Protection Capabilities of the Ankle Joint Against the Consequences of Impact Load

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Abstract. The paper presents the results of correlation analyses between the lower limb load conditions and risk of trauma for various load variants. A simplified model of the distal lower limb has been developed, taking into account the stiffness characteristics of the footwear. The influence of stiffening of footwear on the effort occurring in the bone structures and ligaments under the axial impact force for different configurations of the leg position has been analysed.

INTRODUCTION

The lower limbs are most often injured in modern military conflicts [1]. The injuries of lower limbs represent between 26% and 48% of all injuries sustained during the battle. Usually, the most common limb wounds are soft tissue injuries, but in recent armed conflicts, large percent of the cases has led to fractures. The foot is the most complex structure of the human body that is susceptible to injury due to its load pattern and complex structure. In comparison to all other skeletal structures, the foot is more complicated due to the combination of small metatarsals that are characterized by complex geometry [2]. In addition, the distance between the foot tissue and source of the blast is very small. The injury in any of these parts can cause problems elsewhere in the body and vice versa (abnormalities in other parts of the body can cause problems in the feet).

During the explosion of IED (improvised explosive device) under a vehicle, lower limbs are strongly exposed to damage due to their proximity to the source of the explosion. In the sitting position, the pelvis and thigh rest are placed on the seat while the feet rest on the floor. During the explosion, the foot is the first anatomical structure loaded with the deforming floor due to its immediate proximity to the explosion. Then, the load is transferred from the foot to the ankle and to the rest of the leg, which includes the tibia and the fibula bones. The charge mass and speed of increasing load can cause both axial compression and shearing loads, depending on the location of the lower part of the limb and the load direction.

MATERIAL AND METHODS

The analysis has been carried out on the basis of a foot model in which the foot movements in a seating body position have been taken into account. The foot model as a complex structure with many joints performing movements in many planes, contains the following bones: tibia, fibula, talus, calcaneus, cuboid, navicula, three cuneiforms, five metatarsals and 14 components of the phalanges, 33 joints, total 70 ligaments and 4 main muscles.

The bones have been modelled as the solid structure with cortical bone layer outside and trabecular bone. The ligaments have been modelled as the link elements with only tension function. All components work together to provide the body with support, balance and mobility [3]. The muscle elements have played a stabilization role for this structure. The deformation of the floor resulting from the detonation of a strong explosion under the vehicle has been assumed as a load. The parameters of the initial conditions have been selected based on the analytical model of the blast [4] and numerical analyses conducted in the Department of Mechanics and Applied Computer Science using the previously validated numerical model of a military vehicle. The purpose of this investigation has been focused on the sole of the military boots and influence of its material properties on the foot safety.
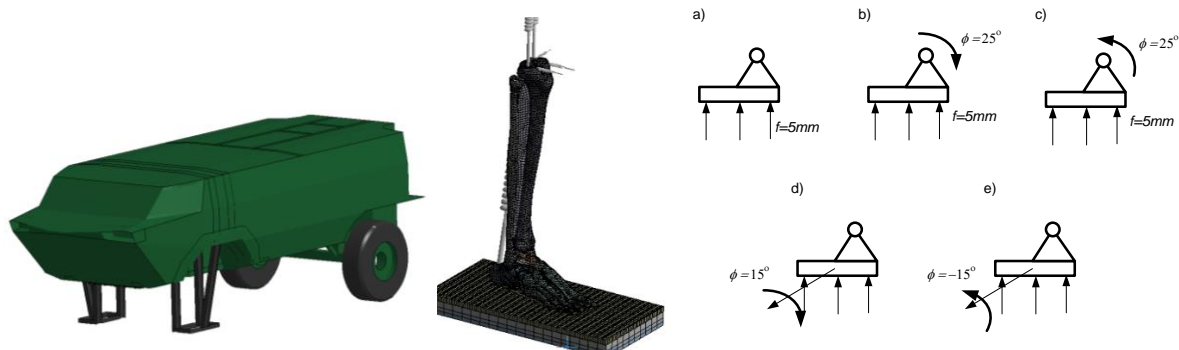

FIGURE 1. The model of the military vehicle, distal part of the lower leg and load variants: a) model, b) axial load, c) load with the dorsiflexion, d) load withe the flexion, e) load with external rotation, f) load with internal rotation.

RESULTS AND CONLUSIONS

The analysis has rendered it possible to gain knowledge about the method of energy transfer during the blast impulse on the foot protected by the boot. In the case of axial loading, the ankle joint is significantly damaged due to the stress concentration occurring on the joint surface. In the appendages of the rotation and inversion rotation, the heels in the calcaneus, tibia and fibula bones have been concentrated around the muscle attachments. The analysis has showed that in all cases the sole reduces the energy transferred to the foot tissues and the risk of limb injury strongly depends on the nature of the load. The results have indicated that the safest load for the limb is the case in which the loading is initiated from the distal part of the foot, midfoot and toes.

The paper presents the analysis of limb loads in terms of tissue protection against overload caused by a strong impulse of axial or axial-torsional force. The model of stiffening of the limb within the ankle has been developed reflecting the protection in the form of a shoe. The results indicate a significant reduction of stress when the joint is properly stiffened.

ACKNOWLEDGMENTS

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