EVALUATION OF A NOVEL FOOT PROTECTION SYSTEM FOR ANTI-PERSONNEL MINE CLEARANCE

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Detailed Abstract

It is estimated that about 70 million anti-personnel (AP) landmines are burried worldwide causing indiscriminate injuries to returning civilian populations long after the end of a conflict. Several Non-Governmental Organizations, the United Nations, and militaries are currently engaged in humanitarian demining. Too often, the personnel carrying out mine clearance tasks are issued personal protective equipment (PPE) that does not provide adequate protection against the threats encountered due to technological limitations, poor understanding of the threat, and budget constaints.

If a technician steps on an AP blast mine, when wearing a conventional combat boot or one of the commercially available *blast boots*, the boot is in direct contact with, or very near, the mine. At this small distance, the peak overpressure generated by the explosion reaches tens of thousands of bars, even for small blast AP mines. The blast overpressure loading, combined with heat and fragmentation, exceeds the structural integrity threshold of the majority of *wearable* material candidates used in the design of PPE footwear. Furthermore, the expansion of the explosion products generates a tremendous vertical force that results in high acceleration of the foot and lower leg. Depending on the mine seize, there exists a high probability of traumatic amputation of the foot. For larger blast AP mines, the lower leg bones and joints can be shattered. Stripping of the soft tissues can often happen and debris can be driven into the lower leg, resulting in the need for amputation of the limb further up the leg.

This study describes the protective advantages of the *Spider Boot*, a novel system designed and engineered based on the principles of blast physics. The Spider Boot provides a *safety, or stand-off distance* from a detonating mine, keeping the feet and legs of deminers as far away as practical from the explosion. Measurements of the resultant acceleration and bending strain near the ankle of a mechanical surrogate leg are used to assess the protective performance of the footwear over a broad range of blast AP mine threats.

DESIGN PRINCIPLES

The Spider Boot consists of a binding system on a platform mounted above a deflector shell, itself mounted on two forward and two rearward protruding legs, each leg terminating with a rubber pod and engaging the ground. The deminer wears the Spider Boot with regular footwear. The deflector shell, legs, and pods provide the necessary stand-off distance by raising the platform to a nominal height of 144 mm above the ground. The physics of blasts clearly points to the benefit of increasing the standoff distance between the technician and the explosion, as the effects of the explosion decay dramatically with distance from the source. It is therefore desired to maintain the maximum permissible standoff distance between the explosive charge and the foot, as well as maximum blast venting, through the engaging *legs* and *protruding pods*. It is deemed essential to deflect the residual blast wave loading and the fragments with a resistant *deflector shell* that extends below the full length of the operator's foot. Sacrificial materials on the underside of the footwear are designed to partially absorb the blast energy. All these design features are incorporated in a manner to facilitate normal demining operations over a diversity of terrain.

PERFORMANCE TESTS WITH MECHANICAL SURROGATE LEG

Full-scale blast tests have been carried out under the auspices of the Canadian Defence Industrial Research Program (DIRP) at the Defence Research Establishment Suffield (DRES). These tests involved an advanced mechanical surrogate leg designed to measure performance parameters such as accelerations, as well as bending, compressive and torsional strains. The test data for the Spider Boot, worn in combination with a standard military combat boot, were also compared to that of a blast boot with reinforced sole. These blast tests included actual blast type AP mines and simulated mines. The explosive content used in the simulated mines ranged from 25 g to 200 g of C4 explosive. Real mines used in the DRES tests included the PMA-1, PMA-2, PMA-3, and PP-Mi-Nal. The tests were conducted with the explosive charge placed under one of the four pods of the Spider Boot. The explosive charge is covered with sand providing an *overburden* over it. The pod of the Spider Boot is then placed over the explosive, which then settles down in the ground resulting in a stand-off distance.

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. The test data with the Spider Boot indicate that the acceleration and bending strain experienced by the surrogate leg increase non-linearly with increasing mass of explosive (Figs. 1 and 2). For the convenience of plotting, equivalent C4 charge masses were computed using a 1.37 factor (C4:TNT) for the PMA and PP-Mi-Nal mines. Figure 1 shows the effect of charge mass on the resultant acceleration with different types of foot protection systems. The graph shows that the resultant acceleration for a detonation under the rear right pod (RRP) of the Spider Boot is higher than that under the front right pod (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 reduces the blast-induced acceleration by more than 90% for a 25 g C4 explosive charge, and by more than 80% for a PMA-3 mine. These figures are relative to a blast boot with an enhanced sole. Figure 2 shows the fore/aft bending strain results near the lower part of the surrogate leg. The blast boot offered far less protection as compared to the Spider 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. The reason for this is that 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 within the mine.

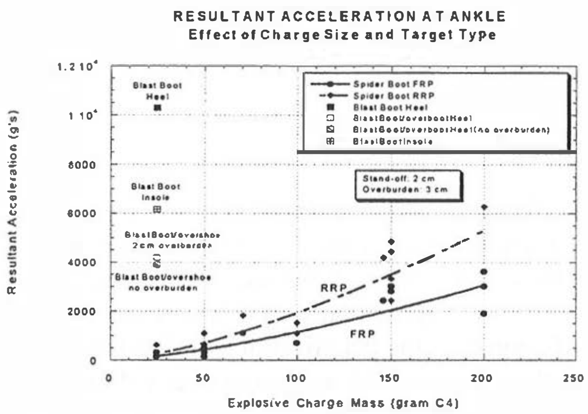

Fig. 1- Resultant accelerations at the ankle of the surrogate leg with different foot protection systems.

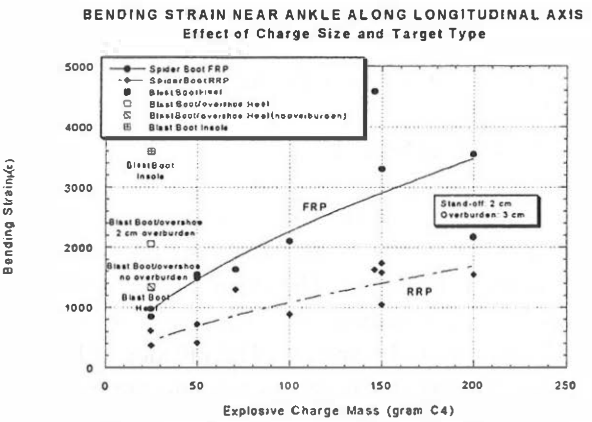

Fig. 2- Bending strains near the ankle of the surrogate leg with different foot protection systems.

CONCLUSIONS

The Spider Boot provides significant protection to the foot over an extensive range of actual and simulated AP blast mine threats. A detonation of 200 g C4 in a simulated mine, or the blast produced by the large AP mines (e.g., PMA-1, 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 simplified compared to a blast boot or a standard combat boot, where the foot and lower leg damage are likely to require amputation or extensive reconstruction and rehabilitation. The overall integrity of the wearer's footwear is expected to be preserved, thus improving the medical output for the injured foot. In conclusion, test results thus far validate the approach and engineering principles built in the Spider Boot to provide improved foot protection against blast AP mines.