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Demonstration Trial of Bozena-4 and MV-4 Flails

ITEP Trial at International Mine Action Training Centre, Nairobi, Kenya

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Technical Report
DRDC Suffield TR 2007-045
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Canada

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Abstract

In October 2006 a trial was conducted by the International Test and Evaluation Program in which the Bozena-4 mini-flail and the MV-4 mini-flail were tested at the International Mine Action Training Centre in Nairobi, Kenya. The trial was designed to examine the performance of both machines in the conditions local to that establishment, and also to attempt to quantify the effects of flail hammer wear on performance. The tests were initially based on the methodology specified in the "European Committee for Standardisation (CEN) Workshop Agreement 15044; Test and Evaluation of Demining Machines" but it was not possible to maintain the standardized conditions necessary for a fully CWA15044-compliant trial.

Neither machine was able to penetrate the extremely hard ground consistently or reliably to depths beyond 11 cm. Due to changing machine parameters throughout the trial no clear conclusions could be reached regarding the effects of hammer wear on performance.

Résumé

Un essai a été conduit, en octobre 2006, par le Programme international d'essais et d'évaluations durant lequel les deux mini fléaux Bozena-4 et MV-4 ont été évalués au Centre de formation antimine à Nairobi au Kenya. L'essai avait été conçu pour examiner le rendement des deux machines dans les conditions locales à cet établissement et pour tenter également de quantifier les effets de l'usure du marteau du fléau sur le rendement. Les essais ont été initialement basés sur la méthodologie spécifiée par « l'Accord du groupe de travail 15044 du Comité européen de normalisation (CEN); Essais et évaluations des machines de déminage » mais il n'a pas été possible de maintenir les conditions normalisées nécessaires aux essais, conformément à l'Accord 15044.

Aucune machine n'a été capable de pénétrer des terrains extrêmement durs, à des profondeurs supérieures à 11 cm, de manière uniforme et fiable. Étant donné que les paramètres de la machine changeaient tout au long de l'essai, aucune conclusion n'a pu être tirée concernant les effets de l'usure du marteau sur la performance.

Executive summary

In October 2006 a test and evaluation project was undertaken to do a side-by-side trial of the Way Industries BOZENA-4 flail and the DOK-ING MV-4 flail at the International Mine Action Training Centre (IMATC) in Nairobi, Kenya. The main participants in this project were Canada, Sweden and the UK, through the Canadian Centre for Mine Action Technologies (CCMAT), the Swedish Explosive Ordnance Disposal and Demining Centre (SWEDEC), and QinetiQ, respectively. The trial was designed to examine the performance of both machines in the conditions local to that establishment, and also to attempt to quantify the effects of flail hammer wear on performance. The tests were initially based on the methodology specified in the "European Committee for Standardisation (CEN) Workshop Agreement 15044; Test and Evaluation of Demining Machines" (CWA15044).

CWA15044 is primarily focused on the performance and survivability tests of machines for demining operations. By comparison, it deals with acceptance tests, or in-country tests in a much briefer and more general manner. The performance test is defined for very specific conditions, including soil types, soil conditions, mine targets, ground profile measurements, etc. When such trials are attempted outside of facilities where the proper conditions and equipment are available, many of the standardized test conditions can be compromised. In the case of this trial, enough of the important conditions were lost that, in all but one test, the mine target data was discarded as invalid and misleading.

Despite the problem with the validity of the mine target data, useful information was obtained, especially regarding the ability of the machines to consistently penetrate the ground to a given depth. Both machines have previously been tested under properly controlled conditions such as the CWA15044 standard, and both have demonstrated very high capabilities. This test at IMATC involved the use of extremely hard soil which is known to be difficult to work.

Maximum effective depth was defined as the shallowest point measured for a given test lane. This was inferred to be the deepest depth to which a deminer could be confident that the machine had processed reliably and consistently with no possibility of missed mines.

Under the test conditions, neither machine was able to penetrate the ground consistently or reliably to depths beyond 11 cm. Most of the measured values showed that the maximum effective depth the deepest either machine could penetrate reliably and consistently, with no possibility of missed mines, was closer to 5 cm – 7 cm.

To further analyze the ground penetration performance, a parameter called penetration efficiency was devised, which is defined as a measure of how much of the ground profile cut by the machine had reached a particular depth of interest. Both machines fared poorly when using bare chains with no hammers, but this is expected since both manufacturers specifically recommended against this practice. When tested with

mines buried flush with the ground surface, both machines achieved penetration efficiencies between 90% and 100% measured at a depth of 5 cm. In the deeper tests, the penetration efficiencies ranged from 31% to 79%. While it could not be confirmed, this variation appeared to have had more to do with speed variations from one run to the next, than with any other factor.

Due to changing parameters (width of flail, speed of operation, etc) throughout the trial no clear conclusions could be reached regarding the effects of hammer wear on performance.

Coley G. (2007). Demonstration Trial of Bozena-4 and MV-4 Flails. (DRDC Suffield TR 2007-045). Defence R&D Canada – Suffield.

Sommaire

En octobre 2006, un projet d'essais et d'évaluation a été entrepris pour effectuer un essai de deux fléaux côte à côte, le fléau BOZENA-4 de Way Industries et le fléau MV-4 de DOK-ING, au Centre international de formation en déminage (IMATC) de Nairobi au Kenya. Les principaux participants au projet étaient le Canada, la Suède et la GB avec le Centre canadien de technologie en déminage (CCTD), le centre suédois de neutralisation des explosifs et munitions et de déminage (SWEDEC) et QinetiQ, respectivement. L'essai avait été conçu pour examiner le rendement de deux machines dans les conditions locales à cet établissent et aussi pour tenter de quantifier les effets de l'usure du marteau du fléau sur le rendement. Les tests ont initialement été basés sur la méthodologie spécifiée lors de l'«Accord du groupe de travail 15044 du Comité européen de normalisation (CEN); Essais et évaluations des machines de déminage » (CWA15044).

L'Accord 15044 est d'abord axé sur les essais de rendement et de survivabilité des machines utilisées durant les opérations de déminage. Il traite, en comparaison, des épreuves d'admissibilité ou des essais dans le pays même d'une manière beaucoup plus brève et générale. Le test de rendement est défini pour des conditions très spécifiques et inclut les types de sols, les conditions de sols, les cibles des mines, les mesures de profil de terrain, etc. Quand de tels essais sont tentés à l'extérieur des installations où les conditions sont bonnes et l'équipement disponible, beaucoup de ces conditions d'essais normalisés peuvent être compromises. Dans le cas de cet essai, assez de conditions importantes avaient été perdues et dans tous les essais sauf un, les données de la cible de la mine ont été rejetées comme invalides et faussées.

On a obtenu des informations utiles, en dépit du problème de la validité des données de la cible de la mine, surtout concernant la capacité des machines à pénétrer le sol uniformément à une profondeur donnée. Les deux machines ont été évaluées antérieurement dans des conditions correctement contrôlées telles que celles des normes de l'Accord 15044 et toutes deux ont fait preuve de très hautes capacités. Ce test, à IMATC, utilisait un sol extrêmement dur ayant la réputation d'être dur à travailler.

On a défini la profondeur maximum efficace comme le point mesuré le moins profond pour une voie donnée d'essai. On avait inféré que celle-ci était la mesure la plus profonde à laquelle un démineur était confiant que la machine performerait de manière fiable et uniforme sans qu'il soit possible qu'elle manque des mines.

Dans ces conditions d'essais, aucune machine n'a été capable de pénétrer le sol de manière uniforme ou fiable à des profondeurs supérieures à 11 cm. La plupart des valeurs mesurées ont démontré que la profondeur maximum efficace à laquelle les deux machines pouvaient pénétrer le sol de manière uniforme et fiable sans qu'il soit possible qu'elles manquent des mines, étaient plutôt de 5 à 7 cm.

On a conçu un paramètre appelé efficience de pénétration pour analyser plus profondément le rendement de la pénétration du sol; ce paramètre est une mesure qui définit de combien le profil du sol coupé par la machine atteint une profondeur particulière à laquelle on s'intéresse. Les deux machines n'ont pas bien fonctionné quand on utilisait les chaines nues sans marteau mais on s'y attendait puisque les manufacturiers recommandent spécifiquement de ne pas le faire. Les deux machines ont réussi à pénétrer le sol à une efficacité allant de 90% à 100% mesurée à une profondeur de 5 cm, quand les mines étaient enfouies affleurant la surface. Pour les essais plus profonds, l'efficacité de pénétration allait de 31% à 79 %. Il semble que cette dernière variation est causée par la variation entre les vitesses d'un passage à l'autre plutôt que par d'autres facteurs bien qu'on n'ait pu le confirmer.

Aucune conclusion n'a pu être tirée concernant les effets de l'usure du marteau sur la performance à cause des variations dans les paramètres (largeur du fléau, vitesse de l'opération, etc.)

Coley G. (2007). Demonstration Trial of Bozena-4 and MV-4 Flails. (DRDC Suffield TR 2007-045). R & D pour la défense Canada – Suffield.

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Acknowledgements

Critical to this project were Capt Andy Carnochan and Mr. Joseph Kamotho from the International Mine Action Training Centre who provided the facilities and ensured that all of the logistics were efficiently looked after. Without their support, and the support from the rest of the International Mine Action Training Centre, the trial would not have been possible.

1. Introduction

The ITEP Mechanical Workgroup was charged with conducting a demonstration test of the Bozena-4 mini-flail and the MV-4 mini-flail currently at the International Mine Action Training Centre in Nairobi, Kenya. Some of the environmental conditions at this site are similar to those in southern Sudan, and it was hoped that the trial might provide some useful information on the possible future deployment of machines in that area.

A second goal was to quantify performance differences between flails with new hammers, worn hammers (this condition predetermined by the manufacturers) and no hammers, i.e., having just bare chains. If such a test were conducted using a single type of machine, it could be argued that the results were machine type specific, and not generally applicable to other machines from other manufacturers. By using two similar machines, both known to be very capable, these two criticisms could be avoided. The result, it was hoped, would be a hammer wear effect that was applicable in a general sense to flails as a whole.

Both the Bozena-4 and the MV-4 have been extensively tested in the past, and performance tests for both have been documented in the ITEP reports database. This particular trial could be viewed primarily as an acceptance trial, with some of the flavours of a CWA15044 performance trial included. It was also a side-by-side demonstration of two machines which are often regarded as competing for the same market.

Despite the fact that these two machines could be seen as competitors, this trial was not conceived as a competition between the machines. It was regarded by ITEP as an opportunity to view the capabilities of the two machines in some very difficult soil conditions, and as a chance for the two manufacturers to showcase their respective machines. The two teams involved, however, were extremely competitive and proved to be politically sensitive which resulted in alterations to some test criteria that had certain implications for the technical conduct of the tests. A commentary is presented in Section 3.8 to explain why some of the parameters of the test were not controlled as they would normally have been.

The ITEP team included the following personnel:

- Geoff Coley, Canadian Centre for Mine Action Technologies (CA)
- Dan Roseveare, Canadian Centre for Mine Action Technologies (CA)
- Maj Göran Danielsson, Swedish Explosive Ordnance Disposal and Demining Centre (SE)
- Lt Tommy Karlsson, Swedish Explosive Ordnance Disposal and Demining Centre (SE)
- Lloyd Wye, QinetiQ (UK)
- Steve Bowen, QinetiQ (UK)
- Franciska Borry, Royal Military Academy (BE)

2. Machine Description

2.1 BOZENA-4 Flail

The Way Industries BOZENA-4 flail shown in Figure 1 is described in CCMAT report TR-2005-138, and in the QinetiQ report by Chris Leach, both available at the ITEP web site (www.itep.ws). A few of the main characteristics of the machine, as provided by the manufacturer, are shown below. Additional information can also be obtained from the manufacturer, Way Industries.

Machine Weight: 5960kg

Working Width: 2225mm with the FU2 flail head shown in Figure 1.

Total Engine Power: 78kW

Figure 1. *Way Industries BOZENA-4*

2.2 MV-4 Flail

The DOK-ING MV-4 flail shown in Figure 2 is described in SWEDEC report “Final Report – Test and Evaluation of Machine for Removal of Anti-personnel Mines MV-4,” available at the ITEP web site. A few of the main characteristics of the machine, as provided by the manufacturer, are shown below. Additional information can also be obtained from the manufacturer, DOK-ING.

Machine Weight: 5310kg

Working Width: 1725mm

Total Engine Power: 129kW

Figure 2. *DOK-ING MV-4*

2.3 Machine Modifications

Through the course of the trial the configuration of the machines was changed slightly to deal with the very difficult soil conditions. Both manufacturers were given the freedom to ‘tune’ their machines as they saw fit to best deal with the hard, dry soil.

Known changes to the machines included:

- The ground contouring system on the MV-4 was removed for all but the final test.
- After the first test, three chains/hammers on each end of the Bozena-4 flail head were removed to bring the clearance width from 2.225m down to 2.0m.
    - This situation was explained to one ITEP team member by stating that one of the Bozena-4 configurations is a 2.0m wide version. The Bozena web site [1] refers to the FU1 flail head as having a 2.0m clearance width rather than the 2.225m width of the FU2 head supplied on this machine. A second ITEP team member was told that the reason for the change was that the machine had been cutting a 2.4m wide path and that this change was an attempt to reduce the width from 2.4m down to the specified 2.225m width. He was also told that, due to the width of the test target layout (the centre 50% band), there was no reason to cut any wider.
- For the final test all but the outermost chain/hammer on each end of the Bozena-4 flail shaft was installed bringing the width to approximately 2.150m.
- Before the first trial, the Bozena-4 team reported that they increased the hydraulic pressure to the Bozena-4 flail circuit, but that the pressure was still within the limits of the specifications for the system.

The MV-4 remote control normally operates at 433MHz, which is the frequency used by the inert WORM targets. DOK-ING modified the remote control system to ensure the WORM targets could be used in this trial.

The ITEP team was not advised that any other changes to the machines were made.

3. Trial Description

The original plan for this trial assumed that it would be conducted more or less like a CWA15044 performance test and that most of the numerical data would come from the WORM mine simulators, with only a supporting role played by the fibreboards to illustrate depth of soil penetration. As the tests progressed it became apparent that the entire trial description would have to be revised significantly.

In order to understand the results (why data could not be compared due to speed changes, for example), it is necessary to describe how the trial evolved from the original concept. Doing so requires that some of the details of what happened in some of the tests needs to be discussed. Some of the information in this section should more properly be discussed in the Results section of the report, but it is useful here to understand the changes to the original trial description, and why those changes were made. This is particularly true of Sections 3.6, 3.7 and 3.8.

3.1 Trial Concept

CWA 15044 contains detailed descriptions of the soil composition, moisture and density that are recommended when performance tests are conducted in established research laboratories. It is also clear about the installation of test targets and witness panels in the test lanes. When the tests are conducted in the field, or in real demining environments, these conditions may not be practical or achievable.

While this trial was expected to provide performance information for a specific set of conditions, many more questions need to be addressed in a full comparison or a competition. Such questions could concern:

- Fuel consumption
- Availability and consumption of spare parts
- Mobility over differing terrain conditions
- Training requirements
- Maintenance requirements
- Transportability

Due to constraints of time, budget, and facilities, it was not possible to include these important questions in this trial. As such, the trial should be viewed only as a snapshot of the capabilities of both machines in a particular set of conditions. Because the manufacturers were free to make modifications between tests as they saw fit, the results from one test may not be directly comparable to the other tests.

3.2 CWA 15044 – Similarities and Differences

Initially this trial was thought of as a CWA1044 performance trial. It quickly became apparent, however, that the local conditions differed so radically from the standardized conditions of the CWA15044 performance test that data could not reasonably be compared with performance tests conducted under the standardized conditions. The

CWA15044 acceptance test is defined with less rigour, and unlike the performance test, is intended to be tailored to local conditions. The test at IMATC resembled a CWA15044 acceptance test with certain aspects of the performance test included.

3.2.1 Performance Test Similarities

The CWA15044 performance test calls for three depths of burial (0 cm, 10 cm, and an agreed maximum depth, usually 15-20 cm). As shown in Figure 3, the depth is always measured from the ground surface down to the top of the mine, not the top of the fuze. It specifies 50 individual mine targets at each depth of burial, and three fibreboard witness panels to measure the ground profile for each test. It also specifies a generic type of mine target which can provide live-triggered-damaged indications. In all of these areas, this trial complies with CWA 15044.

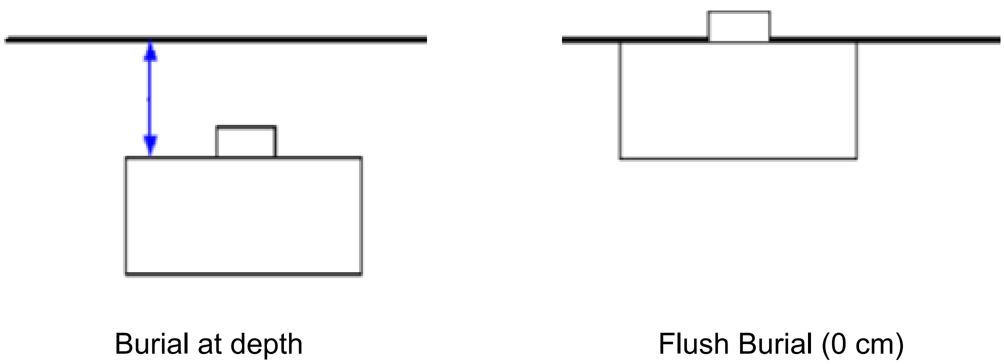


Figure 3. *Depth of Burial (DOB)*

3.2.2 Performance Test Differences

The main area in which the trial differs from the CWA 15044 performance test is in the type of soil and the preparation of the soil. CWA 15044 is very specific about three types of soil which are to be prepared to specific conditions. In this trial, locally available soil was used in the condition available on the day of each test. That is, the soil was not ploughed and compacted to a particular condition for the test. Not only was a single, unprepared soil type used, but the soil was completely unlike any of the standard soils.

Due to the constraints of working in the local soil, and without some of the specialized equipment used at centres like SWEDEC, the mine target holes generally were larger than the narrow holes shown in CWA15044. There was no way to create a narrow slit for the fibreboards, and while the hand-dug trenches were as narrow as possible, they were still too wide. Both of these factors have implications that are discussed below.

In most of the ITEP performance tests conducted to date the soil conditions were measured using a nuclear densitometer. This is generally not practical for field trials in places like IMATC in Kenya, and so the soil was characterized using simple moisture and density measurements as described in Annex A. It had been planned to use a cone penetrometer but this device was held up in customs and could not be obtained in time for the trial. Past experience using the penetrometer suggests that the values would not have been particularly meaningful; it is doubtful that the cone would have actually penetrated more than a few millimetres into the soil.

Finally, this trial also attempted to look at the question of machine effectiveness when using new hammers, worn-out hammers, and no hammers at all. The reason for the first two conditions is reasonably obvious: gauge the performance of the machine with the new hammers, and compare that with the performance of the machine that used the worn out hammers. For this trial, hammers were considered ‘worn out’ when they reached the point where they required replacement, a condition predetermined by the manufacturers themselves. The reason for the third condition, no hammers, is not so clear. It has been reported that some flail users are removing the flail hammers as they are under the impression that the machines somehow work better without hammers. Certainly, machines will run under less load, consume less fuel, cost less in terms of replacement hammers, etc. This test was conceived to look at the difference in ground penetration and mine triggering/neutralizing without the use of hammers.

3.3 Trial Conditions

The weather throughout the trial period was uniformly sunny, hot and dry. While the nights would cool to temperatures in the 10°C -20°C range, afternoon highs were generally in the mid 30°C range. There was no measurable precipitation at the trial site during the course of the trial. Finally, the trial occurred right at the end of the dry season, and so ground conditions were extremely hard and (apparently) dry.

The soil shown in Figure 4 is locally referred to as ‘black-cotton’ soil, which apparently runs about 80 cm deep. In the test area it was exceptionally hard, with deep cracks running randomly through it (Figure 5).

Figure 4. *Black Cotton Soil*

Figure 5. *Cracks in Black Cotton Soil*

3.4 Artificially Worn Flail Hammers

One of the goals of the trial was to attempt to quantify any performance differences that might occur as a result of hammer wear. The intent was to compare performance using new hammers against performance using worn out hammers. In communications before the trial, samples of 'worn-out' hammers were requested from both manufacturers. It was made clear that these would be used as models from which new hammers would be modified by cutting or grinding to match the worn-out samples as closely as possible. It was explicitly acknowledged that the wear induced by cutting or grinding would not be completely realistic, but that it would at least be consistent and uniform across the entire set of hammers used. Both manufacturers complied with this request and supplied samples with no concerns expressed. The samples were measured and templates made (see Figure 6), from which the machine shop could make copies.

Bozena-4 Hammer Template

MV-4 Hammer Template

Figure 6. *Templates for Artificially Worn Hammers*

ITEP purchased two sets of new hammers for each machine, as already noted, and then had one set for each modified at a local Nairobi machine shop. Examples of the machined hammers as compared with the samples provided earlier by the two manufacturers are shown in Figure 7 and Figure 8. Copies will be imperfect, of course; the mushroomed edge on the tail of the MV-4 hammer and the chips on the nose of the Bozena-4 hammer could not reasonably be replicated using this process. Indeed, while the tail on the MV-4 hammer is sharper than the tail on the mushroomed sample MV-4 hammer, the nose of the machined hammer has been shaved off completely, effectively removing any front cutting edge whatsoever. The sample and machined tails on the Bozena-4 hammers are also different. Though imperfect, the artificially worn hammers were at least consistent across their entire sets and, to a reasonable extent, similar to the worn samples provided.

Worn-out Sample Hammer   Artificially Worn Hammer

Figure 7. *Artificially Worn Hammers – MV-4*

Figure 8. *Artificially Worn Hammers – Bozena-4*

3.5 Test Apparatus

3.5.1 WORM

The Canadian WORM (Wirelessly Operated Reproduction Mine) target, shown in Figure 9, was provided for this trial. In each test run, 50 targets were used. While still imperfect, this target has proven useful when testing machines, and appears to compare favourably to the SWEDEC live-fuze-inert-body mine target.

When triggered, the WORM targets send a brief radio signal that is captured by a receiver attached to an ordinary computer, which then logs those targets triggered by the machine. It is necessary to inspect any targets which fail to register as triggered. These may be classified as live, mechanically neutralized, or live-damaged as described in CWA15044. Annex B contains a brief description of the WORM targets. Technical details of the WORM targets, including schematics, parts lists, sources of supply, software, and instructions for assembly and use are available from the Canadian Centre for Mine Action Technologies.

Figure 9. *WORM Targets, Receiver and Antenna*

3.5.2 Fibreboards

As specified in the CEN Workshop Agreement, fibreboards were installed in three places along the first set of test lanes (Figure 10). Buried flush with the surface, the boards are intended to act as witness panels to record the depth of penetration of the flail hammers. Initially the trenches were dug by hand. In an attempt to dig the trenches by machine the DOK-ING team removed all but one hammer from the MV-4. This created a trench much more quickly, but both the hand-dug trench and the machine-dug trench were too wide, and the fibreboards did not give a clear, accurate view of the digging, or cutting pattern of the machine. This was obvious when the loose soil was removed after the first test, as shown in Figure 11. For all following tests, the ground profile was measured (Figure 12) at four locations along each test lane.

Figure 10. *Fibreboard Installation*

Figure 11. *Uneven Profile Not Shown By Fibreboards*

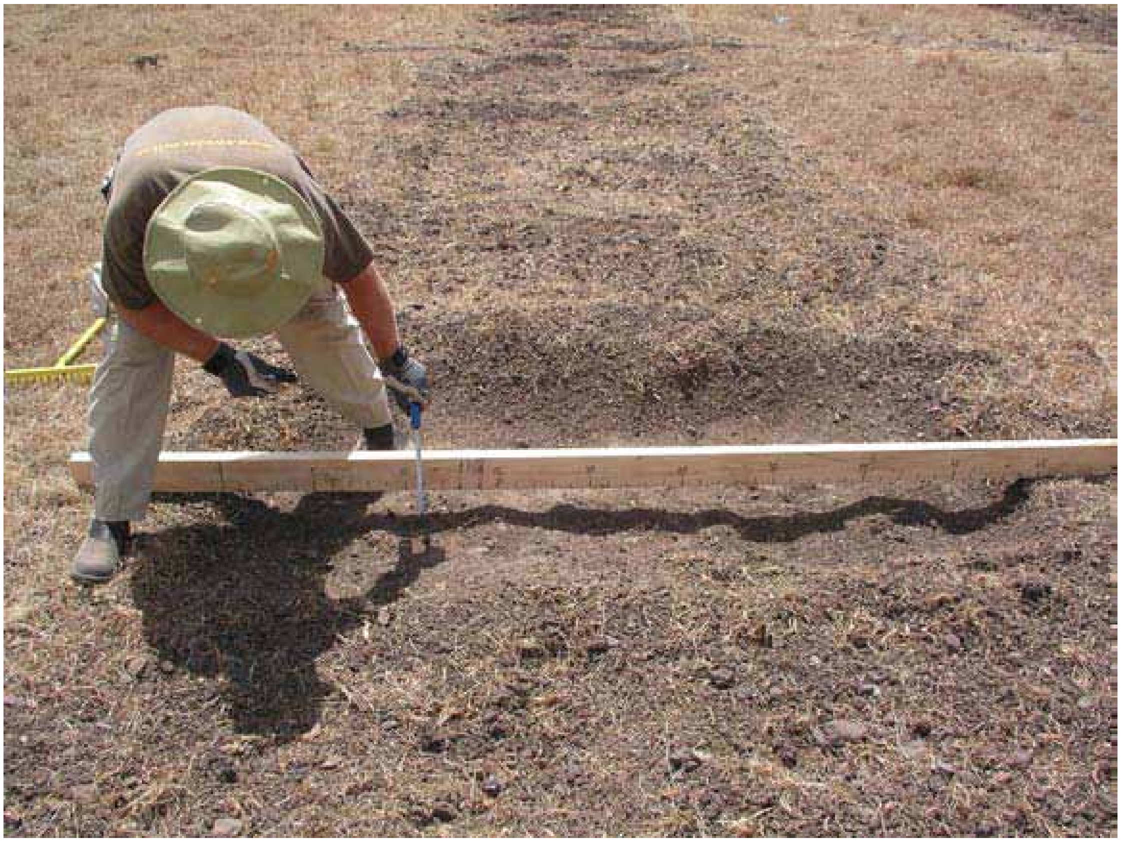


Figure 12. *Modified Profile Measurement Technique*

3.6 Mine Targets v. Ground Profile

There was a curious disconnect between the number of test mines triggered and the apparent ability to penetrate the soil. That is, both machines registered a very high percentage of ‘kills’ on the mine targets while at the same time doing a remarkably poor job of penetrating consistently and uniformly to the depth necessary to engage those same mine targets.

In creating an artificially laid mine-lane for testing, holes are dug into which mine targets are placed, and soil is then poured in on top of the mines to cover them. Ideally the loose soil will be allowed to compact and coalesce with the surrounding undisturbed soil over the course of several years to replicate real minefield conditions. This is not practical for most machine tests, and no practical way of quickly aging the loose soil has been discovered. Hence, for such trials, the soil on top of the mines is very soft, especially in comparison to the surrounding black cotton soil in these tests.

To illustrate the problem, consider the imaginary example, shown in Figure 13, in which mines have been encased in a large block of concrete. At one spot, a mine has been placed in a hole in the concrete, which has been backfilled with a layer of soft leaves. In the first panel of Figure 13, a single flail hammer approaches the hard concrete surface. When it hits the surface, it bounces as shown in the second panel, perhaps chipping the surface, and is pulled around for another strike. With the very hard surface, the hammers have limited surface penetration, and the effectiveness against the mines is minimal. In panel 3 the hammer has reached the soft, leaf-filled hole. Of course it plunges deep into the hole, and triggers or breaks the mine. If the hole is very deep or very narrow, it is more difficult for the hammer to reach the mine, but it is a very easy target if the hole is relatively large and shallow. Finally, in the fourth panel, the hammer has moved on and is prepared to resume the chip-and-bounce process as it hits the hard surface again. Very clearly, the results with the mine in the soft hole are not representative of what the machine is doing to the mines under the hard surface.

While the mines were not encased in concrete in the test lanes, this example is actually reasonably close to the situation encountered in this trial. Consider the image in Figure 14. It is quite obvious that the flail hammers have achieved inconsistent and only relatively shallow penetration in the hard surface. Figure 15 demonstrates that at least some of the apparently deeper hammer penetration is due to the mine burial holes themselves. The deepest part of this particular profile still has the remains of the sand used to fill the hole. It was not possible to determine whether all of the deepest penetrations were due to the mine burial holes.

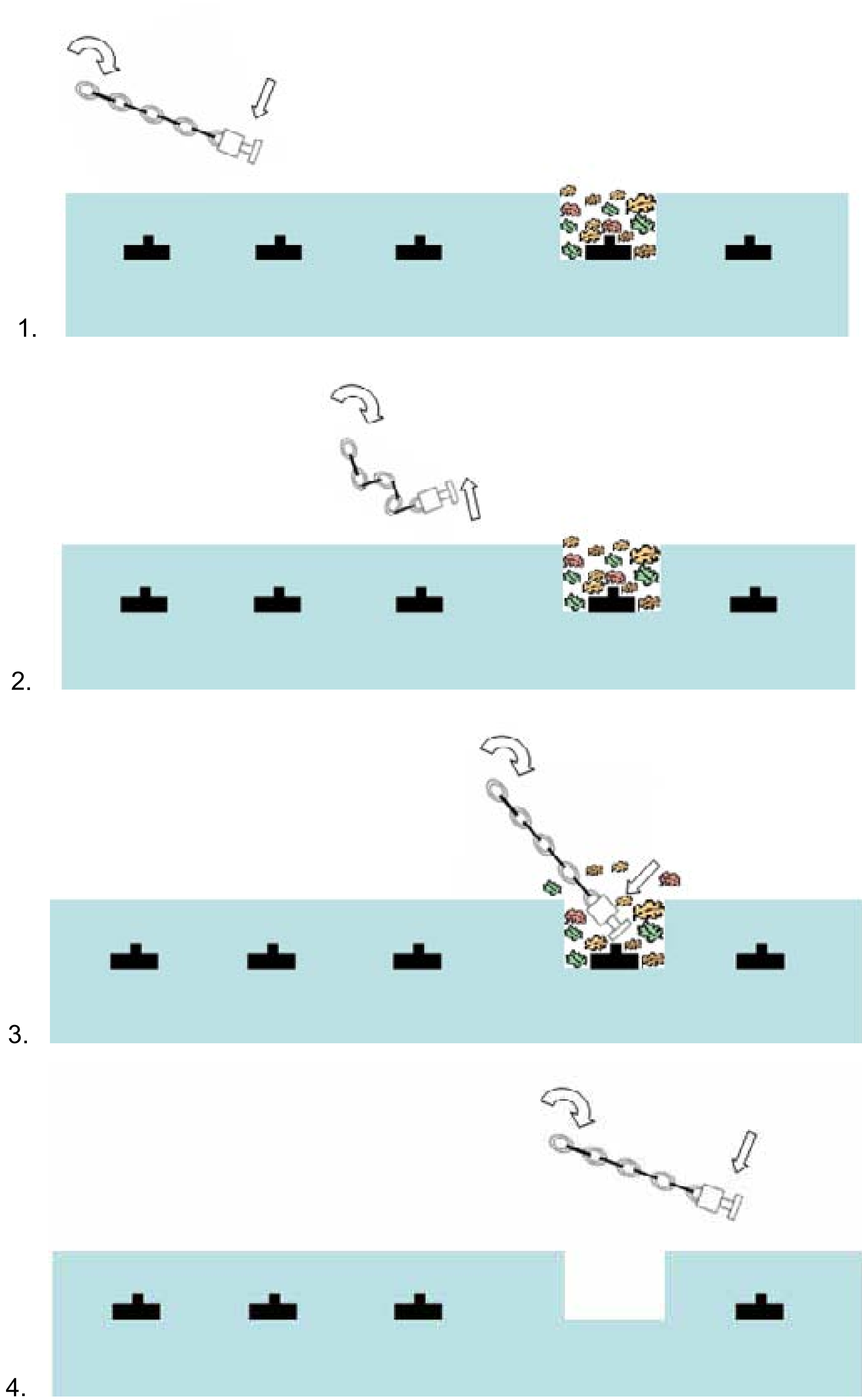


Figure 13. *Hammer Strikes on Hard Surface - Example*

Figure 14. *Poor hammer penetration in hard surface*

Figure 15. *Deep Hammer Penetration in Soft Holes*

While the example of Figure 13 is admittedly extreme and unrealistic, the photographs shown in Figure 14 and Figure 15 demonstrate that the example actually tells the story in an accurate way for the real-world situation encountered in this trial.

From this, one might wonder why all of the mines in the soft soil are not triggered. There are several reasons for this. First, if the machine is moving forward too fast, or if the rotation is too slow, the next hammer strike could be too far forward and could interact with the far wall of the hole before engaging the middle of the hole where the mine is. It is also unlikely that successive hammer strikes will occur exactly in line with the ones before. Some will strike slightly to the left and some slightly to the right, both encountering the surrounding hard soil. By the time another hammer strikes right in line with the first, the machine could have moved too far ahead and the hammers would have effectively passed the hole. As noted above, very narrow or very deep holes make it more difficult for the hammers to reach the mines.

This discussion applies whether one is using the WORM targets, real mines, the SWEDEC live-fuze targets, or any other mine or mine simulator; the problem is not the mine target itself, but rather the hole needed to bury the target.

One might reasonably ask whether all trials conducted in which the mines are placed in holes which are soft, relative to the surrounding soil, are therefore suspect. The answer is that it will depend on the capability of the machine and how hard the surrounding soil is. If the soil is hard enough that the machine cannot reliably cut to the depth necessary to engage the mines, then yes, the data at that depth of burial might be suspect if it shows an apparently good rate of kill. On the other hand, if the machine is able to penetrate the surrounding soil, then one can conclude that the machine is actually engaging the mines and the mine target data is valid.

This all means that when the surrounding soil is extremely hard, and the mines are covered with soft soil in oversized holes (as was the case for these tests), they will be prone to give artificially high performance indications. It is critically important to evaluate the ground profile to see whether the machine is indeed penetrating uniformly, and to the necessary depth. If the profile is smooth and shows a consistent ability to dig to a given depth, then the data from the mine targets is probably realistic. If the ground profile is uneven, it suggests that the soft holes are compromising the mine target data. In this case, the ground profile provides the more valid measurement of performance.

The ITEP team had concerns about the validity of the mine target data after the first test but had not managed to completely work out the problem and the implications until several tests were done. For continuity, and because a final decision had not been reached, the use of the target mines was continued throughout the trial.

3.7 Ground Profiles – What Do They Mean?

If the profile measurements are to be of significant value, there must be some way of quantifying the information and applying it to the needs of demining operations. Particular concerns to be addressed include

- Whether the profiles should be measured across the entire width of the path or, like the mine targets, only in the centre 50% of the path;

- Whether the data should be analyzed focusing on maximum depth, minimum depth, average depth, or some other measurement; and

- How the information can be presented in a way that is both meaningful and easy to understand.

Annex C discusses these issues and develops the rationale behind the use of two measures of depth. The first, '**maximum effective depth**' is defined as the minimum depth at which mines can be hidden in the remaining soil. In other words, if a machine processed some of the ground to 10 cm or deeper but left areas processed to only 6 cm deep, the maximum effective depth would be 6 cm. From the deminer's perspective, this is perhaps one of the most useful measures of performance as it allows the deminer to have some confidence in the results down to that depth.

The second measure of depth is referred to as '**penetration efficiency**', and refers to how much of the processed path would actually have allowed the machine to engage mine targets at a given depth. Hence, if a profile showed that 20 cm depth had been reached across a total of 80% of the width of that profile, the penetration efficiency for 20 cm would be given as PE_{20}=80%. With the basic profile measurement data the penetration efficiency at any other depth could easily be determined.

The results section that follows uses these two measures to quantify machine performance based on depth of ground penetration. Neither of these is an industry-wide standard, nor is either one yet included in CWA15044. It is likely that both will benefit from some refinement. Indeed, better ways of quantifying the information in the depth profiles may well be developed.

3.8 Trial Commentary

As mentioned, this trial was unusual in a number of ways. One of the most obvious is that it was intended to be a parallel demonstration of machines from different manufacturers. This led to problems never before encountered in ITEP mechanical equipment trials, but which, in hindsight, probably should have been anticipated.

With any trial of mechanical equipment for demining, unexpected events often occur. Sometimes there are problems with the test equipment. Sometimes there are problems with the layout or conduct of a test. Sometimes there are problems with the interpretation of the data obtained in the test. When a trial is held outside of the normal environment, in conditions which do not meet the standards that are usually applied, these and other problems can be more significant, and flexibility in modifying the tests is required if any tests are to be done at all.

In the case of this trial, the original intent was to perform a demonstration with a partial CWA15044 performance test on the two machines, but under local soil conditions. In doing so, the standard for soil types was compromised, the standards for soil moisture and density were compromised, and the standards for mine target and fibreboard installation were compromised. The trial team had to make a decision whether to modify the tests and proceed as well as possible or to simply cancel the entire event because things are not precisely according to specification. Given that the event was not a full CWA15044 performance test, it was felt that there was still merit in attempting to conduct more of a CWA15044 acceptance test, which is supposed to emphasize local conditions. The standards around an acceptance test are defined much more loosely and would permit the kind of flexibility needed to continue with a trial. Unfortunately, many of the elements of the CWA15044 performance trial that were included in the test plans (notably the use of mine targets), were not compatible with the local environmental conditions and did not produce valid data. This incompatibility was not fully realized until near the end of the trial, and the process of trying to adapt and modify caused some friction and misunderstandings between the ITEP team and the manufacturers' representatives.

Given that the manufacturer representatives could, and ultimately, did, view this as a competition, almost anything that did not correspond exactly to the CWA15044 definitions, previous experience, or even personal expectations, was raised as some kind of objection.

In retrospect, the trial should probably have been tightly controlled with restricted access to the test site and data, segregation of the teams during tests, and a more rigidly defined set of parameters to which the teams had to adhere or risk disqualification, despite the fact that this would have effectively defined it as a competition. The 'kinder, gentler' approach taken by the ITEP team simply resulted in complaints, accusations of favouritism, and disputes about every possible part of the test right down to which team got to go first on a given day. Hopefully both manufacturers obtained useful information to improve the use of their products. Certainly ITEP learned a few lessons.

3.8.1 Selection of Lane and Order of Testing

Prior to the first test, the Bozena-4 team was asked which lane they wanted to use. The MV-4 team was then given the option of running either first or second. After the test, the teams expressed dissatisfaction with the fairness of the process used for choosing lanes and run order. While it is unclear how anyone could possibly get an advantage or disadvantage from such choices, it was decided that the system would be reversed for the second test (The MV-4 team would choose the lane and the Bozena-4 team would choose whether to run first or second). In all subsequent runs, both choices were made randomly by the flip of a coin.

3.8.2 Cleanup of Target Debris

To avoid any perception of tampering with the data, the manufacturers were asked not to be involved in picking up the pieces of the test targets after their own machines. After the first test, one of the manufacturer personnel was observed to be assisting in the cleanup. It was firmly believed by everyone involved that there was no intent to tamper with the data, but due to the possibility that there could be a perception of wrongdoing, it was decided to ask both manufacturer teams to refrain from picking up after either machine. This request was respected by all participants.

3.8.3 Speed Control

As noted, the manufacturers were asked to 'tune' their machine to obtain their best results in these tests. This included setting the forward speed of the machine. The manufacturers were then asked to select a speed to use for the first test and then to stick to that constant speed for the entire test lane. Then, if desired, different speeds could be selected for subsequent lanes.

In the first test lane the Bozena-4 appeared to maintain a constant speed over the entire run, while the MV-4 speed varied quite significantly. A complaint was immediately raised by the Bozena-4 team over this issue. The average speed of the MV-4 was approximately twice that of the Bozena-4, but it actually stopped completely on at least one occasion when the flail arms dug in, preventing forward movement. While the occasional slowdown might have helped the performance in those few locations, the higher overall speed would actually have worked against the MV-4 performance along most of the test lane; faster forward speed results in shallower flail penetration.

The soil profiles taken for this test run demonstrate this clearly. In one profile there was a very deep penetration which may have been due to a slowdown; more likely, given that it is only on one side of the path, this penetration was probably due to encountering a large crack in the soil or a spot where a mine target was in an oversized hole.

While the inconsistent speed could not have given an advantage to the MV-4, it was agreed that the request for constant speed had not been met. It was also decided that there was no practical way to police such a requirement, and that, for all subsequent tests, both manufacturers would have complete freedom about what speeds they used without any restriction regarding consistency of speed. This could include an extremely slow stop-start pattern that would allow a machine to sit in one location for as long as desired. This could have a big, negative impact on the 'rate of clearance' but it was also recognized that under extremely difficult ground conditions, this might be an entirely acceptable machine operation technique.

The ITEP team realized that this would compromise the ability to compare test runs, but without a reliable method of enforcing a consistent speed requirement, there was no other choice.

3.8.4 Depth Control

There had been no restriction on what the two manufacturers could do with respect to depth control of the machines. In the first test the Bozena-4 team stayed with their normal skid-controlled depth system, although it was operated under remote control rather than using the available 'float' mode. In contrast, the DOK-ING team removed their depth control wheels and operated under manual control, often having the flail head so low to the ground that the flail rotor could well have been touching the ground.

The Bozena-4 team suggested that the MV-4 technique would not be practical under normal demining operations as it could risk significantly more damage to the shaft and chain attachment points when mines were encountered. While this might or might not be so, there had been no instruction about how depth control was to be achieved. Indeed, it had been made clear to both manufacturers that they could set up or tune their machines to deal best with the environmental conditions.

It was simply decided to reinforce to both manufacturers that they were completely free to deal with depth control in any way they liked.

3.8.5 Errors in Lane Layout

The test lane layout in CWA15044 specifies that the mine targets must be located within the centre 50% of the working width of the flail. This is done for two main reasons which are discussed in detail in Annex C – to allow for overlap of successive passes in real world operation, and to eliminate driver error influencing the measurement of machine performance.

Due to a measuring error, at least one of the targets in the first MV-4 test lane was placed outside of that centre 50% area. In fact, this target was in the shoulder or edge region of the cut width and had only been partially engaged by the machine. It was decided by the entire ITEP team that it would be inaccurate to characterize this target as missed, when it was outside of the CWA15044-specified centre 50% area; indeed it was in the very place that the centre 50% area was created to avoid. Therefore, this target was neither counted for or against the machine performance; it was removed completely from the data set for not being within the specified area. The Bozena-4 team protested the decision and suggested that the ITEP team was not impartial.

The ultimate conclusion was that the ITEP team decided to maintain its position and remove the data point from consideration, but to identify the situation with a discussion in the final report. In addition, the remaining lanes were checked to ensure that the target locations all fell within the CWA15044-specified centre 50% area.

Ironically, the mine target data for this test and for all but the final test were deemed invalid, and have been excluded completely, as described in Sections 3.6 and 4.1.

3.8.6 Hammer Replacements and Worn Hammers

After the initial test, the MV-4 hammers displayed a significant amount of wear, especially when compared with the Bozena-4 hammers. In preparation for the second test the MV-4 team installed new hammers on their machine. The Bozena-4 team objected that, in their view, both machines were to use only the set of hammers procured by ITEP for all of the ‘new hammer’ tests. This topic is covered in more detail in Section 4.5.1.

The Bozena-4 team also raised an objection regarding the realism of the ‘worn hammer’ test and demanded a complete retest in accordance with a procedure they provided. This objection was only raised after the test, and the ITEP team rejected the demand as discussed in Section 4.5.2 and Annex D.

3.8.7 Evaluation of Mine Targets

The process used by ITEP for using mine targets in mechanical equipment tests has always been to count the number of triggered mines and then to evaluate the debris to determine the state of all of the targets including those recorded as triggered, where possible. This is the process when using the SWEDEC targets which have live fuzes which can normally be heard to detonate when triggered, and it is the process when using the WORM targets which will normally be recorded on a computer when triggered. Specific to the WORM targets, there can be occasions where there are problems with the electronic systems, and the targets must all be manually inspected. In most previous trials, the inspections have been done in full view of all trial participants.

In any case there may be a few situations in which some targets cannot be found or cannot be evaluated with complete confidence. In these cases the test team must decide how to handle those data points. If there are enough problem targets in a given run, a decision might be taken to do a retest. There is no defined number of targets at which a retest is required, so the team must make a judgement call.

After the first test in this trial series, the targets were inspected, as usual, in full view of everyone. At a meeting the following morning to address several issues raised by the Bozena-4 team, the Bozena-4 team leader requested that the targets be inspected privately by the ITEP team. As discussed in Annex D, they requested a viewing of the targets and data immediately after the next test (which was granted), and subsequently implied in a letter that the ITEP team was not operating in a transparent manner and was somehow restricting access to the test setup. This suggestion of wrongdoing was completely rejected by the ITEP team and is dealt with in detail in Annex D.

4. Test Results

4.1 WORM Mine Target Results

Statistical mine-kill data for both machines is available in reports at the ITEP website. Normally this type of data is collected in CWA15044 performance tests, which is then supplemented by other types of data obtained in acceptance tests. Given that this trial of the two machines at IMATC is not a proper CWA15044 performance test, one might well argue that it was a mistake to attempt to bring the 50-target-3-depth character of the performance tests into this trial. Whether or not this is true, the ITEP team is determined not to compound the error by publishing information which it believes to be flawed, as described above in 3.6.

In the unanimous opinion of the ITEP team, the tabulated values of mine targets triggered, damaged or left live significantly overestimate the capabilities of the machines under all but one of these test conditions. Stated another way, the ITEP team believes that most of the mine target data is inaccurate and misleading. If these results are misunderstood, misrepresented, misinterpreted or taken out of context they may easily lead to the belief that one or both of the machines is capable of triggering a certain percentage of mines to the depths the mines were laid in these tests. The ITEP team believes that there could be serious safety issues resulting from mistakenly trusting this data. The ITEP team has taken the position that the ethical and professional decision is to refrain from publishing data believed to be misleading and possibly dangerous. Hence, except for the one test shown below, the statistical data from the mine targets is not included in this report. For both machines, the ground profiles produced in this trial suggest the level of performance that should be regarded as valid.

4.1.1 Surface-Flush Mine Burial (0 cm DOB) Test

This one test is believed to contain mine target data that is reliable. The imaginary example in Figure 13 corresponds to a situation where all of the mines are buried with their top surfaces and fuzes at the surface of the concrete block, and accessible to every hammer strike. In this case, there are no soft holes to cause problems with the data.

The final of 5 tests conducted during this trial used surface-flush mine burial. In this test both machines used their mechanical depth control systems (skids for the Bozena-4 and roller wheels for the MV-4), and travelled at what appeared to be relatively normal forward speeds, especially when one is confident that the mines are at or very near the surface. Figure 16 and Figure 17 show the two machines in their configurations for this test. Figure 18 shows representative samples of the hammers from each machine prior to the test runs.

Figure 16. *0 cm DOB Test Run – Bozena-4*

Figure 17. *0 cm DOB Test Run – MV-4*

Bozena-4 Hammers MV-4 Hammers

Figure 18. *Condition of Hammers Before 0 cm DOB Test*

Figure 19 shows the condition of both test lanes immediately after the runs, with the Bozena-4 having used the lane on the left and the MV-4 the lane on the right. From a macro point of view, both lanes appeared very much alike. In both cases there were many pieces of debris at the surface (which is not surprising given that the mines were visible to begin with), and the soil surface had been broken and mixed with the grassy vegetation.

The more important examination of the test lanes – the evaluation of the ground profile − is discussed in Section 4.3.

Figure 19. *Test Lane After Bozena-4 (Left) and MV-4 (Right) in 0 cm DOB Test Run*

Table 1 shows the condition of the mine targets following this test. It also shows the linear speeds of the machines based on the time over a measured 25m distance during the test. The raw data, shown in Annex E, indicates that two of the 50 targets in the Bozena-4 lane could not be evaluated with complete confidence by the ITEP team; these two targets could not be definitively said to fit into any of the four categories, and were therefore removed from the data set. Hence, the Bozena-4 data set is listed for 48 targets and the MV-4 for 50 targets.

Table 1. *Mine Targets Conditions After Processing – 0 cm Depth of Burial*

Hammers/ DOB	***Live***	***Live-Damaged***	***Mech. Neutralized***	***Triggered***	***Speed (m/h)***
Bozena-4	0/48	1/48	11/48	36/48	300
MV-4	0/50	2/50	8/50	40/50	692

The data can be presented in a useful, statistical manner as shown in Figure 20. Since the Bozena-4 test uses 48 samples, and the MV-4 uses 50 samples, the two machines are shown with separate curves; the Bozena-4 data is shown in green, dashed lines while the MV-4 is shown in red, solid lines. These curves combine the triggered and mechanically neutralized targets for each machine, nominally 48/50, or 96% for the MV-4 and 47/48, or 97.9% for the Bozena-4. Remembering that a test using a finite number of samples is only an estimate of the actual performance capability of a machine:

The important thing to take from Figure 20 is that

- you can be 95% confident that the 'actual' performance capability of the MV-4 lies between 86% and 99.5%; and

- you can be 95% confident that the 'actual' performance capability of the Bozena-4 lies between 89% and 99.9%.

The overlap in the ranges indicates that there is no real difference between the two machines based on this set of performance numbers.

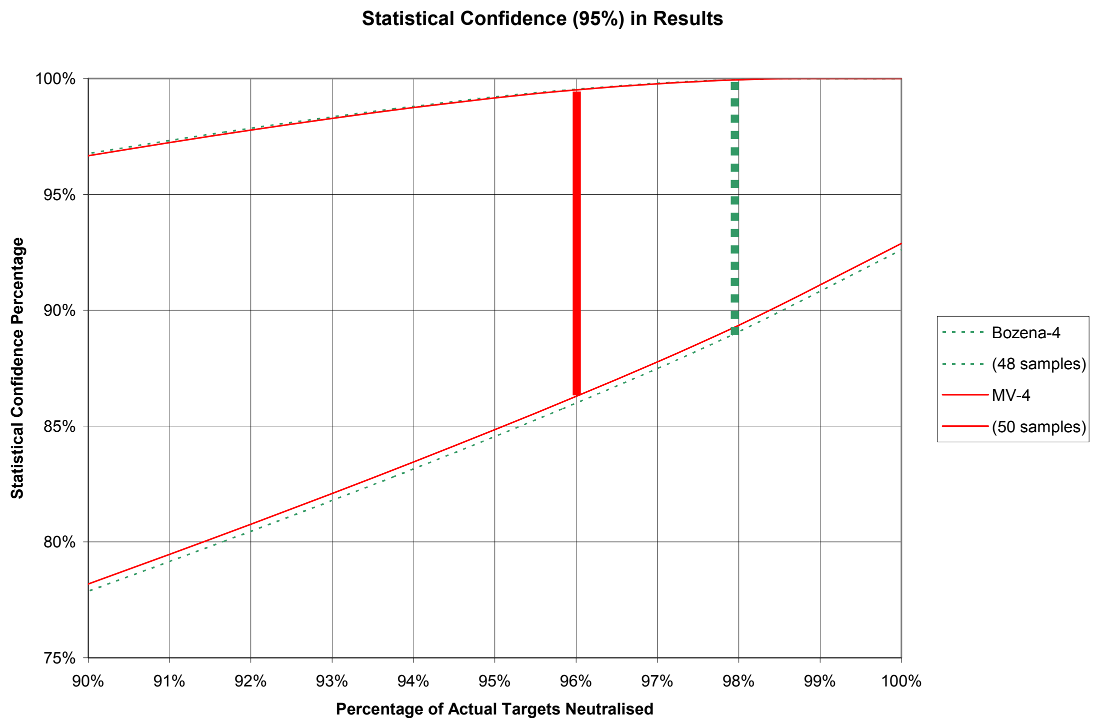


Figure 20. *Statistical Presentation of WORM Data for 0 cm DOB Test*

The curves for 48 and 50 data points in Figure 20 shows that there is very little difference between the size of these two samples, so it is reasonable, if not strictly accurate to use Figure 21, even though it is only properly used for sample sets of 50 data points for both machines. With the nominal data

(48/50 and 47/48) drawn on this chart, the lines interest above the blue diagonal indicating that there is no statistical difference between the data sets. If the intersection of the two lines were very close to the blue diagonal, there might be some debate over the suitability of Figure 21 for this comparison.

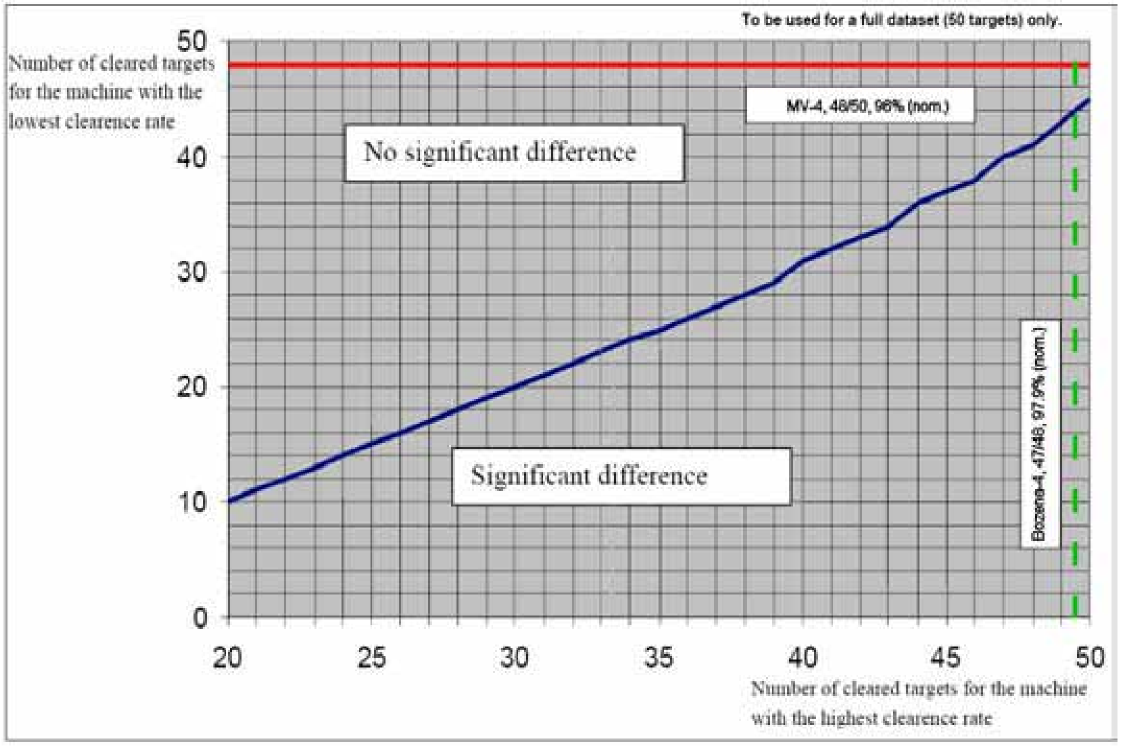


Figure 21. *Statistical Comparison of Machines for 0 cm DOB Test*

The one difference that does show in Table 1 is that the speed of the MV-4 was approximately double that of the Bozena-4. It is indeed possible that either or both machines could have been operated at faster speeds without compromising performance, especially at this shallow mine depth. Unfortunately, it was well beyond the scope of this test to determine the maximum speed at which this performance could be achieved; it could have taken more than a week conduct just that one test.

In other words, based on these tests, the performance of the two machines is virtually identical when considering the number of mines successfully engaged at 0 cm depth of burial. It is not realistic to select one of these machines over the other based on this mine target data. As discussed above, the data for the deeper burial depths is not considered valid.

4.1.2 Surface Debris in 0 cm DOB Test

After each run the test lanes were combed for any debris that was visible at the surface. Broken or obviously destroyed mine pieces were simply collected, while targets that were basically intact or which might be partially or fully functional were collected and listed for later analysis. The reason behind this was that, if hazardous material were left behind, it would be preferred that this material be visible, and at the surface where secondary clearance operations could find it easily. After collecting this debris, the pieces could be evaluated to determine which hazardous pieces, if any, were at the surface and which were buried. Figure 22 shows a typical example of the scatter of debris on the surface after a test run. This image is typical for all runs and for both machines.

Figure 22. *Surface Scatter of Mine Target Debris*

The final test (0 cm DOB) is the only test in which the mine target data is considered valid. In this test the MV-4 left two targets in a potentially hazardous condition (live-damaged). One of these was visible, on the surface, within the path of the machine while the other was visible, on the surface, but outside of the path of the machine (a ‘throw-out’). In the case of the Bozena-4 lane, one target was left in a live-damaged state which was also visible and on the surface, but outside of the path of the machine (a ‘throw-out’).

As noted, if potentially hazardous pieces are left behind it is highly desirable that they be at the surface and easily found by secondary clearance methods. In this test, all such pieces were left on the surface and visible. Given that the targets started out visible at the surface before the tests, this is really not a remarkable achievement. The fact that two of the three were outside of the path of the machine should not be a surprise given that flails, by their nature, tend to throw debris, and that there is a random element to the distance and direction.

4.1.3 Surface Debris – All Tests

One other aspect of debris scatter should be mentioned. As stated, flails throw debris. This debris may be thrown forward and reprocessed as the machine proceeds, it may be thrown to the side into previously worked or as-yet untouched areas, or it may be thrown forward beyond the spot where the machine stops, either contaminating previously worked or untouched areas. To a degree this is a statement of the obvious, but the amount of scatter and the direction of scatter may be significant, and may also be significantly different between machines.

A very few flails use a shroud that almost completely covers the flail head to trap debris and prevent throw-outs or scatter of mines and mine pieces. Few such machines are actually seen in practice for a variety of reasons. Some flails use a shroud behind the flail head which is basically a vertical shield between the flail and the machine. Others, including both the Bozena-4 and the MV-4, use a curved shroud which arches part way over the flail head. The vertical plates can let debris (soil, stones, mines, mine fragments, etc) fly in almost any direction except straight back; a significant portion of the debris can, and often does, still end up being thrown up and back, often landing on or around the vehicle. Flails with a curved shroud, like the two in this test, tend to deflect the debris forward. A small amount can still escape to the rear and sides but most is forced forward.

Common to both the straight and curved shrouds, however, is that material thrown forward does not necessarily go straight forward. Debris can be thrown forward in an arc that has the potential to extend almost 90º to either side depending on how a particular hammer hits a mine, rock, soil clod, etc. One need only shank a golf ball to realize how material can be sent in a random direction. By using a curved shroud, this effect can be reduced but not completely eliminated.

In these tests both machines threw soil and mine debris ahead and to the sides by distances ranging from a few centimetres to more than 25 metres. In almost all cases the mine debris was from targets which had been triggered or mechanically neutralized. The target thrown 25m beyond the end of the lane (almost 28m from its original location) had been triggered but was physically intact. While there is the possibility that a live, fully functional mine could be 'golfed' into an adjacent area, these tests did not show any examples of this. There was, however, ample evidence that the possibility existed that broken fragments of mechanically neutralized targets could be thrown into adjacent areas. Such debris would be either right at the surface or covered by a very thin layer of dust/soil. In any case, it should be easily detected by secondary clearance methods. Again, this is a function of the nature of flails, and is not a reflection on the performance of these two machines in particular.

4.2 Soil Characteristics

As noted, CWA15044 requires certain soil characteristics for performance tests. There is no similar requirement for the acceptance test, but it makes good sense to characterize the soil conditions used in the trials.

The density and moisture content of the soil in the test area was measured in accordance with the procedure outlined in Annex A. The data is tabulated in Annex E and is summarized in Figure 23 and Figure 24.

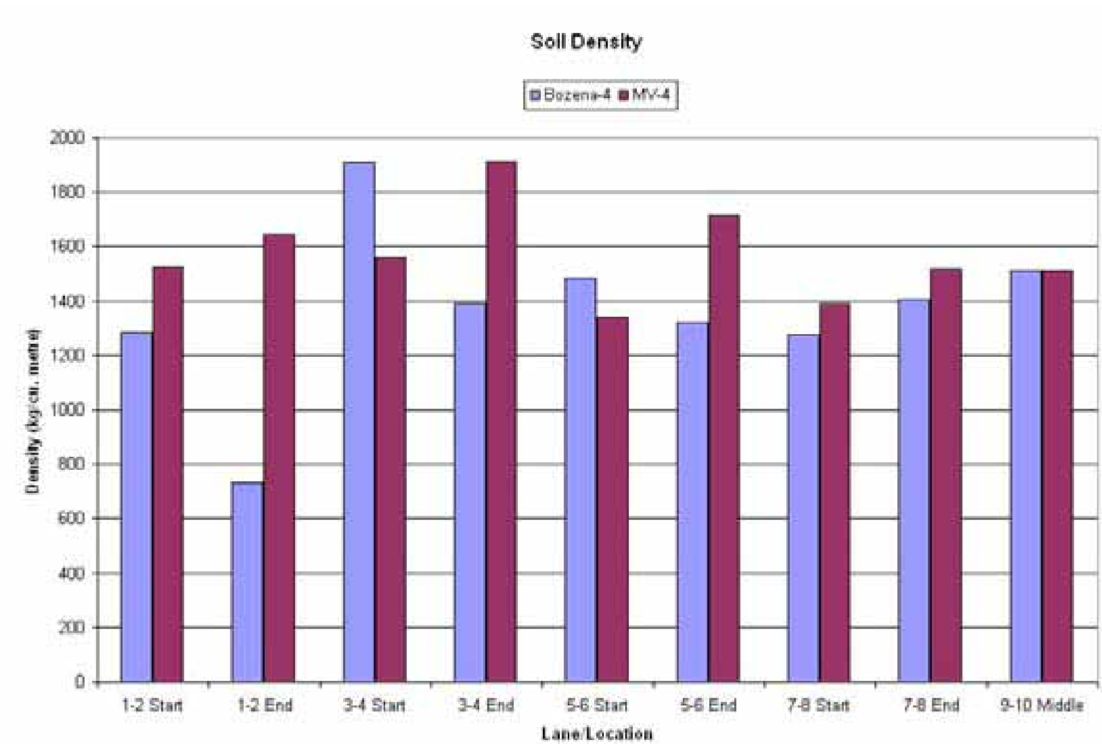


Figure 23. *Soil Density in Test Area*

Figure 23 shows the soil densities for each of the tests. In each test except the final one on 12 October, one sample was taken near the start of each test lane, and one near the end (two for each machine). To facilitate the timing of the test runs, some of the samples were taken before the test runs and some just after, but in all cases they were taken within an hour of the run. Samples taken before the runs could have been taken directly in the path of the machine, but samples taken after the run would have had to be taken outside of the disturbed soil in the machine path. Hence, all were taken approximately 30 cm outside of the area processed by the machine. In the test on 12 October, only a single sample was taken. That sample was approximately midway between the two test lanes, and about half way along the length of the lanes. In all cases the samples were taken in a pseudo-random location. That is, they were taken at a consistent distance outside of the machine path and near the start or end of the runs, but no effort was made to select a spot that was particularly hard or soft, or free from vegetation, etc.

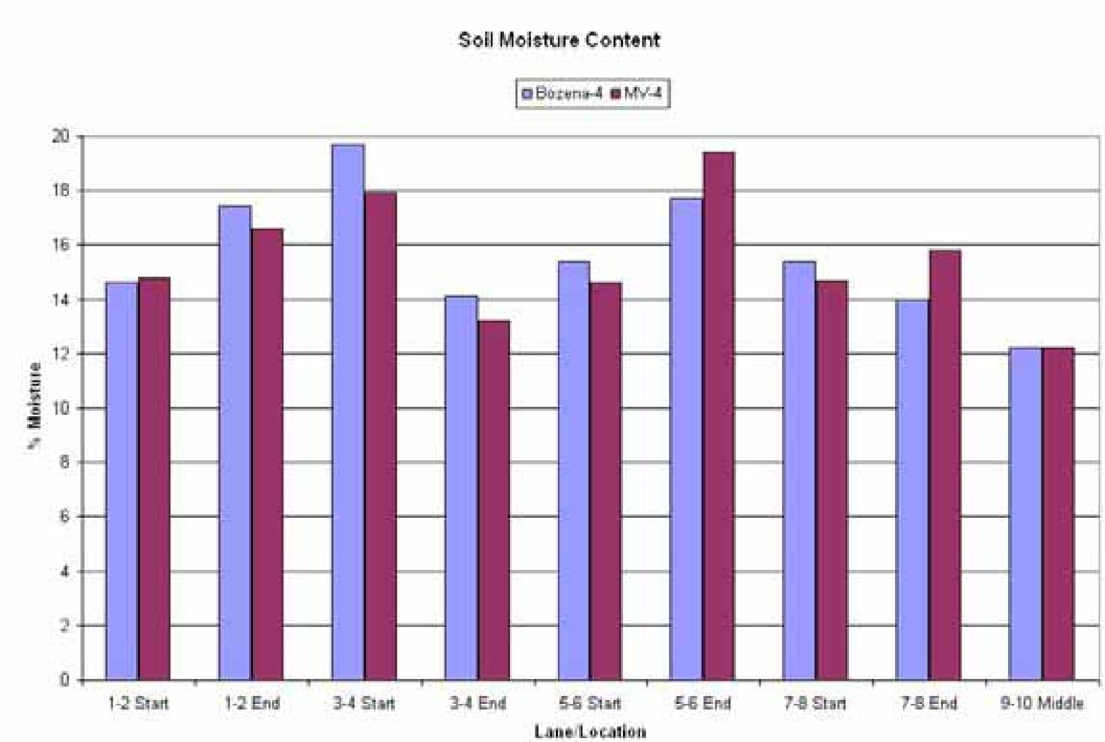


Figure 24. *Soil Moisture Content in Test Area*

The samples show some variation that is consistent with the cracked nature of the black cotton soil. Some of the samples are bound to be lower density if they were taken close to a crack. Similarly there are a few samples that are slightly higher than average. With a few anomalies, most of the density values compare well between the lanes for the two machines. For example, the samples taken at the start of lanes 6 and 7 are very similar to each other. The overall average density of all of these samples is just over 1450kg/m^3.

Looking at the soil moisture content values in Figure 24, all of the tests compare very closely between the lanes for the two machines with the values ranging overall between about 12% and 19% moisture.

One other soil sample of similar size was taken to examine the range of soil moisture contents. This sample was split into two parts to examine (i) soil from the top 3 cm, and (ii) soil from 3-7 cm. In this test the upper layer was found to have a moisture content of 10.5% compared with the deeper sample value of 19.2%. It is not at all surprising that the surface layer would have a lower moisture content considering the hot, dry conditions at the time. The entire sample, taken as a whole, had a moisture content of about 15.5% which is consistent with the rest of the samples taken during this trial.

Soils in the machine test lanes at the ITEP test facilities are generally quite soft and wet at moisture contents such as these, and so the ITEP team had to consider whether errors had been made in sampling, measuring or calculating. No errors could be found but the local descriptions of the soil itself provided a clue. The online version of the Encyclopaedia Britannica [1] defines a vertisol as "one of the 30 soil groups in the classification system of the Food and Agriculture Organization (FAO). Vertisols are characterized by a clay-size-particle content of 30 percent or more by mass in all horizons (layers) of the upper half-metre of the soil profile, by cracks at least 1 cm (0.4 inch) wide extending downward from the land surface, and by evidence of strong vertical mixing of the soil particles over many periods of wetting and drying." According to the internet-based Wikipedia [3], vertisols are dominant in southern Sudan. This area at IMATC was selected specifically because the soil was said to be similar to southern Sudan. Intriguingly, the vertisols entry in Wikipedia is linked directly to the term "Black Cotton Soils." The Wikipedia entry cites similar information at the United States Department of Agriculture [4], the University of Florida [5] and the University of Idaho [6]. While one must be careful about applying too much confidence to information on Wikipedia, the supporting evidence from these other credible sources suggest that the soil in these ITEP tests is very likely a vertisol.

In "Soil moisture related properties of Vertisols in the Ethiopian highlands" by Kamara and Haque [7], soil moisture levels in the 14% range would be hard and dry, exactly like the samples in these trials. While it is not certain that the Vertisols in the Kamara and Haque paper are exactly the same as the 'black cotton' soil in these tests, the characteristics of vertisols described in this document by the Food and Agriculture Organization of the United Nations and in the other references appear to be very similar to the black cotton soil in these ITEP tests. Even if the soils are not identical, there are enough parallels that the characteristics measured during the trials can be considered realistic. This suggests that the moisture content values obtained during the ITEP tests are reasonable and realistic. The plots of moisture content against density in the Kamara and Haque paper also suggest that the spread of density and moisture content data in the ITEP tests is reasonable.

As mentioned, the team had planned to measure soil surface conditions with a cone penetrometer but was unable to do so due to the penetrometer being unavailable for the tests. Based on previous tests where the cone penetrometer was used, it is considered likely that those results might not have been particularly meaningful in the extremely hard soil conditions at the test site. In his paper "Physical Properties of Ethiopian

Vertisols," Woldeab[8] states "when dry, Vertisols are hard and impossible to plough with oxen-drawn implements and may even be difficult to cultivate with heavy machinery." This is certainly consistent with the subjective descriptions of the soil given by the Kenyan personnel at the site, and helps explain the difficulty that both machines had in penetrating the soil (see Section 4.3).

4.3 Ground profiles

As discussed in Section 3.6, the ITEP team is of the opinion that measurement of the ground profile is of far greater value than the measurement of mine target neutralization in these test conditions. In this section the ground profiles are presented for each of the runs of each machine, in the order that the tests were conducted. Because the manufacturers were given complete freedom about how to set up their machines for all but the first test, the conditions for the tests vary and may not be directly comparable. Also, as previously mentioned, the fibreboards were not used, and the ground profile was measured directly instead.

As discussed in 3.7, and then in greater detail in Annex C, the depth profiles are evaluated in terms of maximum effective depth and penetration efficiency. The details of these analyses are given in Annex C, and the results summarized here.

While a reasonably accurate outline of the WORM mine shape is used in examining these ground profiles, there are two caveats that should be noted. First, CWA15044 does not describe the detailed geometry of the mine targets, and so the actual dimensions of the fuze portion may skew the results somewhat. A more puck-like mine with a shorter fuze assembly (similar to an M14 mine for example), would likely be able to hide in a few more spots than one like the WORM which has the fuze poking out in a more vulnerable manner. The second caution is that the sampling frequency across the width of the profiles (steps of 5 cm) does not compare well with the smallest relevant dimension of the WORM (just over 2 cm across the fuze). Using straight line interpolation between the 5 cm-spaced depth measurements does not reflect with perfect accuracy where the mine target might lie untouched. In both cases, however, there could be situations which underestimate the penetration very slightly, and situations which overestimate the penetration very slightly. The differences will be extremely small, and will, in all probability cancel each other out over the 100+ measurements taken in each test lane. Additionally, both machines in this comparison are subject to the same technique so neither machine would be favoured or disadvantaged by either shortcoming in the evaluation technique.

4.3.1 Maximum Effective Depth Summary

Based on the methodology described above in Section 4.3, the maximum effective depth based on the ground profiles taken in these tests is summarized in Table 2. Annex C shows how these values were found for each of the tests.

Table 2. *Ground Profile – Maximum Effective Depth*

Hammers	***Mine Target DOB (cm)***	***Effective Depth Full Width (cm)***		***Effective Depth Centre 50% (cm)***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***
New	10	4.0	4.0	5.5	4.0
New	15	3.5	3.5	8.0	11.5
Worn	10	4.5	5.0	7.0	7.5
None	10	3.5	3.0	3.5	4.5
New	0	3.5	3.5	6.0	3.5

The maximum depth to which either machine can be said to have penetrated consistently (maximum effective depth) is 11.5 cm, and that is only based on the centre 50% of the path (MV-4, new hammers, 15 cm DOB targets). In that same test, the Bozena-4 achieved its best result of 8 cm maximum effective depth, but again, only in the centre 50% of its path.

For both machines, the shoulder regions usually provided hiding places for mines--places where mines remained undamaged by the machines; when the shoulder regions are included for that test, the maximum effective depth to which either machine can be considered to have penetrated consistently or reliably is less than 4 cm.

In comparing the machines for the full width case, it is clear that there is no difference between the two. The maximum effective depths are within 0.5 cm of each other in every case. When the centre 50% band is compared, the machines are equally effective. One test showed the MV-4 deeper (11.5 cm v. 8.0 cm), one showed the Bozena-4 deeper (6.0 cm v. 3.5 cm), and the other three were within 1.5 cm of each other.

It may be tempting to look at the centre 50% band to find differences between the machines or to find evidence of consistent ground penetration beyond 3 cm – 5 cm. The difficulty with accepting the slightly deeper penetration numbers in the centre band is that it implies that you are willing to overlap passes of the machine by at least 25% to ensure that the areas only processed once are those in that centre 50% band. This may be an acceptable situation but it then becomes important to base area coverage expectations on only half of the published flail width.

4.3.2 Penetration Efficiency Summary

Based on the methodology described above in Section 4.3, the penetration efficiency for each of these tests is summarized in Table 2. Again, Annex C shows how these values were found for each of the tests.

Table 3. *Ground Profile – Penetration Efficiency*

Hammers	***Mine Target DOB (cm)***	***Penetration Efficiency Full Width***		***Penetration Efficiency Centre 50%***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***
New	10	PE_{10}=42%	PE_{10}=46%	PE_{10}=54%	PE_{10}=64%
New	15	PE_{15}=31%	PE_{15}=51%	PE_{15}=42%	PE_{15}=62%
Worn	10	PE_{10}=70%	PE_{10}=66%	PE_{10}=78%	PE_{10}=79%
None	10	PE_{10}=0%	PE_{10}=1%	PE_{10}=0%	PE_{10}=3%
New	0*	PE_5=100%	PE_5=91%	PE_5=92%	PE_5=94%

For the trivial case of penetration efficiency at 0 cm DOB, PE_0=100% in all cases.

In looking at the ground profiles through the lens of penetration efficiency, it is clear that the performance with no hammers is unacceptable for both machines, but this is as expected, and is also in line with the recommendations from both manufacturers against operating their machines without hammers.

Of course both machines achieved a perfect score for penetration efficiency at 0 cm depth (PE_0=100%), but this is immaterial – every conceivable machine can achieve this, without even touching the ground. To make the 0 cm DOB test a little more meaningful, the penetration efficiency is examined at a shallow depth of 5 cm. Both machines achieved a score of PE_5>90% for both the centre 50% band and the full width cases.

In the test with mines at 15 cm DOB, the MV-4 achieved a greater 15 cm penetration efficiency than the Bozena-4 in both the centre 50% band and the full width cases, but the best result was still only 62%. Put another way, despite the low speed and best efforts to reach mines at 15 cm DOB, the best result still left almost 40% of the test lane in a condition where such mines could remain untouched.

Comparing the machines for the new hammers with mines at 10 cm DOB (the first test), the values for penetration efficiency are very similar, with the MV-4 having a small advantage. That said, even the MV-4 did not reach more than 64% of the target depth over the centre 50% band, and missed over half of the target depth when looking at the full width of the profiles.

The worn hammer test also showed similar performance between machines in both the centre band and the full width cases. In the full width case, the Bozena-4 showed a very slight advantage but still missed 30% of the target depth.

4.3.3 Ground Profile Summary

The ground profiles show that for the conditions under which these tests were performed, and for the way in which the manufacturer's representatives operated the machines, one would have to be careful about claims of depth and width. There is little difference between the maximum effective depths for the two machines in any given test for the full width case. Only in one test does the centre 50% band show any real difference between the two machines, and even then the difference is between an 8 cm result and an 11 cm result.

The penetration efficiency numbers tell much the same story. Neither machine showed a particular advantage over the other in any consistent way; the results were either very similar, or the machines traded one test for another in showing a slight advantage. Again, the difficult soil conditions are reflected in these results with both machines struggling to reach the target depth in all but the flush-buried test.

This suggests that, based on these tests, there is very little difference between the two machines when considering ground penetration, as defined by either maximum effective depth or penetration efficiency.

4.4 Processing Speed

In Section 4.1.1 the processing speed of the two machines was compared against the number of mine targets triggered, neutralized, etc.

Another way to compare the performance of the machines is to relate the operating speeds to the ground penetration performance. It may be useful to look at speed in terms of the linear forward speed of a machine, or the area coverage (how many square metres per hour). It may also be useful to quantify speed or area coverage along with the depth to which a machine has processed.

With the two machines having different widths, the area processed per unit time will be different even for the same forward speed. For convenience, the relevant dimensions are summarized below.

- MV-4 published width = 1725mm. Centre 50% band = 862.5mm.

- Bozena-4 published width for FU2 head = 2225mm for New/10 cm and New/0 cm runs. Centre 50% band = 1112.5mm.

- Bozena-4 published width for FU1 head = 2000mm for New/15 cm, Worn/10 cm, and None/10 cm runs. Centre 50% band = 1000mm.

It was also stated, however, and it is worth repeating, that either of the two machines might have been able to achieve similar results at higher speeds but that this was beyond the scope of this trial to assess. The analyses that follow can be misleading if this fact is ignored.

4.4.1 Speed Considerations – A Caution

Comparing performance based on speed is often desirable but it can also be very misleading. Consider the simple case of one machine which digs to 5 cm depth and runs at 600 metres per hour, while a second machine digs to 20 cm and runs at only 100 metres per hour. Basing the performance comparison on speed suggests that the first, faster machine is better, but this is only true if your required depth is 5 cm or less. If you need to get deeper than 5 cm, the first machine is of limited value or even no value despite its greater speed.

The same argument holds whether you consider the forward speed of the machine, the area processed per hour, or even a volumetric (cubic metres of soil processed per hour), analysis. It also holds whether you use maximum effective depth, penetration efficiency or any other measure of ground penetration. To illustrate, consider the following hypothetical machine test comparison.

Imagine two hypothetical machines being compared which have the test data shown in Table 4. Machine B has run at 6 times the speed of Machine A which seems good until you look at the depths achieved. If a maximum effective depth of just 2 cm is not acceptable then the high speed of Machine B is of no value in making this comparison. Alternately, considering penetration efficiency, if reaching a depth of 10 cm less than 11% of the time is not acceptable, then the higher speed of Machine B does not provide any advantage.

Table 4. *Hypothetical Speed Example*

Hammers	***Machine A***	***Machine B***
Width (full width)	1.6 m	1.6 m
Maximum Effective Depth (MED)	9 cm	2 cm
Depth of Interest	10 cm	10 cm

PE_{10}	63.0%	10.5%
Forward Speed	500 m/h	3000 m/h
Area Coverage Rate	800 m^2/h	4800 m^2/h
Volumetric Rate (MED)	72.0 m^3/h	96.0 m^3/h
Volumetric Rate (PE)	50.4 m^3/h	50.4 m^3/h

Looking at the area coverage rates makes Machine B look even better – it has processed 6 times the area of Machine A, but again, if the depths are not adequate, then the speed advantage is not an advantage at all.

A volumetric analysis can be done (using the calculations shown in Section 4.4.4). Basing the comparison on Maximum Effective Depth still makes Machine B look faster than Machine A, but at least they are somewhat close. Using Penetration Efficiency makes the machines appear to be exactly equal. In either case, however, it is still critical to decide first whether the depth that either machine has achieved is acceptable before comparing the machines based on some measure of speed.

It may be necessary to perform another trial with Machine B at a lower speed to see if an acceptable depth can be reached, after which the processing rates can be recalculated for a meaningful comparison.

4.4.2 Forward Speeds

The information in Table 2 showed that there was no real difference in the ground penetration performance when the full width of cut was considered. Looking at only the centre 50% of cut there were some relatively minor differences. Table 5 compares the linear processing speed (straight ahead speed) against the effective depth for both machines for both full width and the centre 50% width.

With the exception of the 15 cm DOB test, all of the rest of the runs show the MV-4 at almost double the speed of the Bozena-4, but this does not seem to have translated into any real difference in maximum effective depth.

Table 5. *Maximum Effective Depth v. Processing Speed (Linear)*

Hammers	***Mine Target DOB (cm)***	***Effective Depth Full Width (cm)***	***Effective Depth Centre 50% (cm)***	***Processing Speed (m/h)***

		Bozena-4	MV-4	Bozena-4	MV-4	Bozena-4	MV-4
New	10	4.0	4.0	5.5	4.0	231	474
New	15	3.5	3.5	8.0	11.5	176	196
Worn	10	4.5	5.0	7.0	7.5	155	290
None	10	3.5	3.0	3.5	4.5	307	612
New	0	3.5	3.5	6.0	3.5	300	692

Table 6 shows the comparison of penetration efficiency against machine speed. With the changes to machine speed and effective width from one test run to the next, it is difficult to make conclusive statements about this relationship, but the numbers in the first three tests seem to suggest that, when speeds are close, the MV-4 appears to have a slightly higher penetration efficiency. In the few examples we have here, the MV-4 penetration efficiency numbers seem to compare favourably to the Bozena-4 numbers even when the MV-4 speeds were higher than the Bozena-4 speeds. Clearly there are not enough tests to make definitive statements about this, but Table 6 does ask whether there is a pattern. The way that the two machines were operated (see Section 4.6.1) may also have implications that should be considered when forming opinions about depth and speed.

Table 6. *Penetration Efficiency v. Processing Speed (Linear)*

Hammers	***Mine Target DOB (cm)***	***Penetration Efficiency Full Width (cm)***		***Penetration Efficiency Centre 50% (cm)***		***Processing Speed (m/h)***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***	***Bozena-4***	***MV-4***
New	10	PE_{10}=42%	PE_{10}=46%	PE_{10}=54%	PE_{10}=64%	231	474
New	15	PE_{15}=31%	PE_{15}=51%	PE_{15}=42%	PE_{15}=62%	176	196
Worn	10	PE_{10}=70%	PE_{10}=66%	PE_{10}=78%	PE_{10}=79%	155	290
None	10	PE_{10}=0%	PE_{10}=1%	PE_{10}=0%	PE_{10}=3%	307	612
New	0	PE_5=100%	PE_5=91%	PE_5=92%	PE_5=94%	300	692

4.4.3 Area Coverage Rates

An area coverage rate can be calculated based on the centre 50% band measurement or on the full width measurement. This creates two different 'speeds' so the data is presented in separate tables for clarity.

To illustrate the calculation used in this analysis, consider the centre 50% band for the MV-4 in the first test – 10 cm DOB, new hammers.

Width: 862.5mm (See Section 4.4.)

Forward speed: 474m/h (See Table 6.)

0.8625m x 474m/h = 409m^2/h (This value is shown below in Table 7.)

Table 7 compares the machines based on area coverage rates looking at the centre 50% band. Since the width of the centre 50% band was based on the published working width for the machine (as discussed in Section 4.3), this same 50% of the published width is used in the calculation of the area coverage rates.

Table 7. *Maximum Effective Depth v. Area Coverage Rate (Centre 50%)*

Hammers	***Mine Target DOB (cm)***	***Effective Depth Centre 50% (cm)***		***Area Coverage Rate (m^2/h)***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***
New	10	5.5	4.0	257	409
New	15	8.0	11.5	176	169
Worn	10	7.0	7.5	155	250
None	10	3.5	4.5	307	528
New	0	6.0	3.5	334	597

While the differences are slight, the data in Table 7 suggests that in 2 cases the MV-4 processed at twice the rate of the Bozena-4 but could not match its effective depth. In one case the processing rates were almost the same but the MV-4 achieved a deeper effective depth, and in two cases the MV-4 achieved a slightly greater depth at a higher speed. The differences are small enough that they may not be important in real demining operations.

In evaluating the effective depth over the full width, the actual processed path was used (see Section 4.3). For the full width calculation, the forward speed is therefore multiplied by the average of the four widths actually measured on the ground profiles for that test run. The results of this are shown in Table 8.

Table 8. *Maximum Effective Depth v. Area Coverage Rate (Full Width)*

Hammers	**Mine Target DOB (cm)**	**Effective Depth Full Width (cm)**		**Area Coverage Rate (m^2/h)**	
		Bozena-4	**MV-4**	**Bozena-4**	**MV-4**
New	10	4.0	4.0	514	818
New	15	3.5	3.5	361	338
Worn	10	4.5	5.0	326	529
None	10	3.5	3.0	610	1117
New	0	3.5	3.5	686	1237

The full width values shown in Table 8 show negligible differences in effective depth. In four of the five tests, the MV-4 processed the areas at higher speeds than the Bozena-4, but again, it is not certain that the differences are significant, especially when the effective depths are restricted to only 5 cm or less.

The area coverage rates can also be compared with the penetration efficiency as shown in Table 9 and Table 10 for the centre 50% band and the full width cases respectively. As expected, in the test with no hammers both machines did poorly regardless of speed or area coverage. In the case of the flush-buried targets, both machines achieved penetration efficiency numbers over 91% but the area coverage rate of the MV-4 was almost double that of the Bozena-4.

For the centre 50% band in the first three tests, Table 9 suggests that the MV-4 was able to achieve penetration efficiency numbers that were similar to, or somewhat better than, those for the Bozena-4, while covering equal or greater area coverage per unit time. The full width situation in Table 10 is not quite as clear.

Again, there is not much data on which to base firm conclusions, and there are other implications arising from the way the machines were operated.

Table 9. *Penetration Efficiency v. Area Coverage Rate (Centre 50%)*

Hammers	***Mine Target DOB (cm)***	***Penetration Efficiency Centre 50% (%)***		***Area Coverage Rate (m^2/h)***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***
New	10	PE_{10}=54%	PE_{10}=64%	257	409
New	15	PE_{15}=42%	PE_{15}=62%	176	169
Worn	10	PE_{10}=78%	PE_{10}=79%	155	250
None	10	PE_{10}=0%	PE_{10}=3%	307	528
New	0	PE_{5}=92%	PE_{5}=94%	334	597

Table 10. *Penetration Efficiency v. Area Coverage Rate (Full Width)*

Hammers	***Mine Target DOB (cm)***	***Penetration Efficiency Full Width (%)***		***Area Coverage Rate (m^2/h)***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***
New	10	PE_{10}=42%	PE_{10}=46%	514	818
New	15	PE_{15}=31%	PE_{15}=51%	361	338
Worn	10	PE_{10}=70%	PE_{10}=66%	326	529
None	10	PE_{10}=0%	PE_{10}=1%	610	1117
New	0	PE_{5}=100%	PE_{5}=91%	686	1237

4.4.4 Volumetric Processing Rates

Finally, it is possible to compare the machines based on volumetric coverage. If a machine has processed consistently and reliably to a certain depth, it is a simple matter to multiply the area coverage by the depth to examine the amount of soil processed per unit time. It is not known how useful this kind of ranking might be for the end user, but it attempts to quantify the performance in a way that includes not only the area per unit time, but also the effective depth.

Table 11 compares volumetric processing rates with maximum effective depth for the centre 50% band, while Table 12 shows the full width case.

To illustrate the calculation in this case consider the same example used in 4.4.3 (MV-4, centre 50% band, 10 cm DOB, new hammers).

Width: 862.5mm (See Section 4.4.)

Forward speed: 474m/h (See Table 6.)

Maximum Effective Depth: 4.0 cm

0.8625m x 474m/h x 0.04m = 16.4m^3/h (This is shown in Table 11)

Table 11. *Maximum Effective Depth v. Volumetric Coverage Rate (Centre 50%)*

Hammers	***Mine Target DOB (cm)***	***Effective Depth Centre 50% (cm)***		***Volumetric Coverage Rate (m^3/h)***	
		Bozena-4	***MV-4***	***Bozena-4***	***MV-4***
New	10	5.5	4.0	14.1	16.4
New	15	8.0	11.5	14.1	19.4
Worn	10	7.0	7.5	10.9	18.8
None	10	3.5	4.5	10.8	23.8
New	0	6.0	3.5	20.0	20.9

Table 11 shows that, for the centre 50% band only, the MV-4 processed more soil per hour than the Bozena-4 in virtually every test run, based on maximum effective depth. While this is true, the depths to which the soil was processed, and the differences between the depths for each machine, are very small. In the worn hammer test for example, neither machine managed to penetrate consistently beyond 7.5 cm, and the machines differ by **only 5mm** in maximum effective depth. Differences in the values for the other runs should be viewed with a similar sceptical eye.

Table 12. Maximum Effective Depth v. Volumetric Coverage Rate (Full Width)

Hammers	Mine Target DOB (cm)	Effective Depth Full Width (cm)		Volumetric Coverage Rate (m^3/h)	
		Bozena-4	MV-4	Bozena-4	MV-4
New	10	4.0	4.0	20.6	37.2
New	15	3.5	3.5	12.6	11.8
Worn	10	4.5	5.0	14.7	26.5
None	10	3.5	3.0	21.4	33.5
New	0	3.5	3.5	24.0	43.3

The full width values in Table 12 should be viewed with the same caution as the values for the centre 50% band. While the full width volumetric coverage rates for the MV-4 are almost all higher than those for the Bozena-4, neither machine was able to penetrate consistently beyond 5 cm across its entire width.

Table 13 compares the volumetric processing speed of the two machines based on the penetration efficiency In this case the area coverage rate is multiplied not by the maximum effective depth, but instead, by the target depth being considered and then by the PE rating. The same example (MV-4, centre 50% band, 10 cm DOB, new hammers) is again used to illustrate the calculation.

Width: 862.5mm (See Section 4.4.)

Forward speed: 474m/h (See Table 6.)

Penetration Efficiency Depth of Interest: 10.0 cm

Penetration Efficiency: PE_{10} = 64% or PE_{10} = 0.64

0.8625m x 474m/h x 0.10m x 0.64 = 26.2m^3/h (This is shown below in Table 13.)

This value should be interpreted as follows: At the speed that the machine ran in this test, it would have processed 40.9m^3 of soil down to a depth of 10 cm in one hour **if it had reached the 10 cm level perfectly**. In fact, it only reached 10 cm 64% of the time, so it only processed 26.2m^3 soil in that hour. If reaching 10 cm only 64% of the time is acceptable, then the speed of 26.2m^3 h is of value. If not, it should be ignored entirely.

Table 13. Penetration Efficiency v. Volumetric Coverage Rate (Centre 50%)

Hammers	Mine Target DOB (cm)	Penetration Efficiency Centre 50% (%)		Volumetric Coverage Rate (m^3/h)	
		Bozena-4	MV-4	Bozena-4	MV-4
New	10	PE_{10}=54%	PE_{10}=64%	13.9	26.2
New	15	PE_{15}=42%	PE_{15}=62%	11.1	15.7
Worn	10	PE_{10}=78%	PE_{10}=79%	12.1	19.8
None	10	PE_{10}=0%	PE_{10}=3%	0	1.6
New	0	PE_5=92%	PE_5=94%	15.4	28.1

Table 14. Penetration Efficiency v. Volumetric Coverage Rate (Full Width)

Hammers	Mine Target DOB (cm)	Penetration Efficiency Full Width (%)		Volumetric Coverage Rate (m^3/h)	
		Bozena-4	MV-4	Bozena-4	MV-4
New	10	PE_{10}=42%	PE_{10}=46%	21.6	37.6
New	15	PE_{15}=31%	PE_{15}=51%	8.2	12.9
Worn	10	PE_{10}=70%	PE_{10}=66%	10.9	16.5
None	10	PE_{10}=0%	PE_{10}=1%	0	0.5
New	0	PE_5=100%	PE_5=91%	16.7	27.2

Table 13 and Table 14 both show higher volumetric processing rates for the MV-4 over the Bozena-4 on every test. Whether this is of value to the user depends on whether the depths achieved by either machine are acceptable. A high speed (by any calculation method) is only useful if the depth meets the deminer's needs.

4.5 Hammer Observations

Several issues surrounding flail hammers were raised through the trial. On behalf of ITEP, CCMAT purchased two sets of hammers from each manufacturer to facilitate the trials. One set was to be modified, as described below, to simulate worn-out hammers, while the other was for use by the manufacturers in the tests since there was no way of knowing the condition of the existing hammers on the machines at IMATC.

4.5.1 MV-4 and Bozena-4 Hammer Wear

Prior to the trial, DOK-ING had asked to have two different types of hammers tested on the MV-4. They were advised that there was no possibility of doing trials with both sets of hammers, as it would effectively double the time, cost and resources for the MV-4 tests. To be fair to the Bozena-4 team, the same option would have to have been offered, which would have doubled the scope of the entire trial.

During the tests it was found that the MV-4 hammers wore out extremely fast, and showed significant damage after as little as a single run of nominally 25m. The MV-4 team acknowledged the fact that the hammers selected were ill-suited to these conditions. They stated that the second set of hammers they had proposed would have been much better, but stayed with their initial selection despite it being very clear that these hammers were not the best choice for this type of soil.

In contrast, the Bozena-4 team used a single set of hammers throughout all of their ‘new hammer’ tests. Whereas the MV-4 hammers showed considerable wear after as little as a single test run, the hammers on the Bozena-4 showed no appreciable amount of wear throughout the entire trial.

Figure 25 and Figure 26 show new hammers, and examples of the wear after the first test run for each machine.

New Hammer

Hammer Wear After One Test

Figure 25. *MV-4 Hammer Wear Examples*

New Hammer

Hammer Wear After One Test

Figure 26. *Bozena-4 Hammer Wear Examples*

Due to the deformation in the hammers after the first test run (10 cm), the MV-4 team replaced the entire set of hammers in preparation for the second test (15 cm DOB). The Bozena-4 team objected strenuously that in their view the objective was to use the single set of hammers purchased by CCMAT for the three 'new hammer' tests.

As discussed above in Section 3.2.2, one of the goals of this trial was to examine the differences in performance when using new hammers, used hammers and no hammers at all. If a set of hammers is badly worn after a single test run, subsequent runs would not have 'new' hammers and this comparison would be impossible. For the comparison to be possible, the hammers would need to be replaced, and so the ITEP team allowed the replacement despite the Bozena-4 team's objection.

4.5.2 Realism of Artificially Worn Hammers

Annex D contains a letter from the Bozena-4 team in which they dispute the results of the worn-out hammer test. One of their concerns relates to the realism of the hammers. The detailed response from ITEP to this concern, and to the other concerns in the letter are included in Annex D. Regarding the hammer realism question, the final position is that both manufacturers had agreed to the use of the artificially worn hammers with full knowledge that they might not necessarily represent realistic wear in this or any other specific scenario. The Bozena argument about hammer realism is therefore rejected.

4.5.3 New Hammer / Worn Hammer / No Hammer

Originally it had been planned that the test runs would all be conducted with the machines operating at the same speed throughout each run, and the same speed from one run to the next. From this we expected that we would be able to see a degradation of performance from new hammers to worn hammers to no hammers at all. For the reasons outlined in Section 3.8, the consistent speeds did not occur. In addition, the procedural problems with using mine targets in the extremely hard soil precluded any such analyses based on ability to trigger or neutralize mines.

Table 15 extracts the relevant test runs from Table 5 and Table 11. Considering the MV-4 tests, the forward speed dropped by about 40% from the new hammer run to the worn hammer run. In the process, the effective depth increased slightly for the full width case and by about 45% for the centre band. When the run with no hammers was done, the forward speed was 30% greater than with new hammers, and yet the effective depth was actually marginally deeper for the centre band and slightly shallower for the full width.

The situation for the Bozena-4 is even more unclear because the effective width of the flail head also changed between runs.

Table 15. *Hammer Wear Effects (1)*

Hammers	**Mine Target DOB (cm)**	**Effective Depth Full Width (cm)**		**Effective Depth Centre 50% (cm)**		**Processing Speed (m/h)**	
		Bozena-4	**MV-4**	**Bozena-4**	**MV-4**	**Bozena-4**	**MV-4**
New	10	4.0	4.0	5.5	4.0	231	474
Worn	10	4.5	5.0	7.0	7.5	155	290
None	10	3.5	3.0	3.5	4.5	307	612

Using the effective depth criteria as shown in Table 15, there does not seem to be any clear relationship between hammer wear and effective depth, for either machine, including the case for no hammers at all. Any correlation that might be there is masked by the changes to speed, and in the case of the Bozena-4, changes to the width of the flail. It may be possible to suggest that, under the test conditions, one might be able to use bare chains with no hammers as long as the necessary depth of penetration did not exceed about 3 cm – 4 cm, but even this has not been demonstrated with any certainty.

Looking at the overall depth-of-cut profiles may lead to a subjective opinion that there are, in fact, differences in depth performance which are related to hammer wear; defining 'effective depth' as the deepest penetration consistently achieved by the machine makes this value a reliable assessment of the machines' abilities in this crucial performance area. In Table 16 the penetration efficiency is shown against hammer wear, with speed shown for reference. There appears to be a counter-intuitive result with the worn hammers producing a better result, until the forward speed is factored in. Indeed, the slowest speed resulted in the best Penetration Efficiency, and the highest speed corresponds to the worst Penetration Efficiency. This makes sense but it masks any effects of hammer wear, or the effects of using no hammers at all.

Table 16. *Hammer Wear Effects (2)*

Hammers	**Mine Target DOB (cm)**	**Penetration Efficiency Full Width (%)**		**Penetration Efficiency Centre 50% (%)**		**Processing Speed (m/h)**	
		Bozena-4	**MV-4**	**Bozena-4**	**MV-4**	**Bozena-4**	**MV-4**

New	10	PE_{10}=42%	PE_{10}=46%	PE_{10}=54%	PE_{10}=64%	231	474
Worn	10	PE_{10}=70%	PE_{10}=66%	PE_{10}=78%	PE_{10}=79%	155	290
None	10	PE_{10}=0%	PE_{10}=1%	PE_{10}=0%	PE_{10}=3%	307	612

4.6 Other Machine Observations

4.6.1 Flail Shaft Height Considerations

In comparing the two machines, one thing that is immediately obvious is the length of chains, and the associated height of the flail shaft. Both machines have been designed to operate in their own particular manners and the intent of this discussion is not to second guess either manufacturer. Rather, the intent is simply to offer two observations which were made during the trial period. One observation favours longer chains, while the other favours shorter chains.

With short chains a machine such as the MV-4 is obligated to have the flail shaft closer to the ground, and hence, closer to any mine blasts that might occur. The closer the shaft is to a blast, the more likely the shaft, the chain attachment points, or the shaft bearings might be damaged, especially with larger blasts from anti-tank mines, but even possibly from some anti-personnel mines. Taken to the extreme, with the shaft in contact with the ground, as was observed on occasion during these tests, blast damage of one kind or another would be very likely. Similarly, damage to the chain attachment points would be very likely if they were to be repeatedly pounded against large rocks due to the shaft being in contact with the ground.

Machines such as the Bozena-4, with longer chains, offer a greater standoff between the shaft and the ground. This offers better protection by avoiding more of the mechanical contact between the shaft and large rocks. More significantly, it moves the shaft and associated parts much further from blast effects, potentially allowing machines to absorb anti-tank mine blasts without damage to the shaft or bearings. In fact, this has been demonstrated for the Bozena-4.

On the flip side of the argument, machines with short chains or with the shafts close to the ground may offer the potential for improved performance in one respect. Consider the two flails shown in Figure 27, both of which are set to dig to the same depth.

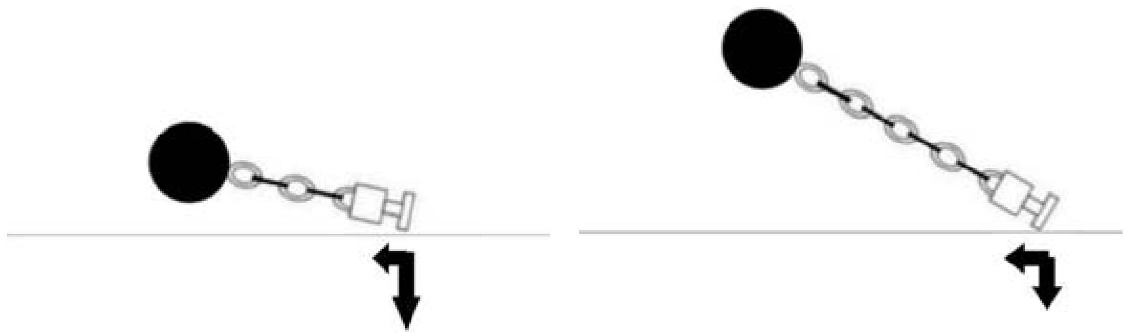


Figure 27. *Shaft Height Geometry*

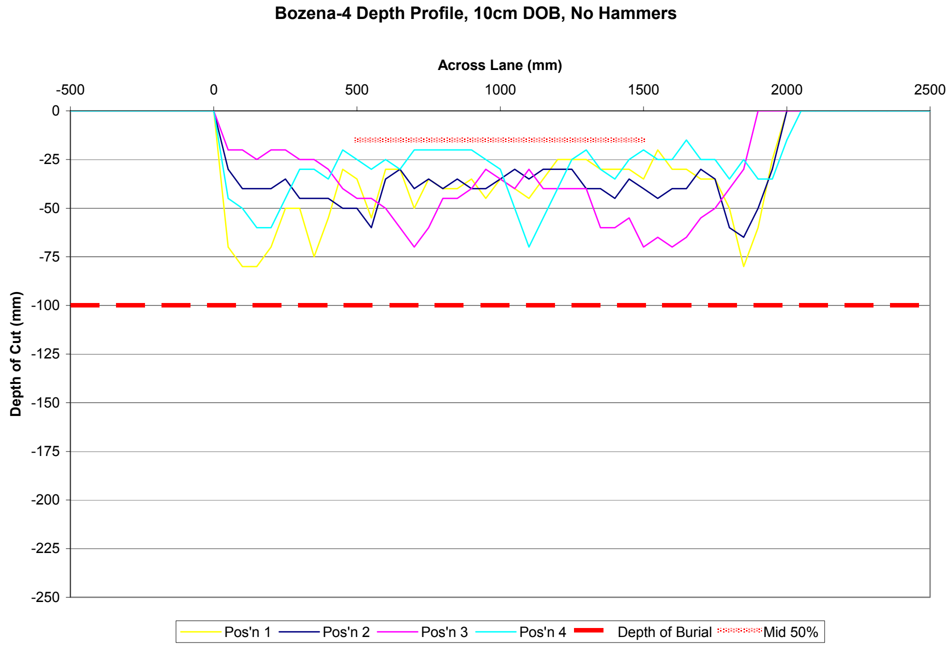
On the left is a flail with short chains and the shaft close to the ground. The hammers strike the ground almost directly downward, so most of the energy is transferred into fracturing the soil or mine. The machine on the right has the hammers striking the ground at a much shallower angle, leading to less downward force on the soil. There may also be a greater chance of the hammer deflecting off the ground instead of cutting into it.

This shaft height effect has not been proven conclusively, but it might be a partial explanation for the results of the no-hammer test. Consider the following:

- While maximum effective depth and penetration efficiency for both machines in the no-hammer test have been covered above, and are basically same for both machines, Figure 28 suggests that, overall, the MV-4 seems to have penetrated a little more deeply than the Bozena-4 in this test.

- In this test the forward speed of the MV-4 was almost exactly twice that of the Bozena-4, and yet the MV-4 ground penetration was slightly better; one would normally assume that the slower machine would have had better results.

- Without regard to the state of the mine targets (triggered, etc) in this no-hammer test, all 50 of the Bozena-4 targets were found intact, and in their original positions. By comparison, 28 of the 50 targets in the MV-4 test lane were intact and in their original positions. (This does **not** suggest that the MV-4 destroyed the remaining 22 targets.)



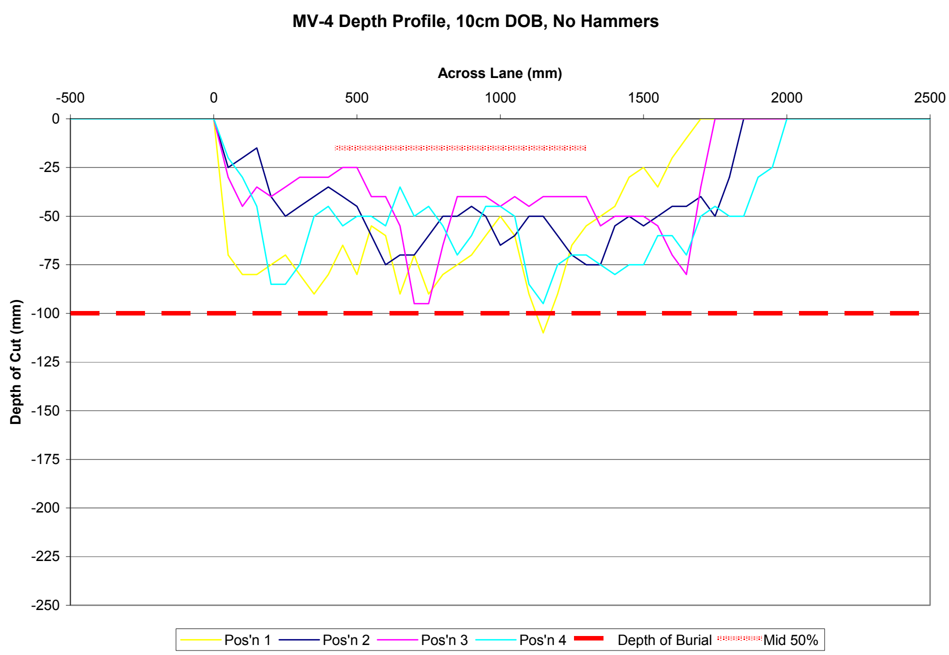


Figure 28. *Ground profile, No Hammers, Mines at 10 cm DOB – Bozena-4 and MV-4*

In the case of no hammers, there is even less energy being directed into the ground, there is little cutting edge to fracture the soil, and so there could be a greater likelihood of the chain simply bouncing instead of fracturing the soil. If so, the effect of lower shaft height might be even more apparent when there are no hammers on the chains. This single example suggests, but does not prove, that it is **possible** that the geometry of shorter chains and lower flail shafts might contribute to greater effective depth.

4.6.2 Flail Head Width v. Track/Machine Width

The MV-4 advertises a working width of the flail head of 1725mm. Measuring across the flail head from the outer edge of the outermost hammer on one side to the same location on the other side, the physical width of the flail hammers appeared to be 1630mm. In the 5 test runs conducted in this trial the narrowest profile measured was 1700mm and the widest was 2050mm. The average width of all 20 profiles was 1778mm. The width of the MV-4, from outside of track on one side to outside of track on the other side was 1530mm.

The Bozena-4 advertises a working width of 2225mm for the FU2 head and 2000mm for the FU1 head. The hammers for the fully loaded FU2 head were not measured but when the 6 hammers were removed to simulate the 2m width of the FU1, the distance from outside of hammer to outside of hammer was approximately 1890mm. In the 5 test runs, the narrowest profile for the FU2 configuration was 2150mm. The widest and average were 2350mm and 2256mm respectively. For the FU1 configuration the narrowest, widest and average widths were 1900mm, 2150mm and 2046mm respectively. If we exclude the no-hammer test, since the manufacturer does not recommend using the machine without hammers, the minimum width measured on the FU1 configuration was 2000mm. The width of the Bozena-4, from outside of track on one side to outside of track on the other side was 1940mm.

On average, in these tests, the MV-4 successfully processed a path in excess of the advertised width. The narrowest path measured was 170mm wider than the tracks of the vehicle, offering a small buffer on either side of the vehicle before the tracks would encounter unflailed ground, at least for straight line operations.

On average, in these tests, the Bozena-4 successfully processed a path in excess of the advertised width for both the FU1 and FU2 configurations. Excluding the no-hammer test, the narrowest path measured was 60mm wider than the tracks of the vehicle, leaving a very small buffer on either side of the vehicle before the tracks would encounter unflailed ground, at least for straight line operations. In the FU2 configuration the narrowest profile was 2150mm, leaving a 210mm buffer.

5. Conclusions and Recommendations

The Conclusions and Recommendations discussion is broken into two separate parts. The first discusses the issues surrounding the conduct of trials. The second addresses performance of the machines.

5.1 Trial Conduct

5.1.1 Competitive Trial Problems

It is only natural that the manufacturers will want their machines to perform as well as possible, and also for them to hope that their competitor performs less well. When the performance is basically equal, or worse, when one's own machine appears to perform less ably than the competition, it is also natural to look for explanations. When there are no obvious or logical reasons, sometimes it may be natural to accept totally illogical arguments. A case-in-point is the question of speed control in the very first test as described in Section 3.8. The Bozena-4 team maintained a constant speed through the test as requested, but the speed of the MV-4 varied from completely stopped to so fast that the overall speed was twice that of the Bozena-4. The complaint that MV-4 had not been run according to the rules was well-founded, but the argument that this could have given some kind of advantage to the MV-4 has little merit.

As stated in the introduction, this side-by-side demonstration turned into a contentious, fractious and hard-fought competition. If such a trial were contemplated in future ITEP work, it is recommended that:

- The manufacturer teams should be completely segregated from each other except for briefings, in which both manufacturers are present with the ITEP team.
- Complaints should be made in writing; verbal complaints should be ignored.
- When one team is being tested, the other team should be entirely removed from the test area with no way to see or hear what is happening.
- If the teams are being tested at or near the same location, the results from one team's efforts should not be visible to the other team. This may mean putting a tarp over the area or otherwise shielding the area from view.
- Depending on the nature of the trial, perhaps a team could have access to its own data as it becomes available, but under no circumstances should they be able to see the other team's data until the production of the final report. This includes the review of draft versions of the report.

5.1.2 Performance Trials in Non-ITEP Facilities

In order to compare data between trials, **all** trials must rigidly adhere to a common set of criteria such as CWA15044. Every time a condition is varied, the validity of the data suffers and useful comparison becomes impossible. Restricting performance tests to facilities where CWA15044 conditions can be met or to ITEP facilities, themselves, will eliminate these difficulties. Information gained from acceptance tests could be used to supplement data from CWA15044-compliant trials.

It was also agreed that there was merit in improving the description of the CWA15044 acceptance tests to include things like soil profile measuring, and the definition of effective ground penetration, in order to allow the results of performance tests to be translated into the local conditions where acceptance tests are conducted.

5.1.3 Use of Fibreboards

While fibreboards can, under the right conditions, provide useful evidence of the ground penetration performance for a machine being tested, soil conditions and other test conditions may make the use of fibreboards difficult. It may also render the information provided by fibreboards of doubtful value. It is particularly important to ensure that the trenches for the fibreboards are only as wide as the boards themselves. Trenches as wide as 10 cm have been shown to invalidate fibreboard data in some cases.

When conditions permit, it is less work and more revealing to measure the ground profile directly, brushing away the loose soil and measuring down from a straightedge across the test lane.

5.1.4 Use of Mine Targets

As noted previously, performance tests should be restricted to proper CWA15044 conditions. When these conditions are not met, comparison of some or all of the data can be precluded, notably the data obtained using mine targets. Including mine targets in the acceptance tests needs to be done with care, especially when local conditions (inappropriate soil, for example), do not meet standard conditions. It is especially problematic when the test looks like a standard test (50 targets, three depths, etc) and there can be an expectation that the data is comparable.

It was clear that the use of statistics in analyzing mine target data, while scientifically valid, is largely ignored or misunderstood by many people. The fact that test runs showing 49/50 and 50/50 are statistically the same (and not even precisely 98% and 100%) was irrelevant to certain people who could only comprehend that one suggested perfection and the other failure. No better way of presenting the data was suggested but the problem was noted.

5.2 Machine Performance

5.2.1 Mine Target Results

Only one test contained mine target results that the ITEP team considered valid. This test, at 0 cm DOB showed no significant difference between the two machines. With both machines being well designed and well constructed, it is no surprise that both produced excellent results, especially with the mine targets flush with the ground surface.

Valid data showing the performance of both machines against mines at deeper burial depths could not be obtained in this trial. The reader is directed to reports already at the ITEP web site for this information as obtained in previous trials.

5.2.2 Hammer Wear Observations

The Bozena-4 hammers exhibited very little visible wear through the entire test period. The hammers certainly showed signs of being used (scratches, blunting of the cutting edges and small dents), but the damage was largely superficial.

In comparison, the hammers on the MV-4 showed significant wear after almost every test, leading the MV-4 team to replace the hammers frequently. Given that each test run was only slightly longer than 25m, this degree of wear was surprising. The manufacturer representatives did indicate that the hammers used were not their preferred hammers for these conditions. Unfortunately, as described in detail above, it was not possible to test the second type of hammer to get a useful evaluation of the level of hammer wear.

5.2.3 New Hammer / Worn Hammer / No Hammer

As a result of the speed changes from one run to the next, no useful conclusions could be drawn regarding the performance effects of hammer wear. The results of removing hammers altogether could be seen clearly by the profiles regardless what depth definitions were used.

5.2.4 Ground Profile and Ground Penetration Results

These tests were conducted in extremely difficult soil conditions and this showed in the performance of the machines. Using four depth profiles across each test lane, the depth of penetration achieved ranged from zero down to just over 22 cm in a few localized spots, but overall, neither machine was able to reliably or consistently process to even 12 cm. Indeed most of the measurements showed maximum effective depths ranging between 3 cm and 7 cm. This was most significant in the shoulder regions, or edges of the flailed path.

In two cases, the expected penetration efficiency was obtained. With no hammers and a high machine speed, ground penetration was poor across the board. With new hammers and mines right at the surface, penetration efficiency measured at just 5 cm below grade was very good across the board. For the tests where both machines were targeting mines at 10-15 cm, the penetration efficiency results were mixed, with the numbers ranging from a low of 31% to a high to 79%. Changes to the machine speeds from run to run make it difficult to draw valid comparisons.

5.2.5 Other Factors Needing Consideration

As stated previously, this trial was expected to provide a snapshot into the performance capabilities of the two machines for a certain, specific set of conditions. It was not, and could not have been, intended to answer all of the important questions that would need to be addressed in doing a thorough, comprehensive comparison of the two machines. Such questions should encompass:

- Fuel consumption
- Availability and consumption of spare parts
- Mobility over differing terrain conditions
- Training requirements
- Maintenance requirements
- Transportability

Without considering these and other relevant questions, any comparison of these two very capable machines would be incomplete.

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Annex A – Soil Moisture & Density Measurements

The following is a step by step method of measuring soil density and moisture content:

Soil Density

Apparatus:

- Digging tools – Shovel or trowel, screwdriver or heavy knife.
- Containers for storing samples
- Non-porous material, e.g.: poly bag
- Graduated container or container of known volume
- Container of water
- Scale
- Marking implement – felt marker, grease pencil etc.

Method:

1. Weigh the sample container
2. Mark the weight of the container weight on the sample container
3. Mark the container with the sample number and location
4. Place non-porous material on ground next to location of hole
5. Place sample container on non-porous material
6. Using shovel or trowel, excavate hole ensuring that **ALL** material from the excavation is placed in the sample container
7. Seal and weigh the container immediately
8. Mark the container with the gross weight
9. Smooth the sides and bottom of the excavation with the trowel or knife, without removing any additional material
10. Place non-porous material in the excavation ensuring that it is in contact with the sides and bottom
11. Fill the graduated container from the water container
12. Note the amount of water in the graduated container
13. Pour water from the graduated container into the lined excavation. Fill the excavation with water as close as possible to ground level without overflowing
14. Note the amount of water left in the graduated container. (NOTE: Alternately, the non-porous material can be removed from the hole, being careful not to spill any water. This water is then poured into a container and weighed. This mass can be converted into volume.)
15. Subtract the amount remaining from the starting amount. The difference is the amount in the excavation and represents the volume of the excavation
16. Mark this on the sample container

Calculations:

Soil density refers to the mass per unit volume. For our purposes, density, ρ, is given in kilograms per cubic metre.

$$\rho = m/V = kg/m^3$$

Example: A soil sample has a wet mass of 1174.75 grams; the excavation the soil was removed from has a volume of 500ml or 500 cm^3.

$$\rho = m/V$$

$$= 1174.75g/500ml$$

$$= 1.17475kg/0.0005m^3$$

$$= 2349.5kg/m^3$$

In the above example the object is to convert the mass of the sample from grams to kilograms and the volume of the excavation from millilitres to $metres^3$.

Moisture Content

Apparatus:

- Shallow containers with lids
- Scale
- Heat source (hot plate, heat lamp or oven etc)
- Spatula
- Fan (optional)

Method:

1. Weigh a shallow container and record the weight
2. Place the soil from one of the sample containers in a shallow container
3. Place the shallow container on the heating element of the hot plate or in the oven. DO NOT OVERHEAT. Small pieces of paper mixed with the soil will act as an indicator and turn brown if overheated.
4. If heated on a hot plate, frequently turn the soil with a spatula during heating
5. Drying time will vary. (Check weighing should be done to determine the minimum drying time necessary.)
6. Remove the shallow container from the heat, cover and allow to cool
7. The container can be weighed as soon as it is cool enough to handle
8. Record this weight
9. Reheat cool and weigh the sample until the weight no longer changes.

Calculations:

The moisture content of a soil is expressed as a percentage of the dry mass:

moisture content, w = loss of moisture/dry mass x 100%

In the above example of soil density calculations, the wet mass was 1174.75g. Suppose that, after drying the soil, the mass was 1147.65gr. Moisture content can then be calculated by:

$$w = (\text{wet mass} - \text{dry mass})/\text{dry mass} \times 100\%$$

$$w = (1174.75g - 1147.65g)/1147.65g \times 100\%$$

$$w = 27.1g/1147.65g \times 100\%$$

$$w = 0.0236 \times 100\%$$

$$w = 2.36\%$$

Annex B – WORM Description

the CCMAT WORM system

In the test and evaluation of machines for demining applications, it is not always possible or desirable to use real mines, especially when collecting statistically significant amounts of data.

The CCMAT Wirelessly Operated Reproduction Mine (WORM) system is the latest development in a series of inert anti-personnel simulator targets for this type of testing. This system has been developed specifically to be compatible with the Performance Tests described in CEN Workshop Agreement CWA 15044 (available at www.itep.ws); the WORM system may be useful beyond the scope of the agreement. The CCMAT WORM has also been used to form the functional part (fuze) of an anti-tank mine simulator and could be used as part of a training system.

The CCMAT WORM system includes the following main components

- Target body components
- Target transmitter
- Receiver
- Antenna & cables
- User interface software
- Computer (supplied by user)

The CCMAT WORM target requires a force between 10kg and 15kg on the plunger to activate as specified in CWA 15044. Each target transmits a unique identification number 200 times for a total of 0.5 seconds when triggered If no message is received from a target in a particular trial, it must be excavated as it will either have been completely destroyed or left completely untouched. This is similar to testing using real landmines. Unless a target is mechanically damaged, it is completely reusable.

how it works

The CCMAT WORM system uses low-cost, low power radio transmitters to transmit a serial number associated with an individual target to indicate triggering. The system is available in two frequencies; a 433.92MHz version and a 315 MHz version. As the 433.92MHz version is more robust, it is recommended for use except where a different frequency is required due to interference with other equipment. The typical range from a buried target to the receiver is in excess of 25 meters.

limitations

The CCMAT WORM system is not intended for use by the general public. It is not a consumer-ready product, nor is it completely user friendly. It is expected that persons using the system will have a background in test and evaluation of mechanical equipment, especially relating to demining equipment.

When properly used by personnel familiar with testing mechanical equipment, the CCMAT WORM system provides useful performance data. It may not work in all circumstances.

materials & sources

Note: The sources listed below were used for a CCMAT purchase in the Fall of 2005. Some components may be available from other suppliers. CCMAT does not necessarily endorse these suppliers.

Individual WORM Targets

SER	Part	Supplier	Description
1	plastic bodies	Triplan AB Box 30 28070 Lönsboda SWEDEN Contact: Jonas Malm	Truppmina plastic parts to CCMAT specifications Part numbers 14391500 and 14401500
2	circuit boards	Automation Artisans 2335 Tanner Road Victoria, BC V8Z 5P8 CANADA Contact: John Dammeyer www.autoartisans.com	WORM transmitters 433.92 MHz or 315 MHz
3	plunger	emachineshop.com 666 Godwin Ave Midland Park, NJ United States	Injection molded plastic part Use same mold as job #: 160892 Machines: 686. Injection Mold Tool, 685. Injection Mold Run Material: Polycarbonate Color: RAL 5015 - Blue
4	sorbothane washer	McMaster-Carr PO Box 4355 Chicago, IL 60680-4355 United States	3/8" Sorbothane 12"x12" Durometer 50
5	sorbothane tip	McMaster-Carr	1/8" Sorbothane, 12"x12" Durometer 50
6	battery	www.digikey.com	CR2032 battery N189-ND
7	screws		self threading #6 x 3/8"

Receiver (quantity 1 required)

SER	Part	Supplier	Description
1	receiver	Automation Artisans	receiver module For 433.92 MHz: WORM-433RX-A (USB) For 315 MHz: WORM-315RX-A (serial)
2	antenna	Hutton Communications www.huttononline.com	Maxrad Yagi antenna For 433.92 MHz: Maxrad MYA4303N For 315 MHz: Maxrad MYA3003N
3	antenna cable	Hutton Communications	6' antenna cable SP42-72NMNM
4	notebook computer		433 MHz: requires a USB port 315 MHz: requires a serial port

Annex C – Ground Profile Evaluation – Techniques and Details

Ground Profile Evaluation

As noted, the information contained in ground profiles must be analyzed and presented in a way that is meaningful, easy to understand, and appropriate to the needs of demining operations. Topics to address include:

- whether the profiles should be evaluated across the entire width of the path or, like the mine targets, only in the centre 50% of the path;

- whether the analyses should focus on maximum depth, minimum depth, average depth, or some other measurement; and

- how the information can be presented in a logical, easily applied manner.

The discussion that follows addresses these questions, and comes to two basic definitions of how well a machine has fared in penetrating the ground. This is followed by a detailed analysis of each of the profiles measured in each of the tests, the summary of which is presented in the main body of this report.

Beyond the methods described herein, any number of other ways of evaluating the ground profile might be devised. A few possibilities were discussed among the ITEP team members, and while some offered certain advantages from a scientific-thoroughness point of view, none was very easy to translate into anything meaningful for a deminer.

Of course, this entire discussion is understood to be limited by the fact that only four sample profiles were taken in each test lane, rather than having a continuous, three dimensional map of the entire area. Still, each profile had up to 40 or more data points, so a single test lane could have around 160 individual depth measurements, so the data is not based on only four measurements.

Ground Profile Measurement Locations

While it has been established that this trial is not a CWA15044 performance test, the ITEP team still attempted to be consistent with the aims of CWA15044 wherever possible. CWA15044 specifies that only the centre 50% of the flail head width be used for laying out the target mines. There are two main reasons for this.

- If targets are located across the entire width of the tool, minute errors in steering can result in mines being missed by the machine. In this case, it is a combination of operator performance and machine performance that is measured rather than just machine performance.

- With flails, the edges of the cut are usually not straight, but rather are curved, or show a shoulder section as shown in Figure 29. Targets that lie very close to the edges of the flail will normally be processed by subsequent passes of the machine which are always overlapped to avoid missed areas and to ensure that this boundary condition does not create a skip zone. CWA15044 recognizes this and restricts the targets to the centre 50% of the flail width.

Figure 29. *Curved Edges of Flail Cut*

There is no similar directive relating to the use of fibreboards or other ways to measure ground profile. With the direct measurement of ground profile, as done during these trials, there is no concern with a steering error for ground profile measurements, but the rounded edges are still a legitimate concern. Whether the profiles should be measured across the full width of the cut, or only across the centre 50%, or perhaps across some other portion of the full width, was the subject of considerable discussion. One suggestion was that this should be based on the intended overlap of successive passes of the machine, but this will vary depending on the operator, the demining organization, the local conditions, and a number of other factors which are beyond the control of the ITEP team to establish.

Being unable to come to any other recommendation, the ITEP team decided to evaluate the entire profile and also the centre 50% and let the reader draw his or her own conclusions. Even this decision is loaded with subjectivity – one needs to determine exactly what the centre 50% band should be. It could be based on the widest of the four profiles, or the narrowest, or the published working width of the machine, or the measured width across the flail hammers, or perhaps some other definition. With no established guideline from CWA15044, the decision was taken, again to at least be consistent with the rule governing the placement of mine targets, to base the centre 50% width on the published working width of the flail head. The centre 50% band is located simply by measuring from the left edge of the cuts, or the 'zero' point on the profiles, despite the fact that some of the profiles are slightly wider or narrower than the others; in effect, the centre 50% band is not perfectly centred over each and every profile.

Similarly, a question could be asked about what full width should be used to evaluate the entire profile. For this case, it was decided to simply use the individual profiles, as cut. When measurements of the full width are needed, the arithmetic average of the four profiles for that lane would be used. The total widths cut on each profile can be taken from the tabulated data in Annex E.

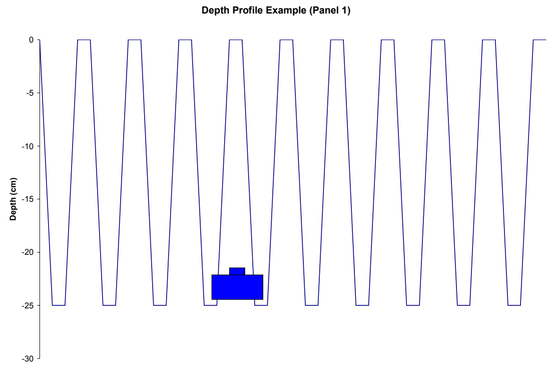
Maximum Effective Depth

When a machine such as a flail cuts consistently and uniformly down to a certain depth, one can be reasonably sure that the mines will at least be engaged by the hammers. In this case the condition of mine targets can be a useful indicator of what happens to the mines when engaged by the hammers. On the other hand, if the flail does not cut uniformly to the depth necessary to engage the mines, the condition of the mine targets is highly suspect, as described in Section 4.1, and the ground profile left by the flail hammers offers a more valuable measurement of machine performance. While it is quite easy to measure the ground profile, it is very difficult to quantify performance based on these measurements.

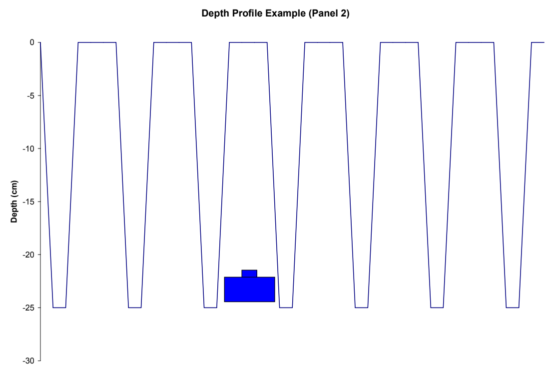
Consider the hypothetical ground profiles depicted in Figure 30. In each of these, a machine has failed to cut uniformly to a particular depth. In panel 1, the machine has left numerous skip zones, but none of them are wide enough to hide a mine. Panel 2 shows a similar cut but where mines could well be hidden in any of the skip zones. In panel 3 the machine has done well for most of the cut but has left a single skip zone capable of hiding mines. Finally, panel 4 shows a machine that has cut very deeply in places but which has left large areas cut to a much shallower depth. In each panel, a sample target mine is shown. Clearly, all four examples point to different levels of performance, but it is difficult to define which represents the best performance.

One way to quantify the performance based on ground profiles would be to simply read off the minimum depth achieved. In this case the first two panels would result in equal performance with effectively zero depth achieved. The third panel would achieve an effective depth of 10 cm, and the panel 4 would get a 1 cm rating. While this is simple, it may not be a particularly meaningful way to measure performance.

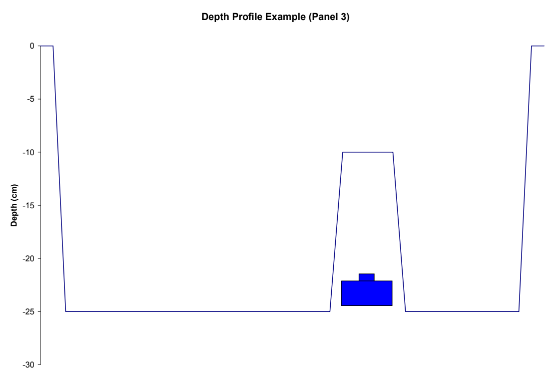
A second method might be to calculate the amount of soil that should have been removed and then to calculate the amount that remains. In panels 1, 2 and 3, the maximum depth appears to be 25 cm. If we assume a total width of 100 cm, then the total amount of soil that <u>should</u> have been removed (as seen in this profile view) would be 2500 cm^2. In panel 1, approximately 1250 cm^2 remains, so only 50% of the soil to 25 cm depth has been removed. Panel 2 is similar but only about 30% of the soil to 25 cm depth has been removed. In panel 3 about 90% of the soil to 25 cm depth has been removed, but fully 100% of the soil to 10 cm depth has been removed. The fourth panel could be evaluated in a similar way. As with the first method, this is relatively simple way to quantify the ground profiles, but again, it may not be very meaningful. Neither of these two methods gives any consideration to the possibility of mines being hidden in the surface irregularities.



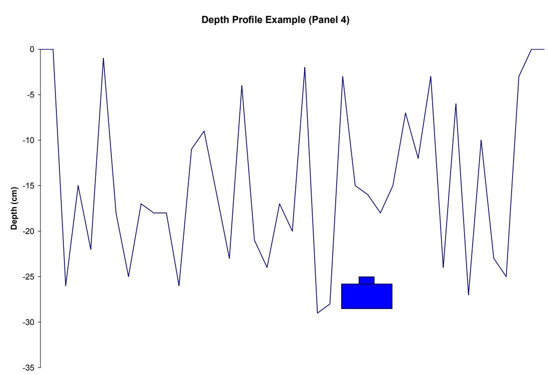
1.



2.



3.

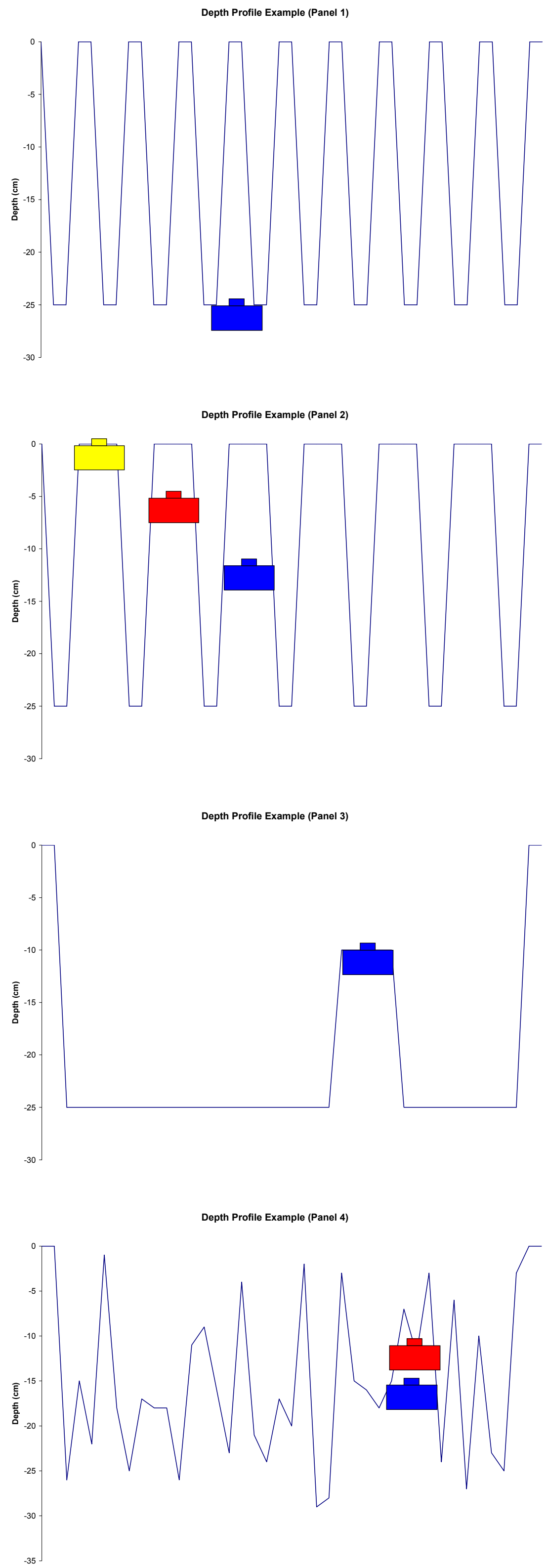


4.

Figure 30. *Hypothetical Ground profiles*

A third technique for measuring performance is to determine at which depth a mine could be hidden from the chains as shown in Figure 31. Using this technique, the profile in Panel 1 would be rated to a depth of 25 cm. Any mines above 25 cm depth of burial would be contacted by the chains and either triggered or damaged somehow. Below that depth, mines would escape the flail chains. Panel 2 shows three possibilities. The blue mine begins to peek out of the skip zone at about 12 cm DOB. The red mine has the corners exposed a little more at about 5 cm DOB, and the yellow one shows 0 cm DOB where most of the mine is still hidden but where the fuze is exposed. Which of these three depths one chooses will depend on whether one assumes damage to the mine will occur with only a small slice of the mine exposed. Panel 3 is a little easier to evaluate; the mine stays entirely hidden until the fuze pokes out at 10 cm DOB. Finally, in Panel 4, the blue mine begins to be exposed at about 15 cm DOB, but one might debate whether it would actually incur damage with only the corner exposed. Certainly the red mine at 11 cm DOB would likely be triggered or broken.

It was decided to show the profiles as measured and then to use the third technique – the minimum depth at which mines can be hidden in the remaining soil – to define the '**maximum effective depth**.' From the deminer's perspective, this was the most useful measure of performance; it allowed the deminer to be confident in the results down to that depth.



1.

2.

3.

4.

Figure 31. *Hypothetical Ground profiles – Technique 3*

Penetration Efficiency

The definition of maximum effective depth is easily understood and relevant to the deminer, but it may not tell the entire story. Consider the case where one machine had three perfectly smooth, consistent, uniform profiles, each measuring to 25 cm, and a fourth profile which was similar except for one 8 cm wide skip zone, 8 cm wide and 10 cm long that reached the surface. In this case the single skip zone reduces the maximum effective depth to 0 cm. Consider a second machine which had four uniformly poor profiles, in which there were no penetrations deeper than 3 cm and where most of the ground was not penetrated at all. This machine would also be considered to have a maximum effective depth of 0 cm. Using maximum effective depth in such a case may not accurately portray the two machines.

A second method for quantifying and presenting the profile information would be to look at how effectively the machine achieved ground penetration to a particular depth. The depth in question might be the depth at which mines were buried, or it could just as easily be a randomly selected depth of interest. The same method is applied in either case.

To illustrate this technique, consider the example case shown in Figure 32. In this example mine targets had been placed at 10 cm DOB, so the example will evaluate the penetration efficiency to that depth. In addition, for convenience, the analysis will be restricted to only the centre 50% band. The same procedure would be followed exactly to take the analysis to the full width, or to look at a different depth.

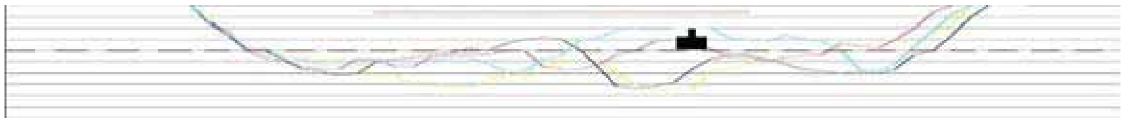
Each panel in Figure 32 shows the profiles as measured and also includes the outline of a WORM-type mine target (to scale) in the maximum effective depth location. In the first panel, only the maximum effective depth is shown.

- The second panel examines the profile taken at location 1, which is shown in yellow. In this case, the profile was deep enough all the way across the centre 50% band that no mines buried at 10 cm DOB would have escaped the flail hammers.

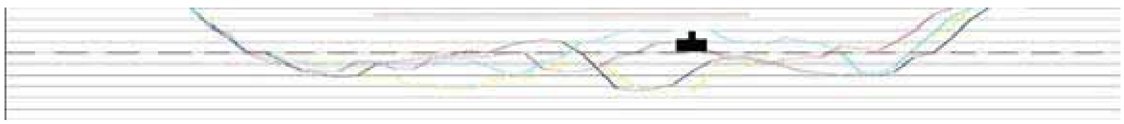
- Profile #2, shown in dark blue, is shown in the third panel. In this case there is an area where mines at 10 cm DOB might have been able to hide from the chains/hammers. One mine outline is shown at the left edge of this area and one at the right edge, with the arrow showing the complete width of the affected area.

- The light blue profile (#3) is shown next. In this case, there is also an area where 10 cm DOB mines could hide. The mine outline on the left is clear, and the one on the right partially overlaps the mine that shows maximum effective depth. Again, the arrow shows the width of the area.

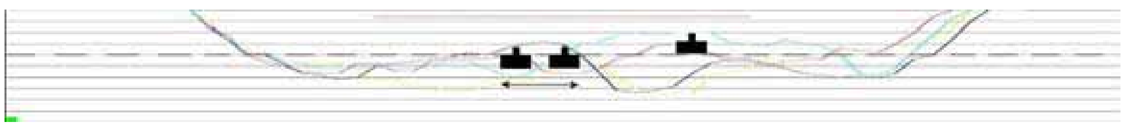
- Finally, the fourth profile is seen with the light purple line in the bottom panel of Figure 32. Again, two mine shapes and an arrow affected area.



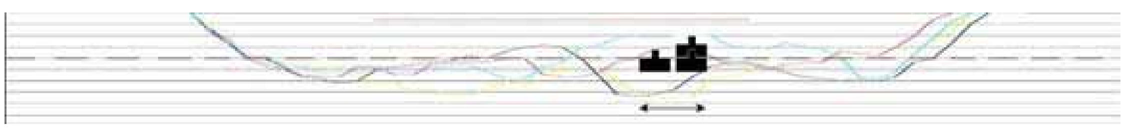
Maximum Effective Depth Only



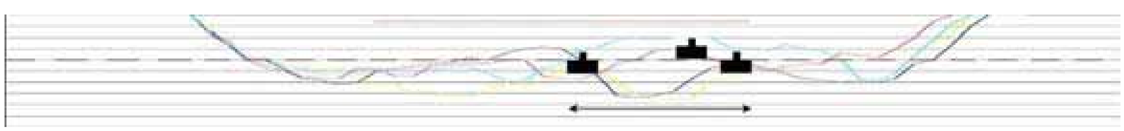
Profile 1



Profile 2



Profile 3



Profile 4

Figure 32. *Penetration Efficiency Example 10 cm*

The width of each of the areas of interest are measured and compared as shown in Table 17. In this case, the measurements are in pixels as taken from the digital images themselves but they could as well have been measured directly in metres, inches or any other convenient unit since the final values are not dependent on the units used.

*Table 17. Penetration Efficiency – Example – 10 cm (**Figure 32**)*

Profile #	***Centre 50% Band Width*** ***(pixels)***	***Missed Area Width*** ***(pixels)***	***Percentage of Width Missed*** ***(%)***
Profile 1	845	0	0%
Profile 2	845	177	21%
Profile 3	845	150	18%
Profile 4	845	409	48%
Overall Missed Width	3380	736	22%
PE_{10}=78%			

In the example of Figure 32 and Table 17, there was the possibility that mines at 10 cm DOB could have escaped the flail hammers across 22% of the centre band area. However, the machine in this test lane achieved sufficient ground penetration to ensure that, for 78% of the centre band, no WORM-type mine targets at 10 cm DOB would be missed. Hence PE_{10}=78% for this test lane.

Again, the same analysis could be done for the full width or for other depths of interest on this same set of profiles, and because the final rating is a percentage, it does not matter what units are used to measure the widths. Finally, it is possible, as will be seen in the following analyses, that there could be several areas where a given profile could hide mines at the depth of interest. In this case, the widths of the individual areas are simply added together to give the overall width of missed area in that profile.

Detailed Ground Profile Analyses

This section examines each of the profiles and presents the information in the following manner:

- The four sets of profile data for each test lane are graphed in an aspect ratio that allows the variations to show clearly. The individual measurements are given in Annex E.

- The set of four profiles are then shown at the correct aspect ratio, stretched as widely as possible to enlarge the detail as much as possible. This image includes an outline of a WORM target at the maximum effective depth point both for the centre 50% band and the full width case.

- The maximum effective depth location(s) is/are then shown enlarged to reveal the details of that location.

- The penetration effectiveness is then shown for each individual profile. For reference, these images also include the maximum effective depth indicator for that test lane.

The summary of these detailed analyses is given the main body of the report, under Section 4.3, and following.

Bozena-4, New Hammers 10 cm DOB

In this first test the Bozena-4 was set up with its full complement of 42 chains and hammers to meet the published working width of the FU2 flail head (2.225m). The width of the centre 50% band is therefore set to 1.11m. Photographs of the four ground profiles are shown in Figure 33.

For this test run, Figure 34 shows that, based on only the centre 50% of the flail width, the deepest depth to which the Bozena-4 penetrated consistently is approximately 5.5 cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only about 4 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 10 cm, as shown in Figure 35 for the centre 50% band and in Figure 36 for the full width case. Table 18 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 18. *Penetration Efficiency – Bozena-4, New Hammers, Mines at 10 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	941	725	77	1875	1588	85
Profile 2	941	240	26	1875	850	45
Profile 3	941	629	67	1791	1019	57
Profile 4	941	137	15	1875	838	45
Overall Missed	3764	1731	46	7416	4295	58
PE_{10}			54			42

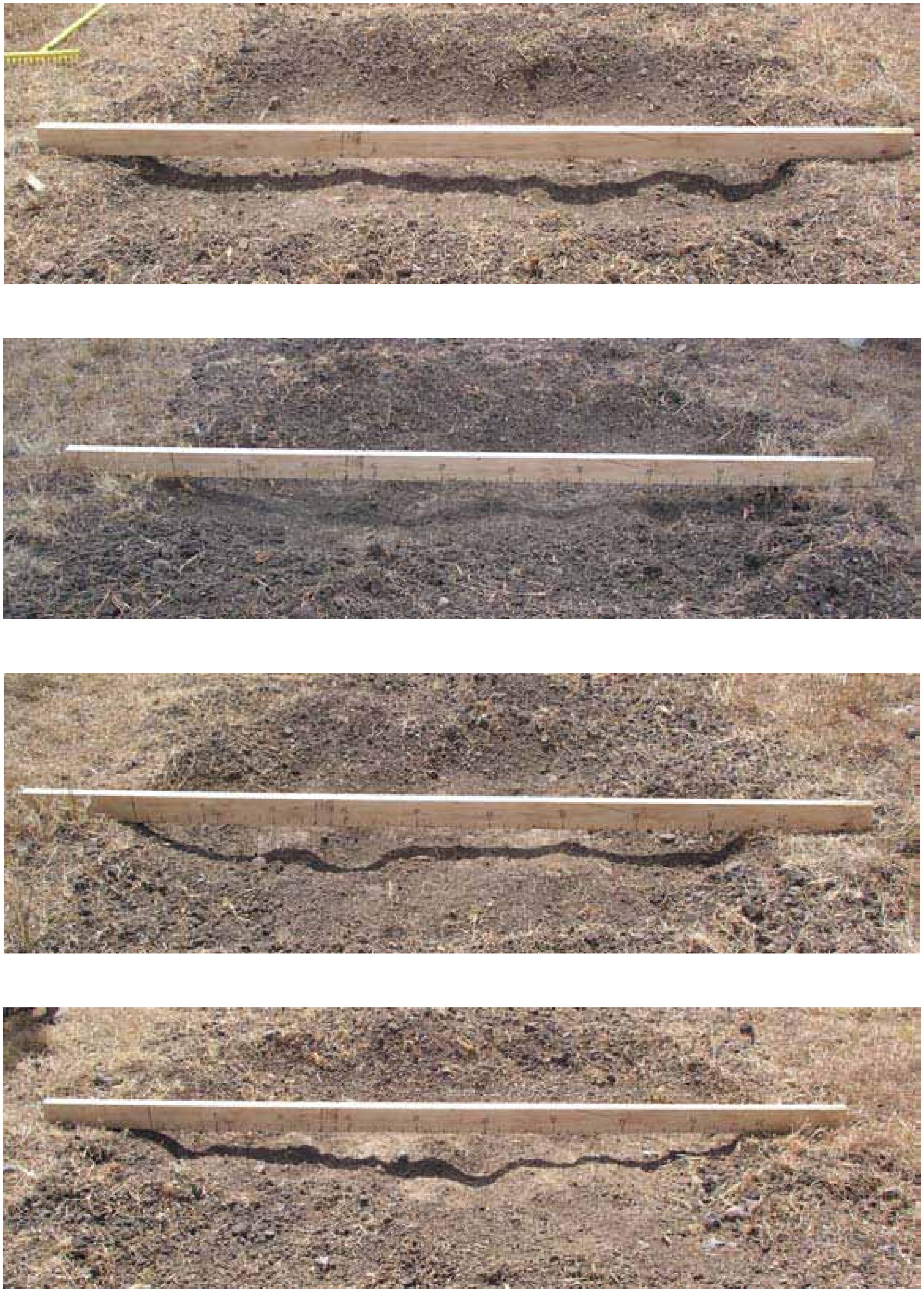


Figure 33. *Bozena-4 Ground Profile Photographs, New Hammers, Mines at 10 cm DOB*

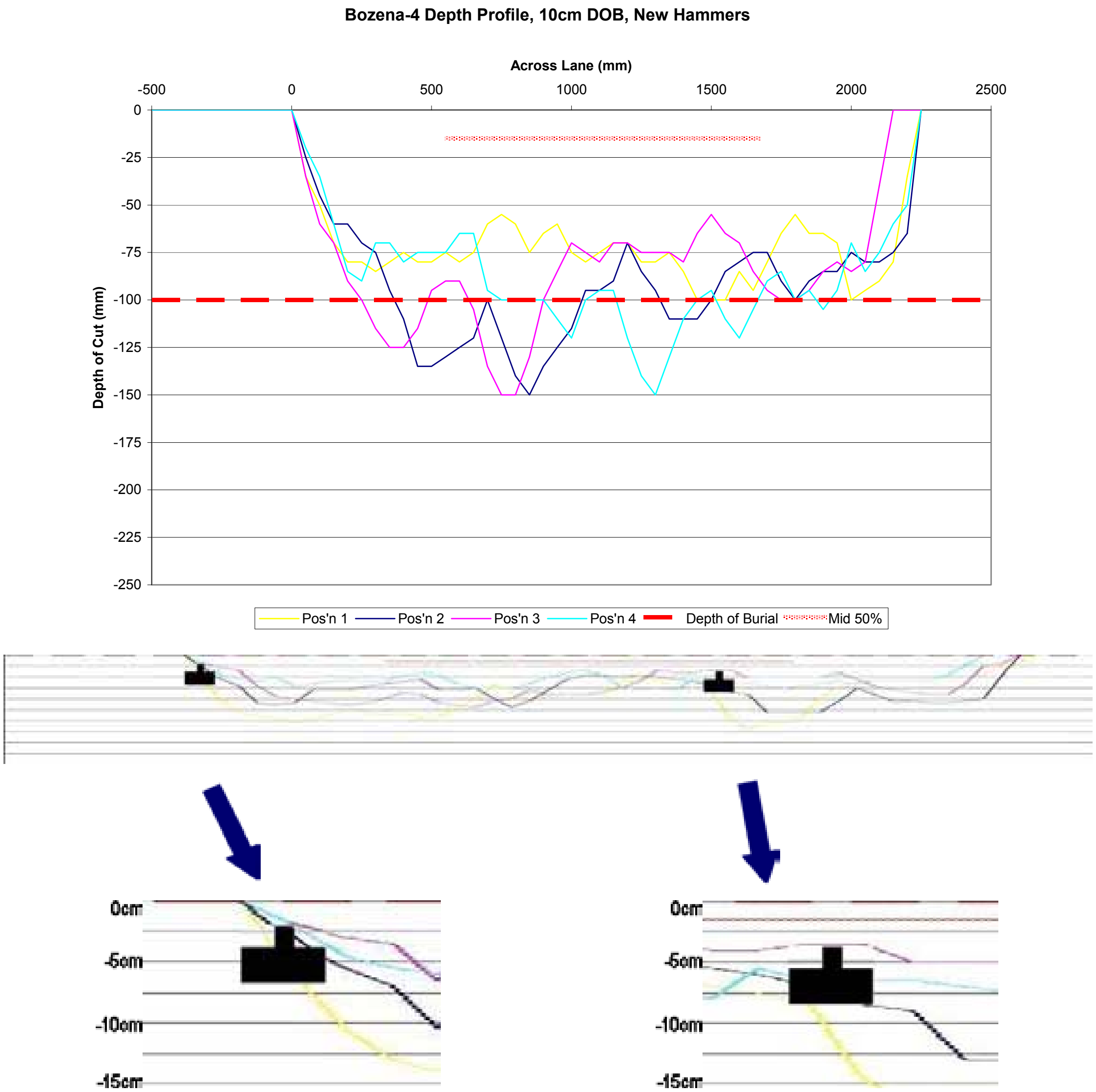
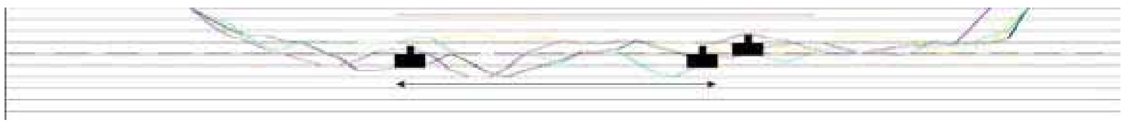
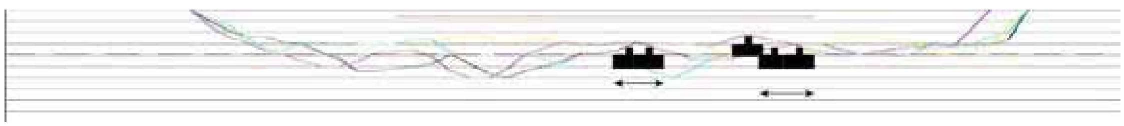


Figure 34. *Bozena-4 Ground profile, New Hammers, Mines at 10 cm DOB*

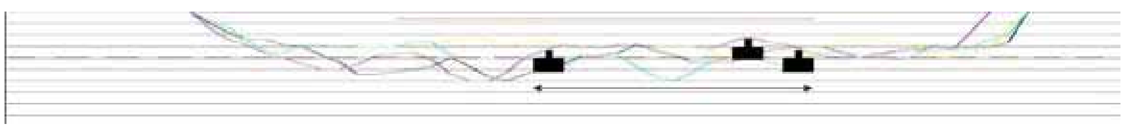
Maximum Effective Depth Only



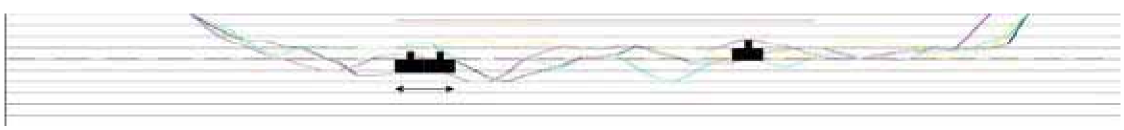
Profile 1



Profile 2



Profile 3

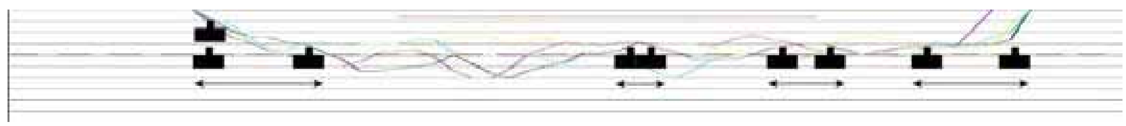


Profile 4

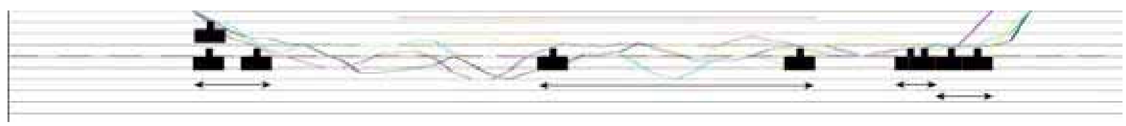
Figure 35. *Bozena-4, New Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Centre Band Only*

Maximum Effective Depth Only

Profile 1



Profile 2



Profile 3

Profile 4

Figure 36. *Bozena-4, New Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Full Width*

Bozena-4, New Hammers 15 cm DOB

As noted above, following the first test (10 cm, new hammers), the Bozena-4 team reduced the working width from 2.225m to 2.0m to match the published width of the FU1 flail head. This was accomplished by removing three chains/hammers from each end of the flail shaft. In this case the width of the centre 50% band is set to 1.0m. Photographs of the four ground profiles are shown in Figure 37.

For this test run, Figure 38 shows that, based on only the centre 50% of the flail width, the deepest depth to which the Bozena-4 penetrated consistently is approximately 8 cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only about 3.5 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 15 cm, as shown in Figure 39 for the centre 50% band and in Figure 40 for the full width case. Table 19 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 19. *Penetration Efficiency – Bozena-4, New Hammers, Mines at 15 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	846	201	24	1672	586	35
Profile 2	846	108	13	1753	781	45
Profile 3	846	811	96	1710	1646	96
Profile 4	846	846	100	1710	1710	100
Overall Missed	3384	1966	58	6845	4723	69
PE_{15}			42			31

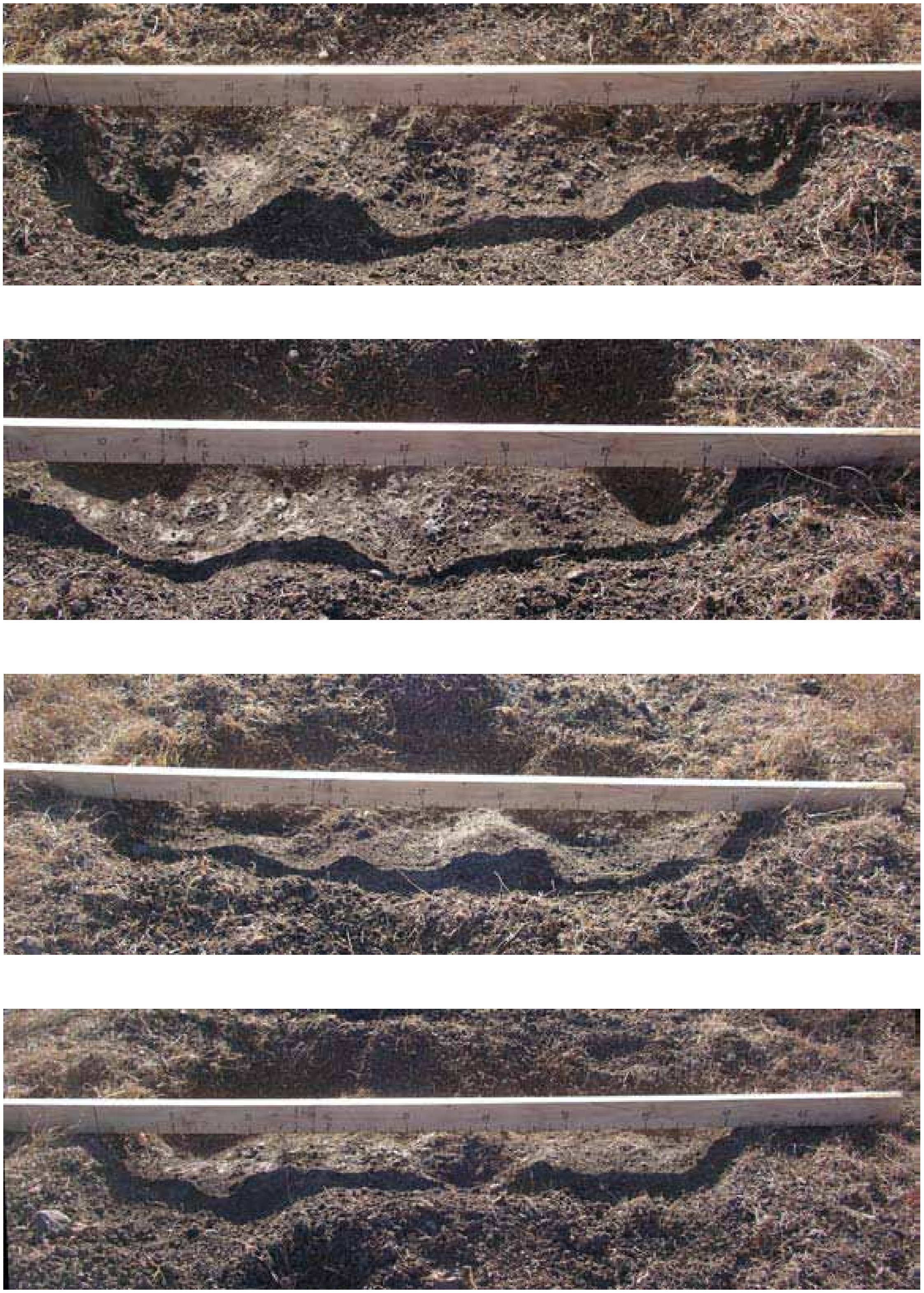


Figure 37. *Bozena-4 Ground Profile Photographs, New Hammers, Mines at 15 cm DOB*

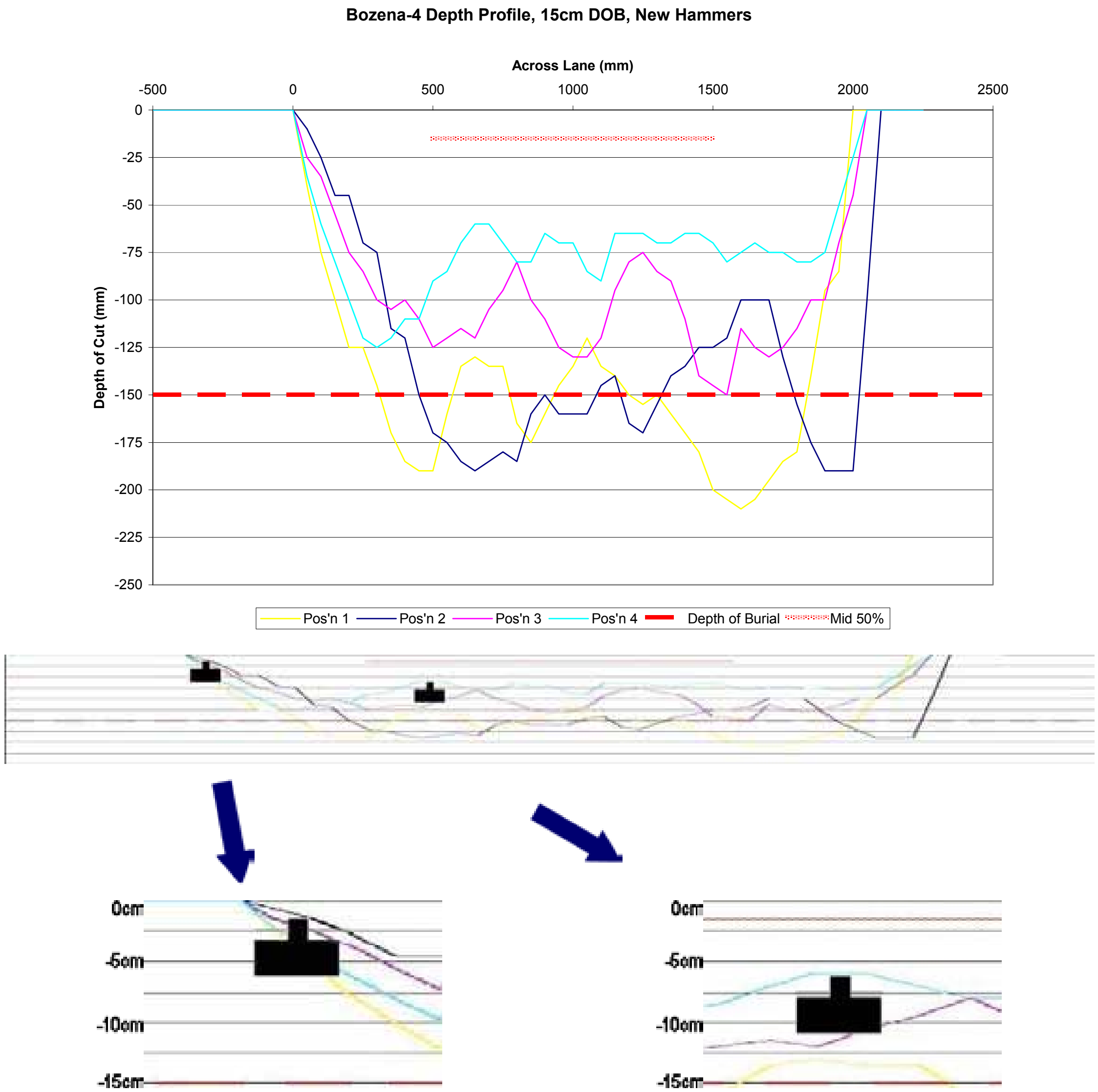
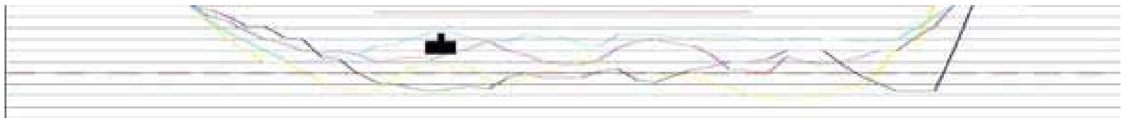
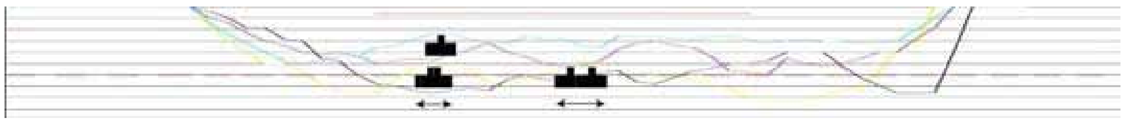


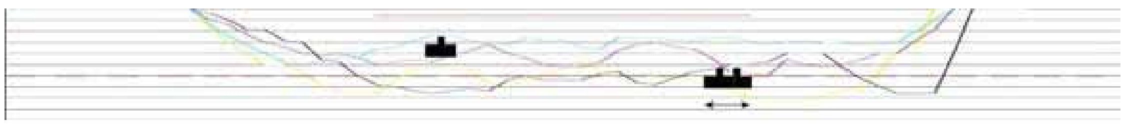
Figure 38. *Bozena-4 Ground profile, New Hammers, Mines at 15 cm DOB*



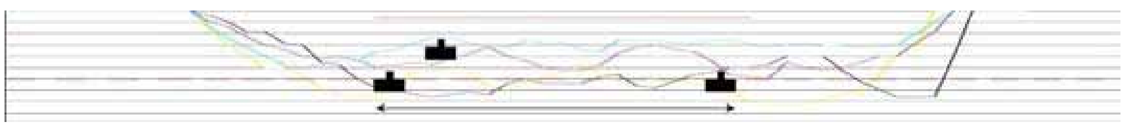
Maximum Effective Depth Only



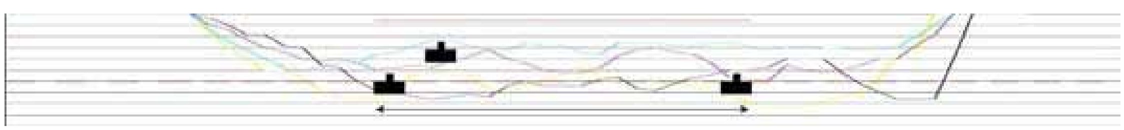
Profile 1



Profile 2

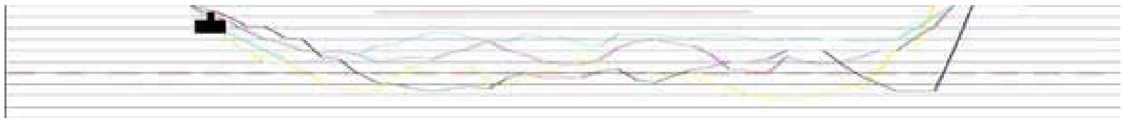


Profile 3

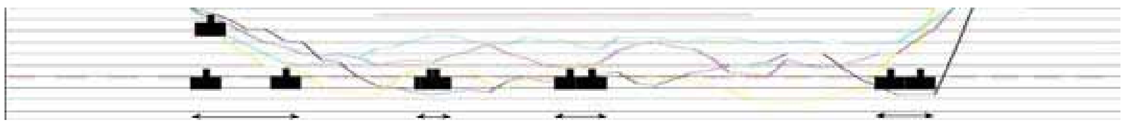


Profile 4

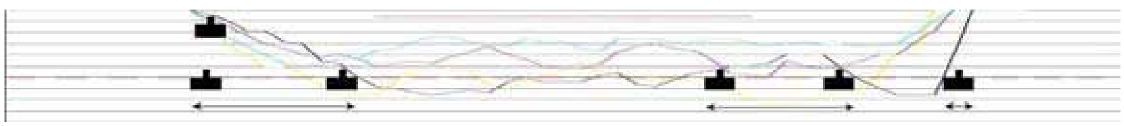
Figure 39. *Bozena-4, New Hammers, Mines at 15 cm DOB, Penetration Efficiency at 15 cm, Centre Band Only*



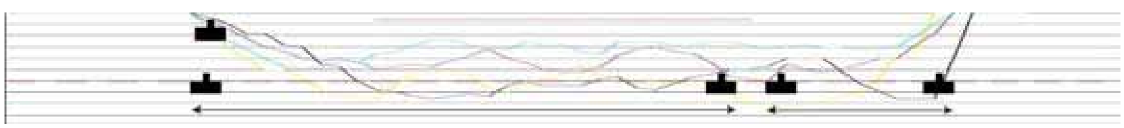
Maximum Effective Depth Only



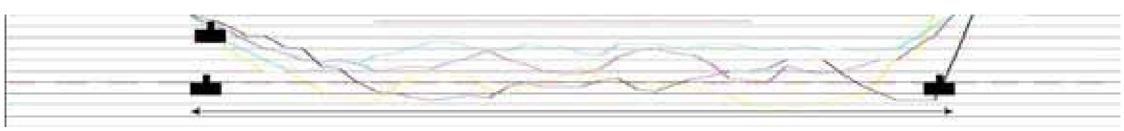
Profile 1



Profile 2



Profile 3



Profile 4

Figure 40. *Bozena-4, New Hammers, Mines at 15 cm DOB, Penetration Efficiency at 15 cm, Full Width*

Bozena-4, Worn Hammers 10 cm DOB

In this test, the flail width was maintained at 2.0m with 36 chains. This test used the hammers which had been artificially worn by cutting/grinding. Photographs of the four ground profiles are shown in Figure 41.

For this test run, Figure 42 shows that, based on only the centre 50% of the flail width, the deepest depth to which the Bozena-4 penetrated consistently is approximately 7 cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only 4.5 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 10 cm, as shown in Figure 43 for the centre 50% band and in Figure 44 for the full width case. Table 20 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 20. *Penetration Efficiency – Bozena-4, Worn Hammers, Mines at 10 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	845	0	0	1749	323	18
Profile 2	845	177	21	1788	447	25
Profile 3	845	150	18	1705	446	26
Profile 4	845	409	48	1749	870	50
Overall Missed	3380	736	22	6991	2086	30
PE_{10}			78			70

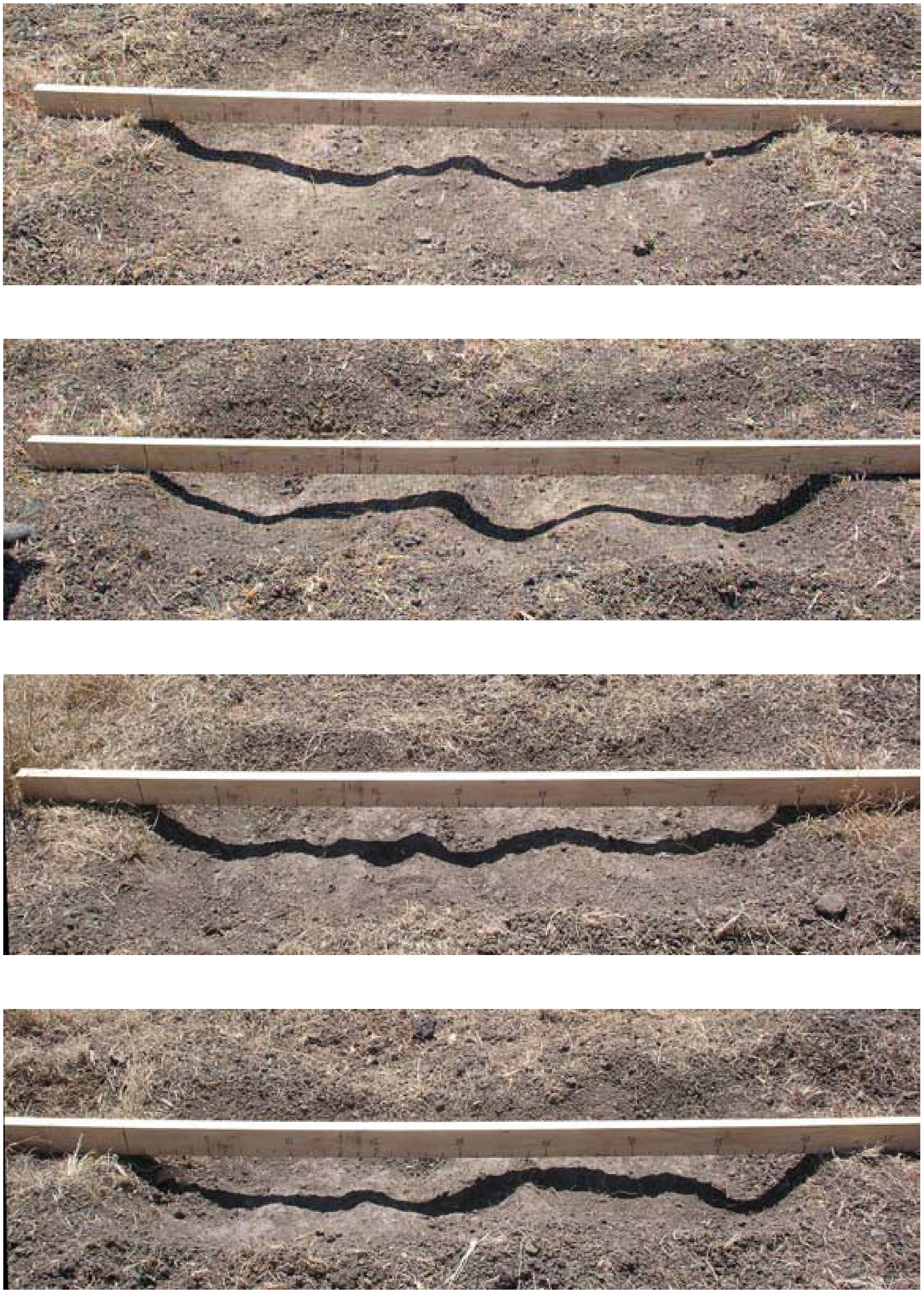


Figure 41. *Bozena-4 Ground Profile Photographs, Worn Hammers, Mines at 10 cm DOB*

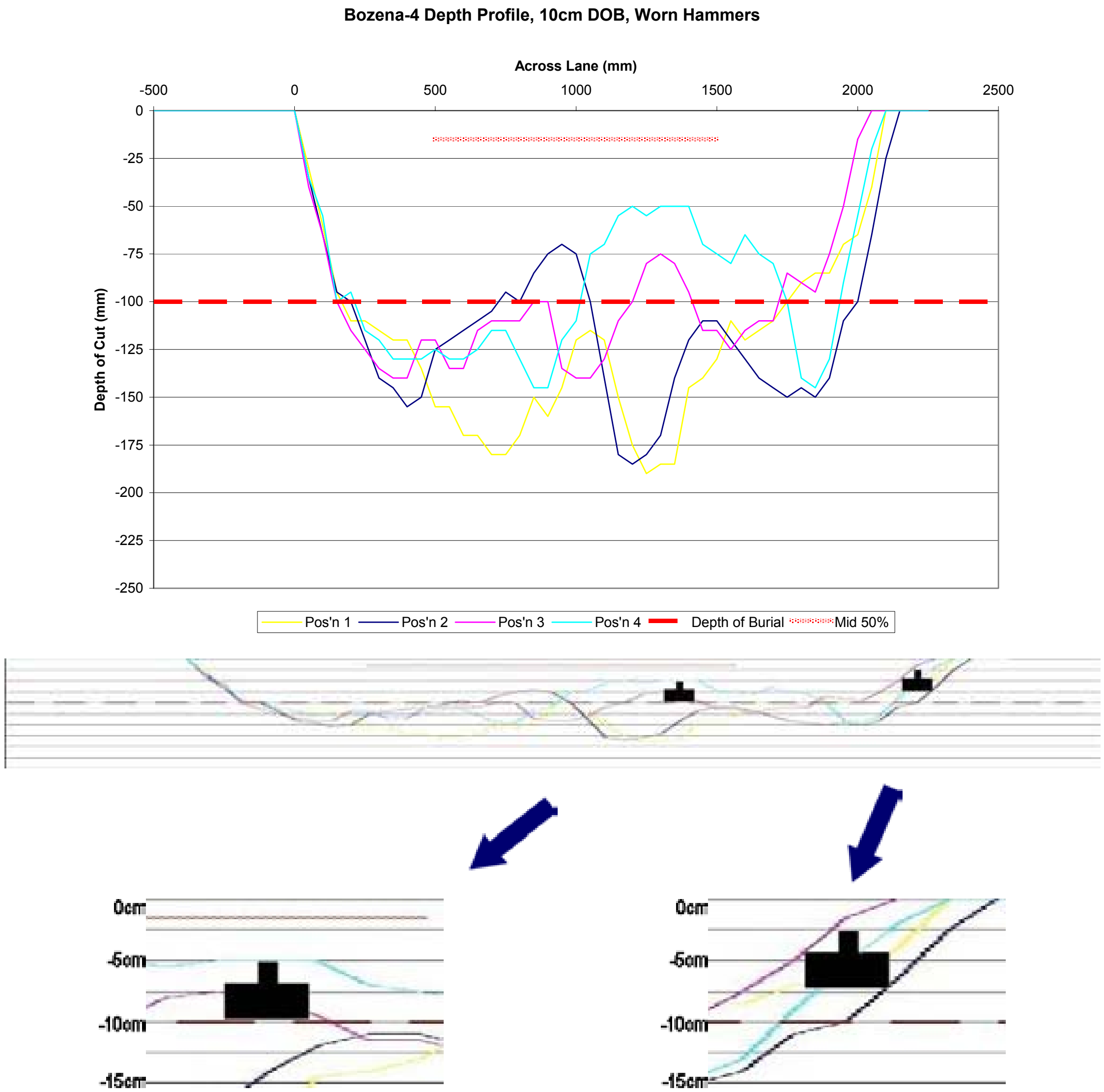
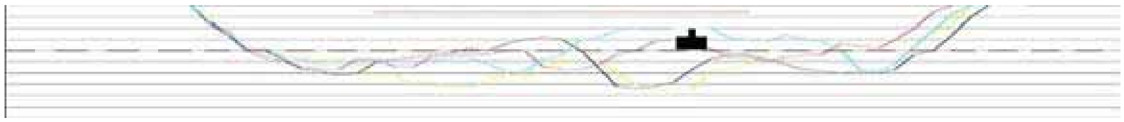
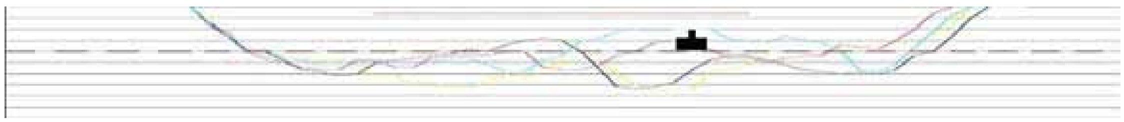


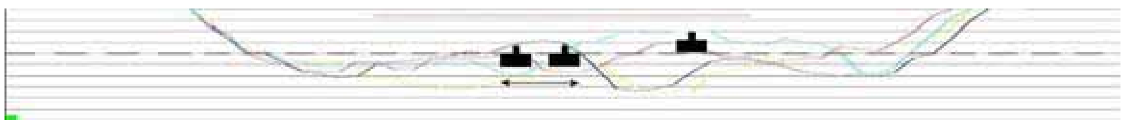
Figure 42. *Bozena-4 Ground profile, Worn Hammers, Mines at 10 cm DOB*



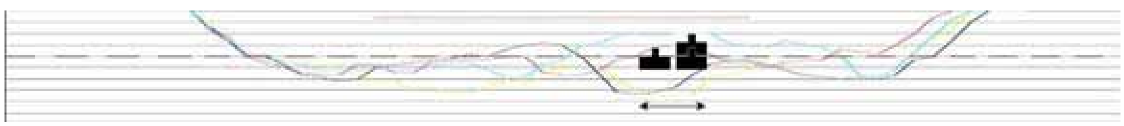
Maximum Effective Depth Only



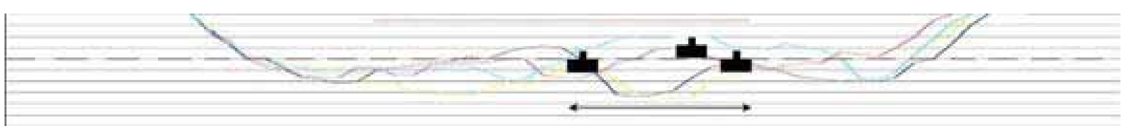
Profile 1



Profile 2

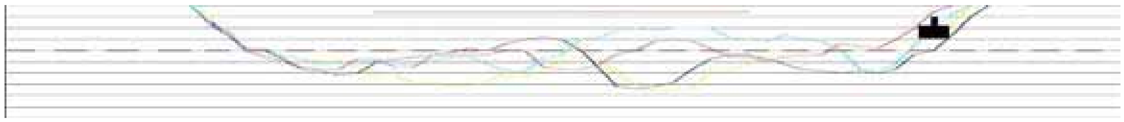


Profile 3

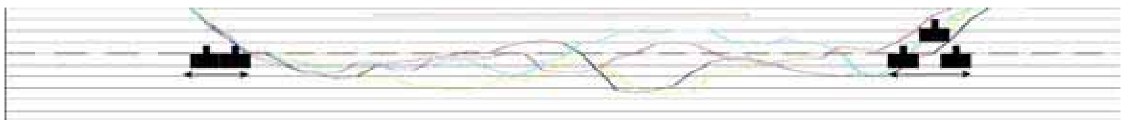


Profile 4

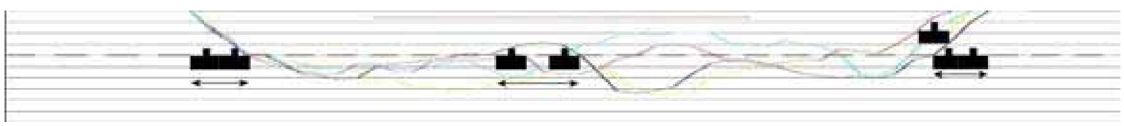
Figure 43. *Bozena-4, Worn Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Centre Band Only*



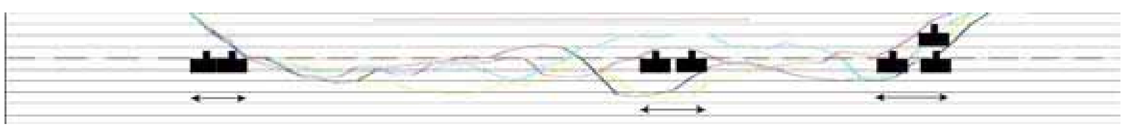
Maximum Effective Depth Only



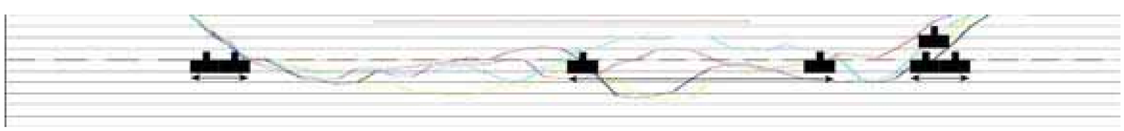
Profile 1



Profile 2



Profile 3



Profile 4

Figure 44. *Bozena-4, Worn Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Full Width*

Bozena-4, No Hammers 10 cm DOB

In this test the Bozena-4 retained the set of 36 chains, having cut off the machined hammers. Photographs of the four ground profiles are shown in Figure 45.

For this test run, Figure 46 shows that, based on only the centre 50% of the flail width, the deepest depth to which the Bozena-4 penetrated consistently is approximately 3.5 cm DOB (measured, as always, to the top of the mine body). In this test, the shoulder regions would not provide any more shelter for the mine targets, and the full-width effective depth is also about 3.5 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 10 cm, as shown in Figure 47 for the centre 50% band and in Figure 48 for the full width case. Table 21 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 21. *Penetration Efficiency – Bozena-4, No Hammers, Mines at 10 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	845	845	100	1663	1663	100
Profile 2	845	845	100	1663	1663	100
Profile 3	845	845	100	1579	1579	100
Profile 4	845	845	100	1703	1703	100
Overall Missed	3380	3380	100	6608	6608	100
PE_{10}			0			0

Figure 45. *Bozena-4 Ground Profile Photographs, No Hammers, Mines at 10 cm DOB*

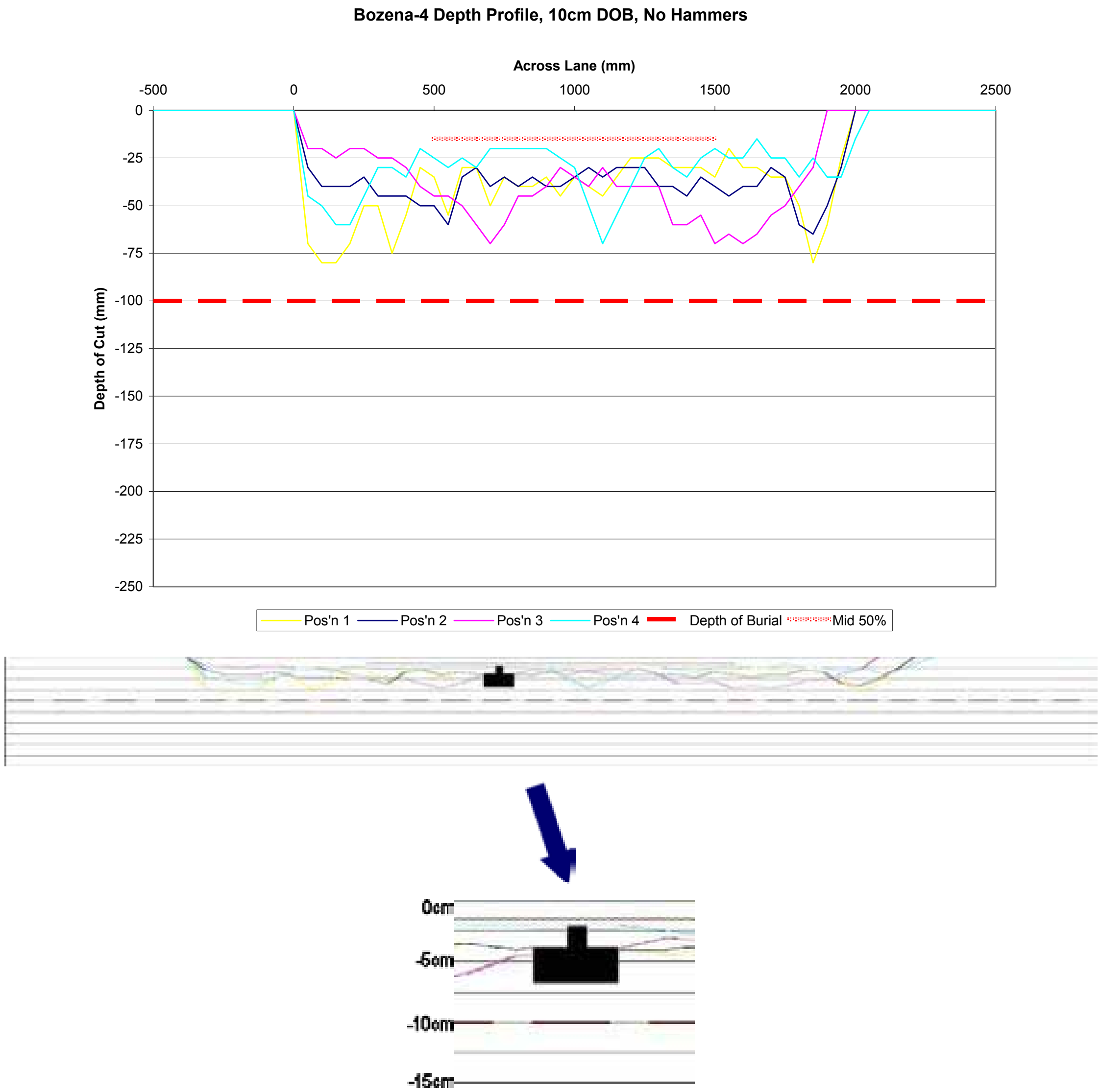
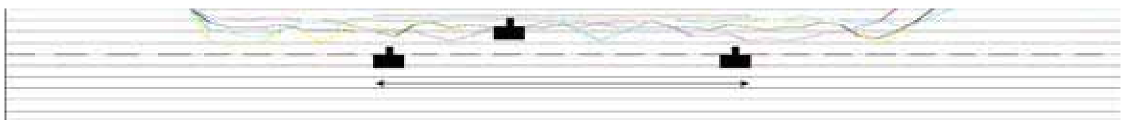


Figure 46. *Bozena-4 Ground profile, No Hammers, Mines at 10 cm DOB*

Maximum Effective Depth Only

Profile 1



Profile 2

Profile 3

Profile 4

Figure 47. *Bozena-4, No Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Centre Band Only*

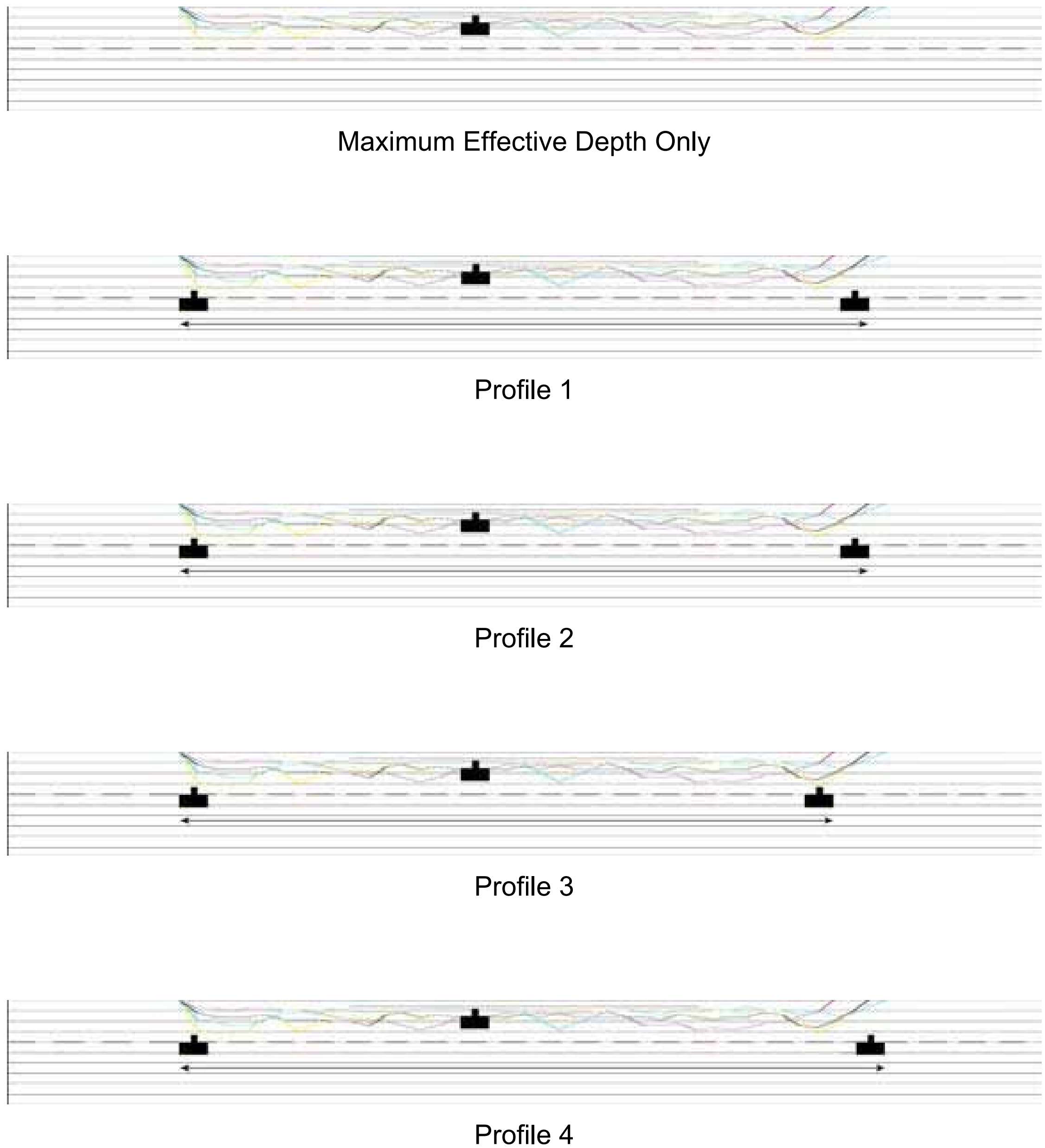


Figure 48. *Bozena-4, No Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Full Width*

Bozena-4, New Hammers 0 cm DOB

In this test the Bozena-4 team used 40 chain/hammers, for an approximate width of 2.15m. This is beyond the width of the FU1 flail head so the width of the FU2 head (2.225m) is used in calculating the width of the centre 50%

band (1.11m). Photographs of the four ground profiles are shown in Figure 49.

For this test run, Figure 50 shows that, based on only the centre 50% of the flail width, the deepest depth to which the Bozena-4 penetrated consistently is approximately 6 cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only about 3.5 cm DOB.

It bears repeating that penetration efficiency can be evaluated at any depth of interest, and not only at a depth where mine targets have been placed. Any machine, no matter how good or poor, will be able to achieve a penetration efficiency of 100% for a depth of 0 cm. All the machine needs to do is pass over the area and it will have managed to dig to 0 cm. For this trivial case then, PE_0=100% for both the full width case and the centre 50% band. To give a more meaningful evaluation, the penetration efficiency will be evaluated at 5 cm DOB. Note that the manufacturers knew that the mine targets were at the surface in this test, and so they did not attempt to dig deeply on this run; thus, it would not be reasonable to evaluate penetration efficiency on this run for deeper burials.

The four profiles are evaluated for penetration effectiveness values for a depth of 5 cm, as shown in Figure 51 for the centre 50% band and in Figure 52 for the full width case. Table 22 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 22. *Penetration Efficiency – Bozena-4, New Hammers, Mines at 0 cm DOB (PE_5)*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	941	0	0	1959	114	6
Profile 2	941	0	0	1916	70	4
Profile 3	941	0	0	1916	234	12
Profile 4	941	0	0	1831	170	9
Overall Missed	3764	0	0	7622	588	8
PE_5			100			92

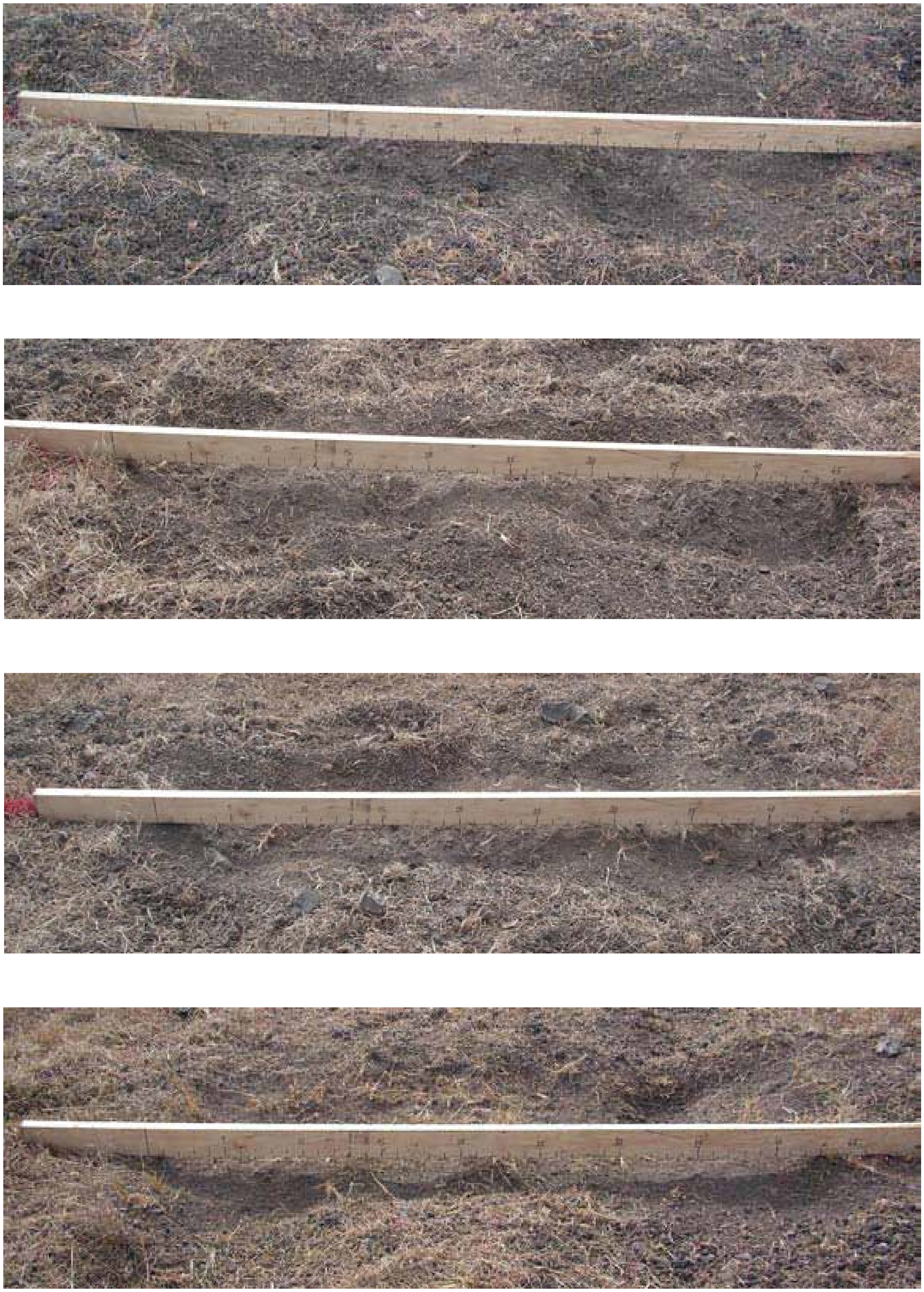


Figure 49. *Bozena-4 Ground profile Photographs, New Hammers, Mines at 0 cm DOB*

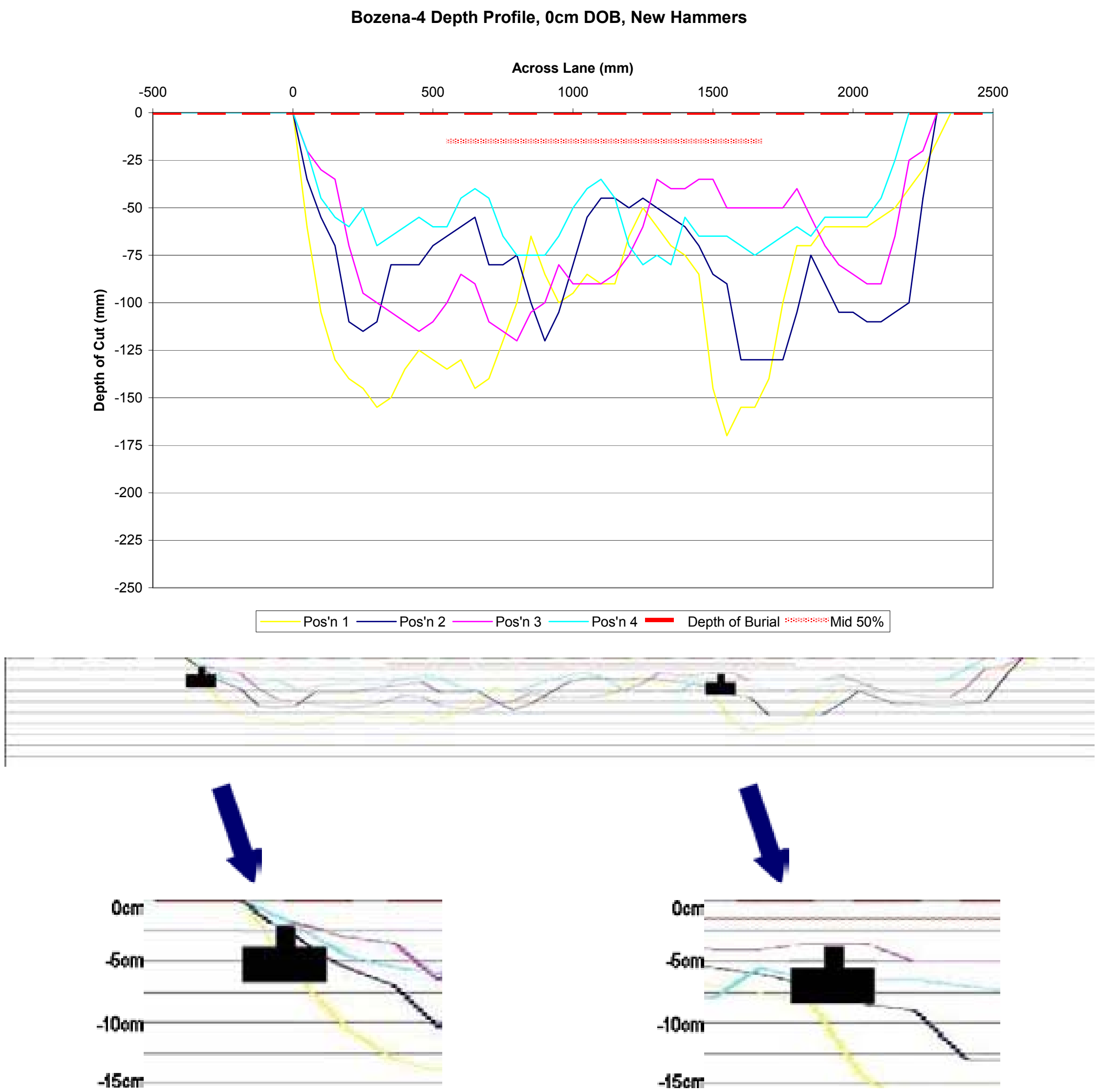
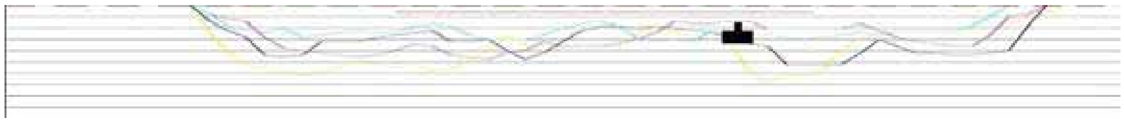
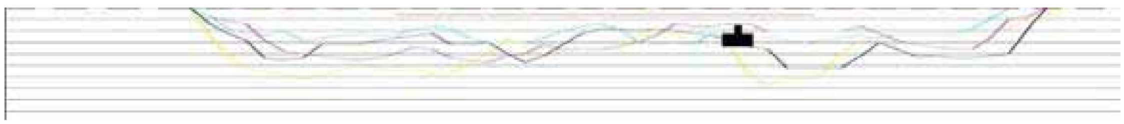


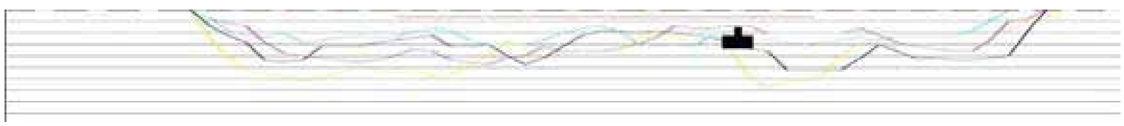
Figure 50. *Bozena-4 Ground profile, New Hammers, Mines at 0 cm DOB*



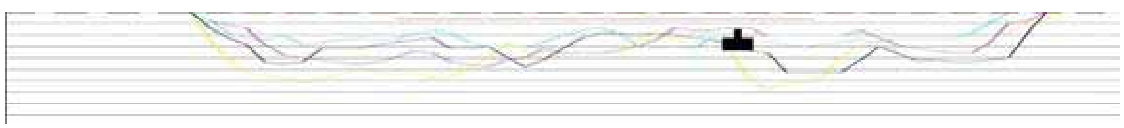
Maximum Effective Depth Only



Profile 1



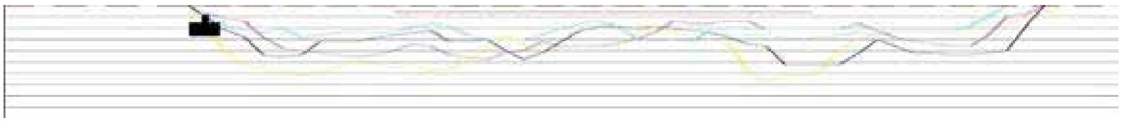
Profile 2



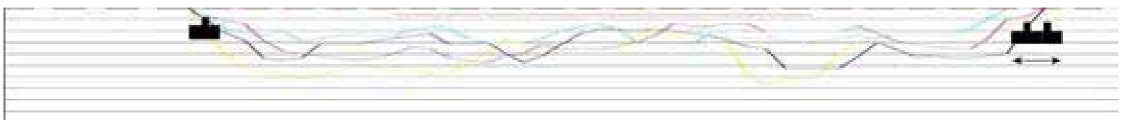
Profile 3

Profile 4

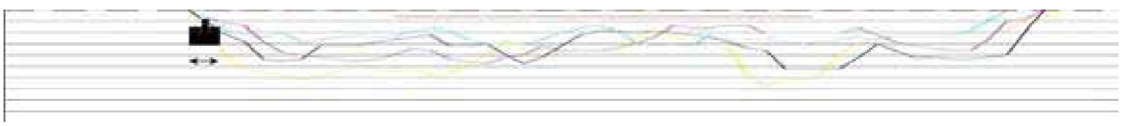
Figure 51. *Bozena-4, New Hammers, Mines at 0 cm DOB, Penetration Efficiency at 5 cm, Centre Band Only*



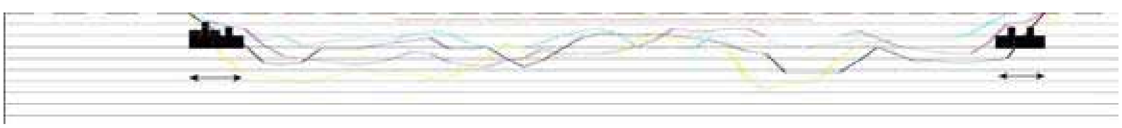
Maximum Effective Depth Only



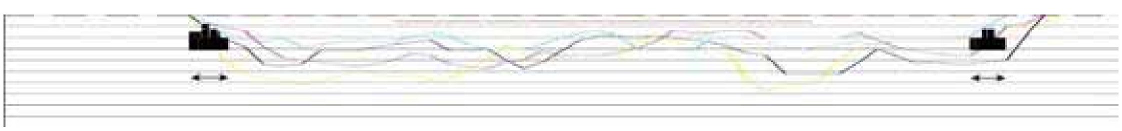
Profile 1



Profile 2



Profile 3



Profile 4

Figure 52. *Bozena-4, New Hammers, Mines at 0 cm DOB, Penetration Efficiency at 5 cm, Full Width*

MV-4, New Hammers 10 cm DOB

In all of the tests the MV-4 was equipped with its full set of chains for an overall width of 1.725m. The width of the centre 50% band is therefore set at 0.86m. Photographs of the four ground profiles are shown in Figure 53.

For this test run, Figure 54 shows that, based on only the centre 50% of the flail width, the deepest depth to which the MV-4 penetrated consistently is approximately 4 cm DOB (measured, as always, to the top of the mine body). In this test, the shoulder regions would not provide any more shelter for the mine targets, and the full-width effective depth is also about 4 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 10 cm, as shown in Figure 55 for the centre 50% band and in Figure 56 for the full width case. Table 23 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 23. *Penetration Efficiency – MV-4, New Hammers, Mines at 10 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	728	0	0	1414	447	32
Profile 2	728	70	10	1457	308	21
Profile 3	728	349	48	1457	1036	71
Profile 4	728	641	88	1414	1323	94
Overall Missed	2912	1060	36	5742	3114	54
PE_{10}			64			46

Figure 53. *MV-4 Ground Profile Photographs, New Hammers, Mines at 10 cm DOB*

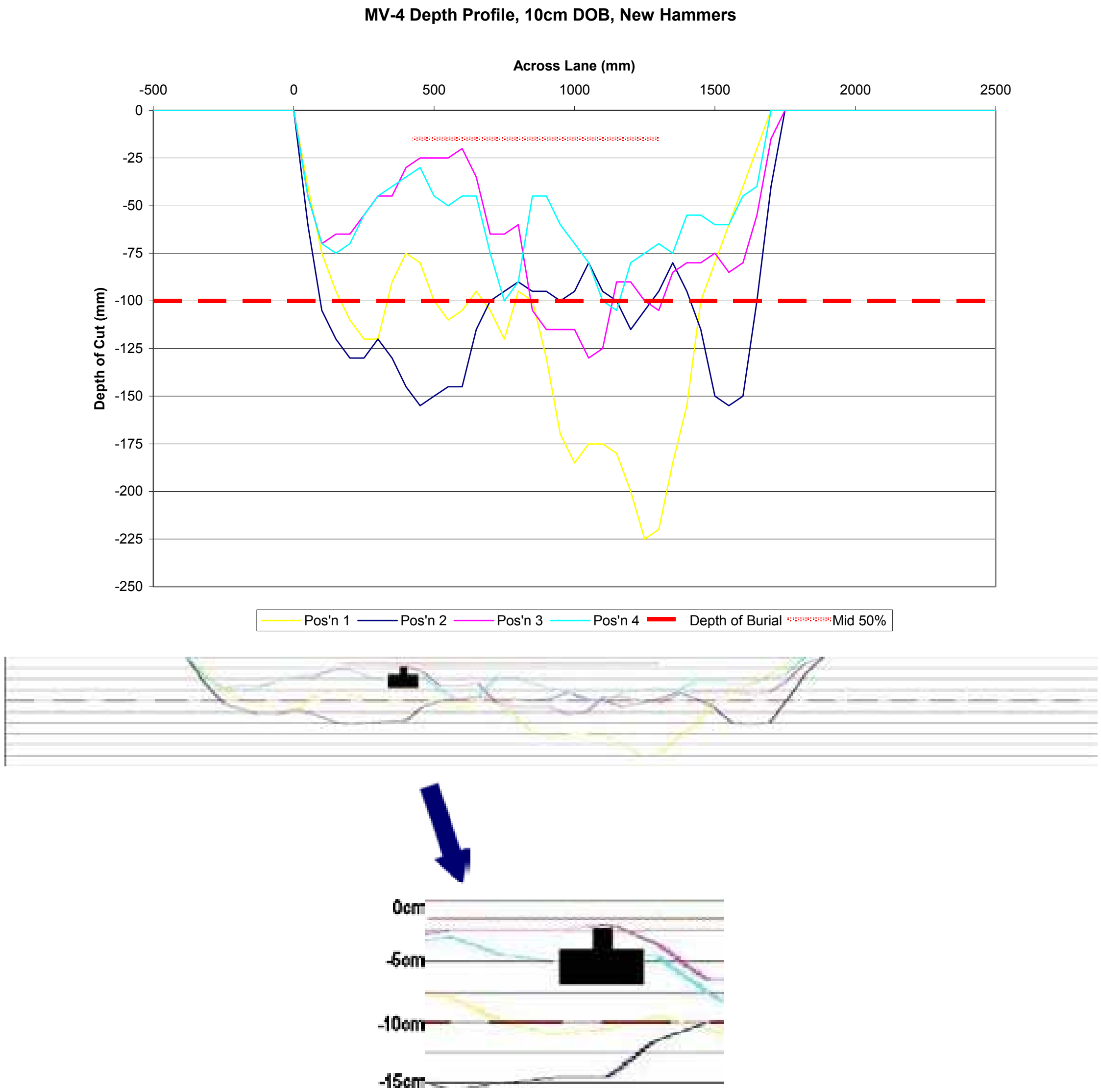
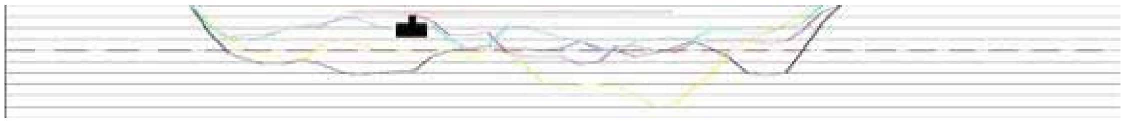
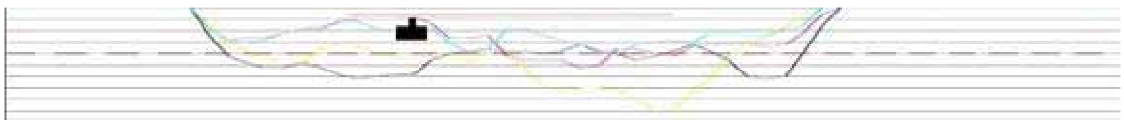


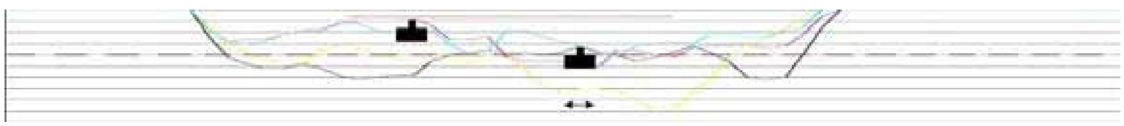
__Figure 54.__ MV-4 Ground profile, New Hammers, Mines at 10 cm DOB



Maximum Effective Depth Only

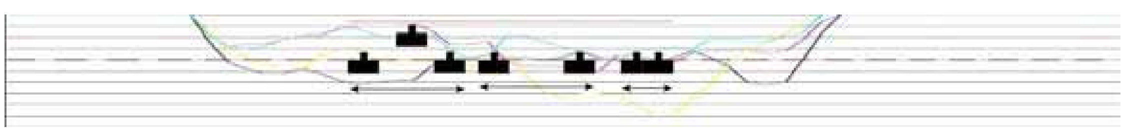


Profile 1



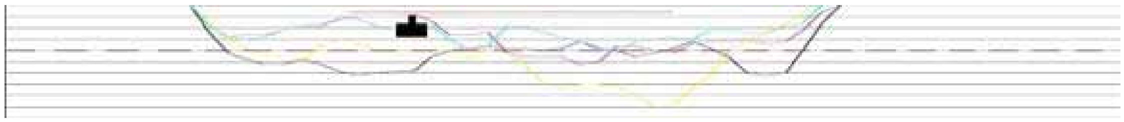
Profile 2

Profile 3



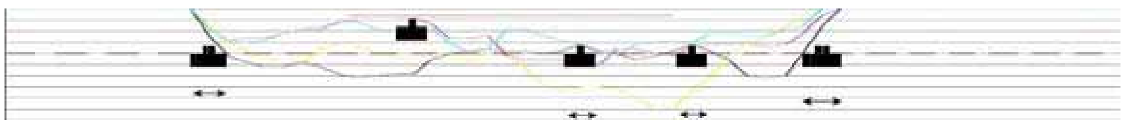
Profile 4

Figure 55. *MV-4, New Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Centre Band Only*



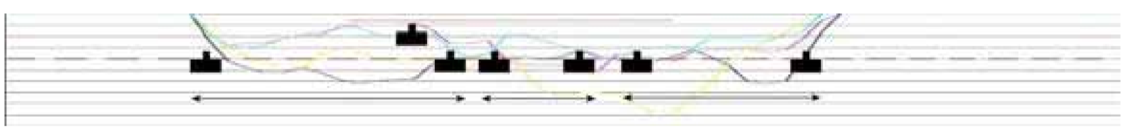
Maximum Effective Depth Only

Profile 1



Profile 2

Profile 3



Profile 4

Figure 56. *MV-4, New Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Full Width*

MV-4, New Hammers 15 cm DOB

Photographs of the four ground profiles for this run are shown in Figure 57. Figure 58 shows that, based on only the centre 50% of the flail width, the deepest depth to which the MV-4 penetrated consistently is approximately

11.5 cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only about 3.5 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 15 cm, as shown in Figure 59 for the centre 50% band and in Figure 60 for the full width case. Table 24 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 24. *Penetration Efficiency – MV-4, New Hammers, Mines at 15 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	729	133	18	1457	476	33
Profile 2	729	412	57	1416	1055	75
Profile 3	729	467	64	1416	600	42
Profile 4	729	95	13	1457	670	46
Overall Missed	2916	1107	38	5746	2801	49
PE_{15}			62			51

Figure 57. *MV-4 Ground Profile Photographs, New Hammers, Mines at 15 cm DOB*

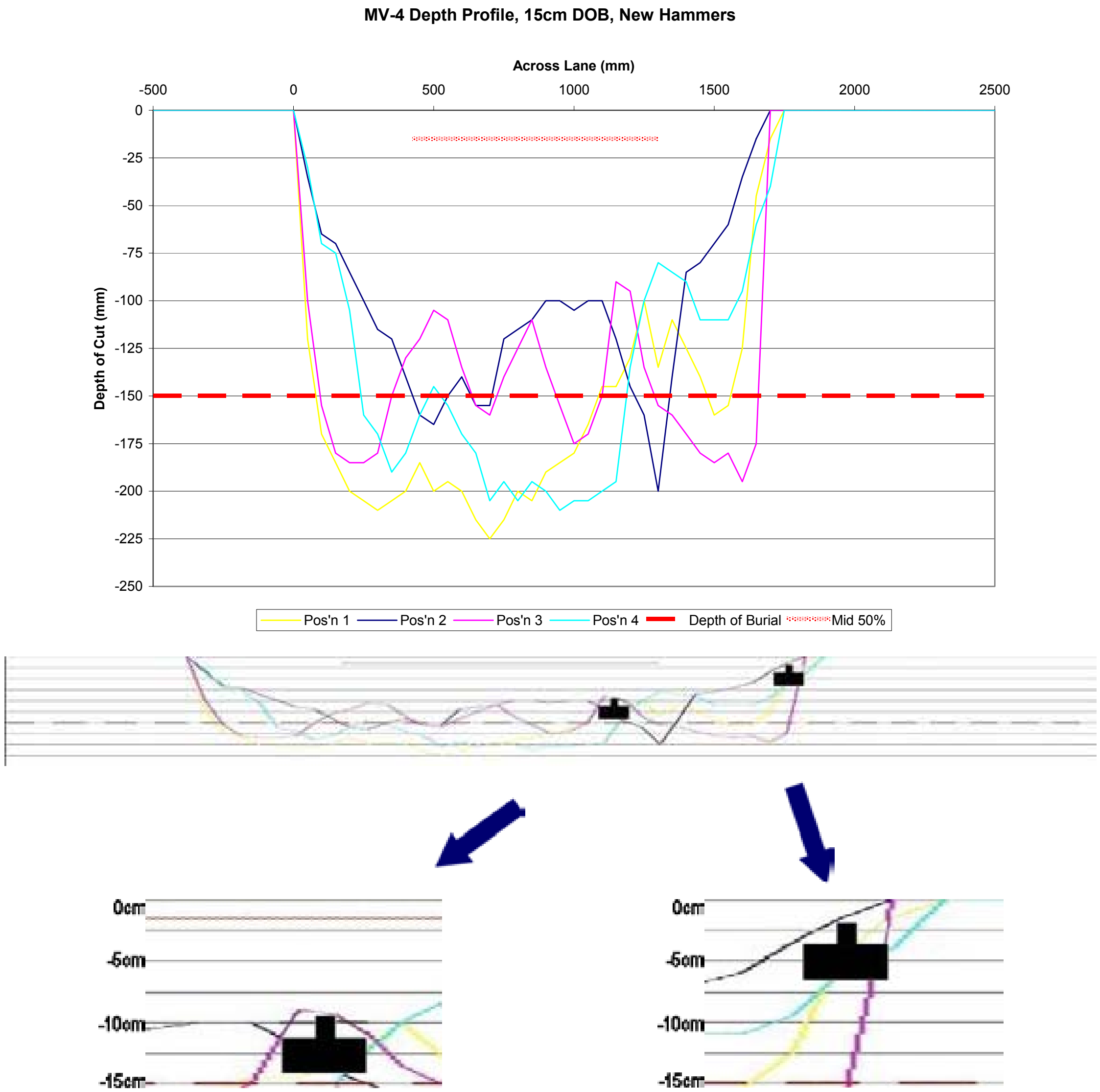
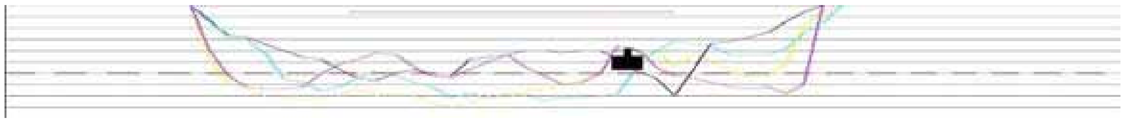
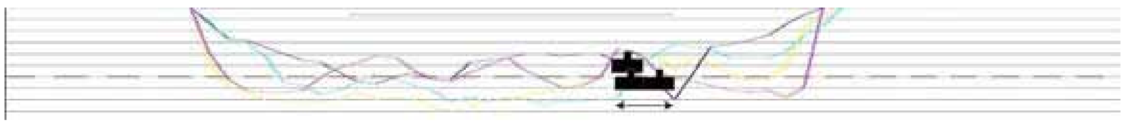


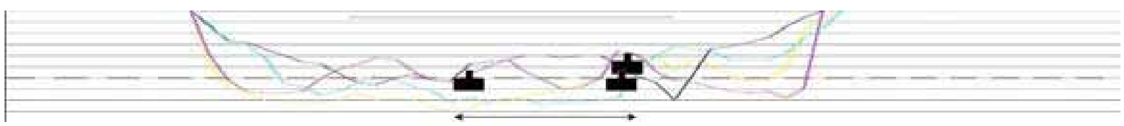
Figure 58. *MV-4 Ground profile, New Hammers, Mines at 15 cm DOB*



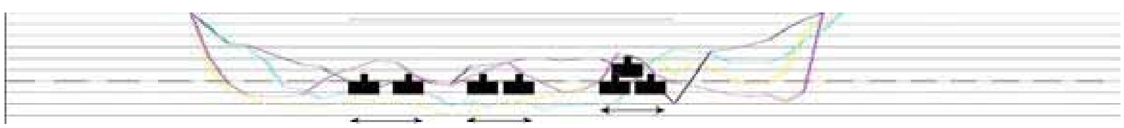
Maximum Effective Depth Only



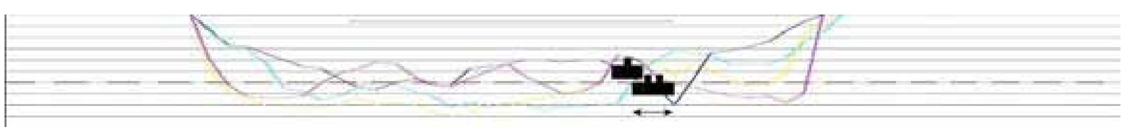
Profile 1



Profile 2



Profile 3



Profile 4

Figure 59. *MV-4, New Hammers, Mines at 15 cm DOB, Penetration Efficiency at 15 cm, Centre Band Only*

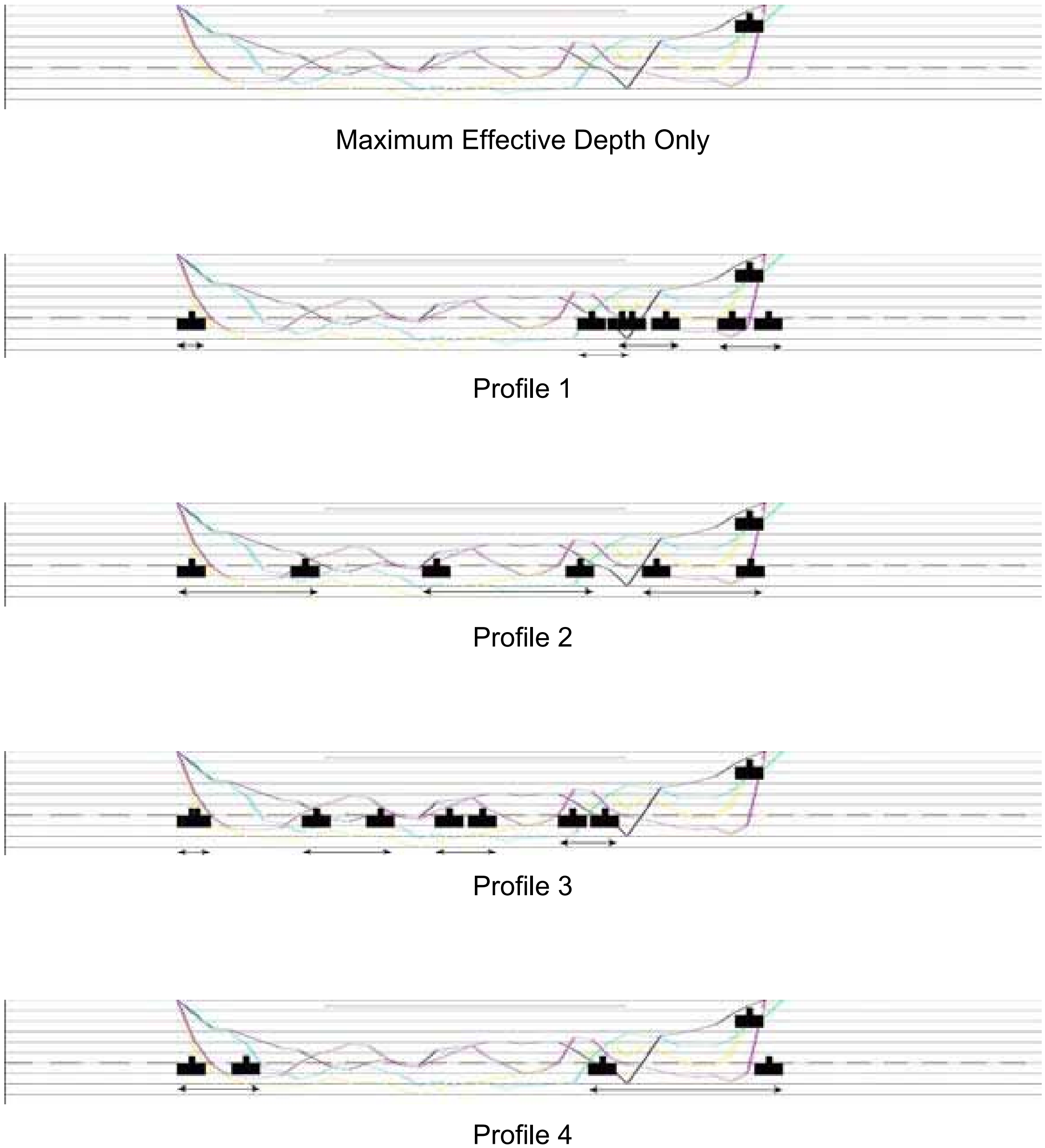


Figure 60. *MV-4, New Hammers, Mines at 15 cm DOB, Penetration Efficiency at 15 cm, Full Width*

MV-4, Worn Hammers 10 cm DOB

Photographs of the four ground profiles for this run are shown in Figure 61. Figure 62 shows that, based on only the centre 50% of the flail width, the deepest depth to which the MV-4 penetrated consistently is approximately 7.5

cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only about 5 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 10 cm, as shown in Figure 63 for the centre 50% band and in Figure 64 for the full width case. Table 25 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 25. *Penetration Efficiency – MV-4, Worn Hammers, Mines at 10 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	728	200	27	1502	710	47
Profile 2	728	0	0	1418	148	10
Profile 3	728	323	44	1712	985	58
Profile 4	728	103	14	1460	304	21
Overall Missed	2912	626	21	6092	2147	34
PE_{10}			79			66

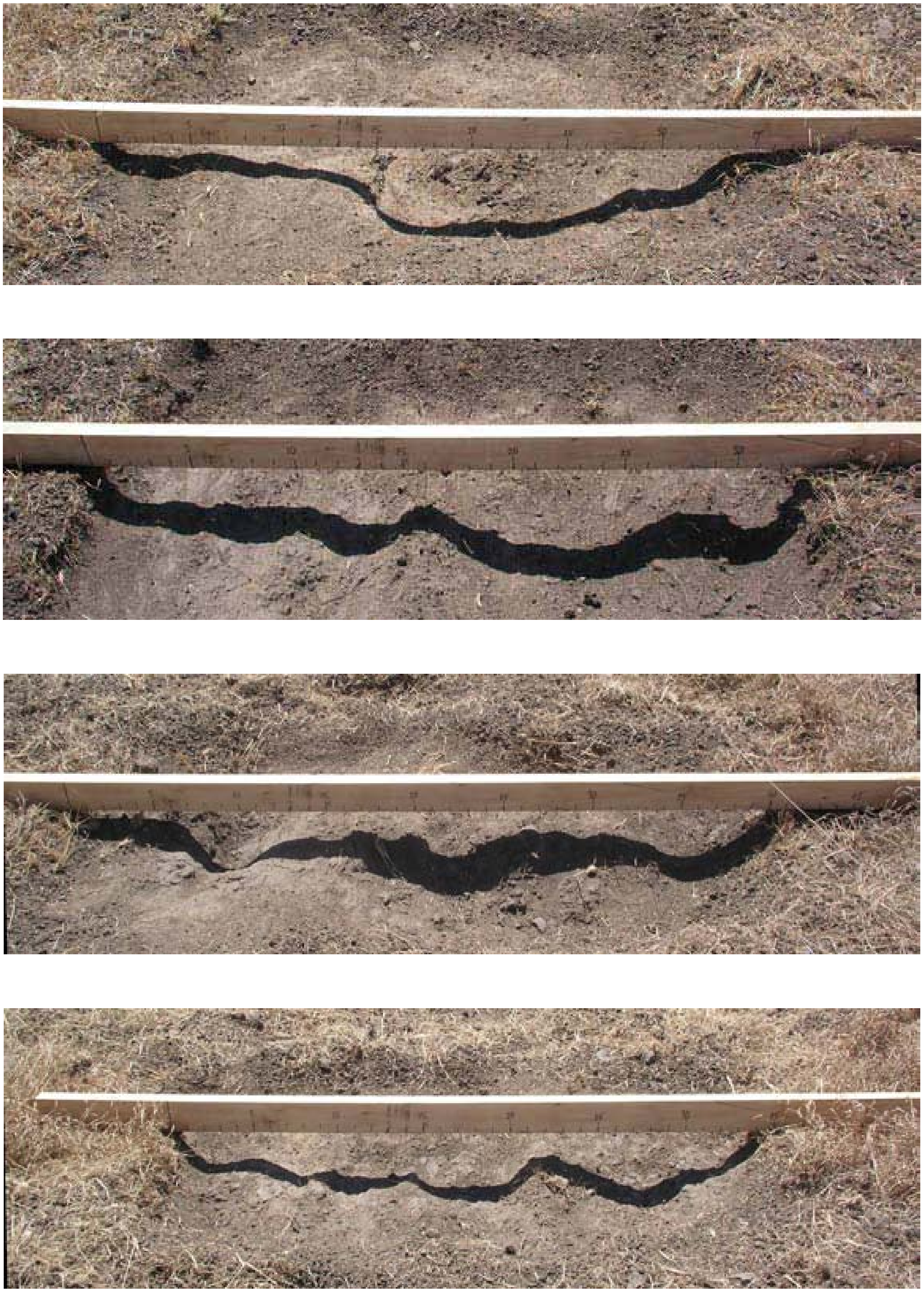


Figure 61. *MV-4 Ground Profile Photographs, Worn Hammers, Mines at 10 cm DOB*

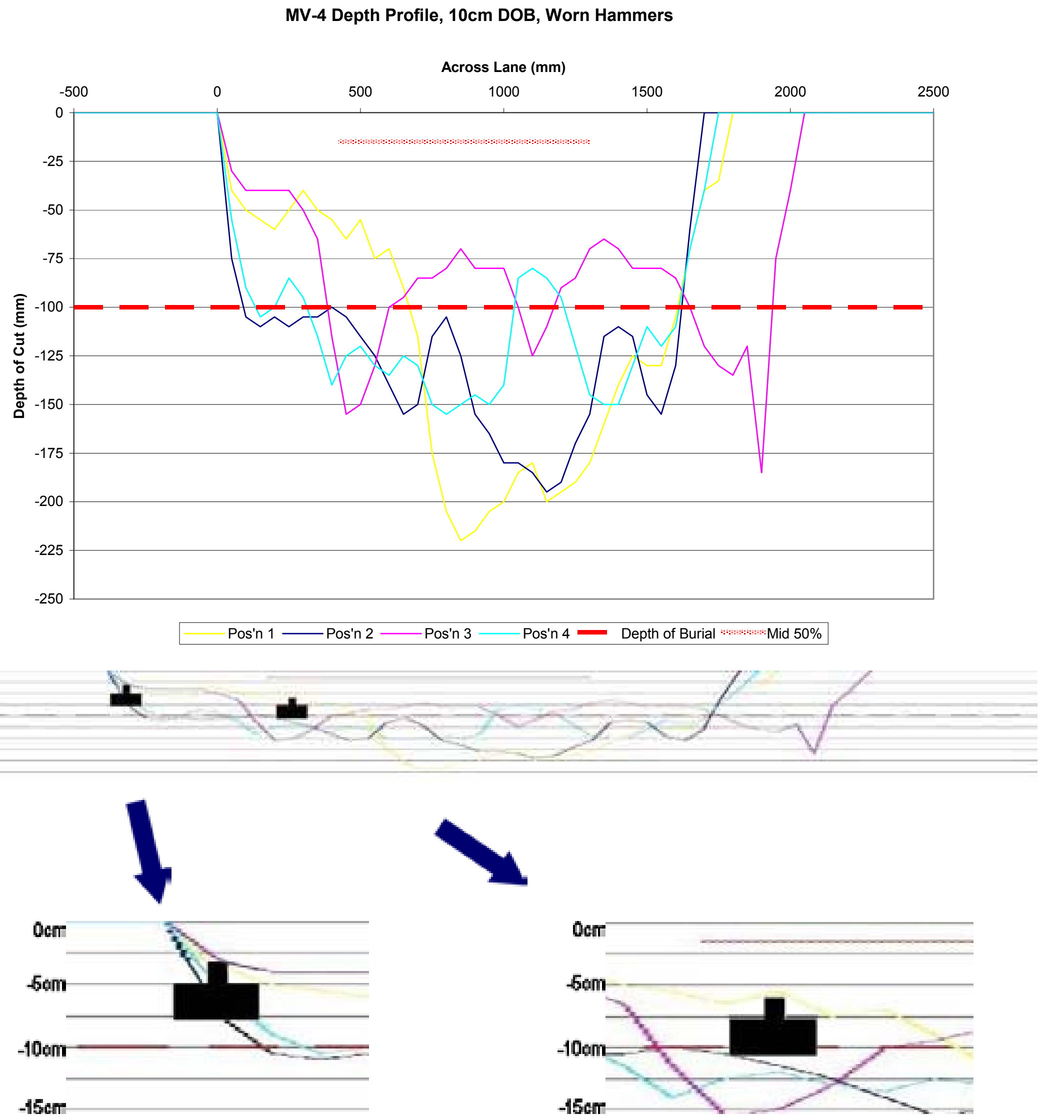
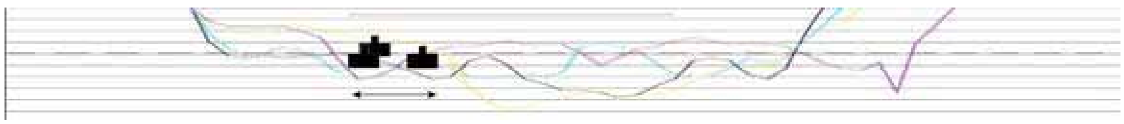
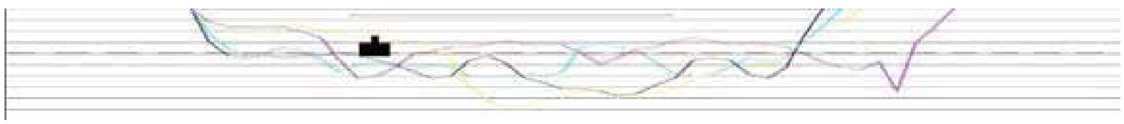


Figure 62. *MV-4 Ground profile, Worn Hammers, Mines at 10 cm DOB*

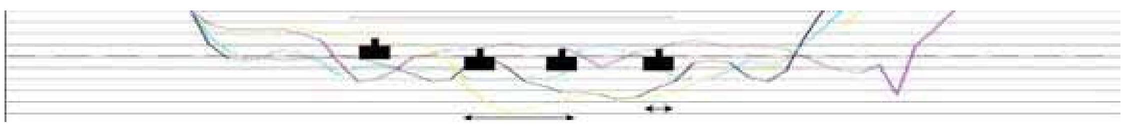
Maximum Effective Depth Only



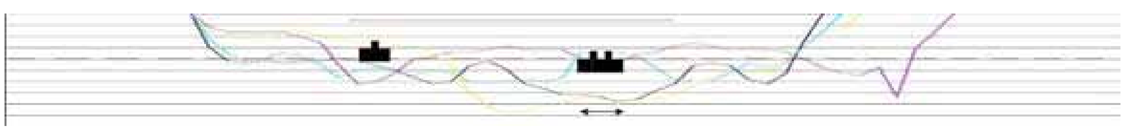
Profile 1



Profile 2



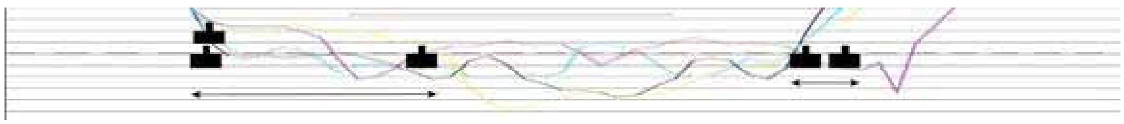
Profile 3



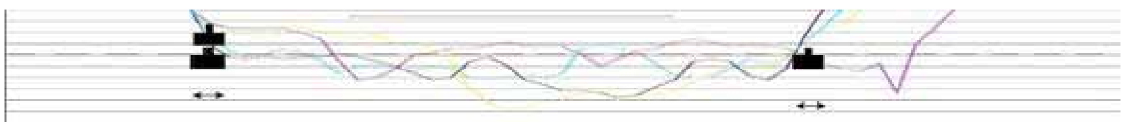
Profile 4

Figure 63. *MV-4, Worn Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Centre Band Only*

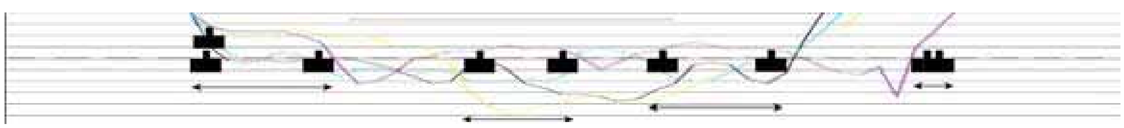
Maximum Effective Depth Only



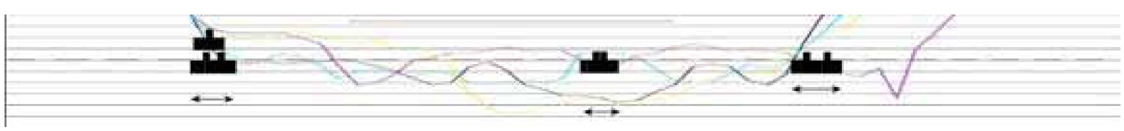
Profile 1



Profile 2



Profile 3



Profile 4

Figure 64. *MV-4, Worn Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Full Width*

MV-4, No Hammers 10 cm DOB

Photographs of the four ground profiles for this run are shown in Figure 65. Figure 66 shows that, based on only the centre 50% of the flail width, the deepest depth to which the MV-4 penetrated consistently is approximately 4.5

cm DOB (measured, as always, to the top of the mine body). If the entire width of cut, as claimed by the manufacturer's information, is considered, it is possible for a mine to hide in the shoulder region, and have the effective depth only about 3 cm DOB.

The four profiles are evaluated for penetration effectiveness values for a depth of 10 cm, as shown in Figure 67 for the centre 50% band and in Figure 68 for the full width case. Table 26 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 26. *Penetration Efficiency – MV-4, No Hammers, Mines at 10 cm DOB*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	730	678	93	1415	1361	96
Profile 2	730	730	100	1546	1546	100
Profile 3	730	712	98	1460	1440	99
Profile 4	730	717	98	1668	1656	99
Overall Missed	2920	2837	97	6089	6003	99
PE_{10}			3			1

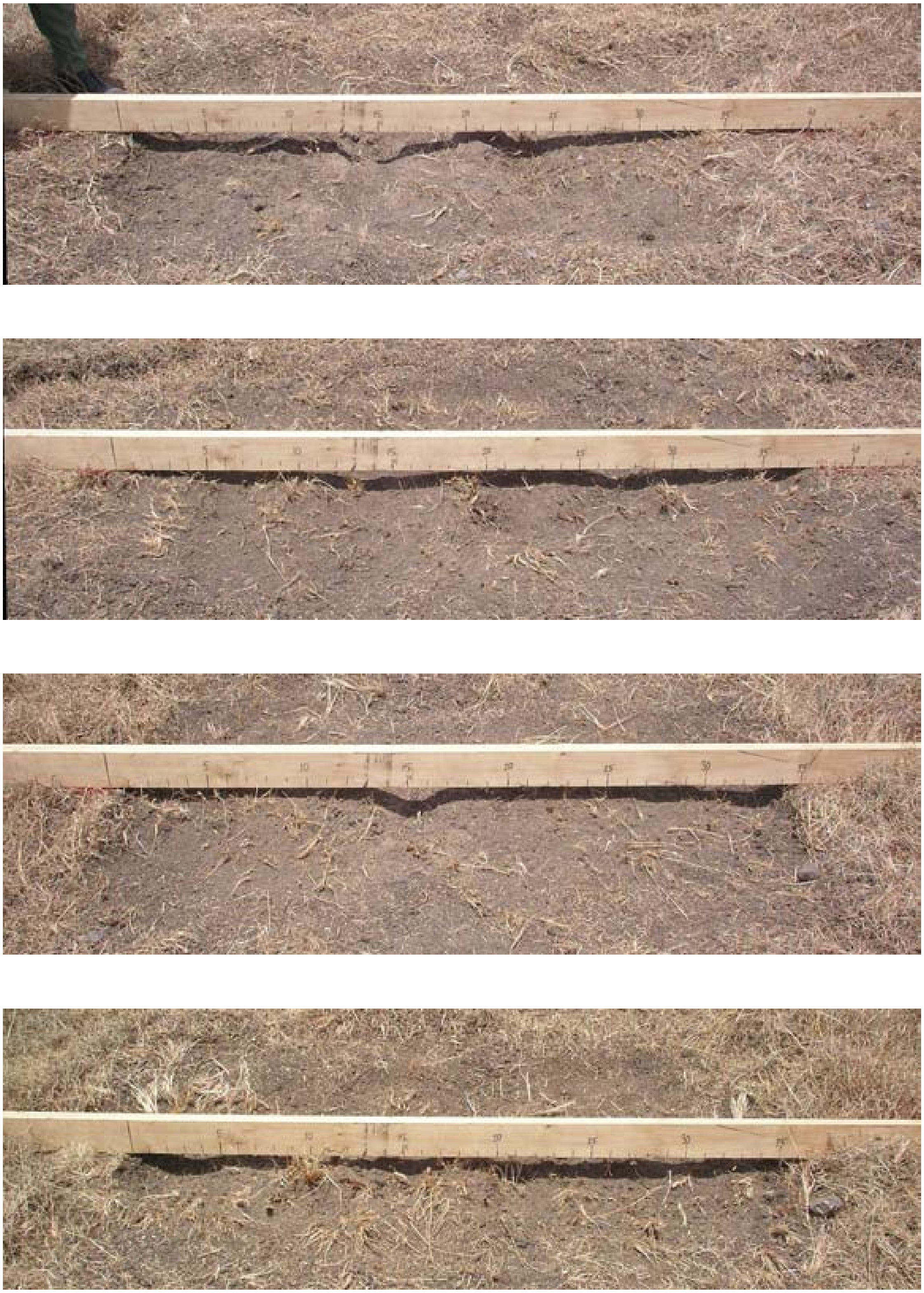


Figure 65. *MV-4 Ground Profile Photographs, No Hammers, Mines at 10 cm DOB*

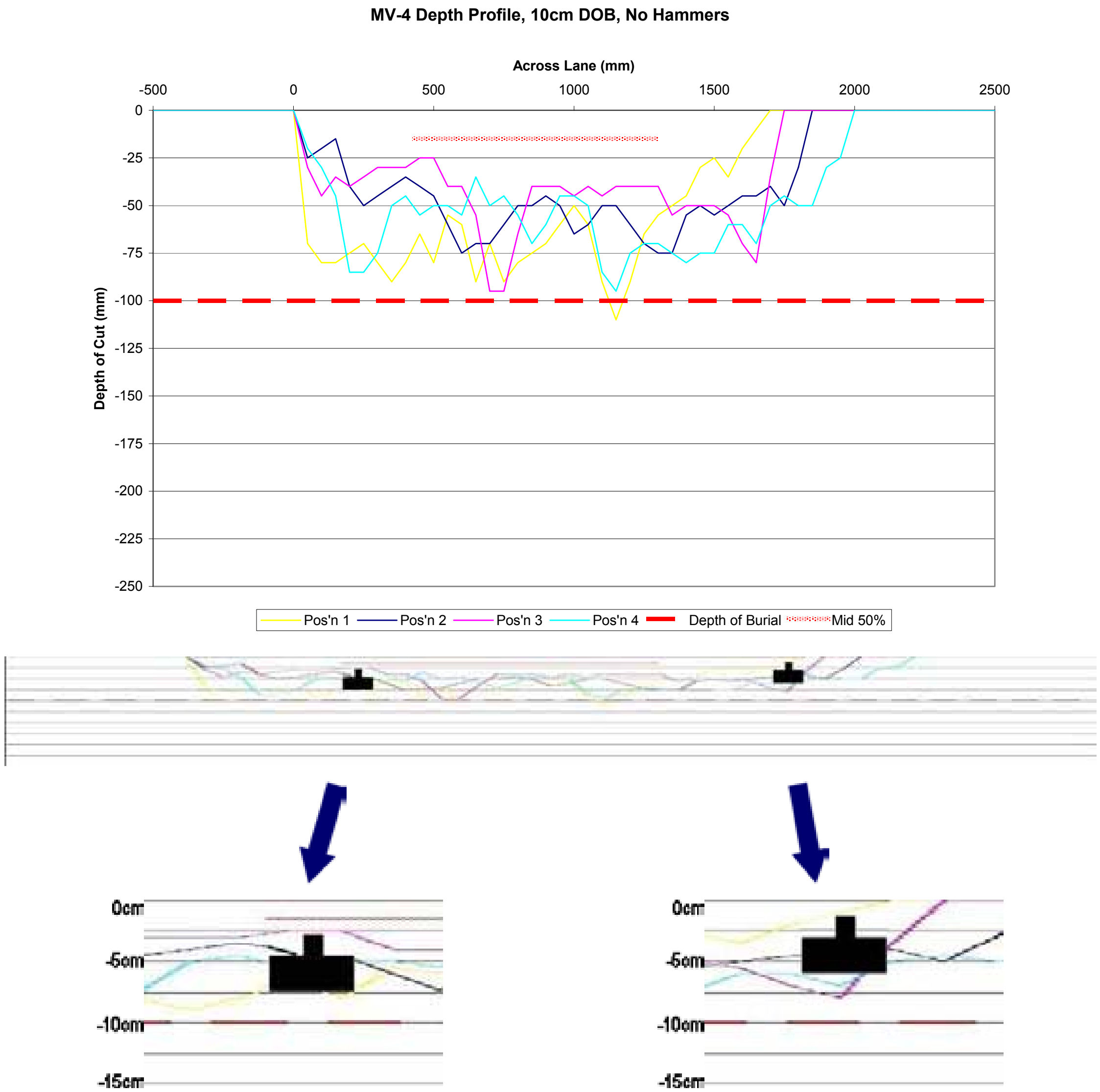
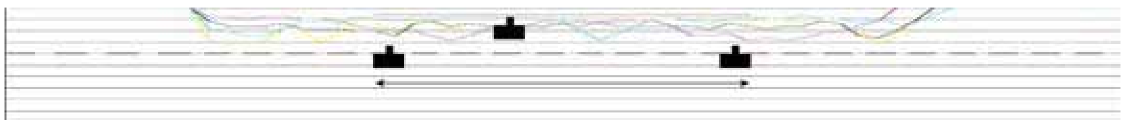


Figure 66. *MV-4 Ground profile, No Hammers, Mines at 10 cm DOB*

Maximum Effective Depth Only



Profile 1

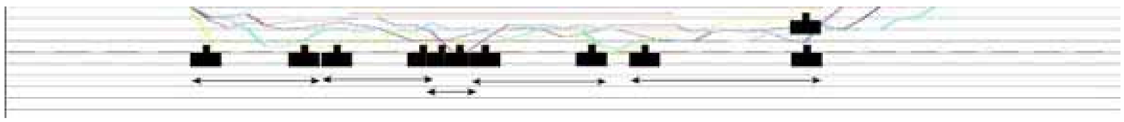
Profile 2

Profile 3

Profile 4

Figure 67. *MV-4, No Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Centre Band Only*

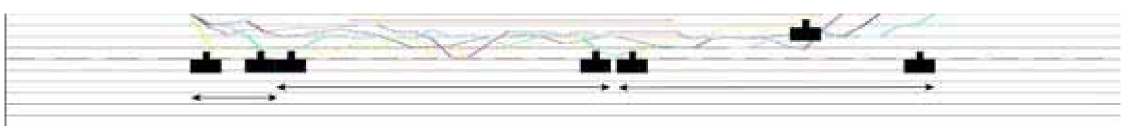
Maximum Effective Depth Only



Profile 1

Profile 2

Profile 3



Profile 4

Figure 68. *MV-4, No Hammers, Mines at 10 cm DOB, Penetration Efficiency at 10 cm, Full Width*

MV-4, New Hammers 0 cm DOB

Photographs of the four ground profiles for this run are shown in Figure 69. Figure 70 shows that, based on only the centre 50% of the flail width, the deepest depth to which the MV-4 penetrated consistently is approximately 3.5

cm DOB (measured, as always, to the top of the mine body). In this test, the shoulder regions would not provide any more shelter for the mine targets, and the full-width effective depth is also about 3.5 cm DOB.

As discussed above for the Bozena-4 test, the trivial result for penetration effectiveness at 0 cm is PE_{15}=100% for both the full width and centre 50% band but this is not useful. The more useful measure of penetration efficiency at a shallow depth of 5 cm is evaluated instead.

The four profiles are evaluated for penetration effectiveness values for a depth of 5 cm, as shown in Figure 71 for the centre 50% band and in Figure 72 for the full width case. Table 27 shows the measurements taken from these two figures and shown in detail in Annex E.

Table 27. *Penetration Efficiency – MV-4, New Hammers, Mines at 0 cm DOB (PE_5)*

Profile #	***Centre 50% Band***			***Full Width***		
	Total Width (pixels)	***Missed Width (pixels)***	***Percentage Missed***	***Total Width (pixels)***	***Missed Width (pixels)***	***Percentage Missed***
Profile 1	728	0	0	1499	0	0
Profile 2	728	0	0	1454	148	10
Profile 3	728	0	0	1499	96	6
Profile 4	728	182	25	1499	308	21
Overall Missed	2912	182	6	5951	552	9
PE_5			94			91

Figure 69. *MV-4 Ground Profile Photographs, New Hammers, Mines at 0 cm DOB*

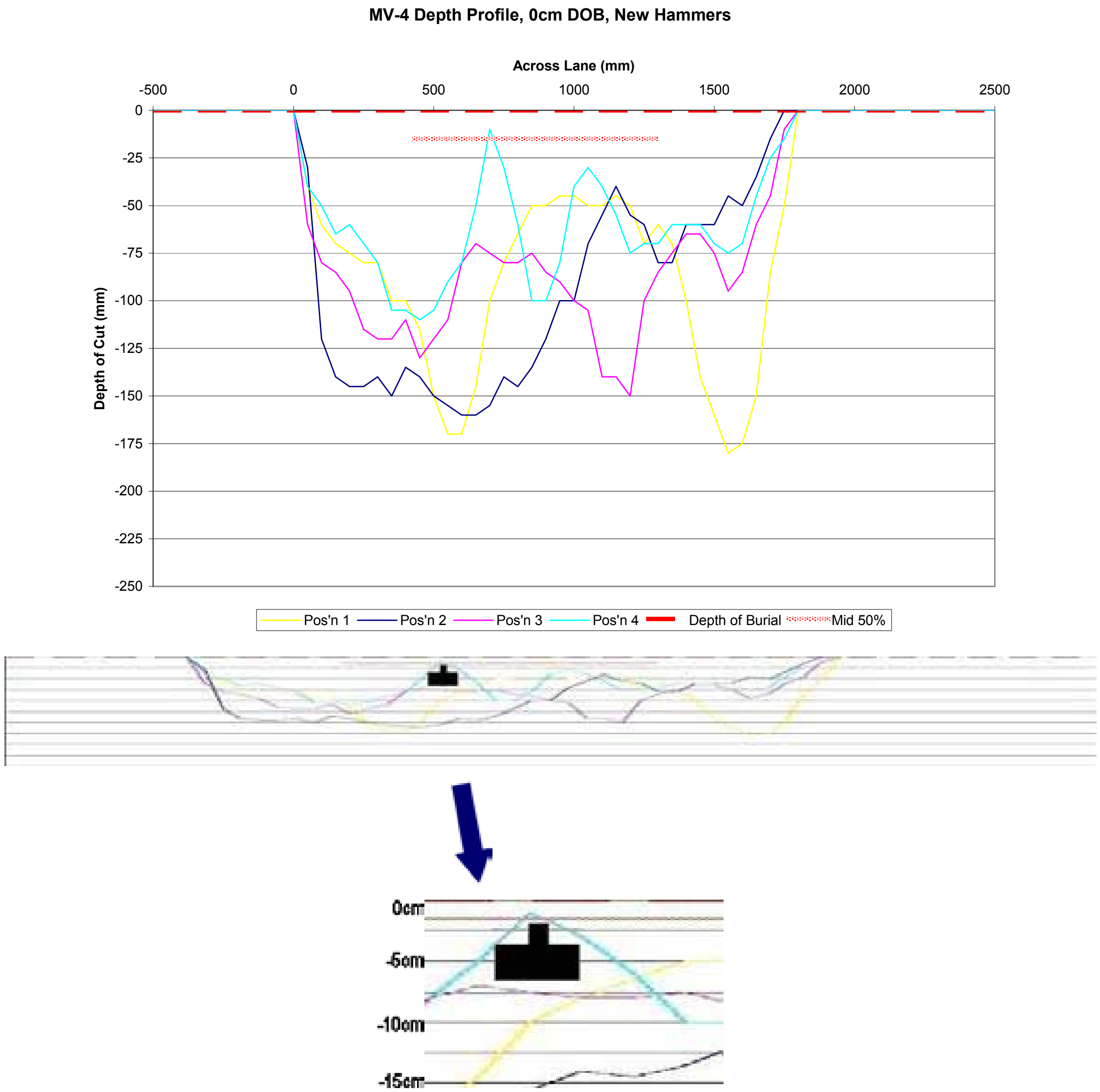


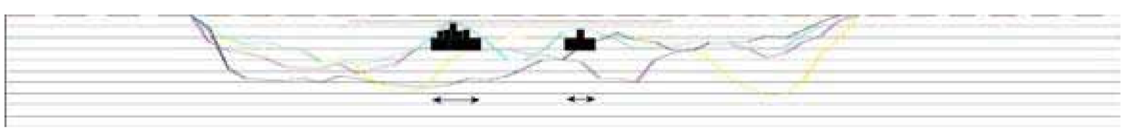
Figure 70. *MV-4 Ground profile, New Hammers, Mines at 0 cm DOB*

Maximum Effective Depth Only

Profile 1

Profile 2

Profile 3



Profile 4

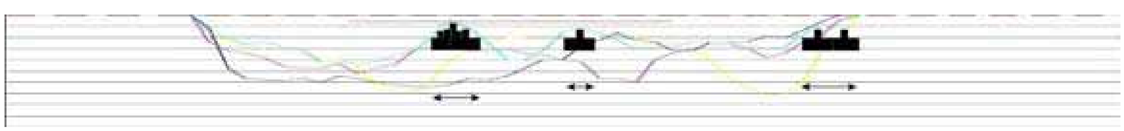
Figure 71. *MV-4, New Hammers, Mines at 0 cm DOB, Penetration Efficiency at 5 cm, Centre Band Only*

Maximum Effective Depth Only

Profile 1

Profile 2

Profile 3



Profile 4

Figure 72. *MV-4, New Hammers, Mines at 0 cm DOB, Penetration Efficiency at 5 cm, Full Width*

Annex D – Worn Hammer Test – Objection and Response

The following letter was given to the ITEP team approximately one day after the worn hammer test runs. The ITEP response to each of the objections is given after the letter.

To: Mr. Geoff Coley
Coordinator, ITEP Mechanical Equipment Test & Evaluation Workgrouproup
Neutralization Research Engineer
Canadian Centre for Mine Action Technologies
Military Engineering Section
Defence R&D Canada / Suffield

From: Mr. Vladimir Zbodak
Team leader for ITEP test of flails in Nairobi
Way Industry, a.s.
Krupina, Slovakia

Date: 8 October 2006

Subject: A recurrence of the test with "worn-out" hammers

Way Industry Company requests an annulment of entire test results and a recurrence of the test with "worn-out" hammers that were performed during ITEP test of flails in Nairobi on 7 October 2006 from the following reasons:

1. The break-down of a computer system for monitoring the surrogate mines clearance for more than half of trial executed by the Bozena-4 machine caused that 27 out of 50 targets could not be evaluated comparatively with performance of the MV-4 machine.

2. The "worn-out" hammers prepared for the MV-4 machine remained with a new untouched cutting edge on more than 40% of a hammer head perimeter (see page 2, Pics. 3 and 4). The hammers used by MV-4 for the test were far from to resemble worn-out hammers (see page 2, Pics. 1 and 2) which had been shown to all members of the ITEP team during tests executed on 5 and 6 October 2006 when these cutting edges were abraded from brand new hammers during less then 20 m long forward flailing in testing lanes.

Way Industry Company is convinced that results gained in the above mentioned conditions by both the Bozena-4 and MV-4 machines were not comparative and did not provide reliable information for customers and/or manufacturers and hardly can reveal any truths or myths. Therefore, Way Industry Company does not accept test results of 7 October and requests the test recurrence during any day of the period 9 to 12 October 2006. We also recommend that artificially prepared "worn-out" hammers are used for the test but the both machines will flail at least 100 m long lane with an arbitrary speed and length before the test commencement to gain the best conditions for adaptation of the "worn-out" shapes.

In addition, Way Industry Company requires all next test will be executed with the same transparent approach as we enjoyed during previous CEN tests we participated in Sweden and/or Croatia. We request to have a chance to do checks of mines placement and DOB (to avoid such mistakes for which MV-4 had missed one target during the test on 5 October), to be allowed doing checks of monitoring computer screen before and immediately after each run irrespective it is Bozena or MV-4

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machine (to avoid quite serious misunderstandings that happened with the computer system failure on 7 October).

Thank you very much for your excellent cooperation.

Best regards.

Pictures No. 1 and 2

Shape of MV-4 hammers after flailing approx. fifty square meters (50 sqm) during the tests in IMATC.

Pictures No. 3 and 4

Shape of MV-4 hammers prepared for performance of the "worn-out" hammers' test (an untouched cutting edge of new hammers clearly visible on more than 40% of a hammer head perimeter).

Picture No. 5

Shape of BOZENA-4 hammers prepared for performance of the "worn-out" hammers' test. The whole cutting edge abraded equally to flailing of fifty thousand square meters (50,000 sqm) which is the maximum life span of the hammers.

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There had been a malfunction of the WORM system which prevented part of the data from being collected by the WORM system software. The initial information provided to the Bozena-4 team was that the software had successfully logged 23 signals before the malfunction occurred. What transpired after that time is that the remaining targets were examined manually to determine the state of the remaining 27 targets. In all, 41 of the 50 targets could be definitively classed in one of the four categories listed in CWA15044. The remaining 9 targets were ambiguous and were therefore deleted from the data set to avoid biasing the results one way or the other. It was felt, however that a test in which 82% of the targets produced useful data was satisfactory, and this was not sufficient grounds for a retest.

The second point raised in the Bozena letter relates to the realism of the worn hammers. It is acknowledged that the type of wear showing on the MV-4 hammers from these tests is not the same as the wear on the artificially worn hammers, but this was dealt with well before the trial started. In communications before the trial, samples of “worn-out” hammers were requested from both manufacturers. It was made clear that these would be used as models from which new hammers would be modified by cutting or grinding to match the worn-out samples as closely as possible. It was explicitly acknowledged that the wear induced by cutting or grinding would not be completely realistic, but that it would at least be consistent and uniform across the entire set of hammers used. Both manufactures complied with this request and supplied samples with no concerns expressed. As agreed, ITEP took one of the two sets of new hammers purchased from each team and had them modified at a local Nairobi machine shop. No concerns about the artificially worn hammers were expressed by either team before the tests.

It might also be pointed out that the modifications to the MV-4 hammers effectively removed the entire ‘nose’ or striking edge of the hammers, rounding it off completely. By contrast the modified Bozena-4 hammers had both an upper and lower sharp edge on the striking edge.

There is no dispute with their comments about the relative rates of ‘natural’ wear of the two types of hammers, but this has nothing to do with the type of wear.

Even without the discussion about the nature of the modifications to the two types of hammers, the ITEP team felt that the prior agreement of both teams to the artificial wear, and the failure to raise any objections prior to the test rendered this objection invalid and of insufficient grounds for a retest.

For these reasons, the demand for a retest was rejected.

In the final paragraph of the letter the Bozena-4 team implies that the ITEP team was somehow conducting the tests in a manner that was not open and transparent. Both manufacturers had full access to the test site at all times with one exception: when pieces of the targets were being collected, access by manufacturer’s representatives was restricted to avoid any possible appearance of manufacturers tampering with the data. They were free to measure or check anything at any time, before or after any test (as seen in Figure 73), and nobody was denied any opportunity to view the computer screen before or after any test.

The ITEP team prefers to examine data in plain view of everyone with explanations and demonstrations offered to anyone who is interested, as was done with the data from the first set of tests (10 cm DOB, new hammers) (Figure 70). In a meeting the following morning, the head of the Bozena-4 team requested, in the presence of the entire ITEP team, that the targets be collected and evaluated privately by the ITEP team, with the final results being given to the manufacturer teams. While this was not the preferred option for the ITEP team, there were enough other issues on the table that this was agreed to as a point on which we could compromise. Almost immediately after the second test (15 cm DOB), the Bozena-4 team asked to view the targets and the data, and after the third test, the letter appeared. The Bozena-4 representatives were objecting to the procedural change that they, themselves, requested.

Figure 73. *Unrestricted Access to Test Site Before and After Tests*

The Bozena-4 team did point out a flaw in the procedure used for evaluating the mine target debris after a test. Their observation has led to improved evaluations, and for that they are commended.

MV-4 targets in plain view Bozena-4 targets in plain view

Figure 74. *Open, Transparent Evaluation Of Targets After The First Test*

Annex E – Test Data

This annex shows the WORM target mine data from the 0 cm depth of burial test, plus measurements of ground profiles, machine speeds, and soil moisture and density.

Table 28. *Soil Density and Moisture Content*

Date (2006)	***Machine***	***Lane & Loc'n***	***WORM DOB (cm)***	***Vol (ml)***	***Mass Wet (g)***	***Mass Dry (g)***	***Moisture (g)***	***Moisture Dry Mass (%)***	***Density Wet (kg/m^3)***
Oct. 5	B-4	1 Start	10	800	1029	898	131	14.6	1286
Oct. 5	B-4	1 End	10	910	669	570	99	17.4	735
Oct. 5	MV-4	2 Start	10	600	914	796	118	14.8	1523
Oct. 5	MV-4	2 End	10	500	822	705	117	16.6	1644
Oct. 6	B-4	4 Start	15	600	1147	958	189	19.7	1911
Oct. 6	B-4	4 End	15	675	938	822	116	14.1	1389
Oct. 6	MV-4	3 Start	15	650	1015	861	154	17.9	1561
Oct. 6	MV-4	3 End	15	625	1198	1058	140	13.2	1916
Oct. 7	B-4	6 Start	10	700	1040	901	139	15.4	1485
Oct. 7	B-4	6 End	10	900	1189	1010	179	17.7	1321
Oct. 7	MV-4	5 Start	10	675	905	790	115	14.6	1340
Oct. 7	MV-4	5 End	10	650	1115	934	181	19.4	1715
Oct. 10	B-4	7 Start	10	650	830	719	111	15.4	1276
Oct. 10	B-4	7 End	10	625	880	772	108	14.0	1408
Oct. 10	MV-4	8 Start	10	1125	1564	1364	200	14.7	1390
Oct. 10	MV-4	8 End	10	600	910	786	124	15.8	1516
Oct. 12	B-4 & MV-4	Middle	0	900	1361	1213	148	12.2	1512
Oct. 12	None	Middle - upper 1"	-	N/A	820	742	78	10.5	N/A
Oct. 12	None	below 1"	-	N/A	1192	1000	192	19.2	N/A

Table 29. *Ground Profile Measurements (1)*

Machine	Bozena-4		***Lane:***	1	
DOB::	10 cm		***Time (s)***	390	***(for 25m)***
Hammers:	New		***Speed (m/h)***	231	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	35	25	35	20
2	100	50	45	60	35
3	150	70	60	70	60
4	200	80	60	90	85
5	250	80	70	100	90
6	300	85	75	115	70
7	350	80	95	125	70
8	400	75	110	125	80
9	450	80	135	115	75
10	500	80	135	95	75
11	550	75	130	90	75
12	600	80	125	90	65
13	650	75	120	105	65
14	700	60	100	135	95
15	750	55	120	150	100
16	800	60	140	150	100
17	850	75	150	130	100
18	900	65	135	100	100
19	950	60	125	85	110
20	1000	75	115	70	120
21	1050	80	95	75	100

22	1100	75	95	80	95
23	1150	70	90	70	95
24	1200	70	70	70	120
25	1250	80	85	75	140
26	1300	80	95	75	150
27	1350	75	110	75	130
28	1400	85	110	80	110
29	1450	100	110	65	100
30	1500	100	100	55	95
31	1550	100	85	65	110
32	1600	85	80	70	120
33	1650	95	75	85	105
34	1700	80	75	95	90
35	1750	65	90	100	85
36	1800	55	100	100	100
37	1850	65	90	95	95
38	1900	65	85	85	105
39	1950	70	85	80	95
40	2000	100	75	85	70
41	2050	95	80	80	85
42	2100	90	80	40	75
43	2150	80	75	0	60
44	2200	35	65	0	50
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 30. *Ground Profile Measurements (2)*

Machine	Bozena-4		***Lane:***	6	
DOB::	15 cm		***Time (s)***	510	***(for 25m)***
Hammers:	New		***Speed (m/h)***	176	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	40	10	25	35
2	100	75	25	35	60
3	150	100	45	55	80
4	200	125	45	75	100
5	250	125	70	85	120
6	300	145	75	100	125
7	350	170	115	105	120
8	400	185	120	100	110
9	450	190	150	110	110
10	500	190	170	125	90
11	550	160	175	120	85
12	600	135	185	115	70
13	650	130	190	120	60
14	700	135	185	105	60
15	750	135	180	95	70
16	800	165	185	80	80
17	850	175	160	100	80
18	900	160	150	110	65
19	950	145	160	125	70
20	1000	135	160	130	70
21	1050	120	160	130	85
22	1100	135	145	120	90

23	1150	140	140	95	65
24	1200	150	165	80	65
25	1250	155	170	75	65
26	1300	150	155	85	70
27	1350	160	140	90	70
28	1400	170	135	110	65
29	1450	180	125	140	65
30	1500	200	125	145	70
31	1550	205	120	150	80
32	1600	210	100	115	75
33	1650	205	100	125	70
34	1700	195	100	130	75
35	1750	185	130	125	75
36	1800	180	155	115	80
37	1850	140	175	100	80
38	1900	95	190	100	75
39	1950	85	190	70	50
40	2000	0	190	45	25
41	2050	0	100	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 31. *Ground Profile Measurements (3)*

Machine	Bozena-4		***Lane:***	7	
DOB::	10		***Time (s)***	580	***(for 25m)***
Hammers:	Worn		***Speed (m/h)***	155	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	30	35	40	35
2	100	60	65	65	55
3	150	95	95	100	100
4	200	110	100	115	95
5	250	110	120	125	115
6	300	115	140	135	120
7	350	120	145	140	130
8	400	120	155	140	130
9	450	135	150	120	130
10	500	155	125	120	125
11	550	155	120	135	130
12	600	170	115	135	130
13	650	170	110	115	125
14	700	180	105	110	115
15	750	180	95	110	115
16	800	170	100	110	130
17	850	150	85	100	145
18	900	160	75	100	145
19	950	145	70	135	120
20	1000	120	75	140	110
21	1050	115	100	140	75
22	1100	120	140	130	70

23	1150	150	180	110	55
24	1200	175	185	100	50
25	1250	190	180	80	55
26	1300	185	170	75	50
27	1350	185	140	80	50
28	1400	145	120	95	50
29	1450	140	110	115	70
30	1500	130	110	115	75
31	1550	110	120	125	80
32	1600	120	130	115	65
33	1650	115	140	110	75
34	1700	110	145	110	80
35	1750	100	150	85	100
36	1800	90	145	90	140
37	1850	85	150	95	145
38	1900	85	140	75	130
39	1950	70	110	50	90
40	2000	65	100	15	55
41	2050	40	65	0	20
42	2100	0	25	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 32. *Ground Profile Measurements (4)*

Machine	Bozena-4		***Lane:***	3	
DOB::	10		***Time (s)***	293	***(for 25m)***
Hammers:	None		***Speed (m/h)***	307	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	70	30	20	45
2	100	80	40	20	50
3	150	80	40	25	60
4	200	70	40	20	60
5	250	50	35	20	45
6	300	50	45	25	30
7	350	75	45	25	30
8	400	55	45	30	35
9	450	30	50	40	20
10	500	35	50	45	25
11	550	55	60	45	30
12	600	30	35	50	25
13	650	30	30	60	30
14	700	50	40	70	20
15	750	35	35	60	20
16	800	40	40	45	20
17	850	40	35	45	20
18	900	35	40	40	20
19	950	45	40	30	25
20	1000	35	35	35	30
21	1050	40	30	40	50
22	1100	45	35	30	70

23	1150	35	30	40	55
24	1200	25	30	40	40
25	1250	25	30	40	25
26	1300	25	40	40	20
27	1350	30	40	60	30
28	1400	30	45	60	35
29	1450	30	35	55	25
30	1500	35	40	70	20
31	1550	20	45	65	25
32	1600	30	40	70	25
33	1650	30	40	65	15
34	1700	35	30	55	25
35	1750	35	35	50	25
36	1800	50	60	40	35
37	1850	80	65	30	25
38	1900	60	50	0	35
39	1950	25	30	0	35
40	2000	0	0	0	15
41	2050	0	0	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 33. *Ground Profile Measurements (5)*

Machine	Bozena-4		***Lane:***	10	
DOB::	0		***Time (s)***	300	***(for 25m)***
Hammers:	New		***Speed (m/h)***	300	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	60	35	20	20
2	100	105	55	30	45
3	150	130	70	35	55
4	200	140	110	70	60
5	250	145	115	95	50
6	300	155	110	100	70
7	350	150	80	105	65
8	400	135	80	110	60
9	450	125	80	115	55
10	500	130	70	110	60
11	550	135	65	100	60
12	600	130	60	85	45
13	650	145	55	90	40
14	700	140	80	110	45
15	750	120	80	115	65
16	800	100	75	120	75
17	850	65	100	105	75
18	900	85	120	100	75
19	950	100	105	80	65
20	1000	95	80	90	50
21	1050	85	55	90	40
22	1100	90	45	90	35

23	1150	90	45	85	45
24	1200	65	50	75	70
25	1250	50	45	60	80
26	1300	60	50	35	75
27	1350	70	55	40	80
28	1400	75	60	40	55
29	1450	85	70	35	65
30	1500	145	85	35	65
31	1550	170	90	50	65
32	1600	155	130	50	70
33	1650	155	130	50	75
34	1700	140	130	50	70
35	1750	100	130	50	65
36	1800	70	105	40	60
37	1850	70	75	55	65
38	1900	60	90	70	55
39	1950	60	105	80	55
40	2000	60	105	85	55
41	2050	60	110	90	55
42	2100	55	110	90	45
43	2150	50	105	65	25
44	2200	40	100	25	0
45	2250	30	45	20	0
46	2300	15	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 34. *Ground Profile Measurements (6)*

Machine	MV-4		***Lane:***	2	
DOB::	10		***Time (s)***	190	***(for 25m)***
Hammers:	New		***Speed (m/h)***	474	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	40	60	45	45
2	100	75	105	70	70
3	150	95	120	65	75
4	200	110	130	65	70
5	250	120	130	55	55
6	300	120	120	45	45
7	350	90	130	45	40
8	400	75	145	30	35
9	450	80	155	25	30
10	500	100	150	25	45
11	550	110	145	25	50
12	600	105	145	20	45
13	650	95	115	35	45
14	700	105	100	65	75
15	750	120	95	65	100
16	800	95	90	60	90
17	850	100	95	105	45
18	900	130	95	115	45
19	950	170	100	115	60
20	1000	185	95	115	70
21	1050	175	80	130	80
22	1100	175	95	125	100

23	1150	180	100	90	105
24	1200	200	115	90	80
25	1250	225	105	100	75
26	1300	220	95	105	70
27	1350	185	80	85	75
28	1400	155	95	80	55
29	1450	100	115	80	55
30	1500	80	150	75	60
31	1550	60	155	85	60
32	1600	40	150	80	45
33	1650	20	100	55	40
34	1700	0	40	15	0
35	1750	0	0	0	0
36	1800	0	0	0	0
37	1850	0	0	0	0
38	1900	0	0	0	0
39	1950	0	0	0	0
40	2000	0	0	0	0
41	2050	0	0	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 35. *Ground Profile Measurements (7)*

Machine	MV-4		***Lane:***	5	
DOB::	15		***Time (s)***	460	***(for 25m)***
Hammers:	New		***Speed (m/h)***	196	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	120	35	100	30
2	100	170	65	155	70
3	150	185	70	180	75
4	200	200	85	185	105
5	250	205	100	185	160
6	300	210	115	180	170
7	350	205	120	150	190
8	400	200	140	130	180
9	450	185	160	120	160
10	500	200	165	105	145
11	550	195	150	110	155
12	600	200	140	135	170
13	650	215	155	155	180
14	700	225	155	160	205
15	750	215	120	140	195
16	800	200	115	125	205
17	850	205	110	110	195
18	900	190	100	135	200
19	950	185	100	155	210
20	1000	180	105	175	205
21	1050	165	100	170	205
22	1100	145	100	150	200

23	1150	145	120	90	195
24	1200	130	145	95	135
25	1250	100	160	135	100
26	1300	135	200	155	80
27	1350	110	140	160	85
28	1400	125	85	170	90
29	1450	140	80	180	110
30	1500	160	70	185	110
31	1550	155	60	180	110
32	1600	125	35	195	95
33	1650	45	15	175	60
34	1700	15	0	0	40
35	1750	0	0	0	0
36	1800	0	0	0	0
37	1850	0	0	0	0
38	1900	0	0	0	0
39	1950	0	0	0	0
40	2000	0	0	0	0
41	2050	0	0	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 36. *Ground Profile Measurements (8)*

Machine	MV-4		***Lane:***	8	
DOB::	10		***Time (s)***	310	***(for 25m)***
Hammers:	Worn		***Speed (m/h)***	290	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	40	75	30	55
2	100	50	105	40	90
3	150	55	110	40	105
4	200	60	105	40	100
5	250	50	110	40	85
6	300	40	105	50	95
7	350	50	105	65	115
8	400	55	100	115	140
9	450	65	105	155	125
10	500	55	115	150	120
11	550	75	125	130	130
12	600	70	140	100	135
13	650	90	155	95	125
14	700	115	150	85	130
15	750	175	115	85	150
16	800	205	105	80	155
17	850	220	125	70	150
18	900	215	155	80	145
19	950	205	165	80	150
20	1000	200	180	80	140
21	1050	185	180	100	85
22	1100	180	185	125	80

23	1150	200	195	110	85
24	1200	195	190	90	95
25	1250	190	170	85	120
26	1300	180	155	70	145
27	1350	160	115	65	150
28	1400	140	110	70	150
29	1450	125	115	80	130
30	1500	130	145	80	110
31	1550	130	155	80	120
32	1600	105	130	85	110
33	1650	70	60	100	70
34	1700	40	0	120	40
35	1750	35	0	130	0
36	1800	0	0	135	0
37	1850	0	0	120	0
38	1900	0	0	185	0
39	1950	0	0	75	0
40	2000	0	0	40	0
41	2050	0	0	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

__Table 37.__ Ground Profile Measurements (9)

Machine	MV-4		***Lane:***	4	
DOB::	10		***Time (s)***	147	***(for 25m)***
Hammers:	None		***Speed (m/h)***	612	***(average)***
Station	***Dist across (mm)***	***Position 1 Depth (mm)***	***Position 2 Depth (mm)***	***Position 3 Depth (mm)***	***Position 4 Depth (mm)***
0	0	0	0	0	0
1	50	70	25	30	20
2	100	80	20	45	30
3	150	80	15	35	45
4	200	75	40	40	85
5	250	70	50	35	85
6	300	80	45	30	75
7	350	90	40	30	50
8	400	80	35	30	45
9	450	65	40	25	55
10	500	80	45	25	50
11	550	55	60	40	50
12	600	60	75	40	55
13	650	90	70	55	35
14	700	70	70	95	50
15	750	90	60	95	45
16	800	80	50	65	55
17	850	75	50	40	70
18	900	70	45	40	60
19	950	60	50	40	45
20	1000	50	65	45	45
21	1050	60	60	40	50
22	1100	90	50	45	85

23	1150	110	50	40	95
24	1200	90	60	40	75
25	1250	65	70	40	70
26	1300	55	75	40	70
27	1350	50	75	55	75
28	1400	45	55	50	80
29	1450	30	50	50	75
30	1500	25	55	50	75
31	1550	35	50	55	60
32	1600	20	45	70	60
33	1650	10	45	80	70
34	1700	0	40	35	50
35	1750	0	50	0	45
36	1800	0	30	0	50
37	1850	0	0	0	50
38	1900	0	0	0	30
39	1950	0	0	0	25
40	2000	0	0	0	0
41	2050	0	0	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 38. *Ground Profile Measurements (10)*

Machine	MV-4		**Lane:**	9	
DOB::	0		**Time (s)**	130	**(for 25m)**
Hammers:	New		**Speed (m/h)**	692	**(average)**
Station	**Dist across (mm)**	**Position 1 Depth (mm)**	**Position 2 Depth (mm)**	**Position 3 Depth (mm)**	**Position 4 Depth (mm)**
0	0	0	0	0	0
1	50	40	30	60	40
2	100	60	120	80	50
3	150	70	140	85	65
4	200	75	145	95	60
5	250	80	145	115	70
6	300	80	140	120	80
7	350	100	150	120	105
8	400	100	135	110	105
9	450	115	140	130	110
10	500	150	150	120	105
11	550	170	155	110	90
12	600	170	160	80	80
13	650	145	160	70	50
14	700	100	155	75	10
15	750	80	140	80	30
16	800	65	145	80	60
17	850	50	135	75	100
18	900	50	120	85	100
19	950	45	100	90	80
20	1000	45	100	100	40
21	1050	50	70	105	30
22	1100	50	55	140	40

23	1150	45	40	140	55
24	1200	50	55	150	75
25	1250	70	60	100	70
26	1300	60	80	85	70
27	1350	70	80	75	60
28	1400	100	60	65	60
29	1450	140	60	65	60
30	1500	160	60	75	70
31	1550	180	45	95	75
32	1600	175	50	85	70
33	1650	150	35	60	45
34	1700	85	15	45	25
35	1750	50	0	10	15
36	1800	0	0	0	0
37	1850	0	0	0	0
38	1900	0	0	0	0
39	1950	0	0	0	0
40	2000	0	0	0	0
41	2050	0	0	0	0
42	2100	0	0	0	0
43	2150	0	0	0	0
44	2200	0	0	0	0
45	2250	0	0	0	0
46	2300	0	0	0	0
47	2350	0	0	0	0
48	2400	0	0	0	0
49	2450	0	0	0	0
50	2500	0	0	0	0

Table 39. *Mine Target Data (1)*

Machine:	MV-4	
Lane	9	
DOB::	0	
Hammers:	New	
Target ID	***Final State***	***Comments***
09	Triggered	
12	Triggered	
13	Triggered	
15	Triggered	
16	Triggered	
28	Triggered	
33	Triggered	
37	Triggered	
51	Triggered	
53	Triggered	
54	Triggered	
56	Mechanically Neutralized	
57	Mechanically Neutralized	
58	Triggered	
59	Triggered	
97	Triggered	
0A	Triggered	
0E	Mechanically Neutralized	
0F	Triggered	
1C	Triggered	
1F	Triggered	
2B	Mechanically Neutralized	
3A	Triggered	

3B	Triggered	
3C	Triggered	
3D	Live Damaged	
3F	Triggered	
4C	Triggered	
4D	Triggered	
5B	Mechanically Neutralized	
5D	Triggered	
6D	Live Damaged	
7A	Triggered	
7B	Triggered	
A4	Triggered	
A5	Triggered	
A6	Triggered	
AA	Triggered	
AB	Mechanically Neutralized	
AE	Mechanically Neutralized	
C0	Triggered	
C1	Triggered	
C2	Triggered	
C5	Triggered	
C8	Mechanically Neutralized	
CD	Triggered	
F0	Triggered	
F3	Triggered	
FE	Triggered	
FF	Triggered	

Table 40. Mine Target Data (2)

Machine:	Bozena-4	
Lane	10	
DOB::	0	
Hammers:	New	
Target ID	***Final State***	***Comments***
96	Triggered	
8	Mechanically Neutralized	
11	Triggered	
14	Triggered	
17	Triggered	
20	Mechanically Neutralized	
22	Mechanically Neutralized	
23	Triggered	
24	Triggered	
30	Inconclusive	Could not be evaluated with complete confidence
32	Live Damaged	
34	Mechanically Neutralized	
35	Triggered	
36	Triggered	
38	Triggered	
41	Triggered	
42	Triggered	
43	Triggered	
45	Triggered	
46	Triggered	
48	Triggered	
50	Triggered	
55	Triggered	

61	Mechanically Neutralized	
62	Triggered	
63	Triggered	
64	Triggered	
68	Triggered	
69	Mechanically Neutralized	
70	Triggered	
71	Mechanically Neutralized	
73	Triggered	
74	Mechanically Neutralized	
75	Triggered	
77	Triggered	
79	Triggered	
81	Mechanically Neutralized	
82	Triggered	
83	Triggered	
85	Triggered	
87	Triggered	
91	Inconclusive	Could not be evaluated with complete confidence
92	Mechanically Neutralized	
93	Mechanically Neutralized	
98	Triggered	
99	Triggered	
9A	Triggered	
9B	Triggered	
9C	Triggered	
9D	Triggered	

Table 41. *Penetration Efficiency Calculations*

Machine	*DOB (cm)*	*Hammer*	*Profile*	*Full Left Edge (px)*	*Centre Left Edge (px)*	*Centre Right Edge (px)*	*Full Right Edge (px)*	*Centre Width (px)*	*Full Width (px)*	*Missed Centre (px)*	*Missed Full (px)*	*Missed Centre (%)*	*Missed Full (%)*	*PE(DOB) Centre (%)*	*PE(DOB) Full (%)*
B4	10	New	P1	416	873	1814	2291	941	1875	725	1588	77	85	23	15
B4	10	New	P2	416	873	1814	2291	941	1875	240	850	26	45	74	55
B4	10	New	P3	416	873	1814	2207	941	1791	629	1019	67	57	33	43
B4	10	New	P4	416	873	1814	2291	941	1875	137	838	15	45	85	55
B4								3764	7416	1731	4295	46	58	54	42
B4	15	New	P1	416	827	1673	2088	846	1672	201	586	24	35	76	65
B4	15	New	P2	416	827	1673	2169	846	1753	108	781	13	45	87	55
B4	15	New	P3	416	827	1673	2126	846	1710	811	1646	96	96	4	4
B4	15	New	P4	416	827	1673	2126	846	1710	846	1710	100	100	0	0
B4								3384	6845	1966	4723	58	69	42	31
B4	10	Worn	P1	416	826	1671	2165	845	1749	0	323	0	18	100	82
B4	10	Worn	P2	416	826	1671	2204	845	1788	177	447	21	25	79	75
B4	10	Worn	P3	416	826	1671	2121	845	1705	150	446	18	26	82	74
B4	10	Worn	P4	416	826	1671	2165	845	1749	409	870	48	50	52	50
B4								3380	6991	736	2086	22	30	78	70

Table 41. *Penetration Efficiency Calculations*

Machine	DOB (cm)	Hammer	Profile	Full Left Edge (px)	Centre Left Edge (px)	Centre Right Edge (px)	Full Right Edge (px)	Centre Width (px)	Full Width (px)	Missed Centre (px)	Missed Full (px)	Missed Centre (%)	Missed Full (%)	PE(DOB) Centre (%)	PE(DOB) Full (%)
B4	10	None	P1	416	826	1671	2079	845	1663	845	1663	100	100	0	0
B4	10	None	P2	416	826	1671	2079	845	1663	845	1663	100	100	0	0
B4	10	None	P3	416	826	1671	1995	845	1579	845	1579	100	100	0	0
B4	10	None	P4	416	826	1671	2119	845	1703	845	1703	100	100	0	0
B4								3380	6608	3380	6608	100	100	0	0
B4	0	New	P1	416	873	1814	2375	941	1959	0	114	0	6	100	94
B4	0	New	P2	416	873	1814	2332	941	1916	0	70	0	4	100	96
B4	0	New	P3	416	873	1814	2332	941	1916	0	234	0	12	100	88
B4	0	New	P4	416	873	1814	2247	941	1831	0	170	0	9	100	91
B4	PE(5)							3764	7622	0	588	0	8	100	92
MV4	10	New	P1	416	770	1498	1830	728	1414	0	447	0	32	100	68
MV4	10	New	P2	416	770	1498	1873	728	1457	70	308	10	21	90	79
MV4	10	New	P3	416	770	1498	1873	728	1457	349	1036	48	71	52	29
MV4	10	New	P4	416	770	1498	1830	728	1414	641	1323	88	94	12	6
MV4								2912	5742	1060	3114	36	54	64	46

Table 41. *Penetration Efficiency Calculations*

Machine	DOB (cm)	Hammer	Profile	Full Left Edge (px)	Centre Left Edge (px)	Centre Right Edge (px)	Full Right Edge (px)	Centre Width (px)	Full Width (px)	Missed Centre (px)	Missed Full (px)	Missed Centre (%)	Missed Full (%)	PE(DOB) Centre (%)	PE(DOB) Full (%)
MV4	15	New	P1	416	770	1499	1873	729	1457	133	476	18	33	82	67
MV4	15	New	P2	416	770	1499	1832	729	1416	412	1055	57	75	43	25
MV4	15	New	P3	416	770	1499	1832	729	1416	467	600	64	42	36	58
MV4	15	New	P4	416	770	1499	1873	729	1457	95	670	13	46	87	54
MV4								2916	5746	1107	2801	38	49	62	51
MV4	10	Worn	P1	416	770	1498	1918	728	1502	200	710	27	47	73	53
MV4	10	Worn	P2	416	770	1498	1834	728	1418	0	148	0	10	100	90
MV4	10	Worn	P3	416	770	1498	2128	728	1712	323	985	44	58	56	42
MV4	10	Worn	P4	416	770	1498	1876	728	1460	103	304	14	21	86	79
MV4								2912	6092	626	2147	21	34	79	66
MV4	10	None	P1	416	770	1500	1831	730	1415	678	1361	93	96	7	4
MV4	10	None	P2	416	770	1500	1962	730	1546	730	1546	100	100	0	0
MV4	10	None	P3	416	770	1500	1876	730	1460	712	1440	98	99	2	1
MV4	10	None	P4	416	770	1500	2084	730	1668	717	1656	98	99	2	1
MV4								2920	6089	2837	6003	97	99	3	1

Table 41. *Penetration Efficiency Calculations*

Machine	DOB (cm)	Hammer	Profile	Full Left Edge (px)	Centre Left Edge (px)	Centre Right Edge (px)	Full Right Edge (px)	Centre Width (px)	Full Width (px)	Missed Centre (px)	Missed Full (px)	Missed Centre (%)	Missed Full (%)	PE(DOB) Centre (%)	PE(DOB) Full (%)
MV4	0	New	P1	416	770	1498	1915	728	1499	0	0	0	0	100	100
MV4	0	New	P2	416	770	1498	1870	728	1454	0	148	0	10	100	90
MV4	0	New	P3	416	770	1498	1915	728	1499	0	96	0	6	100	94
MV4	0	New	P4	416	770	1498	1915	728	1499	182	308	25	21	75	79
MV4	PE(5)							2912	5951	182	552	6	9	94	91

Table 42. *Area & Speed Calculations*

Machine	Parameter	Units	10 cm DOB New Hammers	15 cm DOB New Hammers	10 cm DOB Worn Hammers	10 cm DOB No Hammers	0 cm DOB New Hammers
B4	Centre 50% Width	m	1.1125	1	1	1	1.1125
B4	Full Width (avg of 4 profiles)	m	2.225	2.05	2.1	1.9875	2.2875
B4	Speed	m/h	231	176	155	307	300
B4	MED (centre 50%)	m	0.055	0.08	0.07	0.035	0.06
B4	MED (full width)	m	0.04	0.035	0.045	0.035	0.035
B4	Depth for PE	m	0.1	0.15	0.1	0.1	0.05
B4	PE (centre 50%)		0.54	0.42	0.78	0	0.92

Table 42. *Area & Speed Calculations*

Machine	***Parameter***	***Units***	***10 cm DOB New Hammers***	***15 cm DOB New Hammers***	***10 cm DOB Worn Hammers***	***10 cm DOB No Hammers***	***0 cm DOB New Hammers***
B4	PE (full width)		0.42	0.31	0.7	0	1
B4	Area Rate (m^2/h)	MED (centre 50%)	257	176	155	307	334
B4	Area Rate (m^2/h)	MED (full width)	514	361	326	610	686
B4	Area Rate (m^2/h)	PE (centre 50%)	14	11	12	0	15
B4	Area Rate (m^2/h)	PE (full width)	22	17	23	0	34
B4	Volumetric Rate (m^3/h)	MED (centre 50%)	14.1	14.1	10.9	10.7	20.0
B4	Volumetric Rate (m^3/h)	MED (full width)	20.6	12.6	14.6	21.4	24.0
B4	Volumetric Rate (m^3/h)	PE (centre 50%)	13.9	11.1	12.1	0.0	15.4
B4	Volumetric Rate (m^3/h)	PE (full width)	21.6	8.2	10.9	0.0	16.7
MV4	Centre 50% Width	m	0.8625	0.8625	0.8625	0.8625	0.8625
MV4	Full Width (avg of 4 profiles)	m	1.725	1.725	1.825	1.825	1.788
MV4	Speed	m/h	474	196	290	612	692
MV4	MED (centre 50%)	m	0.04	0.115	0.075	0.045	0.035
MV4	MED (full width)	m	0.04	0.035	0.05	0.03	0.035
MV4	Depth for PE	m	0.1	0.15	0.1	0.1	0.05

Table 42. *Area & Speed Calculations*

Machine	Parameter	Units	10 cm DOB New Hammers	15 cm DOB New Hammers	10 cm DOB Worn Hammers	10 cm DOB No Hammers	0 cm DOB New Hammers
MV4	PE (centre 50%)		0.64	0.62	0.79	0.03	0.94
MV4	PE (full width)		0.46	0.51	0.66	0.01	0.91
MV4	Area Rate (m^2/h)	MED (centre 50%)	409	169	250	528	597
MV4	Area Rate (m^2/h)	MED (full width)	818	338	529	1117	1237
MV4	Area Rate (m^2/h)	PE (centre 50%)	26	16	20	2	28
MV4	Area Rate (m^2/h)	PE (full width)	38	26	35	1	56
MV4	Volumetric Rate (m^3/h)	MED (centre 50%)	16.4	19.4	18.8	23.8	20.9
MV4	Volumetric Rate (m^3/h)	MED (full width)	32.7	11.8	26.5	33.5	43.3
MV4	Volumetric Rate (m^3/h)	PE (centre 50%)	26.2	15.7	19.8	1.6	28.1
MV4	Volumetric Rate (m^3/h)	PE (full width)	37.6	12.9	16.5	0.5	27.2

List of symbols/abbreviations/acronyms/initialisms

CCMAT	Canadian Centre for Mine Action Technologies
cm	Centimetre
CWA	European Committee for Standardization (French spelling) Workshop Agreement
DOB	Depth of burial
DRDC	Defence Research and Development Canada
FAO	United Nations Food and Agriculture Organization
FU1/FU2	Way Industry product designation for flails heads.
IMATC	International Mine Action Training Centre
ITEP	International Test and Evaluation Program
kg	Kilogram(s)
kg/m^3	Kilogram(s) per cubic metre
kW	Kilowatt
m	Metres
m/h	Metre(s) per hour
m^2/h	Square metre(s) per hour
m^3/h	Cubic metre(s) per hour
MED	Maximum Effective Depth
MHz	Megahertz
mm	Millimetres
PE_x	Penetration Efficiency calculated at depth ‘x’ centimetres
px	Pixels

SWEDEC	Swedish Explosive Ordnance Disposal and Demining Centre
WORM	Wirelessly Operated Reproduction Mine

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In October 2006 a trial was conducted by the International Test and Evaluation Program in which the Bozena-4 mini-flail and the MV-4 mini-flail were tested at the International Mine Action Training Centre in Nairobi, Kenya. The trial was designed to examine the performance of both machines in the conditions local to that establishment, and also to attempt to quantify the effects of flail hammer wear on performance. The tests were initially based on the methodology specified in the “European Committee for Standardisation (CEN) Workshop Agreement 15044; Test and Evaluation of Demining Machines” but it was not possible to maintain the standardized conditions necessary for a fully CWA15044-compliant trial.

Neither machine was able to penetrate the extremely hard ground consistently or reliably to depths beyond 11 cm. Due to changing machine parameters throughout the trial no clear conclusions could be reached regarding the effects of hammer wear on performance.

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