THUMS as a numerical investigation tool to study the effect of anti-personnel mine blast on lower extremity

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I. INTRODUCTION

The lower extremity (LE), being proximal to the origin of the blast, is the most commonly injured part of the body in landmine explosions [1-2]. Understanding the LE injury mechanisms under near-field blast will aid in developing surrogates and evaluating protective structures for effective blast mitigation. Given the complexities involved in blast experiments, numerical analysis is a valuable tool. A finite element (FE) human body model (HBM) is an effective tool that can be leveraged to study human body response in blast environment.

HBMs have been significantly used in the past to evaluate the LE response and have served as an evaluation tool for protective structures in vehicle under-body blast loading [3–8]. However, the use of a LE model to evaluate leg response in near-field blasts, such as anti-personnel (AP) mine explosion, is limited. In the current study the THUMS (Total HUman Model for Safety) lower extremity FE model has been used to evaluate LE response and injuries due to anti-personnel mine blast. The numerical setup includes the modeling of primary (effect of blast wave) as well as secondary/tertiary effect (momentum transfer due to soil) of AP mine explosion on lower extremity. The sensitivity of the leg model was established by assessing its response to the graded input of blast loading.

II. METHODS

This study investigates the response of the THUMS lower extremity FE model exposed to anti-personnel landmine explosion using the Multi Material Arbitrary Lagrangian Eulerian (MMALE) method. Air and soil domains were modeled as a cylinder using 8-noded brick elements. In the cylinder mesh, radial and circumferential mesh lines manage to form a rectangular area at the centre with element size of approximately 2.5 mm. The LE model and explosive were placed within this block. A non-reflecting boundary condition was applied on the outer segment to reduce reflection.

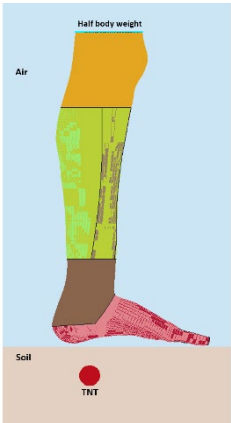

Fig. 1. Simulation setup for AP landmine blast.

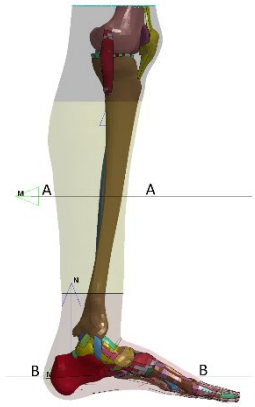

Fig. 2. Various sections for force measurement.

The amount of explosive taken was 40 gm of TNT, consistent with the amount used in small anti-personnel mines [9] and was modeled as a sphere. The charge was positioned with its detonation center 50 mm below the soil surface, vertically below the heel of the LE model, as shown in Fig. 1. The interaction between detonation products and the LE model was provided using fluid-structure interaction (FSI). Force at section A-A, at the middle of the tibia, and at section B-B, at the calcaneus (Fig. 2), was tracked along with the FSI force imparted by the detonation product at the bottom of the leg. An element erosion method was used for injury prediction based on the material failure criteria adapted from [3], [10].

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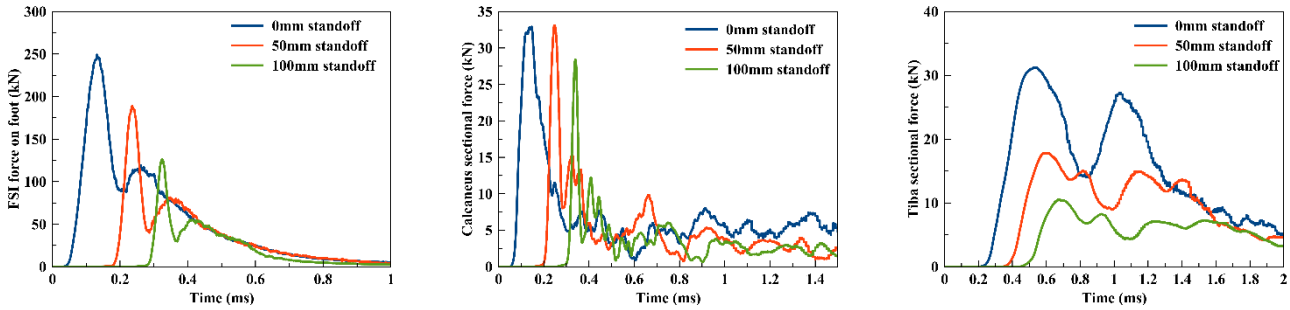
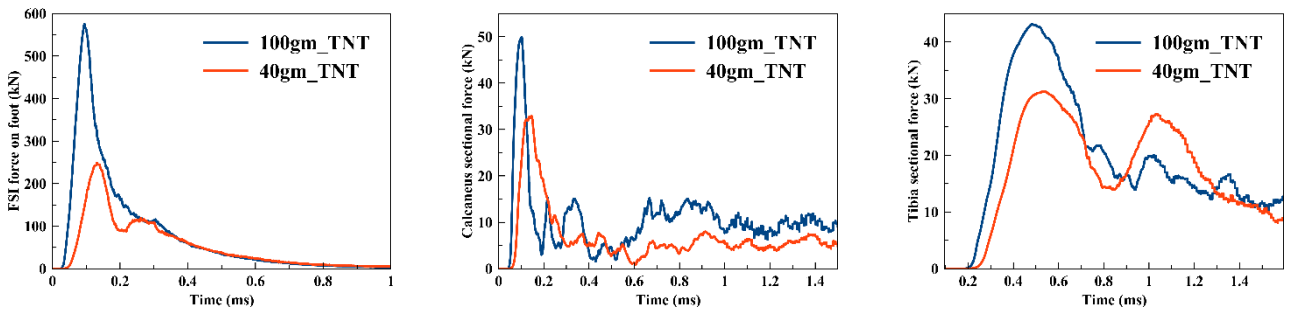
III. INITIAL FINDINGS



(a) (b) (c)

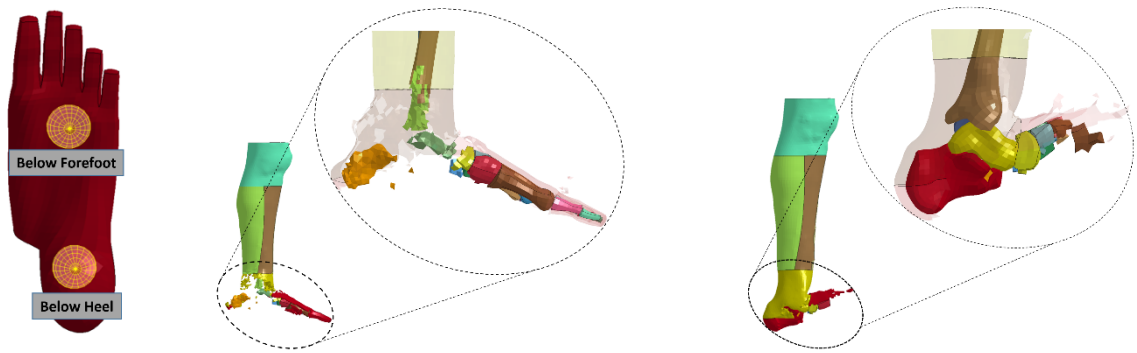
Fig. 3. Force-time variation for varying standoff distance, (a) FSI force at the foot bottom, (b) Calcaneus sectional force, (c) Sectional force at mid tibia.



(a) (b) (c)

Fig. 4. Force-time variation for varying explosive amount with no standoff, (a) FSI force at the foot bottom, (b) Calcaneus sectional force, (c) Sectional force at mid tibia. Standoff distance is zero with amount of explosive variation.

All simulations terminated normally, indicating the stability of the THUMS model in blast loading. The model successfully captured the effect of increase in standoff distance resulting in decrease in peak force magnitude and delayed peak-time of the forces (Fig. 3). Similarly, the increase in the magnitude of forces and the loading rate with increase in explosive amount (Fig. 4) establishes the sensitivity of the model with respect to this threat. It was observed that in contact blast cases (0 mm standoff), the blast effect was localized to the heel pushing calcaneus upwards, not allowing foot ligaments to stretch, and restricting dorsiflexion movement of the foot. This phenomenon resulted in approximately complete transfer of forces from the calcaneus to tibia (Fig. 4(b) and (c)). Whereas, with the increase in standoff distance, the foot undergoes dorsiflexion movement with stretching of foot ligaments, reducing the transfer of forces from the calcaneus to the tibia (Fig. 3(b) and (c)). To study the effect of detonation location below foot on LE response, comparison of forces at calcaneus and tibia would be meaningless as detonation below heel would always result in higher force magnitude at these sections. Detonation location below foot is expected to influence the injury pattern [2], so it was decided to compare the injury outcome when detonation occurs below heel and below forefoot.



(a) (b) (c)

Fig. 5. Effect of detonation point on LE injury pattern, (a) Location of detonation points, (b) Injury pattern when detonation below heel, (c) Injury pattern when detonation below forefoot.

Figure 5 shows a completely distinct injury pattern with variation in detonation location. When the detonation point was below heel, complete erosion of calcaneus and talus was observed along with erosion of approximately 80 mm of distal tibia. When the detonation point was below forefoot, erosion of metatarsals and phalanges was observed along with some damage to cuneiforms. This indicates that anti-personnel landmine explosion results in localized injury pattern, causing major damage to the closest structure. The detonation below heel caused damage to calcaneus, talus and tibia, which are the load-carrying structures of the foot. This can therefore be regarded as a more severe case than when detonation occurs below forefoot. This finding substantiates the consideration of below heel injuries as being the most severe [2], [11].

IV. DISCUSSION

A detailed lower extremity FE model (THUMS) was used to evaluate the leg response in near-field blast loading such as anti-personnel mine blast. The model successfully captured the effect of increased explosive threat and standoff distance variation with respect to peak force magnitude and time to peak force. The model also substantiates the influence of detonation location below foot on injury pattern. However, the response and injuries predicted have not been validated and a realistic prediction may depend on the incorporation of high strain rate material properties as the THUMS model is designed and validated for frontal car crash loadings. Use of element erosion to predict injuries also limits this study as once the elements are deleted, they no longer contribute to the physics of simulated events. Results of this study suggest that THUMS lower extremity model can be used as a numerical evaluation tool for blast protecting structures. Efficacy of the blast protective structures can be evaluated by correlating with the damage to the lower extremity model.

V. REFERENCES

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