FIELD TESTS OF FROST JACKING OF UNEXPLODED ORDNANCE

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ABSTRACT

We hypothesized that frost jacking (net seasonal upward movement) of buried unexploded ordnance (UXO) occurs in cold regions where there is frost-susceptible soil and adequate moisture. We buried 18 inert ordnance shapes in highly frost-susceptible soil in Hanover, NH, to determine whether they would experience frost jacking. Sixteen of the shapes were used for two, three-way factorial experiments to study frost jacking as a function of specific ordnance type, burial depth, and orientation (vertical or at 45˚). Frost jacking of ordnance occurred, and the net upward movement for objects buried from 4 to 36 inches deep ranged up to 3.2 inches for one season. During winter, the ordnance moved upward at approximately the same rate at which the ground heaved; however, during thaw the ground usually subsided to a greater degree than the ordnance. Variability of net upward movement was very high. The group of ordnance that included 2.75-inch rockets and 81-mm mortars buried 24 to 36 inches moved upward more than the smaller 20-mm and 40-mm projectiles buried 4 to 12 inches deep.

1. INTRODUCTION

Frost heave (uplift of ground associated with freezing) occurs when there is frost-susceptible soil, freezing temperatures, and adequate water supply. Soil containing greater than 5% fines smaller than 0.02 mm, such as silt, is typically frost-susceptible, and a water table within 8 feet of the surface is often adequate to promote heave (e.g., Berg and Johnson, 1983). Objects in the soil move upward when the soil heaves. When the frozen soil thaws, the soil often subsides more than the object, and there is a net upward movement of the object in the soil (e.g., Anderson, 1988). The net upward movement of the object due to this process is called frost jacking, or upfreezing.

Frost jacking may be an important factor in certifying the required depth of UXO clearance. Range areas that have once been cleared to a certain depth may no longer be cleared after a period of time elapses that is sufficient for frost jacking to cause UXO to move up to a depth where it poses a safety threat.

We hypothesized that frost heave causes UXO to migrate upwards via frost jacking, and we are conducting field experiments that test this hypothesis. The tests were designed to include examining the influence of UXO shape, depth of placement, and orientation on the amount of frost jacking. We selected two locations for this work: Ft. McCoy, WI, and Hanover, NH. The field tests were constructed during September 2003, and have been monitored for one winter and one spring. We report one season's observations in Hanover only in this paper.

2. FIELD TESTS

2.1 Location

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) is located in Hanover, NH. The mean annual temperature is about 45°F, and freezing conditions occur from October to May. Frost depths vary from 4 to 8 feet, depending on soil and surface conditions (i.e., snow cover). The soil at the site is classified as ML (sandy silt) according to Unified Soil Classification System and is highly frost-susceptible.

2.2 Experimental Design

UXO sites typically host a variety of ordnance types buried at a range of depths. Six UXO shapes, representing a range of sizes and delivery types, were selected for burial—20-mm projectiles, 40-mm grenades, 81-mm mortars, 2.75-inch rocket warheads, 105-mm projectiles and 155-mm projectiles. Sixteen shapes were used to conduct two factorial experiments to study the influence of ordnance shape, orientation and depth of placement and the interaction of these variables on UXO frost jacking (Table 1, Combinations 1-1 through 1-8 and 2-1 through 2-8). Shapes were positioned either vertically, with the nose pointing up, or at a 45 degree angle with the nose pointing up, designated as V or 45 in Table 1, respectively. Depths refer to the lowest position of the ordnance in the ground. For example, the 2.75-inch rocket is approximately 23 inches long, and when buried 36 inches deep, the base of the rockets is at 36 inches and the tip is 13 inches below the surface. Burial depths were selected

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14. ABSTRACT

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based on studies of theoretical ordnance penetration (e.g., Robitaille, et al., 1999). For example, smaller shapes are typically found at shallower depths, and this is reflected in the experimental design. The locations of ordnances and instrumentation were established as shown in Figure 1.

Table 1. UXO shapes, depth, and orientation in field tests in Hanover, NH, 2003-2004.

Combination	UXO	Depth (in)	Orientation
1-1	20-mm	4	45
1-2	20-mm	4	V
1-3	20-mm	12	45
1-4	20-mm	12	V
1-5	40-mm	4	45
1-6	40-mm	4	V
1-7	40-mm	12	45
1-8	40-mm	12	V
2-1	2.75-in	24	45
2-2	2.75-in	24	V
2-3	2.75-in	36	45
2-4	2.75-in	36	V
2-5	81-mm	24	45
2-6	81-mm	24	V
2-7	81-mm	36	45
2-8	81-mm	36	V
3-12	105-mm	36	V
3-2	155-mm	36	V

2.3 Construction

A wood support frame was constructed to provide a stable base to mount data loggers for automatic data collection and rulers for tracking ordnance movement (Fig. 2). The frame posts were installed to minimize the potential for the frame to move due to frost heave—each post was installed to a minimum depth of 4 feet, and was anchored in concrete. At each ordnance location a hole was excavated to the desired depth. Care was taken to ensure that the bottom of the hole was undisturbed, in-situ soil. The ordnance was positioned in the hole and backfilled with the same soil that came from the excavation. Every effort was made to create a condition that mimics the original soil. Soil was placed in the hole at approximately the same depth from which it was removed, and was compacted as closely as possible to the in-situ soil density─in lifts no thicker than two inches. Thin (1.6-mm-diameter) steel rods were attached to the ordnance with epoxy and the rods extended above the ground surface. The rods were enclosed in a nylon tube to allow free rod movement through frozen soil (i.e., surrounding soil adfreezes to the tube and not the rod).

Thermocouples, soil moisture probes, and soil moisture tension probes were placed 4, 12, 24, and 36 inches deep in the center of the site (Fig. 1). Installation of the sensors was similar to ordnance placement—disturbance of the surrounding soil was minimized. A temperature probe was mounted on the frame, 4 feet above ground, to document air temperature.

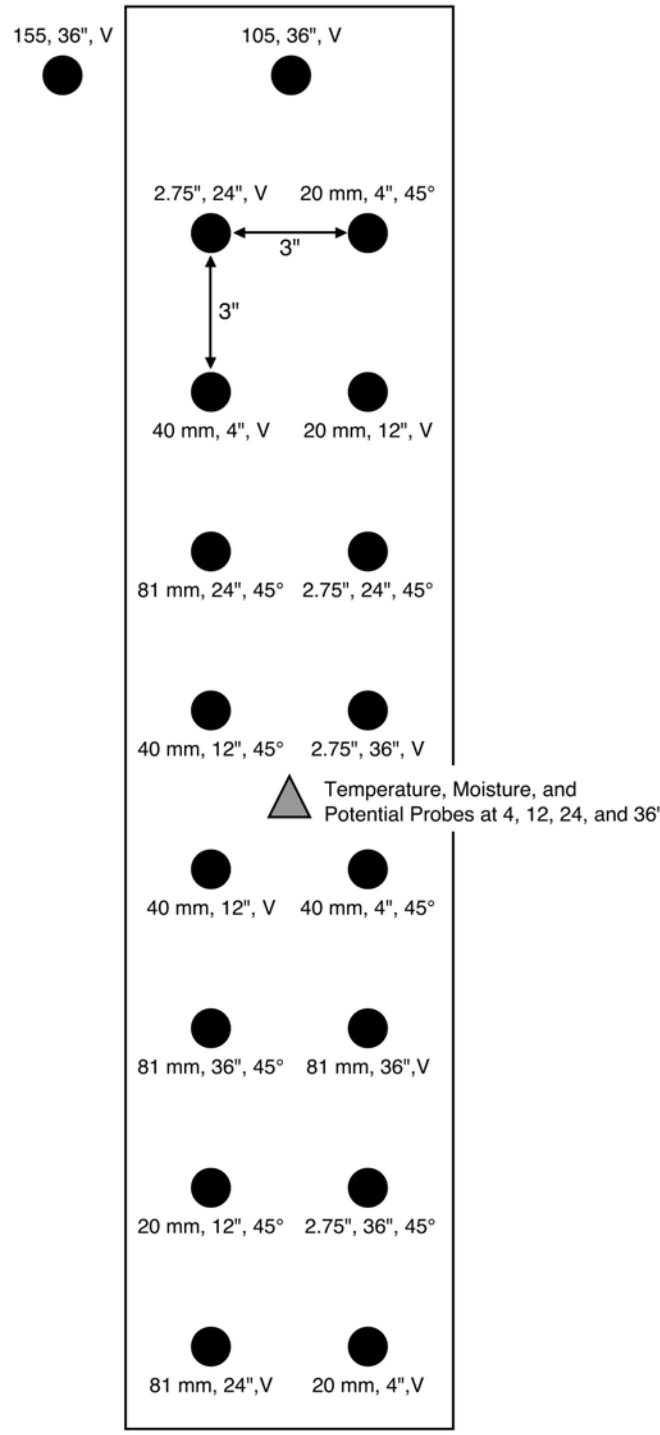

Figure 1. Site plan of UXO frost-jacking experiment, Hanover, NH.

In addition to rulers, linear potential transducers (LPTs) were used on some shapes to continuously monitor UXO position. The LPTs were mounted to the frame with the retractable wire connected to the steel rod.

Weights were added to the connection to counteract the retractable wire tension.

2.4 Instrumentation and monitoring

Electronic readings were recorded hourly, and saved to the data logger. Manual readings for each shape were recorded weekly. The frame's support posts and each UXO position of the frame were surveyed using a benchmark on a nearby building so that level control was documented throughout the winter.

Figure 2. Test frame for frost-jacking experiment.

During the winter, we kept the ground surface of the test area cleared of snow to encourage frost penetration and monitor ground heave. In mid-December we decided to measure the ground surface heave to compare with UXO heave. At that time (16 December 2003), the ground had already started to freeze and we uniformly applied an estimate of the initial ground heave of 2 inches, based on the average heave of the ordnance buried at 4 inches. We surveyed the frame several times and noted that it did heave a small amount (about 1 inch, total depending on the location of the frame). Thus, we corrected ordnance and ground surface heave by adding frame heave to determine the overall heave.

3. OBSERVATIONS

Table 2 contains maximum measured heave and net movement of UXO from 16 Sept. 2003 to 15 May 2004. Typical heave of UXO and the ground surface above the UXO are shown in Figures 3 and 4. One ordnance did not move during the winter—the 155-mm projectile (Fig. 5). Maximum heave recorded was on 24 February, and maximum frost depth, 35 inches, occurred on 29 February.

4. DISCUSSION

The ordnance moved upward at about the same rate as the ground surface; however, during thaw the ground subsided to a greater degree than the ordnance. This is similar to other observations of frost jacking (e.g., Anderson, 1988).

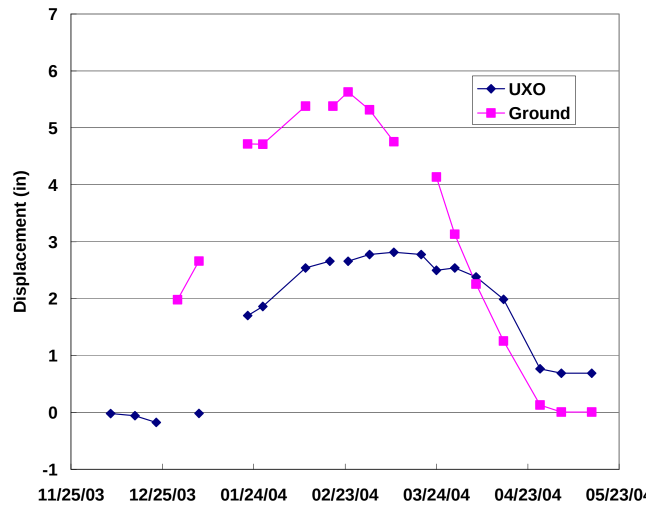

Figure 3. Displacement of surface and 81-mm mortar, buried 24 inches deep, with respect to elevation on 16 Sept. 2003.

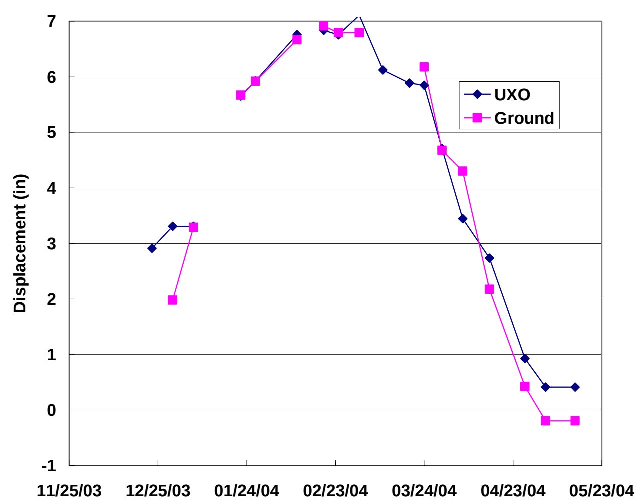

Figure 4. Displacement of surface and 40-mm projectile, buried 4 inches deep, with respect to elevation on 16 Sept. 2003.

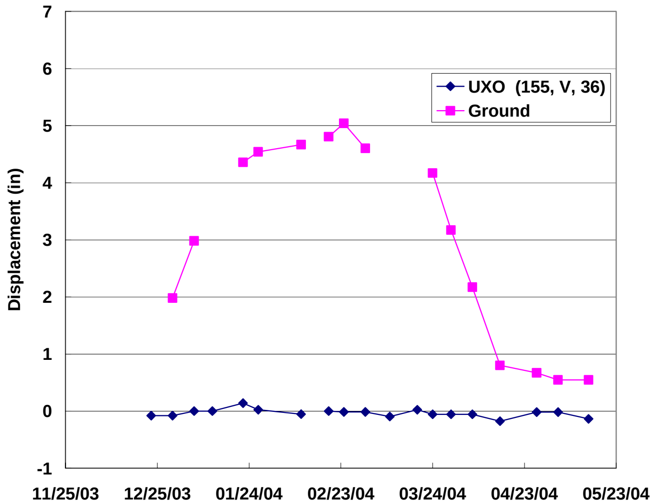

Figure 5. Displacement of surface and 155-mm projectile, buried 36 inches deep, with respect to elevation measured on 16 Sept. 2003.

Net heave of the UXO measurements was highly variable, and analysis of variance at a 95% probability level, within each of the two factorial designs, did not indicate an influence due to orientation or burial depth for either the large or small shapes. That is, the differences in mean values among levels of orientation and depths were not great enough to exclude the possibility that the difference was due to random effects.

Table 2. Maximum UXO heave and Net heave of UXO with respect to measured locations on 16 Sept. 2003, Hanover, NH, 2003-2004.

UXO/ Depth (in.) /Orientation	**Max. UXO heave (in.)**	**Net UXO heave (in.)**	**Mean/ Std. Dev (in.)**
20-mm 4 45	5.32	0.60	0.38/ 0.23
20-mm 4 V	5.03	0.26	
20-mm 12 45	3.26	0.66	
20-mm 12 V	3.34	0.30	
40-mm 4 45	6.75	0.41	
40-mm 4 V	5.05	0.60	
40-mm 12 45	2.89	0.17	
40-mm 12 V	3.13	0.02	
2.75-in 24 45	5.78	2.31	1.53/ 1.24
2.75-in 24 V	3.16	0.05	
2.75-in 36 45	3.18	1.44	
2.75-in 36 V	5.60	3.24	
81-mm 24 45	N.A.	1.78	
81-mm 24 V	2.66	0.69	
81-mm 36 45	4.51	2.82	
81-mm 36 V	2.03	-0.06	
105-mm 36 V	3.36	1.46	Not Applicable
155-mm 36 V	-0.01	-0.13	

Anderson (1988) determined that the maximum possible heave of a buried object is proportional to its length. The data (outside of the two factorial designs) suggest that there was a larger movement of the 2.75-inch rockets and 81-mm projectiles buried 24 and 36 inches (about 1.5 inches) compared to the smaller, 20 and 40-mm projectiles, buried at 4 and 12 inches (Table 2, 4th column).

When treated as two groups of eight measurements, each group has an approximate normal distribution of net heave. We applied a procedure to the two groups of data that determines whether the average of one product exceeds that of another product when the variability of both products are unknown and cannot be assumed equal (Natrella, 1963, p. 3-36). Using a 10% probability of rejecting the hypothesis that the larger UXO heaved more than the smaller UXO, the larger UXO experienced a larger net heave than the smaller UXO. The larger ordnance moved about four times the distance as the smaller ordnance—averaging a net upward movement of 1.5 inches. At this rate, upward movement of the larger UXO would become a concern within a relatively short period of time after certified clearance—e.g., within five years.

The largest ordnance, a 155-mm mortar, did not move upward at all—probably due to its weight counteracting upward heave force (e.g., Anderson, 1988).

Some of the variability in net upward UXO movement probably resulted from ground disturbance due to the burial of the UXO and resulting (unintended) deviations from the undisturbed soil density above each UXO as well as natural variability in soil conditions across the site. Monitoring will continue this coming winter. Because there will have been an additional year since construction of the test site, there is a possibility that there will be less influence due to ground disturbance and, therefore, less variability in net upward movement next year compared to this year. If the variability among net upward movement measurements decreases, potential influences due to shapes and depths of burial may be determined in the future.

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CONCLUSIONS

Based on our observations of frost jacking of UXO in the field for the winter and spring of 2003–2004, frost jacking of ordnance occurs in regions of seasonal freezing when the ordnance is buried in frost-susceptible soil. The ordnance moves upward at approximately the same rate at which the ground heaves; however, during thaw, the ground subsides to a greater degree than the ordnance. The larger ordnance—2.75-inch rockets and 81-mm mortars—buried 24 and 36 inches deep, moved upward at an average of about 1.5 inches—about four times the distance as the smaller ordnance (20- and 40-mm projectiles). At this rate, upward movement of UXO could become a concern within a relatively short period of time after certified clearance. The largest ordnance buried, a 155-mm mortar, did not heave—this is most likely due to its weight counteracting upward forces generated by frost heave.