Reducing the Devastation

The development of improved protection from Anti-personnel (AP) landmines has been an area of international interest since the Second World War. The devastating effect of these devices is well known and may be experienced for many years after a conflict has ended, presenting a significant risk to peacekeepers, humanitarian deminers and civilians living in contaminated areas. The design and improvement of AP protective footwear has required advanced evaluation of injury.

Over the past decade, a renewed interest in protecting people from landmines is leading to improvements in Personal Protective Equipment with a defined focus on protecting lower extremities using advanced protective footwear.

A collaborative initiative has been underway over the past four years with Materials and Manufacturing Ontario, a division of OCE Inc., involving the University of Waterloo, Defence R&D Canada – Valcartier and Suffield, the Canadian Centre for Mine Action Technologies, and Med-Eng Systems Inc., with the goal of developing advanced protective footwear for AP blast mine threats.

Understanding the Threat

At a very early stage in this work, it was found that advances in protection required an improved understanding of landmine injuries and threats as well as a consistent means of evaluation. This led to the development of advanced numerical techniques and a surrogate leg (known as the *Complex Lower Leg or CLL)* capable of predicting injury types and severity in support of protective footwear design.

An estimated 60-70 million landmines, with more than 360 different types including AP and Anti-tank mines, have been deployed worldwide – with the highest concentrations in Afghanistan, Angola, Cambodia, Iraq, and Laos.

AP landmines are generally classified as fragmentation or blast mines, with the former containing fragments that are accelerated by the explosive detonation leading to ballistic injuries and a higher likelihood of fatality. Although fragmentation mines generally have higher levels of fatality, incidents of injury suggest that AP blast mine injuries are much more common.

Blast mines rely on the high pressures from the detonating explosive, and soil or debris ejecta, to cause injury and are designed to injure the victim although larger charges can be lethal. Buried blast mines are the most difficult to detect and are likely to remain buried for a long period after a conflict.

AP blast mines, being the cheapest and most common form of landmine, usually contain 28 to 300 grams of explosive. A typical pressure-activated blast mine consists of an explosive charge, detonator and a device to trigger the detonator. In many cases, the mines contain very few metallic parts and cannot be easily detected when they are buried.

The effects of a close-proximity landmine detonation on the human leg can originate from two sources, the short term shock loading from the initial detonation, and the relatively longer term loading due to expansion and flow of the explosive gases.

The initial detonation results in the transmission of a high amplitude stress wave into the leg which is rapidly attenuated within the leg tissues. Later, the expanding gases and soil ejecta apply lower amplitude, longer duration load to the leg which can be considered as a high rate fluid flow. It was apparent that the relative effect of the shock and expansion loads needed to be understood to develop appropriate test methodologies and address the need for the enhanced blast mine protection.

Landmine Injury to the Lower Extremity

Initial studies of landmine injuries began with various simplified surrogate or simulated polymeric legs to understand the extent and nature of injury. It was recognized that, for small to medium sized blast mines, the injury was localized in the lower leg.

While the effects of landmines are well known, limited scientific data is available regarding injuries correlated to specific blast conditions – and what is available is mostly based on post mortem human subject testing. Although useful in terms of determining the effectiveness of protection, this data does not provide an understanding of the mine/leg interaction and associated injury mechanisms. Further, data from actual landmine inci-

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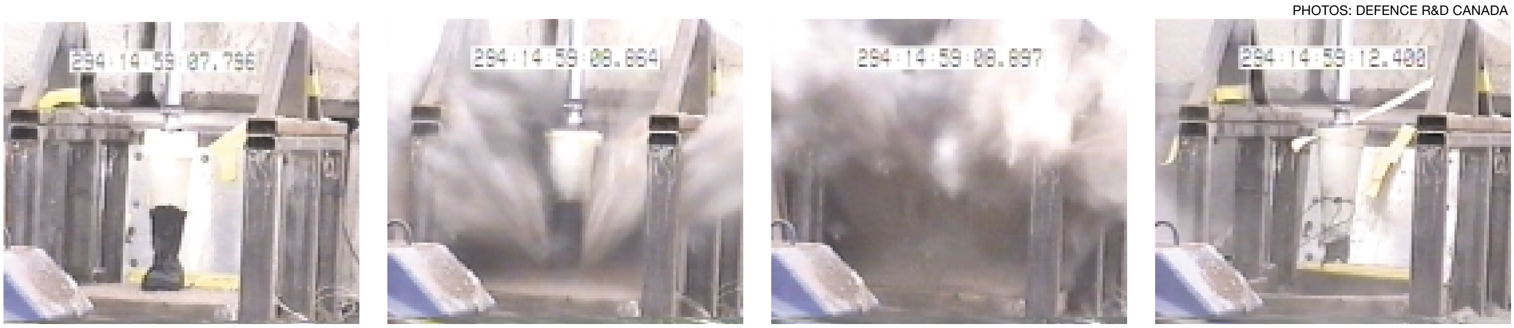


High speed video of a blast test of a surrogate (synthetic) leg wearing a common boot shows view is obscured during critical fractions of time.

dents are often unavailable and incomplete for the purposes of scientific assessment and model validation. Assembling available information, coupled with an ongoing experimental test program led to the understanding that fracture or crushing of the heel bone was one of critical areas to consider in terms of protecting the lower leg. Soft tissue damage is also important, particularly blood supply and nerves, however, these effects are not readily measured in non-living test devices.

As a result of the Ottawa Convention (1997 Mine Ban Treaty), the use and transport of real AP mines was extremely limited, leading to the need for alternatives for experimental testing.

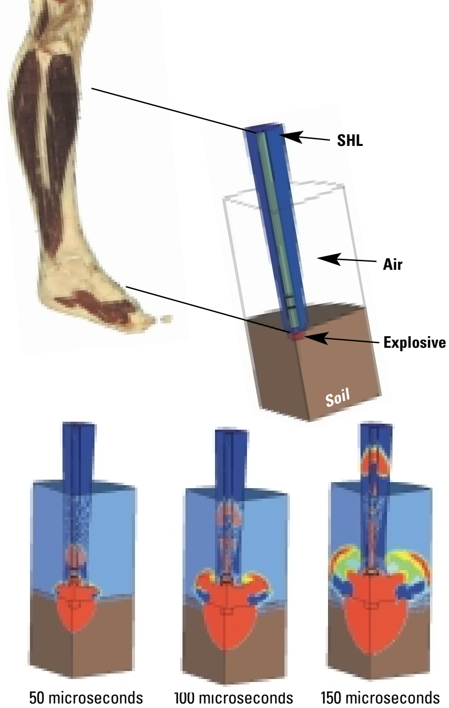
An alternative was developed at DRDC Suffield in the form of mine surrogates utilizing appropriate amounts of C-4 explosive to approximate the actual landmines. The added benefit of this approach was the improved consistency of the mine surrogates found to be representative of the real mines.

Although experimental testing is always necessary to determine the effectiveness of new types of protection, it was found that only limited insight into the physics of the problem could be measured due to the speed of the event.

High-speed x-ray did allow for a 'snap-shot' of the explosion and proved useful for visual confirmation of the numerical models, but was limited to two images per test. Various forms of experimental sensor measurement were also considered but proved to be difficult to implement and interpret.

High-speed video of a typical test using a surrogate lower leg shows that the view is obscured very early in the blast.

The need to understand the timing and severity of these injury mechanisms prompted the development of advanced numerical models, which led to the development of a surrogate leg. This was further motivated by the limited data that could be measured during the experimental testing due to the aggressive conditions of the blast environment.



Above: an unprotected Simplified Human Leg (SHL) modeled as a deformable structure with human biomaterial properties, coupled to a landmine model.

Numerical Modeling

The need to understand injury mechanisms and gain insight into the physics of blast mine effects on the lower extremity motivated the development of advanced numerical models. The first goal of these models was to predict injury levels for an unprotected leg, where the model could then be extended to help design new protection.

Over the course of the project, these models evolved from simple 2-D approaches to a full three-dimensional model consisting of over 500,000 elements – individual blocks of material that represent the various parts of the leg and explosive.

Evaluation of the model against a wide range of landmine types has shown agreement with actual reported injuries. Most importantly, the models provided significant insight into the injury mechanisms and determined that the major injury occurs in as little as 150 microseconds after detonation. Initial detonation leads to crushing of the heel bone, followed by crushing of the ankle and fracture of the tibia. This is accompanied by disruption of the soft tissue leading to significant lower leg injury.

PHOTO: DEFENCE R&D CANADA

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Complex Lower Leg demonstrates blast injury mechanisms from a small explosion.

Complex Lower Leg

The advanced numerical modeling and experimental testing throughout this project ultimately led to the development of a physical lower leg, known as the Complex Lower Leg (CLL), for use in experimental testing of landmine protection. Synthetic materials used to mimic properties within the human leg were designed to match human biological material properties. The basic geometry of the lower leg was then incorporated using data from the Visible Human Project (National Library of Medicine); however, the geometry was simplified where appropriate to reduce the cost of production. Evaluation of the CLL, using a variety of landmines and protection, has demonstrated the expected injury patterns and good agreement with other test devices used to predict landmine injury.

This leg has subsequently been used in the evaluation and development of advanced protective footwear, and is now available from Biokinetics and Associate Ltd. in Ottawa, Ontario and finding applications in other areas of trauma assessment, such as in-vehicle assessment of the effects of anti-vehicle land mines. FL

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