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Effect of dynamic impact loading on finite element head model

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ABSTRACT

Main objective of this project work is to simulate the effect of dynamic impact loading on a Finite Element Head model. The human brain is the most critical part of our body and any injury to it will prove fatal to us. Many tests have been conducted to determine the extent of damage to our skull, but the specimens cannot replicate the exact morphology of the human head. Also they are unable to characterize the intracranial response due to change in load direction. The study of impact to human head is a growing area of research in medical and in defense establishments. This will help us understand better the possible remedies to tackle head injuries. The current project involves development of an approximate CAD model of human head using CATIA V5.Pre-processing work is done using HYPERMESH. The model is meshed with Hexahedral and tetrahedral elements. Critical aspect of this project is the inclusion of visco-elastic material properties for the brain matter, also the head is assumed as elastic material. These values are obtained from existing literature data. The load simulation is done using LS-DYNA solver. Here the human head is simulated to impact on a rigid wall. The test is done for three regions of impact namely the frontal lobe, temporal lobe and occipital lobe respectively. The impact test yields the Von-mises stress and the plastic strain observed for the three cases of loading. Also the relative displacement of brain is measured. This data obtained is very important to study the brain shifts, which is a problem for treating the people with head injuries.

Keywords: Visco-elastic, LS-DYNA, Von-mises stress, plastic strain

1. INTRODUCTION

Many research activities have been conducted in the past to study the impact on human head. With the advent of essential FE tools, the study of intricate human head has been simplified to a great extent. It helps capture the exact physiology of the human head. Anzelius (1943) came up with a mathematical by assuming the entire head to be liquid ball. He observed that pressure variation was more close to the point of impact. But the inclusion of actual material property improved the results. Finite element model was compared with cadaver test (Gilchrist et al 2004). They compared for different cases including the Cerebrospinal fluid (CSF). Impact tests have been also performed with helmeted head models (Praveen Kumar et al 2007), and the helmet is assumed as foam for analytical purpose. The importance of Head Impact Criterion (HIC) is very critical (Mh.Lashkari et al 2013). It explains the extent of damage caused to human head due to impact. Effect of blast loading (Ganpule et al 2012) is studied for dummy and finite element model. Results show that wave transmission affects the load acting on the head. Intracranial pressure development is a major effect of head injury. Removal of this defect (X.G. Li et al 2009) is very complicated procedure. Different pressure loads are tested to observe the effect. Details of accurate head modeling (Kleiven et al 2002) and the types of head injuries are discussed and the finite element model is developed to study effect of road accidents. Detailed brain model is developed using the Magnetic Resonance Imaging (MRI) scans. In the field of medicine (Hu et al 2007) it helps to account for the brain shift during intraoperative procedures. Corrective measures can be undertaken by comparing them with exact finite element model of human brain. Also Computed Tomography (CT) image slices can be used to develop the 3D head model. This model (Erik et al 2008) included all the critical parts of the brain and was compared with injuries suffered by football players, which come under Traumatic brain injuries (TBI). The brain matter shift is mainly obtained by observing the change in C.G under impact. The analysis (Wittek et al 2005) tries to align the preoperative with intraoperative images.

Human head is composed of complex matter such as solid (skull), semi-solid (CSF, brain tissue) material etc. Hence it leads to material and geometric non-linearity. Since the project is aimed to simulate impact test, contact non-linearity is considered as well. To obtain an accurate model of the human head MRI slices (2D) are converted to 3D head model using a suitable algorithm. The main function is to locate the grey and white areas within the brain based upon their color intensity. Then theses coordinates are linked to form spline curves. Later all the regions are mapped to form a solid model of human head. The main components of the head are brain matter, skull bone, Cerebrospinal fluid (CSF) and brain stem. The CSF forms a protective layer around the brain. The left and right hemispheres of the brain are separated by falx cerebri [1]. Similarly the cerebrum and the cerebellum are separated by tentorium cerebelli [1]. The cerebellum is connected to the spinal cord via the brain stem which extends through a cavity known as foramen magnum on the anterior portion of the skull[1].

2. METHOD

Modeling

Due to the complexity involved in image processing technique. Obtaining a model from MRI slices is not considered for the current scope of this project. Instead an approximate model of human head is developed using CATIA V5. The parts modeled include the brain matter, skull and the brain stem respectively as shown in Fig1.1.

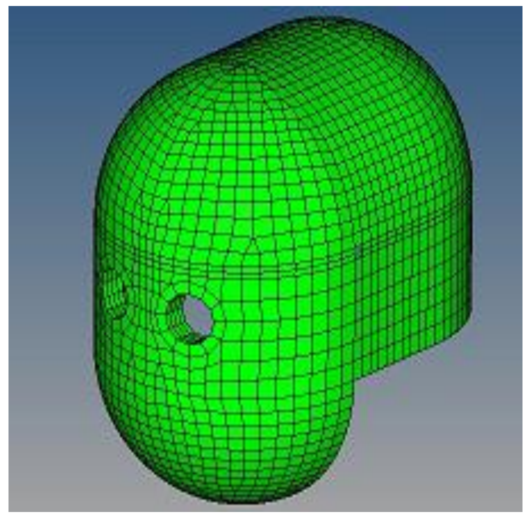

Figure 1.1 Head Model

Pre-processing

Despite the geometric assumptions made in the current project, it still captures the human head morphology to some extent. Hence there will be some complex features associated with it. HYPERMESH is very suitable to mesh such models. It is very critical to develop mesh which follows a certain pattern, especially when it subjected to impact loading. This will ensure better load capturing ability of the individual nodes of elements. For the skull and the brain stem hexahedral element meshing is done. Since the skull will be the first to encounter the strike. The stem is where shear stress will be observed. The brain undergoes shift in its position mainly due to the loading. To quantify this brain model is filled with tetrahedral elements as shown in Fig. 1.2.

Material Property

Incorporating the actual material property is very crucial to obtain desirable results. For the current scope of the project, the brain matter (Giovanni et al) is taken as visco-elastic and the remaining components (Sarkar et al) such as skull, brain stem (Ganpule et al) are elastic and brittle in nature respectively. Material of brain possesses high viscous damping [2]. Hence with shear properties we can perform impact test much better. The impactor takes its material values from (Giovanni et al), also it is assumed to be rigid body [1].

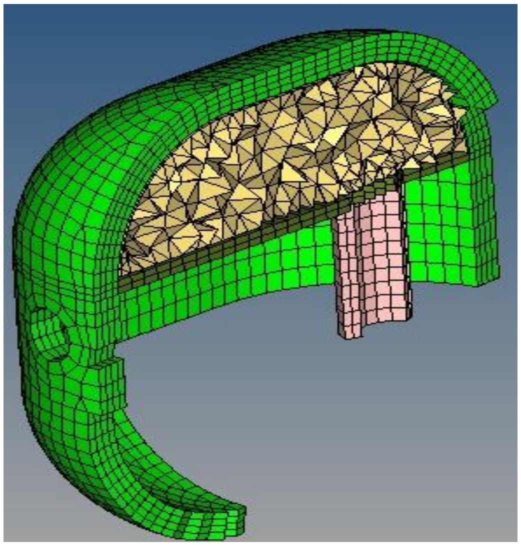

Figure 1.2 Sectional view

The shear modulus for visco-elastic material is characterized as follows.

$$G(t) = G_\alpha + (G_o - G_\alpha)\, e^{-\beta t} \quad (1)$$

Where G_α is the long time shear modulus [MPa]
G_o is the short term shear modulus [Mpa]
β is the decay factor
t time in seconds

The material properties of skull and brain stem are shown in Table 1. Also the brain material properties are shown in Table 1.1 respectively. The decay factor β controls the transition between long and short duration stiffness [2].

Table 1.1 Material property of brain, stem and impactor

Material Description	Young's Modulus [MPa]	Density [Kg/m³]	Poisson's ratio
Skull	6500	1412	0.42
Brain stem	354	2500	0.3
Impactor	210000	5304	0.3

All the above values are entered into a specific card image while working in HYPERMESH. This is done to be identified by the LS-DYNA solver. Also it is very critical to mention the contact conditions. For the current scope a contact card image is established between the impactor-skull and one between skull-brain interfaces.

Table 1.2 Brain material properties

Material Description	Bulk Modulus [Mpa]	G_α [MPa]	G_o [Mpa]	[β] decay factor	Density [Kg/m³]
Brain	5.625	0.0167	0.049	145	1140

Solver

Finite element problems can be solved with implicit and explicit methods. Implicit involves large time steps to calculate for each iteration and hence its time consuming. Whereas in implicit method small time steps are used making less time consuming. For dynamic impact problems implicit is preferred over the other. Hence for the current scope is aimed at performing impact tests from three directions which include frontal, occipital (back) and temporal (side) lobe impacts. The impactor is located at distance of about 2 mm from the head model to create impact. The impactor measures 100x100mm in dimension. The head impacts it at about 6m/sec.

3. RESULTS AND DISCUSSIONS

For each case as mentioned previously, the head model is subjected to impact for 1ms to 5ms. The results of the simulation after solving using LS-DYNA are observed using HYPERVIEW. For the current project Von-mises stress and the plastic strain displacement is important, as shown in Tables 1.2 through 1.4 respectively. So the maximum value observed from each impact case is recorded. Maximum stress pattern is observed at the site of impact. Displacement of brain model is also observed with considerable shear near the brain stem which connects to the neck.

Table 2.1 Frontal impact data

Impact time	Von-mises stress [N/mm²]	Plastic strain
01	1.18E+02	4.14E-02
02	1.19E+02	4.14E-02
03	1.19E+02	4.14E-02
04	1.19E+02	4.15E-02
05	1.19E+02	4.14E-02

Also relative displacement of the brain model inside the skull is plotted against the impact time. This is shown in Fig.1 through Fig.3 respectively.

Table 2.2 Occipital lobe impact data

Impact time [ms]	Von-mises stress [N/mm^2]	Plastic strain
01	1.04E+02	3.36E-02
02	1.311E+02	3.36E-02
03	5.11E+08	3.35E-02
04	4.89E+08	3.36E-02
05	1.82E+09	3.36E-02

Table 2.3 Temporal lobe impact data

Impact time [ms]	Von-mises stress [N/mm^2]	Plastic strain
01	1.37E+02	2.37E-02
02	1.37E+02	2.36E-02
03	1.26E+02	2.37E-02
04	1.37E+02	2.36E-02
05	8.94E+01	2.36E-02

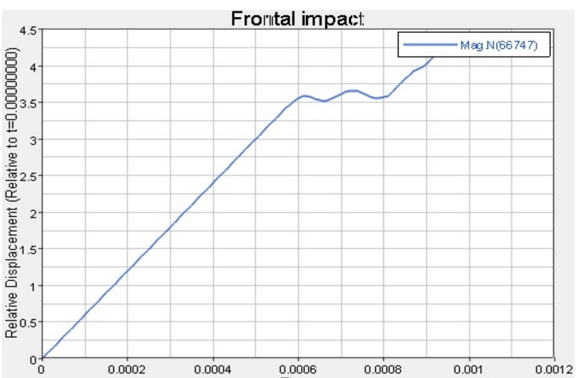

Figure 1.1a Frontal impact 1ms

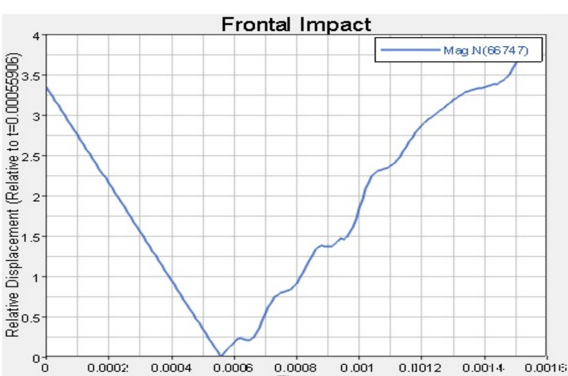

Figure 1.1b Frontal impact 2ms

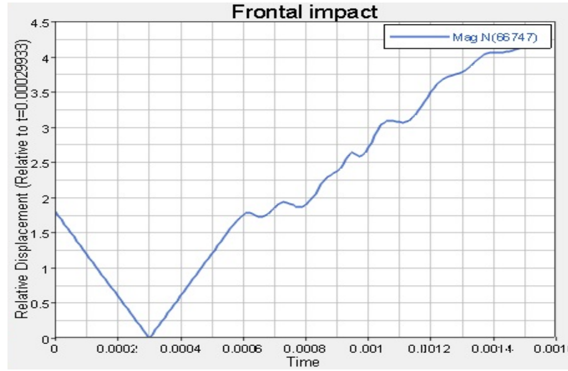

Figure 1.1c Frontal impact 3ms

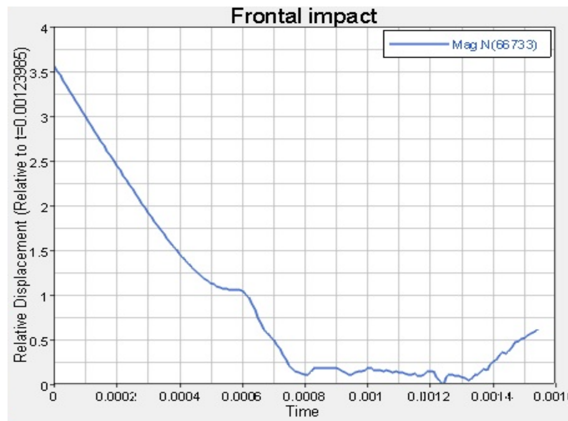

Figure 1.1d Frontal impact 4ms

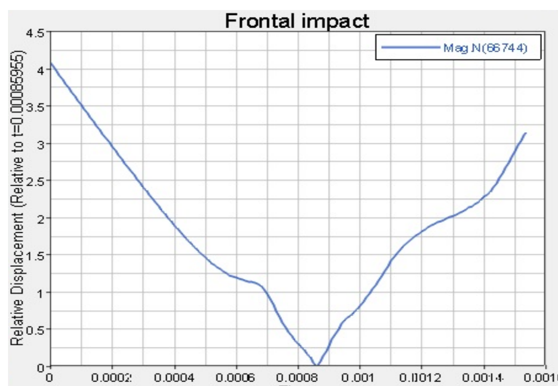

Figure 1.1e Frontal impact 5ms

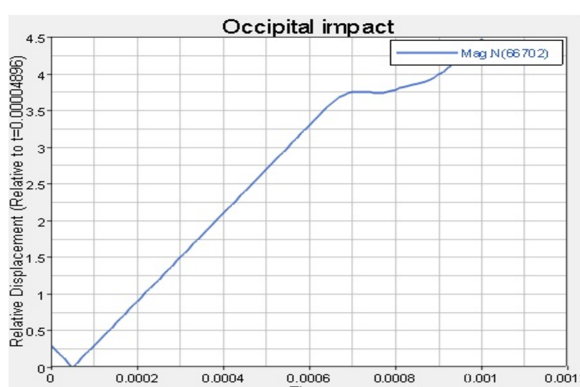

Figure 2.1a Occipital impact 1ms

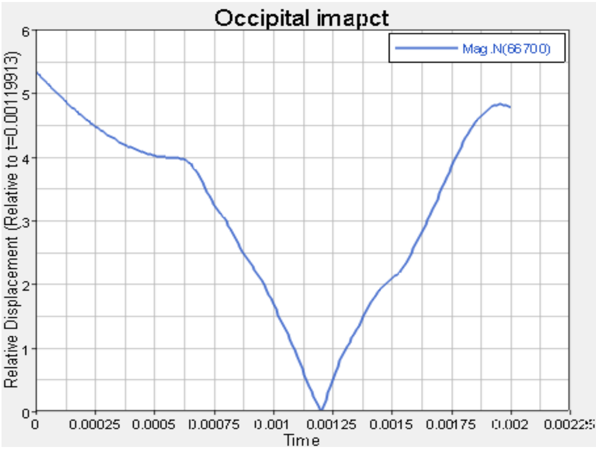

Figure 2.1b Occipital impact 2ms

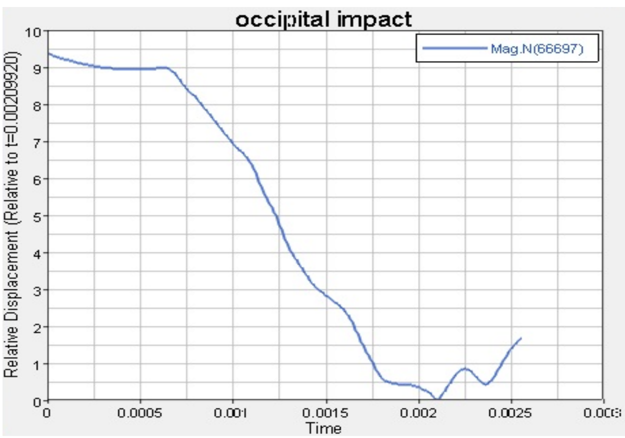

Figure 2.1c Occipital impact 3ms

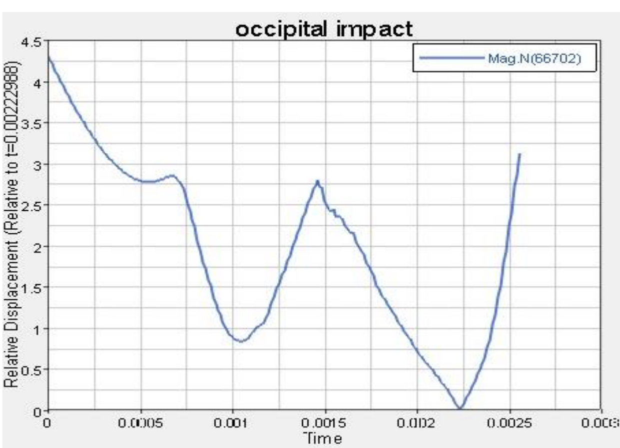

Figure 2.1d Occipital impact 4ms

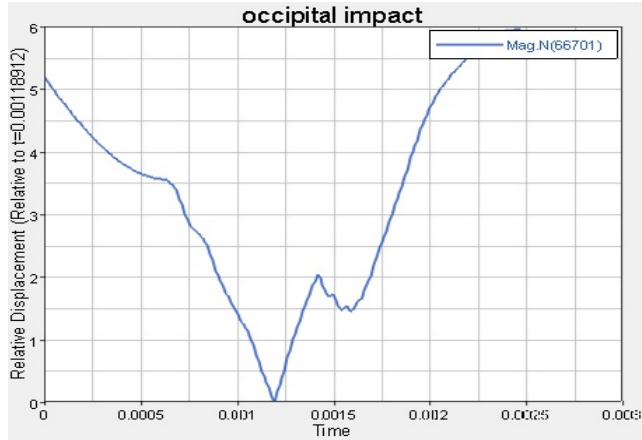

Figure 2.1e Occipital impact 5ms

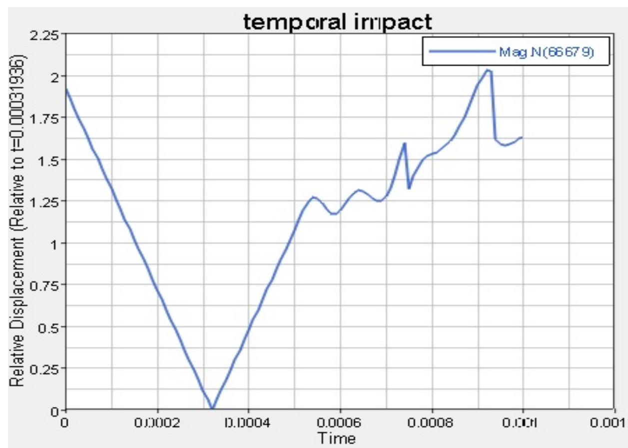

Figure 3.1a Temporal impact 1ms

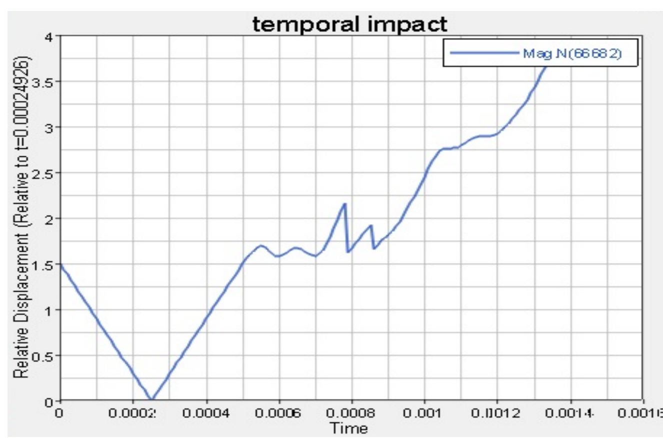

Figure 3.1b Temporal impact 2ms

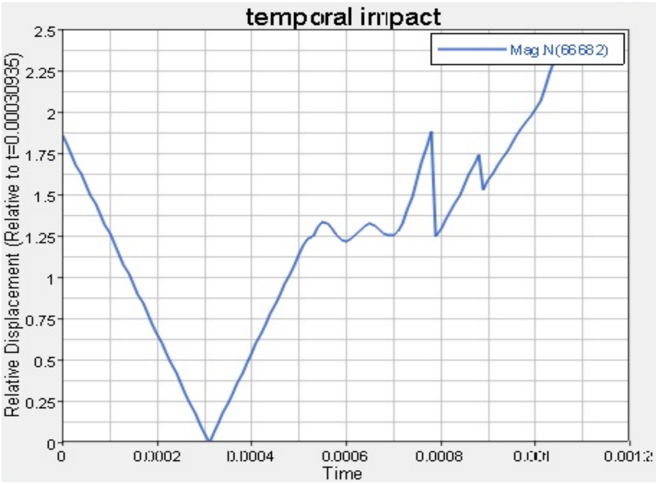

Figure 3.1c Temporal impact 3ms

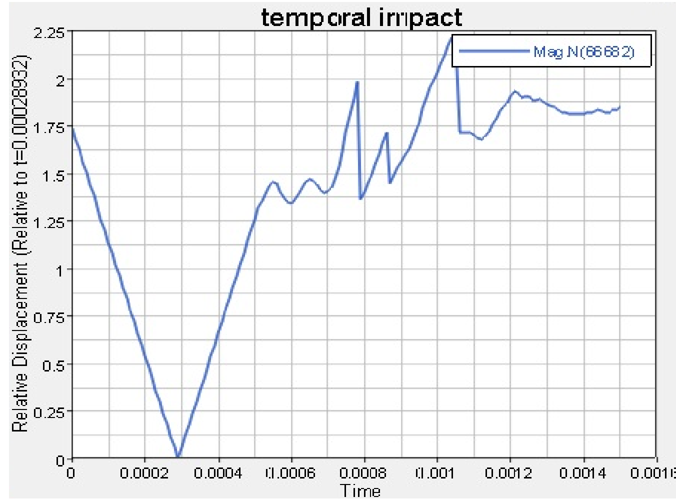

Figure 3.1e Temporal impact 5ms

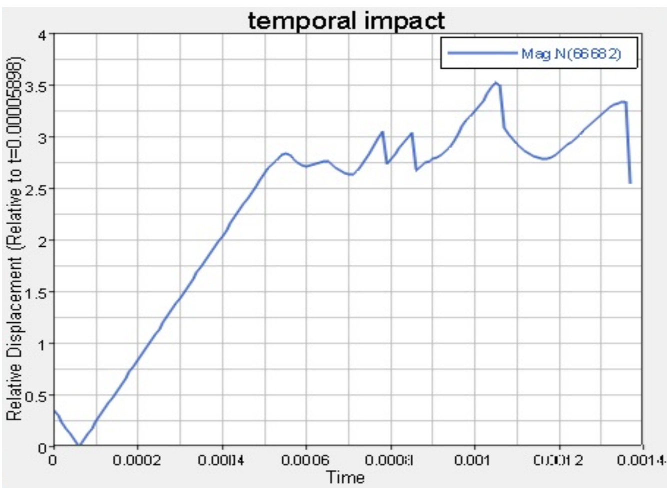

Figure 3.1d Temporal impact 4ms

FUTURE ISSUES

Many authors have come up with much better results for the current scope of the project. Their work has been a source of motivation by itself for this work. A detailed model developed from MRI scans using image processing techniques will help us understand the geometric nonlinearity of the model. Consequently it will also include the additional material properties not included in this work. Also the head model can be subjected to rotational motion in addition to the existing translational motion.

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