DYNA3D Modelling of Head Impact Injuries

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Abstract

Although there have been a number of significant advances in recent years in the field of crash injury mechanisms and assessment, clearly there is still much to be learnt in terms of head injury minimisation and prevention.

A cost-effective approach to designing and optimising head protection systems is to use numerical methods, such as the Finite Element (FE) method. To achieve this a detailed understanding of the behaviour of the major components of the head and how they interact, with wave propagation and focusing effects, during an impact or abrupt deceleration event is required. The resultant stresses, forces, strains, accelerations, etc. which vary as a function of time, then need to be translated into material tissue failure mechanisms that represent observed injuries.

A preliminary FE model of the head and cervical spine is presented and the results from a simulated blow to the head using the FE code LLNL DYNA3D. The skull and brain are modelled with 3D solid 'finite elements' to capture the approximate geometrical structure. The skull is modelled using an existing elastic-plastic material model with failure. The porosity term is used to represent the cellular and crushable bone material, while bone fracturing is modelled using a tension based brittle failure model.

Soft tissues are modelled using a viscoelastic material model, and the interface between the skull and the brain is modelled using a frictional slide-line, thus allowing the brain to rotate within the skull.

Introduction

Numerical modelling of the human body provides a valuable tool for investigating the development of injuries to the human body. Modelling the complete body remains somewhat impractical because of its shear complexity. However, with the advent of ever increasing computer power, such aspirations are becoming a reality. This paper presents the simulation of an impact to the human head, modelled using Finite Element (FE) techniques.

The use of FE techniques offers a number of advantages over more traditional approaches, namely:

- No ethical or health and safety problems.
- Results are repeatable and reproducible.
- Availability of good quality MRI and CT data, together with software that can convert such data into geometrical volumes suitable for FE meshing, produces FE models that are anatomically accurate.
- Can be used as detailed 'add-ons' to models of recognised crash dummies e.g. Hybrid III, via such codes as MADYMO that model whole body response.
- Dissimilar material models can be applied to different parts of the FE mesh.
- A wide range of different types of accelerations and impacts e.g. sharp or blunt, and varying speeds of impact can be modelled.
- Large quantity and variety of output data is generated for interpretation : stress, strain, displacement, velocity, acceleration, energy, etc.
- Data is available at 'any' location within the FE model at 'any' time within the simulation.

Approach to FE Modelling

During a head impact event movement of the brain within an externally loaded skull can pose a complex three-dimensional dynamic boundary problem. Thus a sophisticated FE code is necessary, with the capability of simulating intricate interactions between distinct bodies. LLNL DYNA3D is just such a code. It is an explicit FE code capable of analysing the transient dynamic response of any three-dimensional structure and has been used extensively throughout the general engineering community for many years. It contains over 40 different material models from simple elastic models through to viscoelastic, rubber, etc. It allows non-linear material behaviour and large displacement/geometrical effects to be accurately simulated.

The response of the human head to impact loading depends significantly on the response of the main structural component, specifically the skull. Since serious impact induced injury to the skull usually results in brain injury, understanding the interactions, both translational and rotational, between the skull impact and the resultant behaviour of the brain and the cervical spine is essential. Modelling of the cervical spine provides a constraint to the base of the skull and continuity of the brain/spinal-cord through the Foramen magnum, thus allowing the cerebrospinal fluid (CSF) to flow.

The Human Head and Cervical Spine FE Model

The FE model was generated from MRI/CT data of the human head and cervical spine using the INGRID pre-processor. A contact slide-line which allows contact and separation was placed between the impactor and the outer skull. Half symmetry was used to limit the number of elements involved. The brain material was modelled as a homogeneous gel-like material, with a strain-rate independent bulk modulus very close to that of water. A viscoelastic material relationship was employed. The CSF was modelled as an equation of state, and the spinal cord, vertebra, and discs in the cervical spine region was also modelled using a combination of elastic, viscoelastic and elastic-plastic material failure models. The cervical spine was modelled to accurately represent the correct flexibility of the head/spine combination when subject to impact.

Results

The results show complex wave interactions within the brain producing intricate stress and strain gradients. It is interesting to note that the site of peak acceleration does not necessarily correspond to peak or even high cumulative strains, stresses, strain-rates, etc. The concave curvature of the skull causes waves to reflect and focus at specific locations within the brain. Negative (intracranial) pressures are seen throughout the analysis, initially remote from the impact site. This is due to the compressive pressure gradients at the site of impact, which locally cause potential coup injury, coupled with the differences in inertia of the brain material and the comparatively rigid skull material causing the brain and skull to separate at the opposite side thus producing a 'rarefraction' or tensile effect. This results in cavitation or tearing, which is associated with contre-coup injury.

In addition, rotational acceleration of the head is evident from the analysis and examination of the shear forces within the brain show that shear deformation is a major cause of brain injury, because brain tissue exhibits such a low shear stiffness. However, due to the application of half symmetry to the FE model only rotation in the vertical plane could be simulated.

Conclusions

A FE model of the human head and cervical has been developed and used to assess the injury sustained by an blunt impact to the head. This approach is useful in assessing human response and injury mechanisms in high acceleration environments and is applicable to other components of the human body.

The FE model has a wide range of applications, it can be used to:

- assess the level of injury resulting from vehicle collisions or head accelerations, whether they be on land e.g. tank, car, motorcycle, bicycle; or in the air e.g. seat ejection, parachute landing, ground impact.
- assess the onset of injury.
- examine specific injury mechanisms, thus relating cause and effect phenomena.
- examine injury tolerance, determine specific injury thresholds and sub-injury effects.
- develop and optimise head protection systems to minimise and/or prevent injury by performing parametric studies.
- develop improved constitutive models that better represent soft tissue behaviour, particularly failure, e.g. hyper-viscoelastic material models.