Journal of Conventional Weapons Destruction

Volume 4
Issue 2 *The Journal of Mine Action*

Article 7

June 2000

The Spider Boot: An Effective Foot Protection System Against Anti-Personnel Mine Blasts

S. Islam
Med-Eng Systems Inc.

Aris Makris
Med-Eng Systems Inc.

Denis Bergeron
Med-Eng Systems Inc.

The Spider Boot: An Effective Foot Protection System Against Anti-Personnel Mine Blasts

by Shariful Islam, Aris Makris, and Denis Bergeron

Issue 4.2 | June 2000
Information in this issue may be outdated. Click here to link to the most recent issue.

Background

It is estimated that about 70 million AP landmines are deployed worldwide, slowing down the economic recovery of war torn countries and causing indiscriminate injuries to returning civilian populations long after the end of a conflict. Several military and non-military organizations are currently engaged in mine clearance, either in support of peacekeeping operations or for humanitarian demining.

Too often, the personnel carrying out mine clearance tasks are issued Personal Protective Equipment (PPE) that does not provide adequate protection against encountered threats. Injury statistics confirm that many demining technicians, military or civilian, become victims of accidental mine detonations, resulting in serious physical injuries, loss of limbs and even death. When the foot of the victim is directly on top of the exploding mine, the blast force exceeds the structural integrity threshold of the majority of wearable materials found in PPE footwear. Furthermore, the expansion of the explosion products generates a strong vertical force that accelerates the foot and lower leg directly over the explosion. If the deminer does not have adequate foot protection, there is a high probability of amputation. For the larger blast AP mines, shattering of the lower leg bones and joints located axially over the mine occurs. Stripping of soft tissues also occurs, allowing debris from the compromised footwear, mine casing or surrounding dirt to be driven into the lower leg. This contamination leads to an escalation of the level of injury and the need for amputation of the limb further up the leg.

This paper presents a novel foot protection system called the Spider Boot, which is designed and engineered on the principles of blast physics. The Spider Boot provides a safety or standoff distance from a detonating mine, keeping the feet and legs as far away as possible from the explosion. Its design features provide a significant reduction of the blast induced loading experienced during a detonation. The performance of the Spider Boot, as deduced from resultant acceleration and bending strain measurements taken from a mechanical surrogate of the lower leg, is comparable to that of a conventional blast boot.

Foot Protection Systems for Deminers

Current demining operations expose the technicians to the probability of an accidental mine detonation under the foot. The deminer’s footwear plays an important role in the protection of the foot and the resulting level of injury. The ideal footwear must be adequate to attenuate the blast effects (overpressure, acceleration, fragmentation and heat) to a level where injury to the foot and lower leg can be minimized. Several mine-protective footwear designs have been proposed to meet this goal. The traditional approach is to add materials to the sole of a conventional boot to deflect and absorb some of the blast energy. Another approach is to rest the foot on a platform to increase the distance from the explosion. The Spider Boot combines both of these approaches into a single design.

Conventional Mine Protection Footwear

Mine-protected boots are available commercially. They consist of conventional boots that are modified by adding materials to attenuate the transmission of the leading shock through the sole and to deflect some of the afterflow generated by the expansion of the hot gases from the mine detonation. In some cases, the shock attenuation is obtained by using an aluminum honeycomb encased in a V-shaped steel container to mismatch the impedance between adjacent materials. A porous resin-bonded aggregate is also used for the same purpose. In each design, some of the blast energy is absorbed through deformation of the material. The sole can also be thickened, thereby increasing the standoff from the explosion. At least one manufacturer also produces an over-boot that incorporates shock-attenuating materials and increases the standoff distance.

In practice, mine-protected footwear based on conventional boots can provide effective protection against mines containing up to 30-50g of high explosives. The principal drawback of this type of footwear is that it results in direct contact between the sole and the parcel of ground containing the explosive. This contact increases the shock transmission into the sole. Conventional footwear also puts the foot of the deminer directly above the mine in a region where the expanding flow can impart significant kinetic energy to the relatively high mass of the shock attenuator—energy that must then be absorbed by the foot and lower leg. The foot's relatively close proximity to the explosion also makes it very difficult to select appropriate materials. The extreme pressures in that region exceed the limits of most plastics. As a result, these materials often fail in this pressure regime before they have a chance to perform their job.

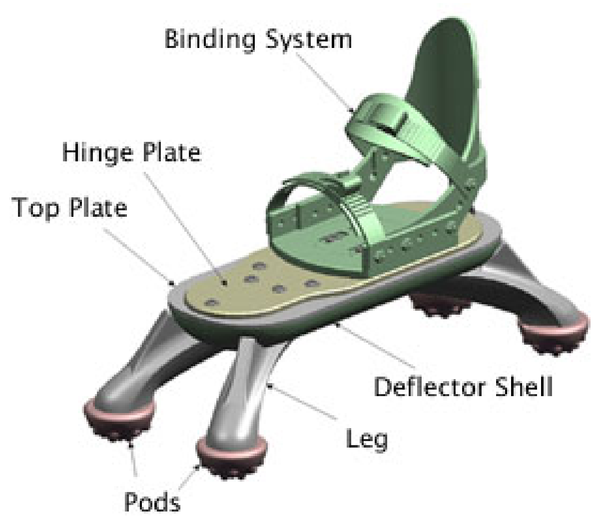
The Spider Boot

One important characteristic of a blast wave is that the blast overpressure decays dramatically with distance from the source, thus providing the concept of a safety or standoff distance in the design of PPE. This principle is incorporated in the design of the Spider Boot along with other fundamental engineering principles, as summarized below:

• Maintain the maximum permissible standoff distance between the explosive charge and the foot, as defined by the structure of the deflector shell mounted on ground engaging legs and pods.

• Maximize the venting of the blast by having the mine detonate, under nominal conditions, away from the foot through the forward and rear protruding pods.

Figure 1: Design features of the Spider Boot.



• Deflect the blast wave and the fragments with a blast and fragment resistant deflector shell that extends below the full length of the operator's foot.

• Absorb most of the residual energy through the choice of sacrificial materials on the underside of the footwear.

• Permit normal demining operations over a diversity of terrain.

The Spider Boot (Figure 1) consists of a binding system on a platform mounted above a deflector shell. It is mounted on two forward and two rear protruding legs, each leg terminating with a rubber pod. The deminer wears the Spider Boot with regular footwear. The deflector shell, legs and pods provide the necessary standoff distance by raising the platform to a nominal height of 144mm above the ground. This configuration is designed to maximize protection while remaining wearable. The protection afforded depends on the explosive content and the relative location of the mine.

Performance Tests of Foot Protection Systems with Mechanical Surrogate Leg

The early selection of materials and geometry for the Spider Boot was guided by fullscale blast tests. Once the blast effectiveness of the design was confirmed, a more detailed study was initiated under the auspices of the Canadian Defense Industrial Research Program (DIRP). Tests were carried out at Defense Research Establishment Suffield (DRES) with an advanced mechanical surrogate leg (Figure 2) designed to provide quantitative measurements of parameters deemed indicative of the potential for leg injury and the relative protection afforded by different foot protection systems. Performance parameters,such as accelerations at the ankle,bending strains near the ankle and knee and compressive and torsional strains at the midsection of the tibia of the surrogate leg, were measured.

Instrumented mechanical surrogate leg used in DRES tests.

Photo c/o Med-Eng System Inc.

Blast tests of the foot protection systems were conducted under realistic conditions with actual and surrogate blast AP mines. The surrogate mines consisted of plastic cylinders containing 25g to 200g of C4 explosive. The real mines used included the PMA-1, PMA-2, PMA-3 and PP-Mi-Na1. The explosive charge was placed under one of the pods of the Spider Boot or under the heel or insole of conventional footwear. The explosive charge was buried in sand, 3cm below the surface, providing an over burden. The pod of the Spider Boot or the heel/insole of the boot was then placed 2cm over the explosive.

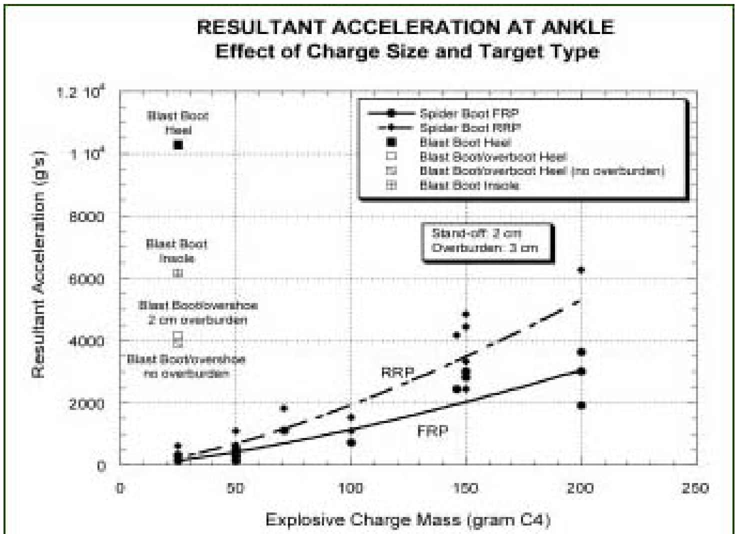


Figure 3: Resultant accelerations at the ankle of the surrogate leg with different foot protection systems.

Results and Discussion

The results of this study are presented in terms of resultant acceleration at the ankle and bending strains in the fore/aft plane through the longitudinal axis of the lower leg. Spider Boot test data indicates that the acceleration and bending strain experienced by the surrogate leg increases non-linearly with increasing masses of explosive. For the convenience of plotting, equivalent C4 charge masses were computed using a 1.37 factor (C4:TNT) for the PMA and PP-Mi-Na1 mines.

Figure 3 shows the effect of charge mass on the resultant acceleration experienced by the surrogate leg with different types of foot protection systems.

The average resultant acceleration varied from 150g for 25g C4 to 2,860g for 200g C4 placed under the Front Right Pod(FRP) and 145g to 6,270g for similar charges under the Rear Right Pod (RRP) of the Spider Boot. On the other hand, the resultant acceleration varied from 4,180g for a PMA-3 AP mine (34g high explosive) under the heel of a blast boot with an over-boot to 10,300g for 25g C4 under the heel of a blast boot without an over-boot. The graph shows that the resulting acceleration for a detonation under the RRP of the Spider Boot is higher than that under the FRP for a same charge size, emphasizing that a target closer to the detonation experiences higher blast loading.

The test results also indicate that wearing the Spider Boot with a regular combat boot reduces the blast-induced acceleration by more than 90 percent for a 25g C4 explosive charge and by more than 80 percent for a PMA-3 mine. These figures are relative to a blast boot based on a standard military boot concept with an enhanced sole.

Figure 4 shows the fore/aft bending strain results near the lower part of the surrogate leg. The average bending strain varied from 370 me for 25g C4 to 1,585 me for 200g C4 under the RRP and from 855 me to 3,440 me for similar charges under the FRP of the Spider Boot. In comparison, the blast boot offered far less protection, as the average bending strain varied from 1,330 me for a 25g C4 charge placed under the heel to 3,595 me for a 25g C4 charge placed under the insole of the blast boot. The test results also indicate that, unlike resultant acceleration, the surrogate leg experiences more bending strain for a detonation under the FRP than for a similar detonation under the RRP of the Spider Boot. This situation occurred because the moment arm associated with the blast force under the FRP to the ankle is greater than that under the RRP and causes more bending of the leg for the same explosive charge.

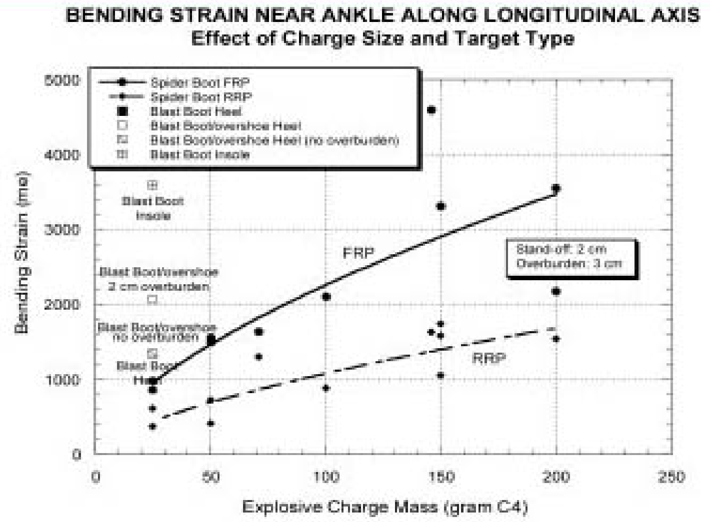


Figure 4: Bending strains near the ankle of the surrogate leg with different foot protection systems.

Figure 5(a)

Figure 5(b)

Figure 5: 25g C4 under the heel of a blast boot with over-boot with a stand-off of 2cm and no overburden. (a) Pre-detonation and (b) post-detonation. The heel of the boot is torn out from the upper ballistic materials and the over-boot exposing the damaged ballistic materials inside the heel.

Figure 6 (a)

Figure 6 (b)

Figure 6: PMA-3 AP mine (35g Tetryl) under the FRP of the Spider Boot, and a combat boot with a stand-off of 2cm and an overburden of 3cm.
(a) Pre-detonation and (b) post-detonation. One front leg is broken, but the remaining parts of the Spider Boot are intact. The combat boot is undamaged.

Figure 7 (a)

Figure 7 (b)

Figure 7: PMA-3 AP mine (35g Tetryl) under the RRP of the Spider Boot, and a combat boot with a stand-off of 2cm and an overburden of 3cm.
(a) Pre-detonation and (b) post-detonation. Two rear legs are broken, but the remaining parts of the Spider Boot are intact. The combat boot is undamaged.

Figure 8(a)

Figure 8(b)

Figure 8: PP-MI-NA1 AP mine (97g TNT) under the FRP of the Spider Boot, and a combat boot with a standoff of 2cm and an overburden of 3cm.
(a) Pre-detonation and (b) post-detonation. Two front legs are broken, but the remaining parts of the Spider Boot remain intact. The combat boot is undamaged.

Figure 9(a) Figure 9(b)

Figure 9: PMA-1 AP mine (200 TNT) under the FRP of the Spider Boot, and a combat boot with a stand-off of 2cm and an over-burden of 3cm.
(a) Pre-detonation and (b) post-detonation. Two front legs are broken, and the front of the Spider Boot is damaged. The combat boot is undamaged.

Representative physical damages to the foot protection systems for various charge threats are shown in Figures 5-9 with explanations. These physical damages are indicative of the level of injury that may be inflicted to the feet and legs of deminers wearing either the Spider Boots combined with the combat boot or blast boot with or without over-boot. The Spider Boot is designed to be of a sacrificial nature—some parts of the boot are destroyed in order to protect the foot as in the “crumple zone” of modern automobiles. In separate tests in 1999, the performance of the Spider Boot was evaluated at DRES with a Frangible Surrogate Leg (FSL) that was developed by the Australian Defense Science and Technology Organization (DSTO). Further analysis of the data from these tests is ongoing.

User Trials

The Spider Boot was subjected to user trials in different terrain and working environments to obtain qualitative performance evaluations for various demining activities. The user feedback was valuable in refining the final design and identifying any limitations in the use of the equipment.

In August 1999, Med-Eng Systems conducted internal trials of the Spider Boot where the subjects wore humanitarian demining ensembles. The trials included various mine detection activities in rugged terrain, up and down hills, grassy fields, wooded areas, crushed stone trail, sandy ground and while carrying casualties from a mine field. The overall performance of the Spider Boot during these trials was found to be highly satisfactory, and the users did not have any significant complaints.

Med-Eng Systems also organized and conducted site trials with end users who would actually be involved in demining operations. Contact was established in various countries with humanitarian and military deminers that would potentially benefit from the use of the Spider Boot. Thus far, user trials of the Spider Boot have been conducted in Cambodia (Figure 10), Canada, Costa Rica, France and Nicaragua (Figure 11).

The military deminers were extremely receptive to the Spider Boot concept. Initial perceptions ranged from enthusiastic curiosity to downright skepticism. After minimal practice, they became very accustomed to using the equipment and then performed various demining activities wearing army uniforms and combat boots. These activities included mine detection, prodding, walking through tall grass, going over obstacles (e.g., tree trunks) and carrying casualties from a mine field. They appreciated the overall design principle of the Spider Boot, recognizing that it was a safer foot protection system than conventional blast boots and showed interest in including it in their humanitarian demining operations.

User trials of the Spider Boot with humanitarian demining suit by a deminer in Cambodia.

Photo c/o Med-Eng Systems Inc.

User trials of the Spider Boot with humanitarian demining suit by army personnel in Nicaragua.

Photo c/o Med-Eng Systems Inc.

Conclusion

Testing of the Spider Boot has shown that it significantly reduces the transmission of shock and forces to the foot and lower leg over an extensive range of mine threats. The detonation of 200g C4 or the blast produced by the large AP mines (PMA-1 and PMN) is expected to injure the foot inside the boot even when a Spider Boot is used. However, the extent of injury and its treatment will be greatly reduced when compared to conventional mine-protected footwear or a standard combat boot where the foot and lower leg damage are likely to require amputation and extensive rehabilitation. Though the Spider Boot is designed to be sacrificially but selectively compromised when a detonation occurs beneath one of the four pods, the deminer's footwear, as a whole, is expected to be preserved, improving the medical outcome for the injured foot. Overall, test results have thus far validated the approach and engineering principles built into the Spider Boot to provide improved foot protection against blast AP mines.

Contact Information

Med-Eng Systems Inc.
2400 St. Laurent Blvd.
Ottawa, Ontario, Canada K1G 6C4
Tel.: (613) 739-9646;
Toll free (U.S. and
Canada): 1 (800) 644-9078
Fax: (613) 739-4536
E-mail: info@med-eng.com
Website: www.med-eng.com