Testing of Mine Protection Boots

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• Reasons for studying mine boots
• The art of the possible
• Test methods
• Previous work
• Future research
Applications

• Main requirement has been from humanitarian demining

• Continuing interest from combat troops and particularly EOD / search units

• Note that -
  – on flat smooth ground vehicles tend to be used
  – mine resistant boots are cumbersome
  – protection is at best limited

• Result
  – If there are mines then stay in vehicle
  – If there aren't then why wear boots
The effect of a small blast

Desert boot
36g PE4 charge
60mm burial depth
35kg mass
Blast Mine Tests Against Footwear

- Frangible or mechanical surrogate with suitable damage assessment method
- Mine surrogate consisting of C4 or PE4 explosive packed in cylindrical containers with prescribed detonation point
- Charge buried in dry medium sand
- Test rig required for guiding the motion of the surrogate vertically
- Defined total reaction mass of the surrogate and guidance system
- Zero preload applied on the soil.
## Surrogates

<table>
<thead>
<tr>
<th>Frangible Surrogate Limb (FSL)</th>
<th>‘Mechanical’ surrogates</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Adelaide T&amp;E Systems/SJH Projects)</td>
<td>DRDC illustrated above</td>
</tr>
<tr>
<td>One time use</td>
<td>Reusable</td>
</tr>
<tr>
<td>Well validated</td>
<td>Instrumented</td>
</tr>
<tr>
<td>Can be instrumented</td>
<td>Requires a transfer function</td>
</tr>
<tr>
<td>Typically assessed by medics</td>
<td>Relatively cheap</td>
</tr>
<tr>
<td>Fairly expensive</td>
<td></td>
</tr>
</tbody>
</table>

Fairly expensive
Injury mechanisms

- **Fracture**
  - Fracture to heel and long bones

- **Compressive failure of heel and foot**
  - Bursting of foot due to compressive loads

- **Flesh stripping**
  - Gas driven up through leg

- **Good agreement with FSL,**
  - Also assessed by peak load
  - Suppressed by standoff

- **Observed on FSL**
  - Loading case less well understood
  - Suppressed by standoff

- **Difficult to reproduce**
  - Only observed in cadavers
  - Requires boot to be intact
Cranfield Trials

- Four boot types tested
  - Three combat boots and one commercial mine resistant boot
- Drop tower impact tests
  - 1ms\(^{-1}\)-8ms\(^{-1}\) impact tests to allow calibration of instrumentation and some assessment of boot behaviour
- Explosive tests
  - Tests using 50g and 35g buried charges to investigate trials methods, effects of burial and boot failure processes
Desert boot

Matterhorn boot

‘Combat’ boot
Drop tower layout

- Displacement gauge
- Striker load cell
- Striker
- Anvil load cell (used for blast tests)
## Drop tower results

<table>
<thead>
<tr>
<th>Boot type</th>
<th>Peak displacement (mm)</th>
<th>Peak impulse (Ns)</th>
<th>Peak Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP-mine boot</td>
<td>27.8</td>
<td>19.1</td>
<td>3.5</td>
</tr>
<tr>
<td>Combat boot</td>
<td>16.5</td>
<td>18.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Matterhorn boot</td>
<td>14.0</td>
<td>18.5</td>
<td>8.0</td>
</tr>
<tr>
<td>Desert boot</td>
<td>20.7</td>
<td>19.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Impact tests at 5.5ms\(^{-1}\)
Thick sole boots have lower forces and higher displacement
Impulse is the same for all cases (Drop weight momentum = 19.8Nm)
Blast tests

Rig support, secured by ratchet straps and placed on concrete block.

35 kg mass on top of rig

LVDT

Accelerometer

Load cell

AP-mine boot

Container filled with kiln dry sand
## 50g charge tests

<table>
<thead>
<tr>
<th>Firing</th>
<th>Depth of burial (mm)</th>
<th>Peak force (kN)</th>
<th>Peak displacement (mm)</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>145</td>
<td>42</td>
<td>BD3</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>115</td>
<td>20</td>
<td>BD3</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>150</td>
<td>33</td>
<td>BD3</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>120</td>
<td>16</td>
<td>BD3</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>145</td>
<td>34</td>
<td>BD3</td>
</tr>
<tr>
<td>4b</td>
<td>60</td>
<td>100</td>
<td>NA</td>
<td>BD3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Boot damage level</th>
<th>Description of damage levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD1</td>
<td>Minor damage to boot (i.e. portion of sole blown off, insole destruction)</td>
</tr>
<tr>
<td>BD2</td>
<td>Structural damage to boot (i.e. minor blast penetration into foot compartment of boot)</td>
</tr>
<tr>
<td>BD3</td>
<td>Breach (i.e. massive blast penetration into foot compartment of boot)</td>
</tr>
</tbody>
</table>
### 35g charge tests

<table>
<thead>
<tr>
<th>Firing</th>
<th>Type of boot used</th>
<th>Depth of burial (mm)</th>
<th>Peak force (kN)</th>
<th>Peak displacement (mm)</th>
<th>Boot Damage level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AP-mine</td>
<td>0</td>
<td>68</td>
<td>NA</td>
<td>BD3</td>
</tr>
<tr>
<td>3</td>
<td>AP-mine</td>
<td>20</td>
<td>79</td>
<td>30.</td>
<td>BD3</td>
</tr>
<tr>
<td>5</td>
<td>AP-mine</td>
<td>30</td>
<td>47</td>
<td>24</td>
<td>BD2</td>
</tr>
<tr>
<td>4</td>
<td>AP-mine</td>
<td>40</td>
<td>43</td>
<td>22</td>
<td>BD2</td>
</tr>
<tr>
<td>2</td>
<td>AP-mine</td>
<td>60</td>
<td>44</td>
<td>14</td>
<td>BD1</td>
</tr>
<tr>
<td>6</td>
<td>Matterhorn boot</td>
<td>60</td>
<td>48</td>
<td>9.4</td>
<td>BD3</td>
</tr>
<tr>
<td>7</td>
<td>Desert boot</td>
<td>60</td>
<td>45</td>
<td>11</td>
<td>BD2</td>
</tr>
<tr>
<td>8</td>
<td>Combat boot</td>
<td>60</td>
<td>42</td>
<td>10</td>
<td>BD2</td>
</tr>
</tbody>
</table>

For AP mine boot, damage reduces from catastrophic to minor as burial depth increases.

In all cases peak force was much greater than typical tibia strength (5.4kN).
Future work

• New test rig under construction
• Investigate boot failure
• Investigate peripheral aspects of protection such as fragmentation and damage to the un-impacted leg
• Deliver a cheap sorting method for development purposes
Summary

• Providing practical mine resistant footwear is very challenging
• Test methods are still underdeveloped
• The link between loading, boot design and surgical outcome needs improvement