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MODELING SHOCK RESPONSE OF HELMETED HEAD USING FLUID STRUCTURE INTERACTION

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INTRODUCTION

Blast induced traumatic brain injury (bTBI) is signature injury in recent combat scenarios involving improvised explosive devices (IEDs). The exact mechanisms of bTBI are still unclear and protective role of helmet and body armor is often questioned [1-3]. High Fidelity finite element models involving fluid structure interaction are built in order to understand effectiveness of helmet in mitigating early time blast induced mild traumatic brain injury.

METHODOLOGY

Two dimensional plane strain finite element models of helmet-head under shock loading are studied to compare effectiveness of helmet. Figure 1 shows the configuration of setup.
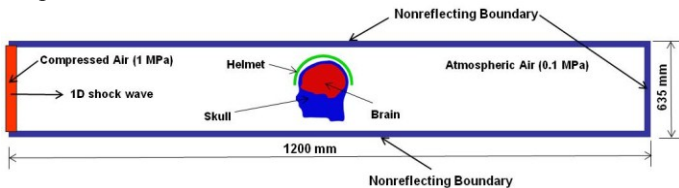

Figure 1 : Simulation setup. Frontal blast is simulated.

Our blast scenarios are simulated by first positioning the head model in an atmosphere of air at ambient conditions as shown in Fig.1. Shock wave is generated by releasing high pressure compressed air into atmospheric air at time equal to zero. The pressure and thickness of compressed air domain is selected so as to generate nonlethal blast wave. The structure of this blast wave is illustrated in Fig. 2.
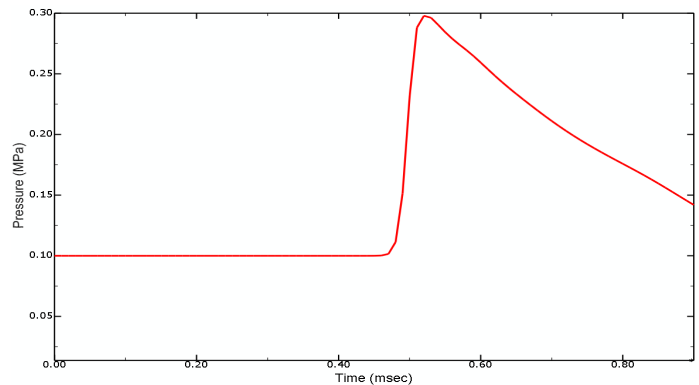

Figure 2 : Wave form of approximated air blast structure of 0.3 MPa magnitude

Our head model consists of skull , facial bones , neck bones and brain. We have used same material properties for skull , facial bones and neck bones hence we do not distinguish them as separate component. skull , facial bones and neck bones together will be referred as 'skull' henceforth. The geometry of these components is obtained by segmentation of MRI dataset available from visible human project of the National Library of Medicine [4]. Since we are interested in 2-dimensioanl head model , the central slice of MRI dataset is chosen. These geometries are imported into finite element software [5] and then meshed to generate 2-dimensional plain strain finite element head model. 2-dimensioanl geometries were selected so that the analysis would not be overly complex and prohibitively expensive.

The brain tissue is modeled as linear, isotropic, viscoelastic material with properties adopted from Taylor et al.[2]. Standard Linear Solid (SLS) model is used to characterize shear response. The skull is modeled as linear, elastic, isotropic materials based on material models suggested in the literature

[6-9]. The Kevlar helmet is modeled as hollow hemiellipsoid with a constant thickness and offset from the skull as described by Reynosa [10], with transversely isotropic elastic material properties given by Aare and Keliven [11]. Dry air, the medium through which blast wave propagates is modeled as ideal gas equation of state.

RESULTS

We have studied how helmets influence the blast-induced mechanical loads in the brain. Helmeted and non helmeted response is compared on the basis of pressure in the helmet cranium subspace , contact pressure on the outer surface of the skull and pressure and shear stresses (mises) in the various regions of the brain. Figure 3 shows pressure at air cranium (skull) interface. The blast pressure increases about 3.6 times due to impedance mismatch.
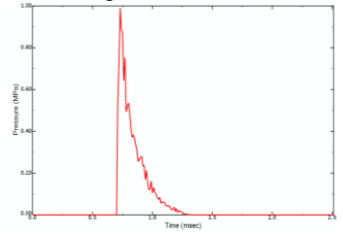

Amplified blast pressure in helmet cranium subspace

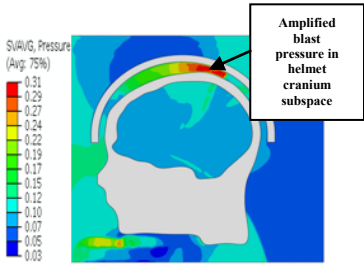**Figure 3: Blast pressure at air skull interface**   **Figure 4: Uderwash effect of the helmet**

Figure 4 is from a blast simulation of a head with helmet. The 1.3 cm gap between helmet and head allows the blast wave to wash under the helmet. When this ''underwash'' occurs, geometric focusing of the blast wave causes the pressures under helmet cranium subspace to exceed those outside the helmet . This is in turn causes additional loads on the top portion of the skull where the ''underwash'' effect is most dominant. Underwash effect is however not dominant in front regions of the skull. Figure 5 (a) and (b) compares pressure in top and front regions of helmet cranium subspace. The pressure in helmet cranium subspace is transferred to skull and brain. Figure 6 (a) and 6 (b) shows pressure in top and front regions of the brain respectively. As seen from these figures helmet reduces the pressure in frontal region of the brain however it increases the pressure in top regions of brain due to "underwash" effect occurring in top regions of helmet cranium subspace. Similar trend is observed for shear stress (mises) in the brain and contact pressures on the outer surface of the skull.
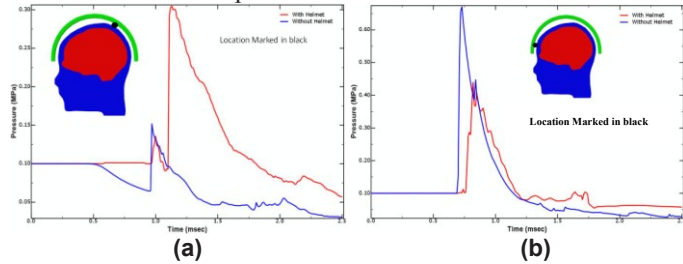

(a)   (b)

Figure 5: Pressure history of marked locations of helmet cranium subspace

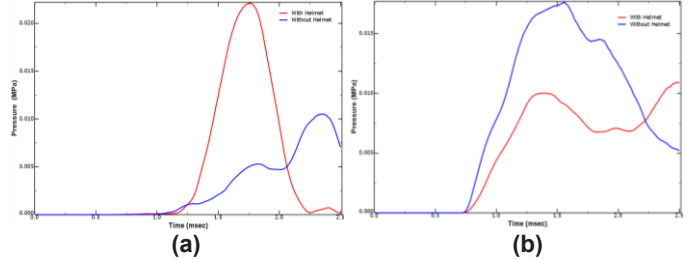(a)   (b)

Figure 6: Average pressure in the brain. (a) Top Region (b) Front Region

CONCLUSIONS

We have conducted blast simulations to understand response of head with protection of helmet. Head was subjected to 0.3 MPa blast overpressure. Our simulation shows peak overpressure rise of about 333.33 % at fluid solid interface. We have simulated 1.3 cm gap scenario between head and helmet. Helmet protects frontal region of brain as it attenuates shock intensity reaching the frontal side of head. On the other hand, helmet has adverse effect in protecting top regions of the head due to 'underwash' effect in top regions of helmet cranium sub space.

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