3-1998

Humanitarian Demining Technology Program Antipersonnel Mine Neutralization Device Test Report

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1. Introduction

The Antipersonnel Mine Neutralization Device (APMINUD) is a mechanical system for safely detonating Antipersonnel mines as part of a peace time mine clearance operation. It is intended to be used in conjunction with a shielded, all terrain vehicle with hydraulic crane. The system would be used to neutralize previously marked AP mines by detonating them one at a time.

The plunger inside the APMINUD is designed to strike the ground when released by the operator. An expendable foot on the plunger applies approximately two tons of impact force over a 10" diameter area when released. The impact force pushes the pressure plate on any mine that is under the foot causing detonation. The blast and fragments created are contained within, or redirected out the top of the cylindrical containment shell and away from surrounding personnel and structures.

The operational clearance concept envisioned for the system assumes the mine locations are known. The clearance vehicle follows a detection and marking team. Whether by detection or probing, the mine locations must be found and marked. The APMINUD vehicle then moves into location and the operator manipulates the APMINUD over the mine marker. The vehicle operator will be in close proximity to the mine, but behind additional protective shielding. The APMINUD shell is not dropped, but slowly lowered around the mine so the operator is able to continually readjust the positioning as it is lowered. After the shell is resting on the ground, the operator releases the plunger inside the shell causing detonation. The shell is then raised and the vehicle moved to the next marked location or backed out for replacement of the expendable foot, depending on the size of the mine. Should the mine fail to detonate the operator can re-strike the location several times or reposition the APMINUD slightly without having to leave the protected vehicle.

2. System Description

The APMINUD unit was designed and manufactured by Israel Aircraft Industries. The design goal for the unit was to have it capable of actuating pressure fuzes in AP mines buried at 2". The prototype is intended to survive and remain functional after

50 mine blasts with 200 grams of high explosive. The overall weight of the APMINUD is 1300 lb.

Table 1. Design Goals for APMINUD

	Design Obective	Associated Numeric Goal
Mine Type	Effective against all pressure fuzed AP Mines	Applies 2 tons of impact force to ground surface
Actuation Depth	Actuates pressure fuzes at maximum depth AP mines typically buried	Actuates all AP mine pressure fuzes to a depth of 2”
Survivability	Unit is sufficiently robust to allow clearance of a large minefield without significant interruption for maintenance, replacement or repair	Shell and unit fully functional when subjected to 50 consecutive shots of .5 lb high explosive
Blast Protection	Contains or directs explosive shock and fragments away from personnel and equipment	No primary fragments launched below 45 degrees elevation angle

The blast containment shell is cylindrical with a diameter of 28" and a height of 28". It is constructed from European plate steel standard ST 52. The top of the cylinder is open except for the space occupied by the plunger and its support structure. Its design confines the explosive blast to vent upward, and prevents any low angle fragmentation from the explosion from escaping (up to 60 degrees).

The plunger runs down the axis of the shell cylinder and is spring driven. The spring is compressed by the weight of the shell as the unit is lifted by the top of the plunger. A release pin engages a race in the plunger when the spring is sufficiently compressed. The plunger spring is compressed to approximately 225 lb. when the release pin engages the raceway. Approximately 25 lb. of pull are required to withdraw the release pin and cause the plunger to strike after the unit is set back down. Although soil dependent, the contractor reports that 2 tons of dynamic force are developed when the plunger impacts the ground.

Each of the components of the plunger assembly are fabricated from 4130 chrome-molybdenum steel. The "business end" of the plunger is covered with an expendable aluminum casting which the manufacturer has given the name "standoff." The standoff's are designed to shatter under large blast loads and in so doing protect the steel in the plunger. Each standoff was estimated to cost around $30 and can be installed in less than 1 minute in the field. The standoffs are a little over 10" in diameter and the ground contact surface is ridged in a series of concentric rings spaced ~1.5" apart. The depth of the ridges is 1.5". These rings were intended by the contractor to help distribute the impact pressure to greater soil depths.

3. Test Plan

The purpose of this field test program is to document the capability of the APMINUD device to neutralize antipersonnel landmines safely and effectively. A sequence of functional and explosive tests was conducted to assess three measures of performance of the device. 1) How effectively the APMINUD triggers mines under various conditions. 2) How effectively the APMINUD reduces the threat of explosion to the working environment around the mine. and 3) How durable the APMINUD is when repeatedly subjected to mine blasts.

We tested the ability of the APMINUD to trigger mine fuzes using non explosive AP mines, placed under a variety of conditions and impacted with the plunger. US M14 and Italian MKII mines were used for these functional tests. Each test conducted with a given emplacement condition with the MKII was performed five times and each test with the M14 was performed three times in order to establish a measure of repeatability in the results. Each mine was tested in clay soil, sand, and grass covered clay soil. In each soil the mines were buried flush with the surface, two inches deep, and four inches deep for the purpose of assessing the impact of burial depth on the resulting functional performance. The final variable in the placement condition was the distance the mine was placed from the center of the impact site of the plunger. The "standoff" on the end of the plunger has a ground footprint 10"- 12" in diameter. At each burial depth mines were placed in the center of the impact site, two inches from center, and four inches from center.

In all, 155 individual tests were performed against the non explosive mines. In each case the mine was buried and the conditions and mine type recorded. The APMINUD was suspended by a chain from the tines of a forklift. The APMINUD was maneuvered into position over the mine and lowered immediately after the mine was buried. The plunger was released by pulling the release lever and the APMINUD was raised with the forklift and moved aside. The mine was recovered and the fuze examined to determine whether the pressure plate had snapped into the "fired" position. The results were recorded and the next mine buried.

The non explosive mine tests were later followed by five live mine tests to verify the functioning of the live fuzes was consistent with the non explosive mines. Live, explosive M14 mines were used for these tests.

Objectives 2 and 3 were tested simultaneously by a series of 50 explosive tests. 1/2 pound blocks of TNT were used in each of these tests in order to replicate the blast effects from the largest of the antipersonnel mines typically available. In order to recreate the fragment hazard present in many of the antipersonnel mines, one hundred carbon steel balls were taped to the surface of each explosive block. The balls were quarter inch diameter which is in the range of 5 to 6 mm reported slug size for many of the bounding type mines. For each of these tests the explosive block was placed in a small hole flush with the ground surface. The APMINUD plunger was released, and then the APMINUD was lowered over the explosive. The "standoff" on the end of the plunger was therefore resting on the explosive block. The drive spring for the plunger reaches its maximum extension before the plunger contacts the ground. Thus, only the weight of the plunger rested on the explosive charge. Once the APMINUD had been placed over the explosive, all personnel moved to a protected bunker and the explosive block was command detonated.

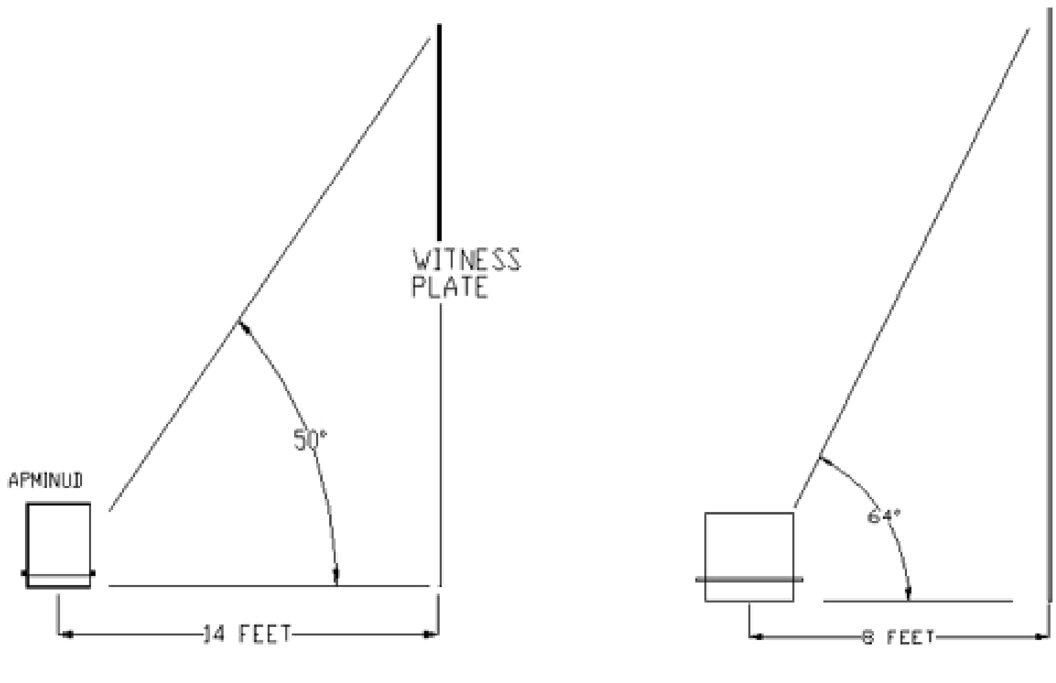

Figure 1 Witness Plate Distances from the APMINUD

In order to provide a measure of the reduction in threat to personnel and equipment in the vicinity of the working APMINUD, three plywood witness plates were placed around the explosion site. Each plate measured four feet wide by sixteen feet tall. The wood was 3/8" thick. The plates were placed on the circumference of a circle surrounding the APMINUD. For the first 23 shots, the plates were fourteen feet from the TNT and therefore witnessed the elevation angle around the APMINUD from 0 degrees to +50 degrees. For shots 24 - 50 the plates were moved in to a distance of eight feet and witnessed the elevation angle from 0 degrees to +64 degrees. The plates were examined after each shot for evidence of penetration by fragments from the explosion or other damage.

A measure of the durability of the APMINUD was obtained by inspecting the device after each explosive shot. Periodic cocking and release of the plunger in between explosive shots was done to discover any loss of function during the explosive tests. Any defects that developed were recorded on the data sheets.

4. Test Results and Analysis

4.1 Non Explosive Mine Tests

All permutations of the mine types, soil type, burial depth, and offset were made with multiple repetitions. This resulted in 128 test observations recorded in appendix 1 and summarized in tables 2 - 5. The data are sorted in each table such that results from all test conditions are combined into a single success rate except for the one parameter which varies from one column to the next. Since several test conditions have been combined into each success percentage recorded in the tables, it is the differences between the numbers recorded in each column rather than the absolute success rate that we are trying to emphasize here. Table 1 for example compares results in clay with results in sand, but the data includes tests made in these soils at depths which are greater than one would normally expect to find these kinds of mines buried.

4.1.1 Soil Type

The kind of soil in which the mines were buried has a definite, measurable effect on the relative ease with which the APMINUD is able to transmit sufficient pressure to actuate the fuze. In all cases, the mines were buried and the test performed immediately. The relatively loose fill placed over top the mine was somewhat spongy and "shock absorbent." The clay in particular provides a compaction layer full of air spaces which until settled must be compressed (see also double strike analysis). The sand on the other hand is almost incompressible and was much more capable of transmitting the pressure to the mine. See Table 2.

Table 2. Comparison of Results in Clay with Results in Sand

Common Test Conditions- Mine Types, Depths, and Offsets	MKII and M14 Mines, Buried Flush to 4” Deep, Mines Placed at 0” to 4” Offset from Center of Plunger	
Variable Test Condition - Soil	**Clay**	**Sand**
Actuations/Number of Tests	45/62	56/66
Percentage of Success	72%	85%

4.1.2 Mine Type

There was significant variance in the success in triggering the two mine types tried in these experiments. Both mines are toe popper style, blast AP mines. Each is easily triggered by light pressure applied by fingers. The large difference between the actuation rates between the two types was unexpected, but quite consistent throughout each of the burial conditions tried. The MKII was arbitrarily established as the baseline for these tests and more repetitions for each burial condition made. The M14 casing proved to be somewhat more fragile and tests at 2" burial and flush placement tended to fracture the case as well as actuate the pressure plate on the fuze. Because of this, fewer tests were made with the M14's. The results listed in table 3 show excellent effects against the M14's but presumably greater impact pressure needed to consistently actuate the MKII mines.

Table 3. Comparison of Results Against the Two Mine Types

Common Test Conditions- Soils, Depths, and Offsets	Clay and Sand Soils, Mines Buried Flush to 4” Deep, Mines Placed at 0” to 4” Offset from Center of Plunger	
Variable Condition - Mine Types	**MKII**	**M14**
Actuations/Number of Tests	65/90	36/38
Percentage of Success	72%	95%

4.1.3 Burial Depth

As expected burial depth has a big influence on the actuation success rate for the mines used in these tests. See table 4. The intended performance goal of the APMINUD is to trigger mines at depths at which we might expect to encounter them in the field. The reduction in mine actuation rate between the mines buried two inches and those buried four inches is definite but not considered a significant problem because finding AP mines this deeply buried is not expected. The actuation rate for mines buried two inches shows no significant reduction from the cases where the plunger had direct contact with the mine (flush buried).

Table 4. Comparison of Results of Mine Buried Flush with Results from 2" and 4" Burial

Common Conditions- Mine Type, Soils, Offset	MKII and M14 Mines, Mines Placed 0” to 4” Offset from Center of Plunger, Clay and Sand Soils		
Variable - Burial Depth	**Flush Buried**	**2” Buried**	**4” Buried**
Actuations/ # of Tests	30/36	36/44	35/48
Percentage of Success	83%	82%	73%

4.1.4 Burial Offset from Plunger Center

The distance at which the mine was placed from the center axis of the plunger had an unexpectedly large influence on the mine actuations. (See table 5) There were apparent "dead spots" in the footprint from the plunger. The standoffs placed on the tip of the plunger have >10" diameters, and the largest offset tried was 4," meaning that the mines were always directly underneath some part of the plunger. The dead spots would seem to be attributable to two possible causes. The annular ridges cast into the impact surface of the standoffs were intended to help transmit the impact pressure to greater depths. The spaces in between the ridges, however, offer small gaps in the contact area with the ground that may result in skip zones at shallower depths. In addition, it was observed that the weight of the APMINUD sinking in the ground as it is placed for use causes a swelling of the soil within the shell. This "swelling" is accompanied by a general fracturing and loosening of the soil as it mushrooms up within the shell interior. This may create an uneven distribution of soil cushioned areas that requires greater impact to compress at certain locations under the standoff.

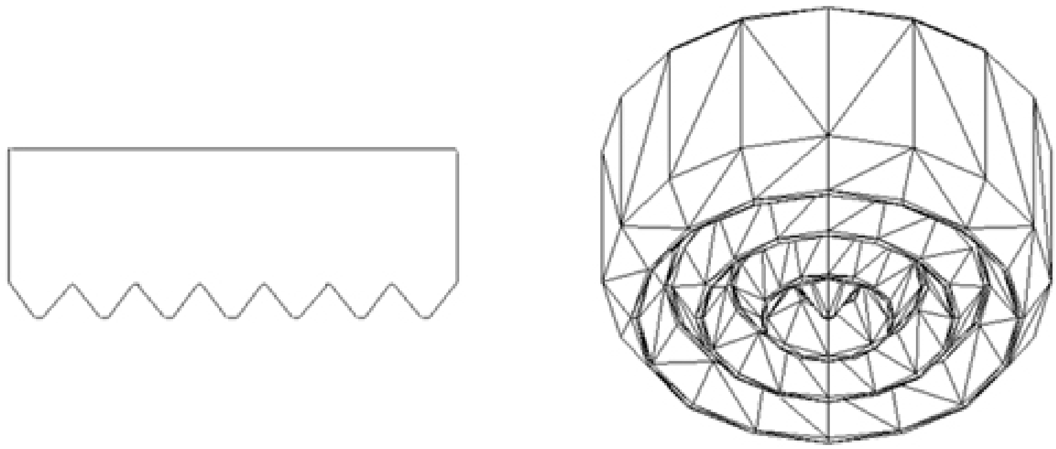

Figure 2 - APMINUD Standoff

Table 5. Comparison of Results with Mines Center Under Plunger with Results with Mine Placed 2" and 4" from Center of Plunger

Common Conditions- Mine Type, Depth, Soil	MKII and M14 Mines, Mines Buried 0" to 4", Clay and Sand Soils		
Variable - Offset	**0" Offset**	**2" Offset**	**4" Offset**
Actuations/ # of Tests	36/44	31/42	34/42
Percentage of Success	82%	74%	81%

4.1.5 Effect of Double Striking

As discussed in the Soil Type Results section and the Offset Results section, there may be some cushioning of the mines from the plunger impact due to the compression of air spaces within the soil loosely placed over the mines. These compressible volumes were attributable to having covered over the mine and proceeding with the test with no settling time and from the mushrooming up of the soil within the APMINUD as it is placed. As discussed, the effect was much more apparent in the clay soil than in the relatively incompressible sand. To further document this effect a small number of trials were conducted in which the mine was buried, the plunger was released, re-cocked, and released a second time. The results of these trials are given in table 6 along with results from trials using the same mine and burial conditions, but only using one stroke of the plunger. The dramatic improvement in the actuation of the MKII mine used in these tests indicates that much of the first blow is absorbed in compressing the voids out of the soil. The second blow in this case was 100% effective in reaching and triggering the mine.

Table 6. Comparison of Results of Using a Single Strike of the Plunger with Two Strikes Over the Same Mine

Common Conditions- Mine Type, Depth, Soil, Offset	MKII Mines, Buried 4", Clay Soil, 0" Offset from Plunger Center

Variable- # of Strikes	**Single Strike**	**Double Strike**
Actuations/Number of Tests	1/5	5/5
Percentage of Success	20%	100%

4.1.6 Vegetation Cover

A short series of 20 tests was conducted in which the mine was buried in clay and covered over with grass clumps. The tests were planned to provide a basis for determining the effect on performance when used in mined areas overgrown with vegetation. This goal was not adequately achieved due to the limitations of the test. Placement of a sod clump on top of a mine in a hole is not believed to replicate the situation in which vegetation has grown up in soil settling over a buried mine. Further these tests were conducted in wet to muddy conditions and probably are more characteristic of the soil being more plastic and less compressible than the results found in unvegetated (and dry) clay reported above. Table 7 lists the results from these tests.

Table 7. Comparison of Results of the MKII Mine and M14 Mine When Placed in Sod Covered Hole

Common Test Conditions	Vegetated clay soil, 4” burial depth, Mines placed on center and offset 2”	
Variable - Mine Type	**MKII**	**M14**
Actuations/Number of Tests	9/10	9/10
Percentage of Success	90%	90%

4.2 Explosive Test Results

4.2.1 Environment

The 50 shots with 1/2 lb. of TNT and 100 steel balls produced no evidence of any fragmentation escaping from the APMINUD at the low angles witnessed by the plywood sheets. The total number of steel ball fragments was 5000, and no embedded balls or holes matching the balls were found in any of the plywood sheets.

The sacrificial "standoffs" at the plunger tip shattered with each shot and produced large fragments (.5 - 10 cubic inches). These aluminum chunks were either confined within the shell or launched at high angles. None impacted the witness plates below 45 degrees elevation angle. A total of 8 fragments impacted the witness plates between 45 and 65 degrees. Several hundred more fragments were launched and could be heard "raining down" from presumably higher elevation launch angles.

At the test conclusion an unconfined charge was detonated with the same quantity of steel ball placed with the charge. Each of the three plywood sheets sustained 8 or 9 penetrations from the 100 balls. On this basis we would expect to find 1200 holes in the plywood over the course of the test if the APMINUD were not present. The fact that none were found and the fact that the large fragments from the disintegrating standoffs were observed only at high launch angles means the APMINUD shell performed as was expected in confining the dangers from the simulated mines.

4.2.2 Durability of the APMINUD

The shell and plunger head were examined for damage in between each explosive shot made. No deformation or damage of any kind was found in the shell or basic structure of the APMINUD over the entire course of the testing. The release mechanism, and the lifting eyes remained fully functional throughout.

The plunger assembly and plunger itself sustained some damage requiring limited field repairs. The plunger assembly consists of the plunger which is a ~3" hollow shaft, the mount for the plunger head, the plunger head and lifting eye. The mount, the head, and the lifting eye are all held in place by a ~1.5" shaft which runs through the hollow length of the plunger. The shaft has a solid cone shaped piece that is used to draw the head and head mount up tight to the plunger. The cone shaped piece is welded to the rest of the 1.5" shaft. This weld broke after the 3rd shot was replaced with a spare that lasted 24 shots. The spare broke and was replaced twice with repaired shafts lasting 8 and 1 shot each. The rod was again repaired and the weld thickened. This rod lasted for the balance of the shots (13).

It was also discovered that somewhere between shot 1 and 38 the weld which holds the shoulder that engages the drive spring with the plunger had broken. This caused the shoulder to move .5" axially along the plunger . This resulted in the plunger not being able to move up high enough in the sleeve that guides the plunger to allow the release pin to engage the raceway in the plunger. The plunger was replaced with a spare after shot 38 and no more problems were encountered.

The standoffs were aluminum castings designed to be sacrificial in order to protect the plunger head. This required a new standoff to be installed after each of the 1/2 lb. shots. Replacement took approximately 1 minute to accomplish.

5. Summary and Recommendations

The prototype built and delivered performed quite close to the goals set for the device at the beginning of the effort. Significant lessons learned over the course of the test will contribute to the improvement of the APMINUD and will allow the design goals to be achieved completely.

Overall, about 80% of the mines tested were actuated. The results of the double strike test and the differences between the sand and clay soil results would seem to indicate that with greater compaction of the soil the actuation number can be made to approach 100%. Allowing multiple strokes with the plunger is one viable possibility. Increasing the impact force by using a stiffer drive spring is also possible. The only tradeoff identified in stiffening the spring is the greater pull required to withdraw the release pin. The withdrawal force is only modest and could be increased without significant operational problems. The dead spots in the impact zone of the plunger could also be eliminated by using a flat instead of ridged face on the standoffs.

The low angle fragmentation from the mines appears to have been eliminated by the APMINUD. The high angle fragments and pieces from the standoffs are still present when the APMINUD is employed against mines with large explosive quantities(>1/4 lb.). The employment SOP's would require that vulnerable equipment be kept from being exposed to the open top of the shell and also that people and equipment within a 100-200 meter radius have cover from the falling debris. It is recommended that the aluminum standoffs be replaced with plastic or rubber standoffs to keep the metallic debris to a minimum within the mined area. An alternative would be to invent a kind of umbrella that catches and deflects debris leaving the top of the shell back down to the ground in the immediate vicinity of the APMINUD.

Each of the survivability failures encountered in the test program can easily be corrected, guaranteeing reliable performance over 50 shots from the most hazardous of mines intended for neutralization with the APMINUD. Smaller blast mines appear to pose no significant threat to the operation of the APMINUD and virtually unlimited life with respect to damage from mine blast due to the toe-popper style mine is expected. The simplicity and low cost of the APMINUD components mean that sufficient quantities of replacement units and spare parts could be kept on hand as part of any demining operations to insure continuous employment.

Correct placement of the APMINUD over the mine to be neutralized is not difficult. However, it is expected that in a demining operation the vehicle operator would need to be in an armored cab with no guidance as the APMINUD is lowered. This combined with the imprecise marking of the mine location, as well as the multiple strike option discussed, mean that there may be some trial and error hunting and repeated re-cocking to trigger the mine. In addition the fact that the standoffs must be replaced after each large shot limits the clearance speed somewhat from the continuous operation envisioned at the program outset. Such continuous operation is still feasible for mined areas consisting of devices in the .5 - 2 ounce explosive weight range.

APPENDIX 1

DATA COLLECTION SHEETS FOR INERT MINE TESTING

Test	Date	Soil	Mine Type	Burial Depth	Burial Offset	Fuze Function	Remarks
1.	1/26	Clay	MKII	Flush	0”	Y	
2.	1/26	Clay	MKII	Flush	0”	Y	
3.	1/26	Clay	MKII	Flush	0”	N	Rings on hammer surround fuze
4.		Clay	MKII	Flush	0”	Y	
5.	1/26	Clay	MKII	Flush	0”	Y	
6.	1/26	Clay	MKII	2”	0”	Y	
7.	1/26	Clay	MKII	2”	0”	Y	
8.	1/26	Clay	MKII	2”	0”	Y	
9.	1/26	Clay	MKII	2”	0”	Y	
10.	1/26	Clay	MKII	2”	0”	Y	
11.	1/26	Clay	MKII	4”	0”	Y	
12.	1/26	Clay	MKII	4”	0”	N	
13.	1/26	Clay	MKII	4”	0”	N	
14.	1/26	Clay	MKII	4”	0”	N	

15.	1/26	Clay	MKII	4”	0”	N	
16.	1/26	Clay	MKII	Flush	2”	N	
17.	1/26	Clay	MKII	Flush	2”	Y	
18.	1/26	Clay	MKII	Flush	2”	N	
19.	1/26	Clay	MKII	Flush	2”	Y	
20.	1/26	Clay	MKII	Flush	2”	Y	
21.	1/26	Clay	MKII	2”	2”	N	
22.	1/26	Clay	MKII	2”	2”	Y	
23.	1/26	Clay	MKII	2”	2”	Y	
24.	1/26	Clay	MKII	2”	2”	Y	
25.	1/26	Clay	MKII	2”	2”	Y	
26.	1/26	Clay	MKII	4”	2”	Y	
27.	1/26	Clay	MKII	4”	2”	N	
28.	1/26	Clay	MKII	4”	2”	Y	
29.	1/26	Clay	MKII	4”	2”	N	
30.	1/26	Clay	MKII	4”	2”	N	
31.	1/26	Clay	MKII	Flush	4”	N	Soil beneath mine loose
32.	1/26	Clay	MKII	Flush	4”	N	Soil beneath mine loose
33.	1/26	Clay	MKII	Flush	4”	Y	
34.	1/26	Clay	MKII	Flush	4”	Y	
35.	1/26	Clay	MKII	Flush	4”	Y	
36.	1/26	Clay	MKII	2”	4”	Y	
37.	1/26	Clay	MKII	2”	4”	Y	

38.	1/26	Clay	MKII	2”	4”	Y	
39.	1/26	Clay	MKII	2”	4”	Y	
40.	1/26	Clay	MKII	2”	4”	Y	
41.	1/26	Clay	MKII	4”	4”	N	
42.	1/26	Clay	MKII	4”	4”	Y	
43.	1/26	Clay	MKII	4”	4”	N	
44.	1/26	Clay	MKII	4”	4”	N	
45.	1/26	Clay	MKII	4”	4”	N	
46.	1/29	Grass	MKII	4”	0”	N	
47.	1/29	Grass	MKII	4”	0”	Y	
48.	1/29	Grass	MKII	4”	0”	Y	
49.	1/29	Grass	MKII	4”	0”	Y	
50.	1/29	Grass	MKII	4”	0”	Y	
51.	1/29	Grass	MKII	4”	2”	Y	
52.	1/29	Grass	MKII	4”	2”	Y	
53.	1/29	Grass	MKII	4”	2”	Y	
54.	1/29	Grass	MKII	4”	2”	Y	
55.	1/29	Grass	MKII	4”	2”	Y	
56.		Clay	M14	Flush	0”	Y	
57.		Clay	M14	Flush	0”		Test not performed due to mine case breaking
58.		Clay	M14	Flush	0”		Test not performed due to mine case breaking
59.		Clay	M14	2”	0”	Y	
60.		Clay	M14	2”	0”	Y	

61.		Clay	M14	2”	0”	Y	
62.		Clay	M14	4”	0”	Y	
63.		Clay	M14	4”	0”	Y	
64.		Clay	M14	4”	0”	Y	
65.		Clay	M14	Flush	2”	Y	
66.		Clay	M14	Flush	2”		Test not performed due to mine case breaking
67.		Clay	M14	Flush	2”		Test not performed due to mine case breaking
68.		Clay	M14	2”	2”	Y	
69.		Clay	M14	2”	2”		Test not performed due to mine case breaking
70.		Clay	M14	2”	2”		Test not performed due to mine case breaking
71.		Clay	M14	4”	2”	Y	
72.		Clay	M14	4”	2”	Y	
73.		Clay	M14	4”	2”	Y	
74.		Clay	M14	Flush	4”	Y	
75.		Clay	M14	Flush	4”		Test not performed due to mine case breaking
76.		Clay	M14	Flush	4”		Test not performed due to mine case breaking
77.		Clay	M14	2”	4”	Y	
78.		Clay	M14	2”	4”		Test not performed due to mine case breaking
79.		Clay	M14	2”	4”		Test not performed due to mine case breaking
80.		Clay	M14	4”	4”	Y	
81.		Clay	M14	4”	4”	Y	
82.		Clay	M14	4”	4”	Y	
83.	1/29	Grass	M14	4”	0”	Y	

84.	1/29	Grass	M14	4”	0”	Y	
85.	1/29	Grass	M14	4”	0”	Y	
86.	1/29	Grass	M14	4”	0”	Y	
87.	1/29	Grass	M14	4”	0”	Y	
88.	1/29	Grass	M14	4”	2”	Y	
89.	1/29	Grass	M14	4”	2”	Y	
90.	1/29	Grass	M14	4”	2”	Y	
91.	1/29	Grass	M14	4”	2”	Y	
92.	1/29	Grass	M14	4”	2”	N	
93.		Sand	MKII	Flush	0”	Y	
94.		Sand	MKII	Flush	0”	Y	
95.		Sand	MKII	Flush	0”	Y	
96.		Sand	MKII	Flush	0”	Y	
97.		Sand	MKII	Flush	0”	Y	
98.		Sand	MKII	2”	0”	Y	
99.		Sand	MKII	2”	0”	N	
100.		Sand	MKII	2”	0”	N	
101.		Sand	MKII	2”	0”	Y	
102.		Sand	MKII	2”	0”	Y	
103.		Sand	MKII	4”	0”	Y	
104.		Sand	MKII	4”	0”	N	
105.		Sand	MKII	4”	0”	Y	
106.		Sand	MKII	4”	0”	Y	

107.		Sand	MKII	4”	0”	Y	
108.		Sand	MKII	Flush	2”	Y	
109.		Sand	MKII	Flush	2”	Y	
110.		Sand	MKII	Flush	2”	Y	
111.		Sand	MKII	Flush	2”	N	
112.		Sand	MKII	Flush	2”	Y	
113.		Sand	MKII	2”	2”	Y	
114.		Sand	MKII	2”	2”	N	
115.		Sand	MKII	2”	2”	N	
116.		Sand	MKII	2”	2”	N	
117.		Sand	MKII	2”	2”	N	
118.		Sand	MKII	4”	2”	Y	
119.		Sand	MKII	4”	2”	Y	
120.		Sand	MKII	4”	2”	Y	
121.		Sand	MKII	4”	2”	Y	
122.		Sand	MKII	4”	2”	Y	
123.		Sand	MKII	Flush	4”	Y	
124.		Sand	MKII	Flush	4”	Y	
125.		Sand	MKII	Flush	4”	Y	
126.		Sand	MKII	Flush	4”	Y	
127.		Sand	MKII	Flush	4”	Y	
128.		Sand	MKII	2”	4”	Y	
129.		Sand	MKII	2”	4”	Y	

130.		Sand	MKII	2"	4"	Y	
131.		Sand	MKII	2"	4"	Y	
132.		Sand	MKII	2"	4"	Y	
133.		Sand	MKII	4"	4"	Y	
134.		Sand	MKII	4"	4"	Y	
135.		Sand	MKII	4"	4"	Y	
136.		Sand	MKII	4"	4"	Y	
137.		Sand	MKII	4"	4"	Y	
138.		Sand	M14	Flush	0"	Y	
139.		Sand	M14	Flush	0"		Test not performed due to mine case breaking
140.		Sand	M14	Flush	0"		Test not performed due to mine case breaking
141.		Sand	M14	2"	0"	Y	
142.		Sand	M14	2"	0"	Y	
143.		Sand	M14	2"	0"	Y	
144.		Sand	M14	4"	0"	Y	
145.		Sand	M14	4"	0"	Y	
146.		Sand	M14	4"	0"	Y	
147.		Sand	M14	Flush	2"	Y	
148.		Sand	M14	Flush	2"		Test not performed due to mine case breaking
149.		Sand	M14	Flush	2"		Test not performed due to mine case breaking
150.		Sand	M14	2"	2"	Y	
151.		Sand	M14	2"	2"	Y	
152.		Sand	M14	2"	2"	Y	

153.		Sand	M14	4”	2”	Y	
154.		Sand	M14	4”	2”	Y	
155.		Sand	M14	4”	2”	Y	
156.		Sand	M14	Flush	4”	Y	
157.		Sand	M14	Flush	4”		Test not performed due to mine case breaking
158.		Sand	M14	Flush	4”		Test not performed due to mine case breaking
159.		Sand	M14	2”	4”	N	
160.		Sand	M14	2”	4”	Y	
161.		Sand	M14	2”	4”	Y	
162.		Sand	M14	4”	4”	Y	
163.		Sand	M14	4”	4”	Y	
164.		Sand	M14	4”	4”	N	
165.	1/26	Clay	MKII	4”	0”	Y	Double strike
166.	1/26	Clay	MKII	4”	0”	Y	Double strike
167.	1/26	Clay	MKII	4”	0”	Y	Double strike
168.	1/26	Clay	MKII	4”	0”	Y	Double strike
169.	1/26	Clay	MKII	4”	0”	Y	Double strike

APPENDIX 2

DATA COLLECTION SHEETS FOR EXPLOSIVE MINE TESTING

TRIAL #	EXPLOSIVE DESCRIPTION	DATE	CONDITION OF APMINUD	DESCRIPTION OF WITNESS PLATES
1	.5 lb TNT 100 frags	1/30 1:30 pm	okay	No fragments
2	.5 lb TNT 100 frags	1/30 2:15 pm	okay	No fragments
3	.5 lb TNT 100 frags	2/2 10:30 am	weld on connect rod broke (replaced with spare)	No fragments
4	.5 lb TNT 100 frags	2/2 11:20 am	okay	No fragments
5	.5 lb TNT 100 frags	2/2 11:40 am	okay	No fragments
6	.5 lb TNT 100 frags	2/2 12:40 am	okay	No fragments
7	.5 lb TNT 100 frags	2/2 1:00 pm	okay	No fragments
8	.5 lb TNT 100 frags	2/2 1:20 pm	okay	No fragments
9	.5 lb TNT 100 frags	2/2 1:44 pm	okay	No fragments
10	.5 lb TNT 100 frags	2/2 2:10 pm	okay	No fragments
11	.5 lb TNT 100 frags	2/2 2:30 pm	okay	No fragments
12	.5 lb TNT 100 frags	2/3 8:30 am	okay	No fragments
13	.5 lb TNT 100 frags	2/3 9:00 am	okay	No fragments
14	.5 lb TNT 100 frags	2/3 9:15 am	okay	No fragments
15	.5 lb TNT 100 frags	2/3 9:35 am	okay	No fragments
16	.5 lb TNT 100 frags	2/3 10:47 am	okay	Dent in shield 1
17	.5 lb TNT 100 frags	2/3 11:05 am	okay	No fragments
18	.5 lb TNT 100 frags	2/3 11:25 am	okay	No fragments
19	.5 lb TNT 100 frags	2/3 11:45 am	okay	No fragments
20	.5 lb TNT 100 frags	2/3 1:42 pm	okay	No fragments
21	.5 lb TNT 100 frags	2/3 2:00 pm	okay	No fragments

22	.5 lb TNT 100 frags	2/3 2:13 pm	okay	No fragments
23	.5 lb TNT 100 frags	2/3 2:27 pm	okay	2 Dents
*24	.5 lb TNT 100 frags	2/10 8:35 am	okay	moved location large frag panel 2 @ 7 ft and large frag panel 3 @ 11 ft
25	.5 lb TNT 100 frags	2/10 8:50 am	okay	No frags
26	.5 lb TNT 100 frags	2/10 9:00 am	okay	No frags
27	.5 lb TNT 100 frags	2/10 9:10 am	okay	No frags
28	.5 lb TNT 100 frags	2/10 9:20 am	weld in connecting rod broke (replaced with shop repaired rod)	No frags
29	.5 lb TNT 100 frags	2/10 10:20 am	okay	No frags
30	.5 lb TNT 100 frags	2/10 10:35 am	okay	Large frag panel 1 @13'6"
31	.5 lb TNT 100 frags	2/10 10:45 am	okay	Large frag panel 3 @ 13'4"
32	.5 lb TNT 100 frags	2/10 10:55 am	okay	No frags
33	.5 lb TNT 100 frags	2/10 11:05 am	okay	Large frag panel 1 @ 14'9"
34	.5 lb TNT 100 frags	2/10 11:15 am	okay	Large frag panel 3 @ 16'3"
35	.5 lb TNT 100 frags	2/10 11:28 am	okay	No frags
36	.5 lb TNT 100 frags	2/10 11:39 am	weld in connecting rod broke (replaced with field repaired MIG rod)	No frags
37	.5 lb TNT 100 frags	2/10 1:30 pm	weld in connecting rod broke (replaced with field repaired rod; increased weld thickness and used 7018 stick)	No frags
38	.5 lb TNT 100 frags	2/10 3:17 pm	okay	No frags
39	.5 lb TNT 100 frags	2/10 3:25 pm	okay	No frags
40	.5 lb TNT 100 frags	2/10 3:38 pm	okay	No frags

41	.5 lb TNT 100 frags	2/10 3:47 pm	okay	No frags
42	.5 lb TNT 100 frags	2/10 3:57 pm	okay	No frags
43	.5 lb TNT 100 frags	2/10 4:06 pm	okay	No frags
44	.5 lb TNT 100 frags	2/10 4:15 pm	okay	No frags
45	.5 lb TNT 100 frags	2/10 4:26 pm	okay	Large frag panel 2 @ 12’
46	.5 lb TNT 100 frags	2/10 4:35 pm	okay	Large frag panel 1 @ 6’
47	.5 lb TNT 100 frags	2/10 4:44 pm	okay	No frags
48	.5 lb TNT 100 frags	2/10 4:53 pm	okay	No frags
49	.5 lb TNT 100 frags	2/10 5:01 pm	okay	No frags
50	.5 lb TNT 100 frags	2/10 5:09 pm	okay	No frags

Notes:

Shots 1-23 in clay conditions with 3 witness towers positioned at 0, 45, and 90 degree locations around the bell at a distance of 14 feet

Shots 25-50 in sandy/clay conditions with 3 witness towers positioned at 0, 90, and 180 locations around the bell at a distance of 8 feet.

Shot 51 used .5 lb of TNT with 100 pellets laying in the open flush with ground surface. 8 pellets pierced each panel at heights from 0' to 4'.

It was discovered that somewhere in between shot 1 and shot 38 that the main plunger assembly had "stretched" a sufficient amount to prevent the holding pin from engaging the raceway in the plunger.