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Techniques for Capturing Radiographic Images of High Speed Penetration Events though Sand

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14. ABSTRACT
Techniques for imaging through sand using radiography have been investigated, but in previous years there has been a lack of documentation on the methods used. Experiments have been conducted that image a shaped charge penetration event into sand as well as a kinetic energy penetrator into sand. Techniques to image through sand are not limited to what is discussed. These are just the methods that were found to give favorable results with what was tried during these sets of experiments with the equipment available. Optimum techniques to include the type of x-ray system, the type of target, and the distances between them are discussed and the results are presented.

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1.0 Introduction

In recent years the Air Force Research Laboratory, Munitions Directorate, Damage Mechanisms Branch has been investigating how to image a high speed sand penetration event, such as a shaped charge jet or kinetic energy penetrator. A number of different engineers have attempted to image the event with varying degrees of success, but with little documentation to outline the process. To achieve better results a number of variables were first tested statically before a dynamic penetration event to include; x-ray system, target shape, target thickness, and source distance. It will be discussed later that the phenomenon of interest plays a major role in deciding the x-ray system to be used. For example, when imaging a shaped charge jet a 1MeV x-ray system should be used if the cavity profile is of interest, while a weaker system is best used to image the compaction zone around the cavity. Although there are other techniques to image events through sand, this paper simply documents the methods that were found to give favorable results with what was tried during these sets of experiments with the equipment available.
[1]

2.0 Shaped Charge Imaging

Methods to image a shaped charge penetration event into sand were investigated. Items of interest in the event were the cavity created by the shaped charge jet, the compaction zone surrounding the cavity, and the jet itself.

2.1 Shaped Charge Setup

While a tube was used in past experiments, it was determined that a square or rectangular profile would be the best choice for use with a shaped charge. This profile would give a near constant thickness of sand the x-rays have to travel through. A static target was built that had walls made of three different materials (1/8” steel, 1/4" Aluminum, 1/2” polycarbonate). The target was designed so it could easily change the thickness of the sand. A tapered hollow cardboard tube was placed in the middle of the target to simulate a cavity.

The three different x-ray systems (150 keV, 450 keV, and 1 MeV) were tested to determine the maximum thickness through which one could still see the simulated cavity. While the images that were produced showed the cavity, a better image was needed to see the fine details of the sand penetration i.e. compressed sand. While discussing the problem with the photo technician, it was determined a method of reducing the x-ray scatter caused by the sand was needed. Medical x-ray grids (Wolf X-Ray Systems[1]) were placed in the film pack (Kodak AR Film[1] with Dupont Cronex[1] intensifying screens) to reduce the scatter. Afterwards the images no longer had a blurry appearance due to the reduction of indirect x-rays caused by the x-ray scatter in the sand. It is also noted that midway through this investigation the testing range switched from analog film to a new digital film system made by Fuji[1]. The new digital imaging plates (Fuji IP[1]) showed an increase in film clarity.

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[1] Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government.

The static experiments used a 12” long by 8” tall target that could vary its thickness. The walls had a wood frame and the three wall materials were attached to this frame. The hollow cardboard tube was about 11” long and had a 1” diameter for the large end. The 150 keV x-ray system used a film to target distance of 15” to 30”. The target had only polycarbonate for the walls. The sand thickness was 4” to 6”. Figure 1 shows a typical experimental setup.

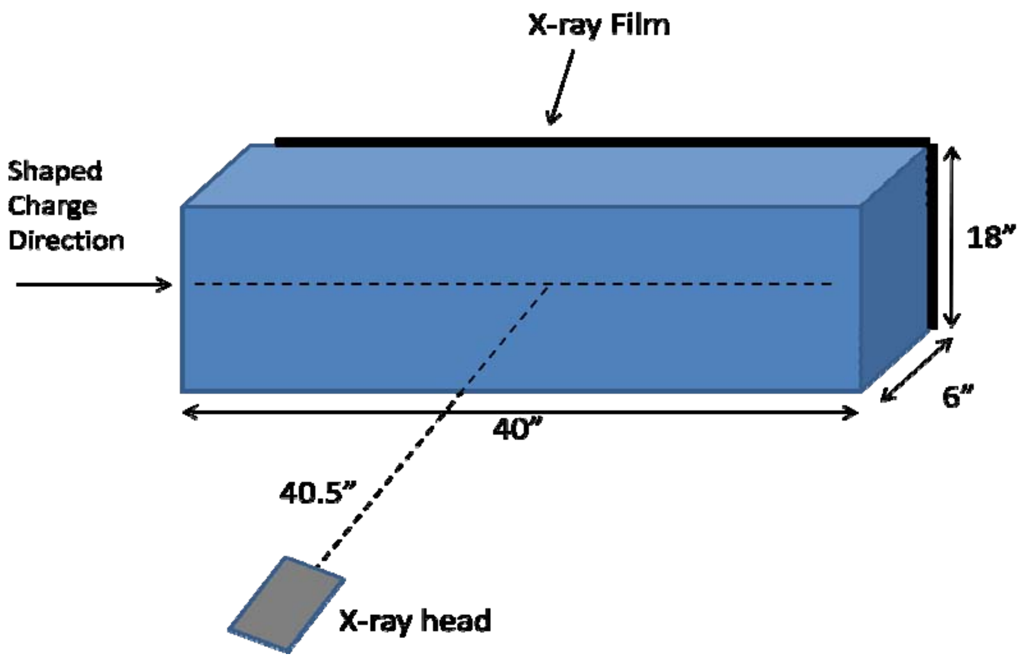

Figure 1: Typical experimental set-up for shaped charge penetration

2.2 Shaped Charge Image Results

For the test in Figure 1, the x-ray head to target distance was 15” and two x-ray heads were used to try to get two separate images of the simulated cavity. It can be seen in Figure 2 that 6” of sand is too thick to see anything but the copper wire. In Figure 3 the sand thickness was reduced to 4” and only one x-ray head was used. In this image the simulated cavity can be seen. Next, the 450 keV x-ray system is tested using the same simulated cavity. The target used for these tests had three different materials for walls (1/8” steel, 1/4" Aluminum, 1/2” polycarbonate). For the test in Figure 4, the x-ray head to target distance was 30”. The target had 6” of sand and used an aluminum wire in the simulated cavity. While the image is not quite the quality of the 150 keV system at 4” of sand, it is close. This will allow larger penetrators to be fired into the sand target.

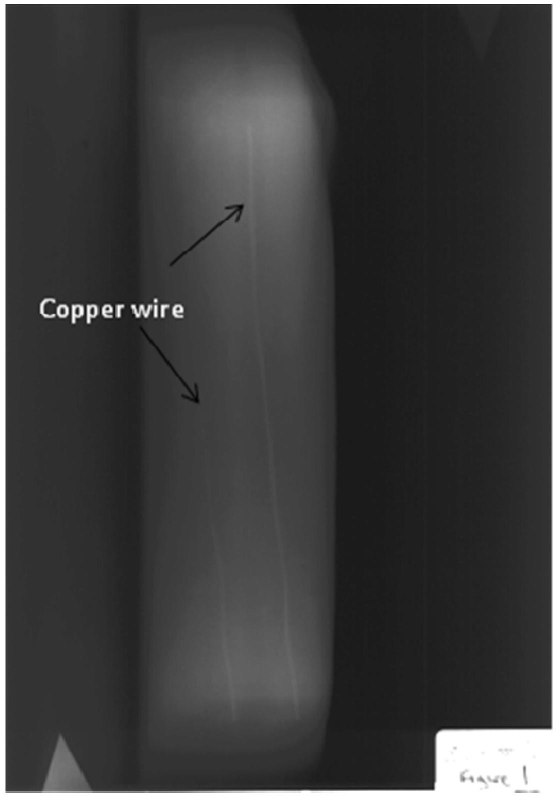

Figure 2: Static test with 6” thick sand and two 150 keV x-ray heads (only see copper wire)

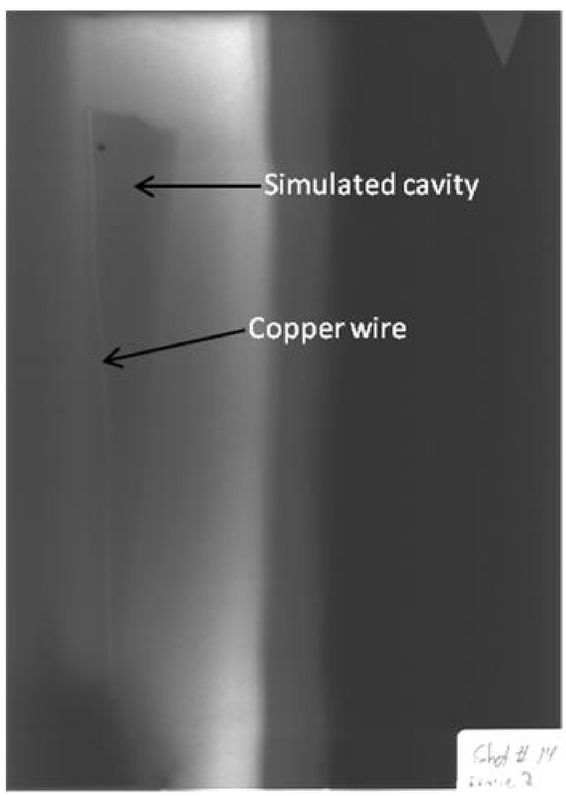

Figure 3: Static test with 4” thick sand and 150 keV x-ray head (simulated cavity and copper wire seen)

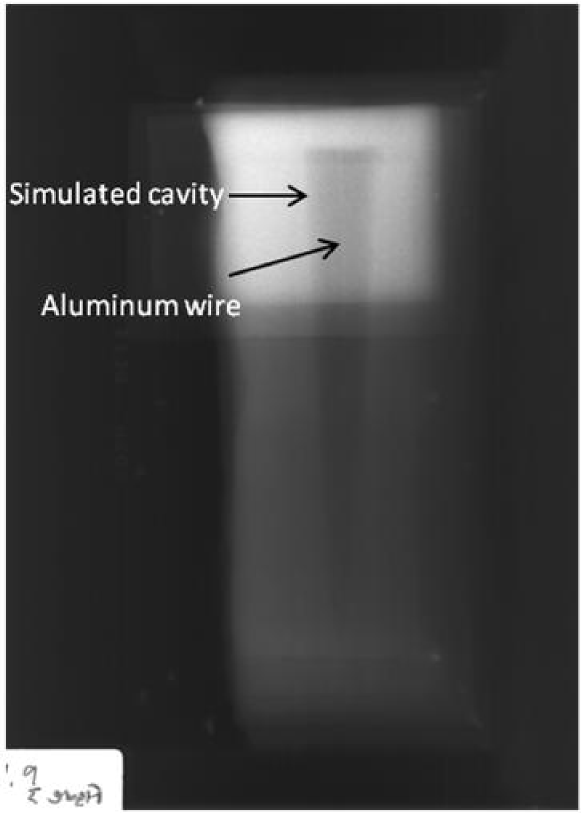

Figure 4: Static test with 6” thick sand, multi material walls and 450 keV x-ray head (simulated cavity and aluminum wire seen)

At the time of these tests (November 2006-February 2007), the 1 MeV x-ray system was inoperable. It was determined that dynamic experiments should start using the 450 keV system. The first dynamic experiments used a copper shaped charge to form the cavity. The target is 6” thick by 18” tall by 40” long. The x-ray head to shot line distance is 40.5” and the x-ray head to film distance is 44.5”. The cavity and surrounding compaction zone caused by the penetration event can be seen in the film (Figure 5). The edges of the cavity and the compaction zone are blurry and the tip of the cavity is hard to see.

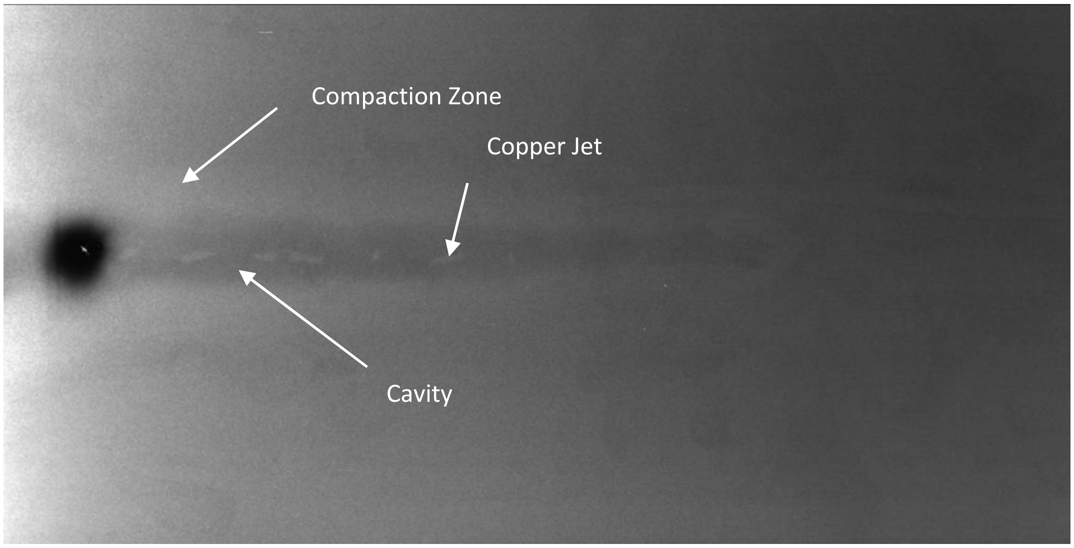

Figure 5: X-ray film from dynamic test using 450keV x-ray system

At this time it was decided to try to reduce the x-ray scatter induced by the sand. The new medical x-ray grids made by Wolf X-Ray Systems were used. The medical grid had 103 lines per inch of aluminum interspacers with a ratio of 6:1. The x-ray head to film distance had to be between 48” to 72” when using the medical grids. The x-ray head to shot line distance was 44” and the x-ray head to film distance was 48” on the film in Figure 6. The same copper shaped charge and target were used. The cavity can be seen much more easily. The compaction zone surrounding the cavity is also more defined along with the tip of the cavity. The black lines are “make” screens inserted into the target, used to measure velocity of the test item and trigger the x-ray system.

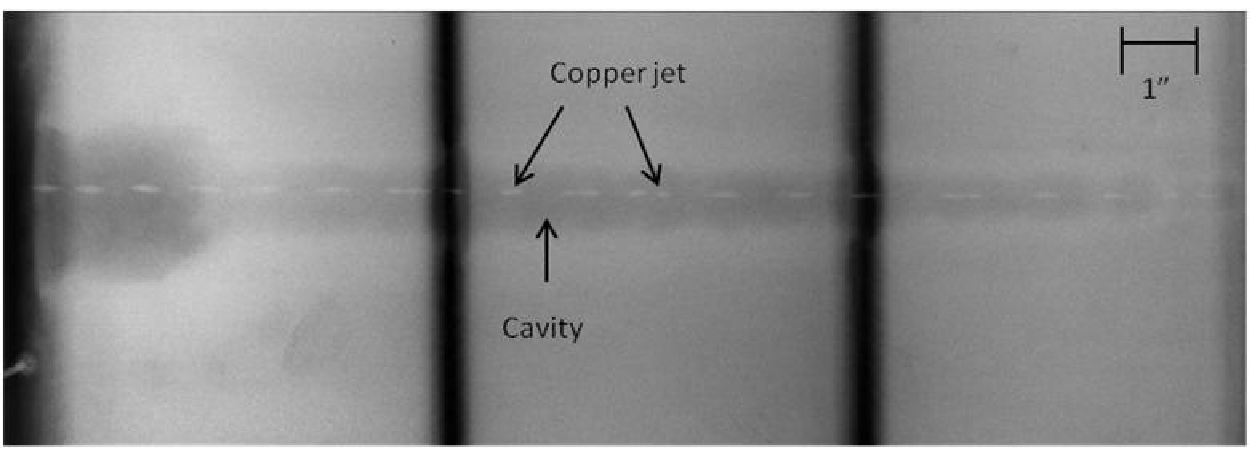

Figure 6: X-ray film utilizing the medical x-ray grids to reduce scatter on the film

Around Aug 2007 the range started to convert from the old analog film to the new digital Fuji system. The 1 MeV system was repaired around the same time, so it was statically tested. The x-ray head to target distance was 47” and the x-ray head to film distance was 51”. The new digital film along with the medical grid was used. The target had polycarbonate walls with 6” of sand. Figure 7 shows a great improvement in the clarity of the simulated cavity over the 450 keV system.

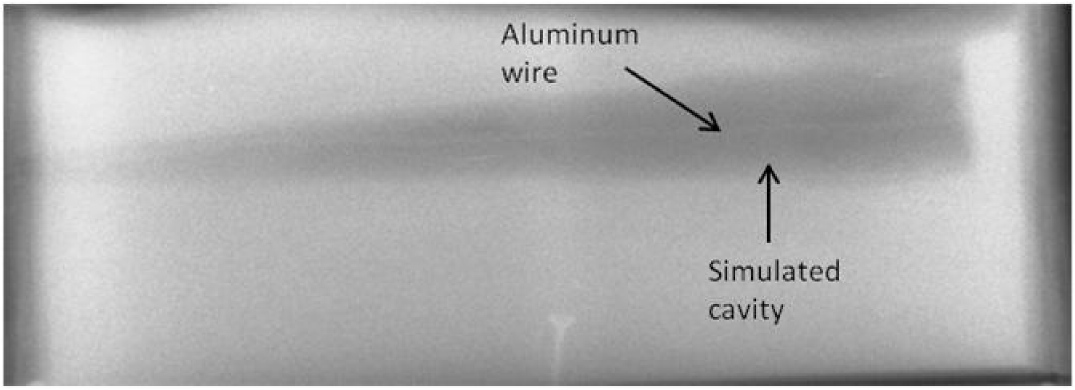

Figure 7: Static test with 6" thick sand and 1 MeV x-ray head (simulated cavity and aluminum wire seen)

Figure 8 shows a dynamic experiment with the 1 MeV x-ray system. The digital film and medical x-ray grid were used. The same 6" thick target was used. The x-ray head to shot line distance was 56" and the x-ray head to film distance was 60". An aluminum shaped charge is used to form the cavity. The 1 MeV system provides a great image of the cavity and aluminum jet but does not provide an image of the compaction zone that is seen using the 450 keV system.

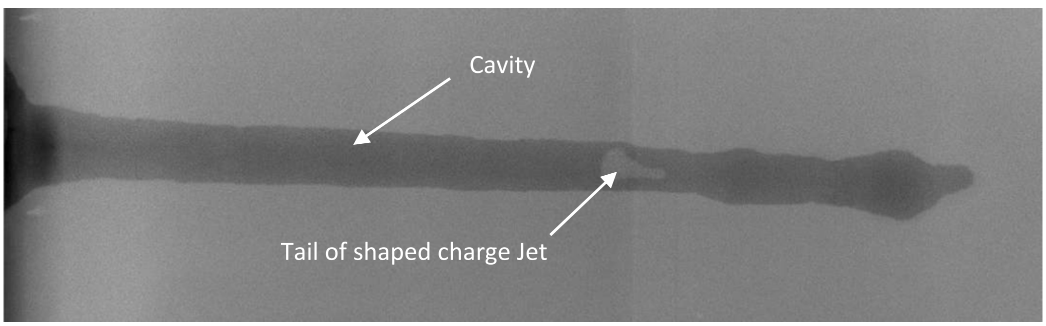

Figure 8: Digital x-ray film utilizing 1 MeV x-ray and medical grid

Table 1 gives a summary of the different configurations that were explained in this paper.

Figure #	X-ray System	X-ray Grids?	Sand Thickness	Static/Dynamic	Film Type
2	150 keV	No	6"	Static	Analog
3	150 keV	No	4"	Static	Analog
4	450 keV	No	6"	Static	Analog
5	450 keV	No	6"	Dynamic	Analog
6	450 keV	No	6"	Dynamic	Analog
7	1 MeV	Yes	6"	Static	Digital
8	1 MeV	Yes	6"	Dynamic	Digital

Table 1: Shaped charge experimental summary

3.0 KE Penetrator Imaging

Methods to produce multiple images of the same penetration event were investigated using a gun launched kinetic energy (KE) penetrator. Items of interest were the cavity surrounding the tail of the penetrator and the higher density region of sand around it.

3.1 KE Penetrator Setup

For kinetic energy experiments a 6” diameter schedule 40 PVC pipe is used for the target. The target was made of two 21” sections and coupled together. Using two shorter pipes allows for the sand to be packed in the target. The sand is packed in roughly 2” increments. Three 150 keV x-ray heads were used to image the length of the penetration event. Digital x-ray film is used but not the medical grids due to the propensity of the KE penetrator to exit the side of the target. To minimize the effects of double exposure, two pieces of lead plate are placed between the x-ray heads.

For the multiple image experiments, the x-ray head to shot line distance is 12” and the x-ray head to film distance is 17.75” The three x-ray heads are placed 8” apart down the length of the target. The target is placed with the front resting against a blast shield and the back of the target is placed on a wooden stand. A strap was placed around the blast shield and target to keep the target from moving during impact (Figure 9).

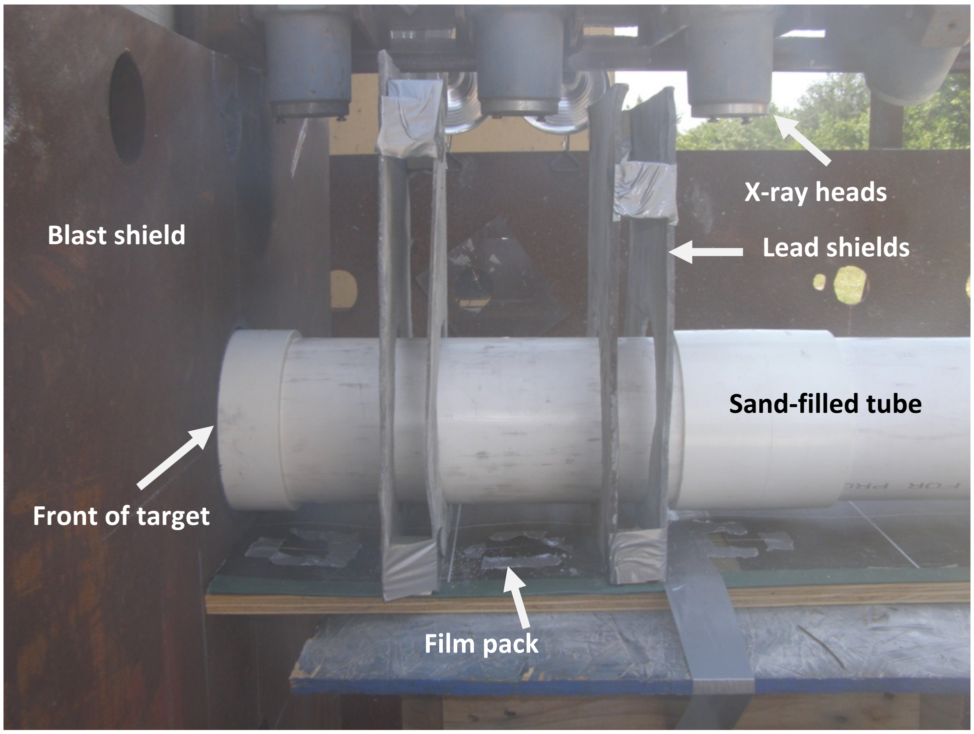

Figure 9: Multiple image set-up for gun launched KE penetrator

3.2 KE Penetrator Image Results

Figure 10 is a static test of the penetrator in a cardboard tube. The dark spot in front of the penetrator is a piece of low density foam that was in the tube, showing the contrast between high and low densities in the target. Figure 11 shows how this set-up can produce images of the penetration event at different points in time. The cavity can be clearly seen surrounding the penetrator, including the unsymmetrical behavior of the sand. The cavity following the penetrator can also be seen between the first pair of lead plates.

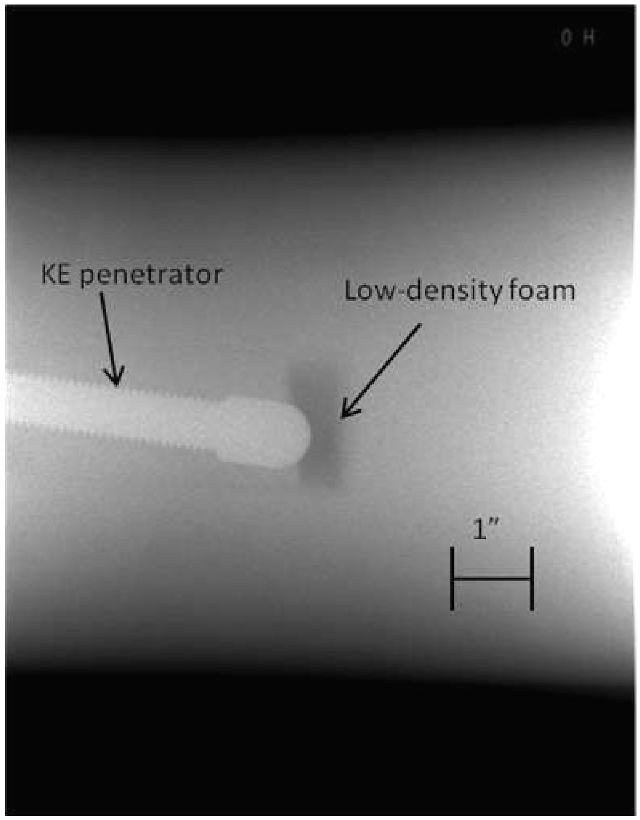

Figure 10: Static Test with 6" thick sand target and foam cavity simulator

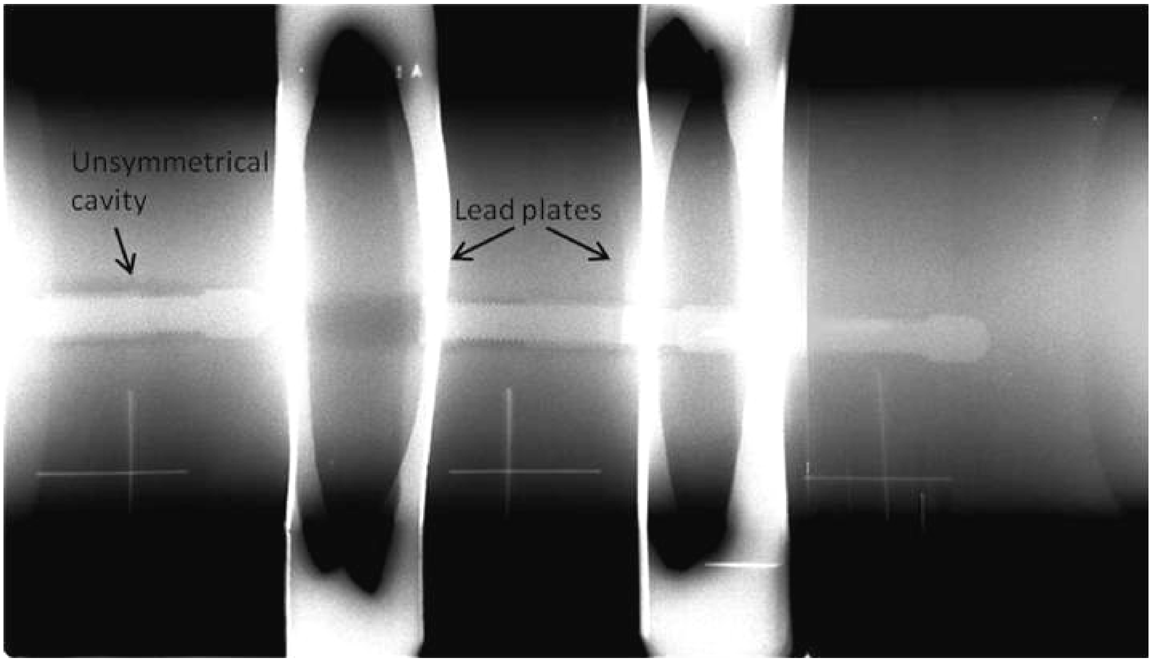

Figure 11: Digital x-ray film showing multiple images of the same penetration event

4.0 Conclusions

Approximately 30 static and 20 dynamic experiments refining this radiographic imaging technique were conducted. A few strengths and weaknesses of each set-up were discovered. If possible always use digital film and the medical grids. If a 6” thick target is used and the compaction zone is of interest, the 150 keV or the 450 keV system shows the best results. If the cavity profile is of more interest then the 1 MeV system is most suitable. When using a 4” thick target, the 150 keV system is favored. If a more powerful system is used with the 4” thick target then the image becomes degraded.

If the experiment calls for multiple images of the same penetration event, use the 6” diameter tube and the 150 keV system. The 450 keV system could be used instead, but the x-ray head to shot line distance will need to be increased and an increased thickness of lead would be required to minimize the double exposure. When using the 6” tube, a gradient is seen on the film caused by the changing thickness of sand, but the cavity more uniformly interacts with the tube walls.

The previous suggestions will provide the best images with the current (2006-2009) equipment available at the Air Force Research Laboratory, Munitions Directorate, Damage Mechanisms Branch.

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