A STUDY OF THE INFLUENCE OF ZERO ENERGY MODES AND BRAIN MATERIAL PROPERTIES ON FINITE ELEMENT HEAD IMPACT ANALYSES

[1] Katrien Baeck, [2] Jan Goffin and [1] Jos Vander Sloten

[1] Division of Biomechanics and Engineering Design, K.U. Leuven, Belgium, email: Katrien.Baeck@mech.kuleuven.be

[2] Division of Experimental Neurosurgery & Neuroanatomy, K.U. Leuven, Belgium

INTRODUCTION

To get a better insight in the mechanisms of head injuries, finite element head models are used. Current FE head models often lack accurate descriptions of the brain material behavior. Also more attention should be paid to the reduction of zero energy modes [1] which arise when reduced integration finite elements are used and which will invalidate the results. This paper therefore starts with the development of a generic simplified head model. Subsequently, small adaptations are made to investigate the influence of the brain material properties and zero energy modes on the results of an impact analysis.

METHODS

A generic simplified FE head model was built in Ls Dyna [2] and consists of a skull, brain and Cerebrospinal Fluid (CSF). All three components are modeled using linear hexahedral reduced integration elements with an assumed strain co-rotational stiffness hourglass algorithm [2]. The skull is modeled as a rigid body and the CSF is modeled as water. The behavior of the brain material is characterized as elastic in compression and viscoelastic in shear where the shear modulus is expressed by:

$$G(t) = G_\infty + (G_0 - G_\infty)e^{-\beta t}$$

with G_∞ the long term shear modulus, G_0 the short term shear modulus and β the decay constant. The values of the brain material properties for this FE model, referred to as FE model 1, are taken from Horgan [3] and they are listed in the second column of table 1. To perform a FE impact analysis, the linear and angular velocities during impact calculated from a real life accident simulation in MADYMO by Doorly et al. [4] were applied to the rigid skull.

Table 1: Brain material properties for the different FE models [3].

Material property	FE model 1-3	FE model 4	FE model 5
Density [kg/m³]	1060	1060	1060
Bulk modulus [GPa]	2.19	0.128	0.069
β [s^{-1}]	80	35	100
G_∞ [Pa]	2500	168000	34500
G_0 [Pa]	12500	528000	17200

Based on this FE model 1, four different FE models were built by changing: the assumed strain co-rotational stiffness hourglass algorithm to the standard Ls Dyna algorithm [2] (FE model 2), the reduced integration method to a selective reduced integration method (FE model 3) and the brain material properties to the ones listed in table 1 [3] (FE model 4, 5). In total, five slightly different FE models were built and the results of the five performed impact analyses were compared.

RESULTS AND DISCUSSION

A study was performed to investigate the influence of the zero energy modes on a FE impact analysis. The results from FE model 1 with a low amount of zero energy modes are identical to the results from FE model 3 with no zero energy modes. When these zero energy modes are not suppressed enough, which is the case in FE model 2, the results differ from the ones without zero energy modes and they are no longer valid. In order to obtain reliable results, a selective reduced integration method or a reduced integration method in combination with an hourglass algorithm that significantly reduces the zero energy modes must be used.

The influence of the brain material properties is studied with FE models 1, 4 and 5. Figure 1 shows that a higher bulk modulus leads to lower Von Mises stresses and that a change in the time dependent shear modulus leads to a different pattern of the Von Mises stress. For example the effect of the head impact, which occurs around 0.05s, is seen around 0.067s in FE model 5 whereas in FE model 4 it is observed around 0.055s. These findings highlight the need for a more accurate description of the brain material properties for predicting head injuries because these properties have a large influence on the biomechanics of brain behavior.

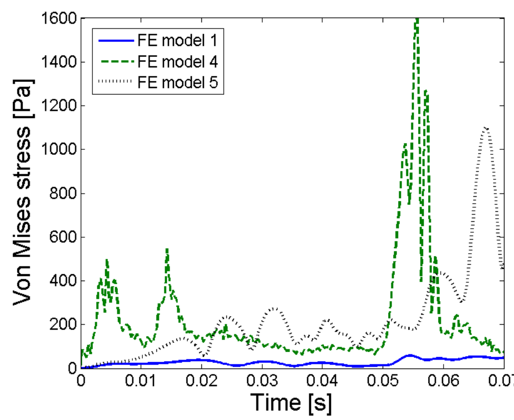

Figure 1: Von Mises stress over time observed in the center of the brain for FE model 1, 4 and 5

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