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Frontal Impact Analysis of Human Skull for Accident Reconstruction

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Abstract: Road traffic accidents, falls and assaults cases are the most frequently cited causes of head impact. Predictive of human head impact index have been developed since 1960s to help the investigation of human head injury. Approaches using finite element method can provide interesting tools for the forensic scientists and car crash evaluations to evaluate various human head injury mechanisms. In this study, a full frontal car collision is reconstructed using finite element method to predict skull fractures. Details from the traffic and collision reports are extracted to create the computational environment. Results shows that the frontal impacts of the human skull involved a concussion between the skull and the windshield. Fractures are predicted at the respective velocity and initiated at the impact contact area.

Keywords: Human skull, frontal impact, accident reconstruction, finite element analysis.

Introduction

Head injury is major cause of morbidity and mortality [1]. Mechanical impact is believed to be the leading cause of injury, death and disability for people aged 45 and below in the USA, Europe and progressively more in third world countries [2]. Despite of using protective devices such as seat belts, airbags, safety restraints and safety helmets, the brain injury accidents have approximately disable or kill a person in every two and a half minutes in the United States. In addition, the financial cost of hospitalization, care and rehabilitation of head injured people has been estimated to be as high as $33 billion per year in the US alone [3]. In the past few decades, most researchers have focused on the biomechanics of traumatic head injury attempting to discover the exact mechanisms of different types of head injury and the tolerance limits of the head and brain to impact [4].

Road traffic accidents (RTAs), falls and assaults cases are the most frequently cited causes of head injury all over the world [5] as illustrated in Figure 1. RTAs tend to be the leading cause of injury related death while falls to be the leading cause of non-fatal hospitalization [6], [7]. Besides, RTAs and falls will lead to different types of trauma. RTAs are likely to cause diffuse and multifocal injuries, while the type of head injuries received from falls have a tendency to be focal. In Ireland, falls are the single greatest cause of hospital admissions for both males and females across most age groups, with head injuries occurring in approximately a quarter of fall admissions [7].

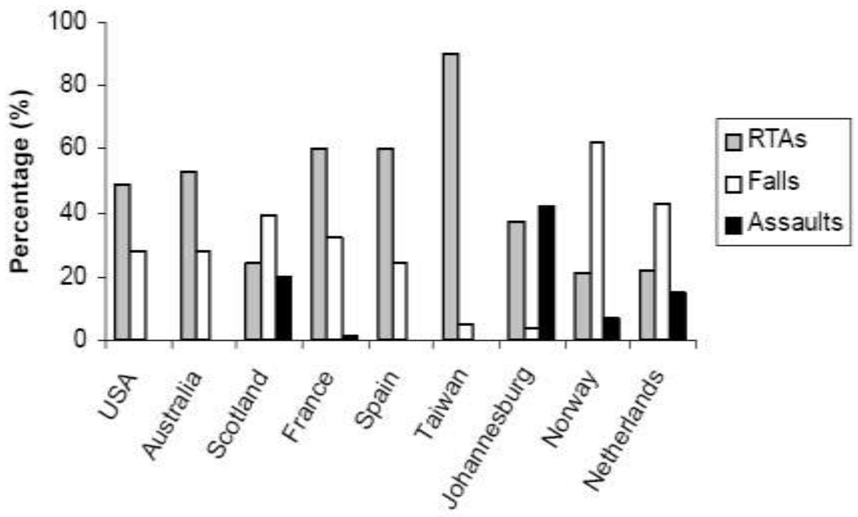

Figure 1. Percentage of head injury causes around the world [2].

Since the 1960s, predictive of human head impact index have been developed to help the investigation of human head injury. Approaches using finite element method can provide interesting tools for the forensic scientists and car crash evaluations to evaluate various human head injury mechanisms. Human skull model are usually used for car crash evaluations and are not common in forensic science [8]. However, recent technological progress of finite element analysis had been acceptable and consider in routine forensic practice in the coming years.

Most of head impact tests are focused on frontal position which the best position for real car accidents impacted on head. The situation can be developed in finite element method (FEM) to evaluate and estimate the stress distribution and total deformation for each tissue [9]. Over the last three decades, several finite element models of human head have been developed. The first geometrically FE model of human head was presented in 1971 by Hardy and Marcal [10] for linear static analysis while another FE head model were also developed in 1975 and 1977 by Ward [11] and Shugar [12], respectively for head impact simulations. Till now, the development of FE analysis of head impact rapidly increased and involved in more complexity. In this paper, the simulation of head impact is adapted from the real case reported by National Highway Traffic Safety Administration which was conducted by U.S. Department of Transportation. Dynamic simulations using finite element method are developed to reconstruct head impact phenomenon based on frontal car collision.

Methodology

A. Development of accident reconstruction

A case study of full frontal accidents resulting in frontal head bone fracture injury is selected from the National Highway Traffic Safety Administration. Only relatively full frontal car crash was considered, in order to facilitate the simulation. Based on the report, medical examination of the victim was carried out within 6h of injury. A collateral history of the accident sequence was also taken from at least one eye-witness. Details of the accident site were also examined in order to determine the layout of the environment, chronology of the accident, and the type of surface road on which the car accident. For the respective case, impact is predicted to be occurred against the surface of windshield [13].

The vehicle had been traveling in the southbound lane of a straight section of dry asphalt, two lane roadways with a speed limit of 11.18 m/s and had stopped at four leg intersections (A1). Then the vehicle began to cross the intersecting five lane roadway and for an unknown reason, veered to the left into the northbound traffic lane, and exited the intersection (A2). The vehicle then departed the east-side of the road, crossed a side street, entered a private drive (A3), and struck a two-story house with its front end (A4). The chronology of the accident is illustrated in Figure 2.

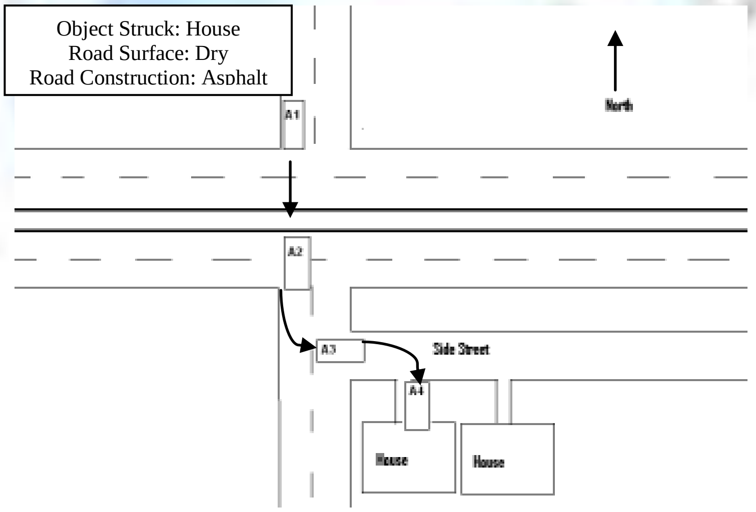

Figure 2. Illustrations of the accident chronology

B. Finite Element Analysis

The accident environment is developed using Ansys-Workbench software. The appropriate size of human skull model (closest in average dimension to the person involved) is positioned within the windshield distance at 830 mm [13], to create the distance of the person just before impact to the windshield. An initial velocity of the whole human skull model is estimated at 0.5 m/s in order to simulate the motion of the person at the time of accident. While a velocity of 11.18 m/s is assigned to the accident reconstruction that would account for any uncertainty of initial conditions. An overall overview environment for the case study is described in Figure 3.

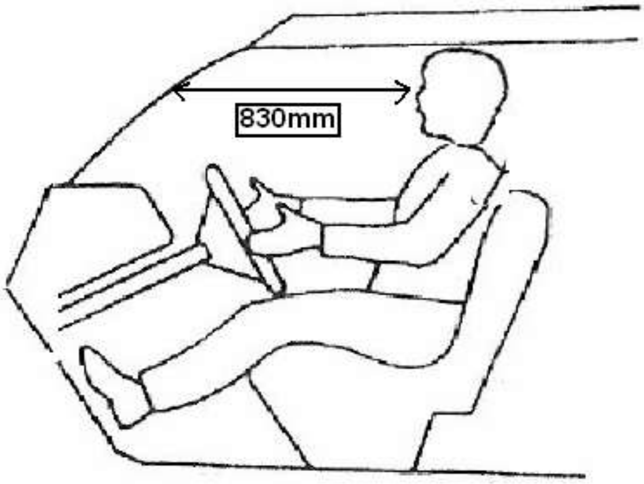

Figure 3. Development of accident reconstruction model

1) **Mechanical properties**

The human skull model is considered to be single layer while the windshield model in triple layer (Figure 4). The material properties of the respective model are described in Table 1 and assumed to be linear elastic material.

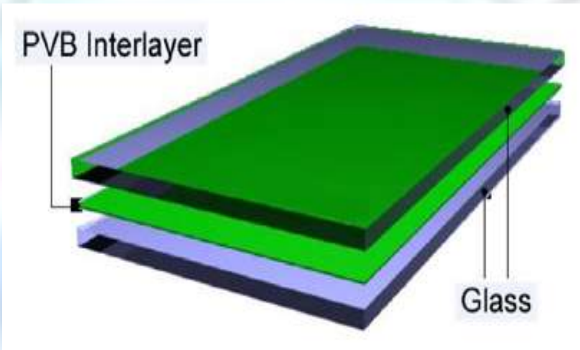

Figure 4. Construction of triple layer of windshield [14].

Table 1: Mechanical properties of human skull [1] and triple layer of windshield model [14]

	Young's Modulus, E (GPa)	**Poisson's Ratio**	**Density, ρ (kg/m³)**	**Thickness (mm)**
Human skull	4.46	0.21	1410	7.19
Glass	74	0.227	2500	4.2
PVB	2.6	0.435	1100	0.76

2) **Loading and boundary conditions**

The impact area between frontal human skull and windshield is described in Figure 5. It is to represent the actual collision on the frontal skull. As per real case of accident, the velocity is considered at the human skull model and hit the windshield. The velocity to consider in this simulation is 11.18 m/s [13] while the car windshield is modeled to be fixed. The loading and boundary conditions of the dynamic analysis is described in Figure 6.

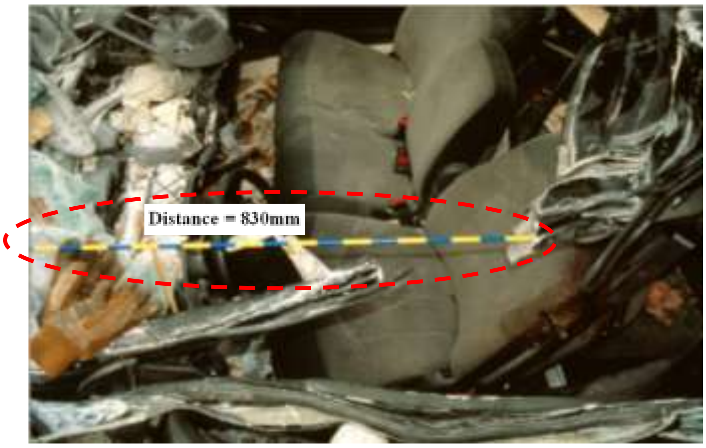

Figure 5. Construction of triple layer of windshield [14].

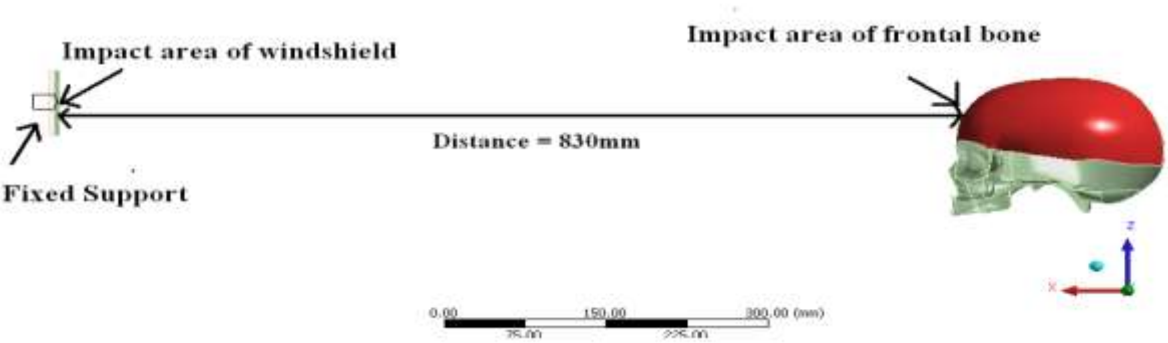

Figure 6. Loading and boundary conditions of frontal skull impact

Results and Discussion

C. Prediction of Impact Fracture

Frontal impacts of the human skull involved a concussion between the skull and the windshield. Findings of the dynamic simulation are represented on the resulting von misses stress as indicated in Figure 7. The maximum stress is predicted at 132.01 MPa and located at the contact area. The resulting high stress is exceed the yield strength for human skull which is 79.2MPa [15]. Thus, the high impact fracture is projected at the contact area as indicated in red. The findings are supported by the forensics report based on the actual condition as the victims' skull was cracked at the frontal region as captured in Figure 8. This value is significant to prove that the simulation findings are somehow contributed to correlate with the actual accident. However, the illustration of the victim shows that the fracture occurred and critical at the left side of frontal skull. This situation may arised due to different angle of impact during the collisions. The current findings did not considered the contact angle due to absent of the data available. Also, it has to be noted that the stress distribution on this model could only be deal with qualitatively and not quantitatively, as every human skull has its own unique form and structure [16]. The current findings also can be further investigate to estimate the probability of the car speed before the collisions happen.

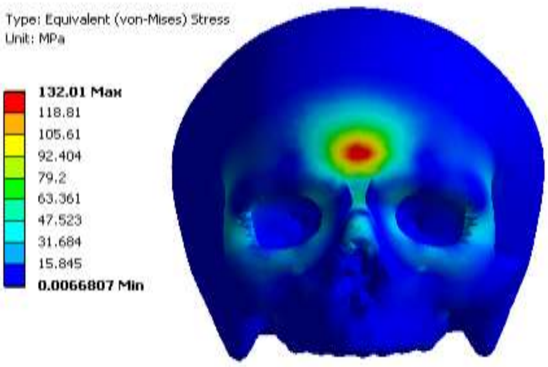

Figure 7. Stress variation of human frontal skull after collison.

Figure 8. Fracture at frontal human skull after impacted with windshield [13]

D. Total Deformation of Impacted Skull

Results of displacement of skull are represented based on contour color difference as indicate in Figure 9. The predicted maximum of total deformation was 10.19mm and located at the impacted area. This is much greater than that measured by Delye et al., 2007 which range between 5.2mm to 7.3mm for cranial bone to fracture [1]. Figure 10 shows the specimen of skull to experience multiple fractures after impacted with high velocity in pendulum experimental. Hence, the current findings that indicate higher total displacement may lead to more severe damage. The results also show good correlation between accident reconstruction and the pendulum experimental.

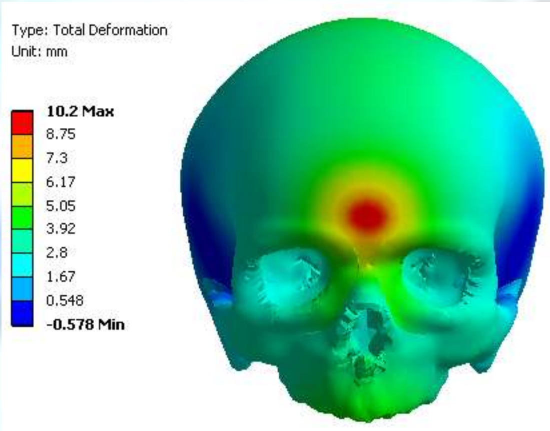

Figure 9. Front view for total deformation of impacted human skull

Figure 10. Specimen from Delye et. al. showing multiple fractures after being impacted at high velocity [1].

E. Correlation to Forensic Report

High impact experienced by the skull is closely correlated to high velocity. Based on the NHTSA report, the shoulder belt being locked in a retracted position shows that the victim do not wearing the available three-point belt which contributes to increase the impact velocity, as indicated in Figure 11. Although the steering-wheel airbag deployed, the victim still moved forward and over the airbag. The airbags is most probably cannot reduce the impact velocity in the collision. The victim also sustained depressed skull fracture to the frontal bones. Table 2 indicates the summary of this accident while Figure 12 illustrates the evidence of impact area of windshield during the head collision. It is also believed that victim body weight may contribute to increase the impact velocity during collisions.

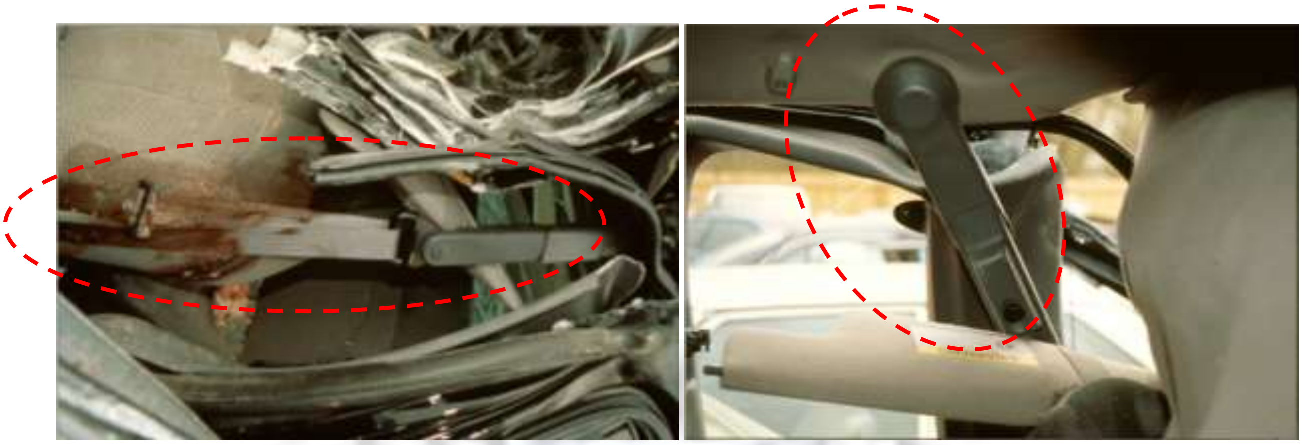

Figure 11. Views of three point belt being locked in a retracted position

Table 2: Case summaries, providing age, sex, description of accident, and head injury sustained [13]

Sex	Age	Height (cm)	Weight (kg)	Brief description of accident	Injury	Fatal or Non Fatal
M	33	178	101	The driver involved in full frontal crash accident. His head impacted into windshield due to not wearing three point's belt.	Frontal bone fracture	Fatal

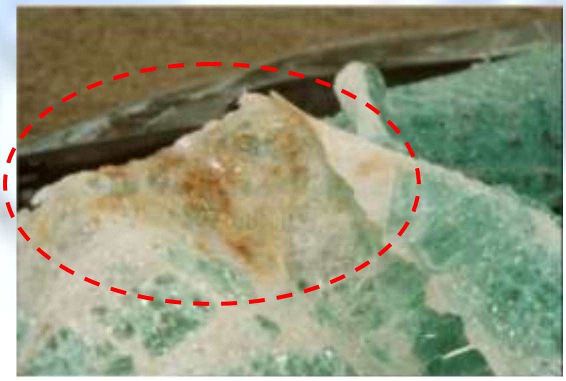

Figure 12. Impact area of windshield with human head produce crack during collision.

Conclusion

Dynamic analysis for frontal human skull is successfully developed for respective accident reconstruction assessment. The findings show that the fracture is predicted at the impact contact area at the respective velocity (11.18 m/s). The fracture occurred as the resulting stress exceeds the yield strength of human skull at 79.2 MPa. In comparison to pendulum experiment, the results of total displacement are much higher than that predicted to be fracture by Delye et al, 2007. The high velocity experienced by the victim due to the collision lead to head impact and fracture. Data from the forensic reports also correlate to the possibility of high impact velocity. Results of the simulations can be improved by considering anistropic model of human skull and the present of details data of the respective collision to be assign in the simulation.

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