---|---|---|---|
| 1 | 400 | 233.19 | 539 | 1.35 | 700.7 | 1.75 |
| 2 | 400 | 233.19 | 539 | 1.35 | 700.7 | 1.75 |
| 3 | 400 | 233.19 | 539 | 1.35 | 700.7 | 1.75 |
| 4 | 1200 | 1865.52 | 1011 | 0.84 | 1314.3 | 1.10 |
| 5 | 1000 | 1865.52 | 1011 | 1.01 | 1314.3 | 1.31 |
| 6 | 1000 | 6715.87 | 1494 | 1.49 | 1942.2 | 1.94 |
| 7 | 800 | 746.21 | 766 | 0.96 | 995.8 | 1.24 |
| 8 | 800 | 390.06 | 629 | 0.79 | 817.7 | 1.02 |
| 10 | 800 | 994.94 | 837 | 1.05 | 1088.1 | 1.36 |
| 12 | 1000 | 1560.24 | 1011 | 1.01 | 1314.3 | 1.31 |

### 3.1.3 SUMMARY OF METHODOLOGY USING THE BURIED EXPLOSION MODULE TO ESTIMATE MAXIMUM KICK OUT DISTANCE

Use of the BEM to estimate the maximum kick out distance requires the following steps:

- Assume a MCE for the OB/OD ground (recommend basing this on available historical information)
- Iterate using the BEM with wet clay, "Other" munition type, 0.001 lb fragment weight, 100 ft/s initial velocity, munition NEW = MCE to determine the depth required to form a camouflet
- Run the BEM again with a depth slightly less than that required to form a camouflet to determine the maximum soil ejecta distance
- Multiply the maximum soil ejecta distance by 1.3 to estimate the maximum kick out distance

Table A-1 in Appendix A shows the estimated maximum kick out distance based on this method for a variety of MCEs. Figure A-1 in Appendix A is a plot of these estimated maximum kick out distances versus MCE. The following equation has been developed from this plot.

$$R = 134.35\, MCE^{0.30324} \qquad \text{Eq. 3-1}$$

Where R = estimated kick out distance (ft)
MCE = Maximum Credible Event (lbs)

## 3.2 ESTIMATION OF KICK OUT DISTANCE USING HAZARDOUS FRAGMENT DISTANCE FOR ANALOGOUS MUNITIONS

An alternative method for estimating the kick out distance may be to use the hazardous fragment distance (HFD) for an analogous munition. For example, the HFD for the 100 lb GP Mk 1 bomb is 441 ft which is 1.9 times the maximum soil ejecta distance for a near surface detonation of 65 lbs of non-fragmenting explosives.

### 3.2.1 DETERMINATION OF HAZARDOUS FRAGMENT DISTANCE FOR ANALOGOUS MUNITIONS

The HFD of either a robust or an extremely heavy cased munition containing a TNT equivalent weight for impulse that is close to the MCE for the OB/OD ground would be determined using the DDESB TP 16 Fragmentation Database [Fragmentation Database, 18 Oct 2011]. This HFD would be used as the maximum kick out distance.

The HFD for a single round with a TNT equivalent weight for impulse that is as close as possible to the total tested NEW is shown in Table 3-3. As shown in Table 3-3, there is not a munition in the DDESB TP 16 Fragmentation Database with a TNT equivalent for impulse over 1306 lbs. For OB/OD grounds with large MCEs this is a limitation of this method.

**Table 3-3 – Hazardous Fragment Distances for Analogous Munitions**

| Total Tested NEW (lbs) | Single Round TNT Equivalent for Impulse (lbs) | HFD (ft) for Single Analogous Munition |
|---|---|---|
| 32.51 | 32.22 | 345 |
| 233.19 | 220.80 | 692 |
| 390.06 | 336.60 | 662 |
| 746.21 | 678.30 | 810 |
| 994.94 | 907.20 | 935 |
| 1560.24 | N/A | N/A |
| 1865.52 | N/A | N/A |
| 6715.87 | N/A | N/A |

Note: There is no analogous munition in the DDESB TP 16 Fragmentation Database with a TNT equivalent weight for impulse greater than 1306 lbs.



ED_001691B_00002460

### 3.2.2 EVALUATION OF USE OF HAZARDOUS FRAGMENT DISTANCE OF ANALOGOUS MUNITION TO ESTIMATE MAXIMUM KICK OUT DISTANCE

The HFD for a single analogous munition shown in Table 3-3 was derived by calculating the TNT equivalent for impulse for the total tested NEW. This value was then compared to the TNT equivalent for impulse for all robust and extremely heavy cased items in the DDESB TP 16 Fragmentation Database dated 18 October 2011 to find the item with the closest TNT equivalent for impulse that was still larger than the TNT equivalent for impulse for the total tested NEW. The HFD of this item is the HFD listed in Table 3-3 for each test. As noted before, this method is limited for use to MCEs less than the item with the largest TNT equivalent for impulse in the Fragmentation Database (i.e. 1306.44 lbs TNT equivalent for impulse).

Table 3-4 presents a comparison of the values determined using the HFD of an analogous munition method to the test data. Since the data from the tests was collected and reported as being within a distance range rather to be conservative in evaluating these methods, it will be assumed that the maximum warhead recovery distance (i.e. maximum kick out distance) corresponds to the upper end of the reported range.

The safety factor using the HFD of an analogous munition to estimate the maximum kick out distance varies from 0.83 to 1.73 with a mean safety factor of 1.37 and a standard deviation of 0.41. If we multiply the HFD by 1.25 to estimate the maximum kick out distance the safety factor varies from 1.12 to 2.34 with a mean safety factor of 1.85 and a standard deviation of 0.56. Since this always results in a positive safety factor the 1.25 multiplier will be used when this method is used.

**Table 3-4 – Hazardous Fragment Distances for Analogous Munitions Method Comparison**

| Test No. | Maximum Kick Out Distance (ft) | Total Tested NEW (lbs) | HFD (ft) for Single Analogous Munition | Safety Factor Using HFD | HFD (ft) for Single Analogous Munition x 1.25 | Safety Factor Using HFD x 1.25 |
|---|---|---|---|---|---|---|
| 1 | 400 | 233.19 | 692 | 1.73 | 934.2 | 2.3355 |
| 2 | 400 | 233.19 | 692 | 1.73 | 934.2 | 2.3355 |
| 3 | 400 | 233.19 | 692 | 1.73 | 934.2 | 2.3355 |
| 4 | 1200 | 1865.52 | N/A | N/A | N/A | N/A |
| 5 | 1000 | 1865.52 | N/A | N/A | N/A | N/A |
| 6 | 1000 | 6715.87 | N/A | N/A | N/A | N/A |
| 7 | 800 | 746.21 | 810 | 1.01 | 1093.5 | 1.366875 |
| 8 | 800 | 390.06 | 662 | 0.83 | 893.7 | 1.117125 |
| 10 | 800 | 994.94 | 935 | 1.17 | 1262.25 | 1.5778125 |
| 12 | 1000 | 1560.24 | N/A | N/A | N/A | N/A |

Note: There is no analogous munition in the DDESB TP 16 Fragmentation Database with a TNT equivalent weight for impulse greater than 1306 lbs.



ED_001691B_00002460

### 3.2.3 SUMMARY OF METHODOLOGY USING THE HAZARDOUS FRAGMENT DISTANCE OF ANALOGOUS MUNITION TO ESTIMATE MAXIMUM KICK OUT DISTANCE

Use of the HFD of an analogous munition to estimate the maximum kick out distance requires the following steps:

- Assume a MCE for the OB/OD ground (recommend basing this on available historical information)
- Using the most recent DDESB TP 16 Fragmentation Database, compare the MCE to the TNT equivalent for impulse for all robust and extremely heavy cased items to find the item with the closest TNT equivalent for impulse that was still larger than the TNT equivalent for impulse for the MCE.
- Determine the hazardous fragment distance for the selected item.
- Multiply the hazardous fragment distance by 1.25 to estimate the maximum kick out distance

## 3.3 ESTIMATION OF KICK OUT DISTANCE USING HAZARDOUS FRAGMENT DISTANCE VIA THE GENERIC EQUATION CALCULATOR

A simpler way of calculating the HFD for a single analogous munition is to use the DDESB TP 16 Generic Equation Calculator v1 (GEQ v1) [TP 16, 2009]. The Generic Equation Calculator estimates the Hazardous Fragment Distance based on a series of equations developed to approximate the properties of all items within the DDESB TP 16 Fragmentation Database. The values calculated using the GEQ are generally conservative. Because the GEQ contains no munition specific information, the tool has an unlimited distribution.

### 3.3.1 DETERMINATION OF HAZARDOUS FRAGMENT DISTANCE USING THE GENERIC EQUATION CALCULATOR

The user inputs the selected MCE into the GEQ which calculates an approximated hazardous fragment distance (HFD) for 3 types of items: robust, non-robust, and extremely heavy cased. The user will then compare the calculated HFD and select larger value of HFD for either the robust or extremely heavy cased items. Table 3-5 shows the worst case hazardous fragment distance for various maximum credible events (MCE) calculated using the GEQ. The MCE shown in Table 3-5 were chosen to correspond to the total net explosive weights (NEW) tested as previously described in Section 2.0.

### 3.3.2 SUMMARY OF METHODOLOGY USING THE HAZARDOUS FRAGMENT DISTANCE VIA THE GENERIC EQUATION CALCULATOR

Table 3-5 presents a comparison of the hazardous fragment distances calculated using the GEQ to the test data. Since the data from the tests was collected and reported as being within a distance range rather to be conservative in evaluating these methods, it will be assumed that the maximum warhead recovery distance (i.e. maximum kick out distance) corresponds to the upper end of the reported range.



ED_001691B_00002460

By inputting the NEW of the MCE and using the largest HFD given by the GEQ (see Table 3-5) the safety factor varies from 1.06 to 1.92 with a mean safety factor of 1.55 and a standard deviation of 0.41. This safety factor is always positive so no multiplier is necessary. However, the maximum MCE remains 1306 lbs.

**Table 3-5 – Hazardous Fragment Distances via the GEQ**

| Test No. | Maximum Kick Out Distance (ft) | Total Tested NEW (lbs) | HFD (ft) using GEQ v1 | SF Using HFD from GEQ v1 |
|---|---|---|---|---|
| 1 | 400 | 233.19 | 768 | 1.92 |
| 2 | 400 | 233.19 | 768 | 1.92 |
| 3 | 400 | 233.19 | 768 | 1.92 |
| 4 | 1200 | 1865.52 | N/A | N/A |
| 5 | 1000 | 1865.52 | N/A | N/A |
| 6 | 1000 | 6715.87 | N/A | N/A |
| 7 | 800 | 746.21 | 958 | 1.1975 |
| 8 | 800 | 390.06 | 845 | 1.05625 |
| 10 | 800 | 994.94 | 1015 | 1.26875 |
| 12 | 1000 | 1560.24 | N/A | N/A |

Note: The maximum MCE is 1306 lbs.

### 3.3.3 SUMMARY OF METHODOLOGY USING THE HAZARDOUS FRAGMENT DISTANCE VIA THE GEQ

Use of the HFD of an analogous munition to estimate the maximum kick out distance requires the following steps:

- Assume a MCE for the OB/OD ground (recommend basing this on available historical information)
- Using the most recent DDESB TP 16 Generic Equation Calculator, input the MCE and select the larger of the calculated HFDs for either the robust or extremely heavy cased items.
- Use the selected HFD from the GEQ as the kick out distance with no additional multiplier.

## 4.0 CONCLUSIONS FROM COMPARISON OF STACK TEST DATA WITH PROPOSED METHODS

The Buried Explosion Module [TP 16, 2009] can be used to calculate the maximum soil ejecta distance for a given MCE. Comparison of the maximum soil ejecta distances with the maximum kick out distances from the stack tests show that the maximum soil ejecta distance is not always conservative. Therefore, the maximum soil ejecta distance must be multiplied by 1.3 to ensure that a maximum kick out distance based on this method is conservative when compared with the stack test data. This method requires some expertise in the use of the BEM but a list of pre-

calculated values has been supplied in Appendix A and a simple equation which already includes the 1.3 multiplier has been developed (Equation 3-1).

The use of the Hazardous Fragment Distance for an analogous munition can be used to estimate the kick out distance for MCE no larger than 1306 lbs. If an analogous munition is selected from the DDESB TP 16 Fragmentation Database [18 Oct 2011] then comparison with the stack test data shows that use of the HFD is not always conservative. Therefore, the HFD from the analogous munition must be multiplied by 1.25 to ensure that a maximum kick out distance based on this method is conservative when compared with the stack test data.

Using the Generic Equation Calculator v1 [TP 16, 2009] with a given MCE to calculate a HFD results in a HFD that is conservative when compared with the maximum kick out distance from the stack tests. This method has the same maximum MCE limit of 1306 lbs as the other HFD method but does not require a multiplier. This method may also be easier to use than the other HFD method.

## 5.0 RECOMMENDATIONS

The Project Delivery Team must determine a reasonable Maximum Credible Event for the OB/OD ground based on historical information. Useful historical information might include location of OB/OD ground with respect to buildings and transportation routes that existed when the OB/OD ground was in use as well as the mission of the installation at the time to determine what munitions were likely to have been destroyed at the OB/OD ground. Any information on items that might have been recovered in the area since closure of the OB/OD ground may also be useful.

If the MCE is less than 1306 lbs then the easiest method to estimate the maximum kick out distance is to use the largest HFD calculated by the GEQ [TP 16, 2009] for the given MCE. For any MCE, the maximum kick out distance may be estimated using the BEM [TP 16, 2009]. This method is fully described, including all assumed input values, in Section 3.1. Table A-1 lists the estimated kick out distances for given MCE based on this method.

## 6.0 REFERENCES

DoD 6055.09-STD "Ammunition and Explosives Safety Standards", Jul 1999.

DoD Explosives Safety Board Technical Paper 16 "Methodologies for Calculating Primary Fragment Characteristics", Revision 3, 1 April 2009.

DoD Explosives Safety Board Technical Paper 16 Fragmentation Database, 18 October 2011.

Houchins, W. D., Swisdak, M. M., and Gould, M. J. A. "Behavior of Large quantities of Hazard Division 1.2 Ammunition in Fires", NSWCDD/TR-98/6, Dahlgren Division of Naval Surface Warfare Center, February 1999.



ED_001691B_00002460

# APPENDIX A

## KICK OUT DISTANCES BASED ON MAXIMUM SOIL EJECTA DISTANCES



ED_001691B_00002460

**Table A-1: Kick Out Distances Based on 1.3 x Maximum Soil Ejecta Distances**

| MCE (lbs) | 1.3 x Max Soil Ejecta Distance | | MCE (lbs) | 1.3 x Max Soil Ejecta Distance | | MCE (lbs) | 1.3 x Max Soil Ejecta Distance |
|---|---|---|---|---|---|---|---|
| 10 | 270 | | 250 | 716 | | 3500 | 1595 |
| 20 | 333 | | 300 | 757 | | 4000 | 1661 |
| 30 | 377 | | 350 | 793 | | 4500 | 1721 |
| 40 | 411 | | 400 | 852 | | 5000 | 1777 |
| 50 | 439 | | 450 | 855 | | 5500 | 1829 |
| 60 | 464 | | 500 | 884 | | 6000 | 1879 |
| 70 | 488 | | 550 | 910 | | 6500 | 1924 |
| 80 | 507 | | 600 | 933 | | 7000 | 1968 |
| 90 | 525 | | 650 | 957 | | 7500 | 2010 |
| 100 | 542 | | 700 | 979 | | 8000 | 2050 |
| 110 | 559 | | 750 | 1000 | | 8500 | 2088 |
| 120 | 573 | | 800 | 1019 | | 9000 | 2124 |
| 130 | 588 | | 850 | 1039 | | 9500 | 2159 |
| 140 | 601 | | 900 | 1056 | | 10000 | 2193 |
| 150 | 614 | | 950 | 1074 | | 11000 | 2258 |
| 160 | 625 | | 1000 | 1091 | | 12000 | 2318 |
| 170 | 637 | | 1500 | 1234 | | 13000 | 2375 |
| 180 | 648 | | 2000 | 1346 | | 14000 | 2430 |
| 190 | 659 | | 2500 | 1440 | | 15000 | 2480 |
| 200 | 670 | | 3000 | 1522 | | | |



ED_001691B_00002460

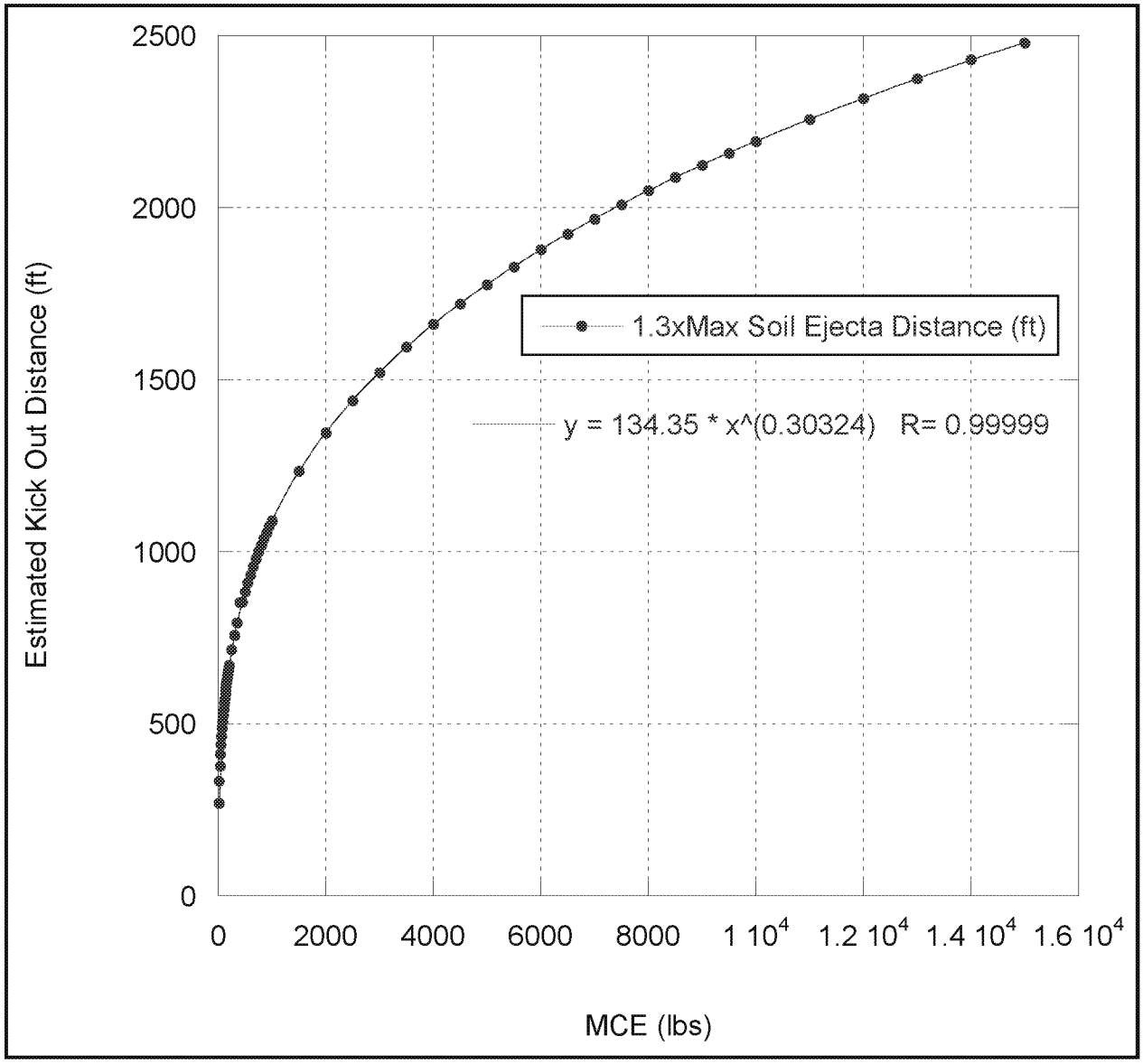


**Figure A-1 – Estimated Kick Out Distance Using 1.3 x Maximum Soil Ejecta Distance**