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APPROACH TO NUMERICAL SIMULATION OF AN AMERICAN FOOTBAL HELMET

Abstract: The article presents the initial analysis of collision of two American football helmets. The aim was to investigate the crashworthiness of the facemask during the collision. In addition, thanks to creating the reference point representing the head inside the helmet it was possible to investigate whether the rotational acceleration occurs. In order to obtain reliable results the Finite Element discrete model was prepared. The study is based on a real helmet model – Riddel Revolution and author's experience as a player.

Key words: American football, helmet, Finite Element Method, facemask

1. INTRODUCTION

During every American football game there are many spectacular tackles. However every contact brings risk of injury. Despite the fact that players on each level are acquainted with possibility to be carted off the field, they still decide to compete on highest possible level. Many former National Football League players as well as usual players suffer different brain injuries. The "Concussion" (2015) movie directed by Peter Landesman has inspired one of the authors to investigate the mechanical aspect of the collision.[1]–[3]

Fig. 1. One of the authors captured by Rafał Seifert during the game [4]

The movie shows the discovery of chronic traumatic encephalopathy, the brain degeneration suffered by players due to many head to head collisions. For that reason the finite element model of an American football helmet was developed. The study encompasses the simulation of collision and analysis of the helmet crashworthiness. Moreover, thanks to introducing a concentrated mass point representing the mass of the head it was possible to investigate whether rotational acceleration occurs on the head.

The article presents the interpretation of already carried out study (Catastrophic head injuries in high school and college football players) to emphasize the necessity to investigate an ongoing problem with brain injuries among players.

Fig. 2. American football helmet used in this study

The current study is initial, that is why the conducted simulation is not symmetrical and does not present real-life collision.

1.1 Injury analysis

American football is one of the most popular sports in United States of America and associates around 1.2 million athletes on college level. However football also associates the highest rate of injuries. That is why it is very important to monitor collisions and create preventing strategies.[5]

Researchers from National Center for Catastrophic Sports Injury Research in the United States have collected data for 13 years (1989-2002) to determine the incidence of catastrophic head injuries, identify new injury patterns and provide preventive strategies on high school and college level.

Catastrophic head injuries in this study are defined as injuries macroscopic brain lesions such as subdural hematomas, epidural hematomas, diffuse brain edema, arteriovenous malformation or aneurysm. Athletes with injuries such as concussion were excluded from the study.

A total of 100 direct injuries were reported, where six did not meet the injury criteria. The overall incidence for this study was calculated as the total number of injuries divided by the total number of players during this period. For the high school and college incidence the calculation was restricted to appropriate playing level. For catastrophic head injuries the incident was calculated by dividing the total number of injuries by total number of players. Incidence proportions were calculated per 100 000 athletes.

During the study period there were 14 650 832 players. The incidence of catastrophic head injury was 0.64 per 100 000 athletes. The injuries occurred statistically 3.5 times more often during the game than at the practice. Most injuries occurred during the regular season (n=46), the rest occurred during the preseason (n=6), off-season (n=2) and an unknown period (n=40).[5]

The injury profile was not known for 4 of them. 46 were classified as nonfatal (permanent neurologic deficit), 36 as serious (no residual neurologic deficits), 8 as fatalities. 75 athletes suffered subdural hematoma, 10 suffered subdural hematoma with diffuse brain edema and 5 suffered diffuse brain edema. In addition, 4 participants were diagnosed with arteriovenous malformation or an aneurysm, 2 sustained a cervical fracture. None of the athletes suffered skull fractures.

According to data collected, 35 athletes already had suffered a head injury prior to the catastrophic injury, 24 had not suffered head injury before. In 25 of 35 cases the previous injury occurred earlier in the season. In 21 of 54 cases the athlete was playing with residual neurologic symptoms from the previous injury.[5]

Table 1. Mechanism injury in the study [5]

Among 70 cases with mechanism injury		
48 tackling/being tackled		8 blocking/ being blocked
14 major collisions		
Among 37 cases with described point of contact		
16 helmet-to-helmet	14 helmet-to-opponent's body	7 helmet-to-ground

In this study there were 8 fatalities as a result of injury. 5 athletes suffered isolated subdural hematoma, 1 subdural hematoma and diffuse brain edema, 1 arteriovenous malformation and 1 diffuse brain edema. One patient remained in coma for 5 years, the rest died 28 days within the injury. 46 participants with nonfatal injury were diagnosed with residual deficits such as: memory loss, slurred speech, paralysis, seizures, personality changes or medical complications. None of them returned to playing football. Within 36 athletes classified with serious injury only 2 returned to football without any know recurrences.

With all the data collected it was established that 20 injuries were potentially preventable. 8 athletes never informed anyone about neurologic symptoms before the catastrophic injury. 7 participants blamed a defective helmet or poor fitting. 3 interviewed blamed the medical personnel's evaluation on allowance to play.[5], [6]

2. MATERIALS AND METHODS

2.1 Computed tomography

The volumetric model separately for the facemask and shell was developed utilizing Computed tomography (Zeiss Metrotom 1500 Metrotomogpahy). Tomography itself is a mean to identify density of the object, dimensions and the 3D model of the specimen, maintaining high level of precision and remaining nondestructive method.

Table 2. Accuracy of single measurement Metrotom 1500 Carl Zeiss [7]

Accuracy of single measurement					
Voltage [kV]	Intensity (μA)	Integration time [s]	Voxel quantity [μm]	Projection number	Cu Filter [mm]
210	500	2	315	1050	1.5

Fig. 3. Setup of the elements inside the Zeiss tomograph

2.2 Model discretization

The mesh assigned to both components is 3D tetrahedral. As the simulation is performed with a complex (irregularities of surface) 3D model it was decided to use this mesh due to its ability to fill complex shapes. For the shell of the helmet the 4 mm tetrahedral mesh was assigned (A 4-node linear tetrahedron). For the facemask the 0.5 mm tetrahedral mesh was assigned (A 4-node linear tetrahedron). The whole number of elements is 3 876 694. [8]

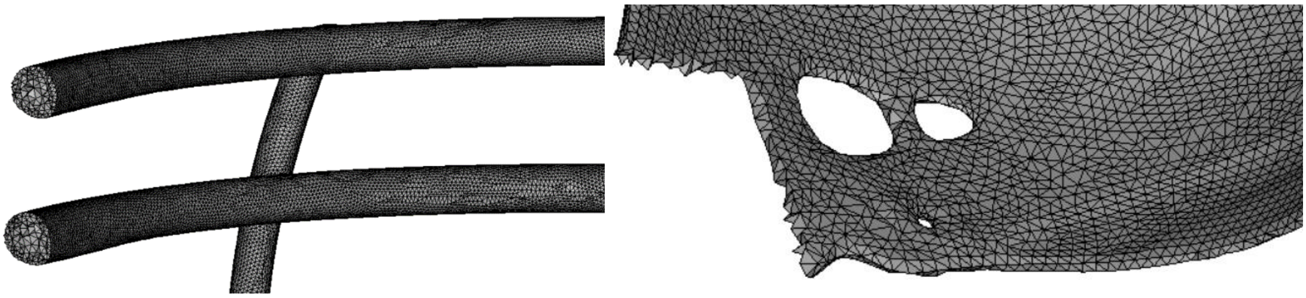

Figure 4. Model discretization

2.3 Material description

The material used to manufacture the shell is polycarbonate, the material used to manufacture the facemask is titanium (Table 3).

Table 3. Mechanical properties of polycarbonate and titanium alloy

Properties/Material		Polycarbonate	Titanium pure annealed
Density	g/cm^3	1.19	4.51
Young's modulus	GPa	2.344	113.7
Poisson's ratio	-	0.38	0.30
Yield stress	MPa	55.1	482

2.4 Simulation description

The aim of this project was to analyze the crashworthiness of the helmet while focusing on the facemask. In addition, the reference point has been added which represents the heads mass. Thanks to this it is possible to establish accelerations acting on the players head. The weight of the head was assumed as 4 kg. The initial velocities are exaggerated for the purpose of the simulation and are equal to 40 km⁄h. The simulation is not symmetrical.

Fig. 5. Simulation setup with the global coordinate system

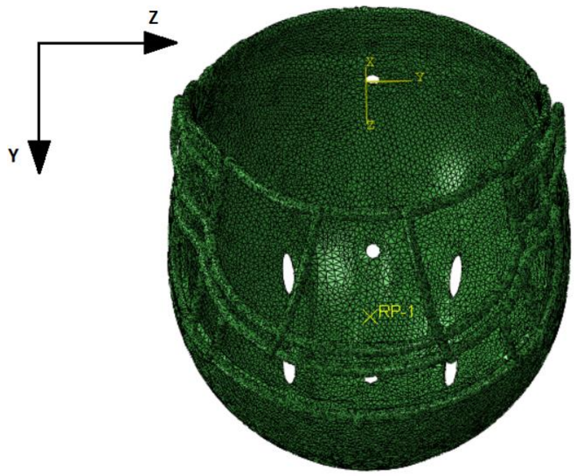

Fig. 6. Setup of concentrated mass point

To check the crashworthiness of the helmet it was necessary to simulate a collision. Firstly it was necessary to assemble the shell with the facemask. Secondly, inside both helmets there is a constrained mass point that represents the mass of the head. The point is modeled according to WG17 (EEVC) [9]. The point is constrained with the geometry of shell using kinematic coupling – RBE2. The next step was to position the helmets as close as possible to minimize the computational time. In this case the distance between the parts is 0.5 mm. The last step was setting the initial velocities for both helmets. The velocity for each helmet is 40 km⁄h.

3. RESULTS

The initial simulation proved that even in such extraordinary conditions the structure of the facemask remains undamaged. The results and Huber – Mises – Hencky stress values of the simulation are presented on Fig. 7.

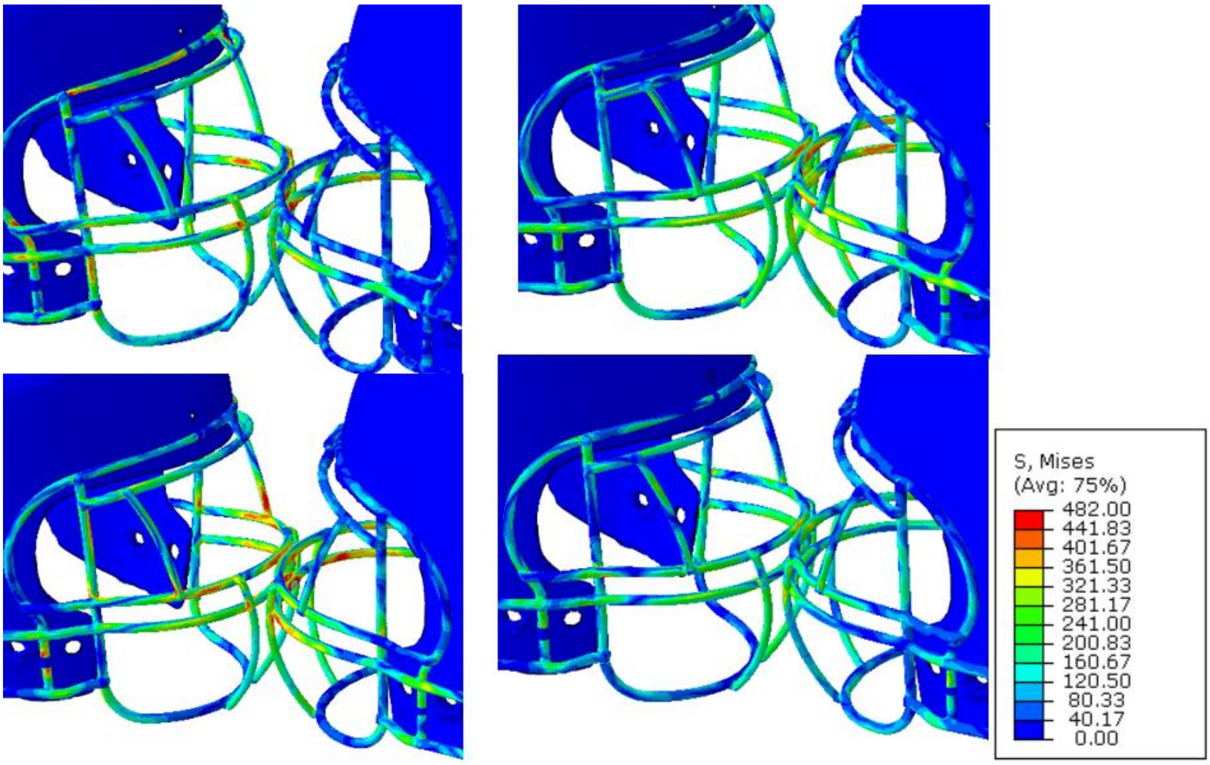

Fig. 7. Magnified view on the course of the simulation during the impact (0.5 ms - 3 ms) with Huber – Mises – Hencky stress values [MPa].

4. DISCUSSION

The initial simulation proved that the structure on the facemask remained undamaged and additionally proved the assumption that there occurs rotational acceleration concerning the heads mass point (Fig. 8). The rotational acceleration presents values around the z axis of the global coordinate system.

The values concerning rotational acceleration were edited using the filter SAE 180. Thanks to this noise was eliminated. Additionally longitudinal acceleration is presented. As expected the longitudinal acceleration oscillates around 0 after the collision. This is one of the proves that the collision occurred.

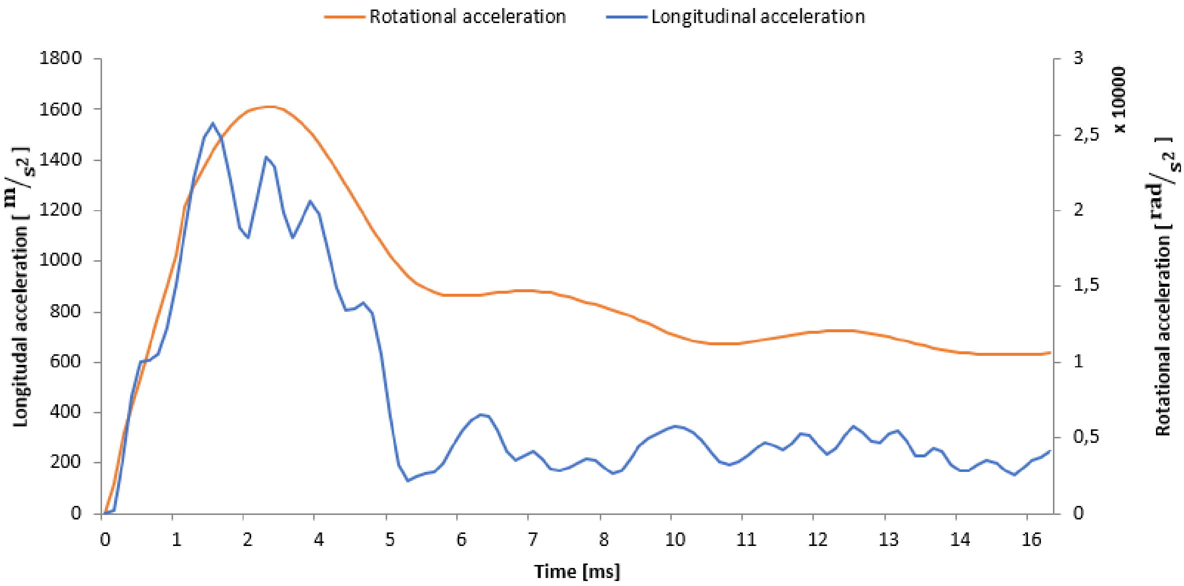

Fig. 8. Accelerations graph
The rotational acceleration in the z axis of global coordinate system

Another confirmation that the collision took place is the analysis of the energy distribution graph. As predicted, a part of kinetic energy was transformed into internal energy. In the simulation it is observed that the helmets bounced, that implies that the kinetic energy is not equal to 0. Fig. 9 displays the energy distribution graph with respect to time.

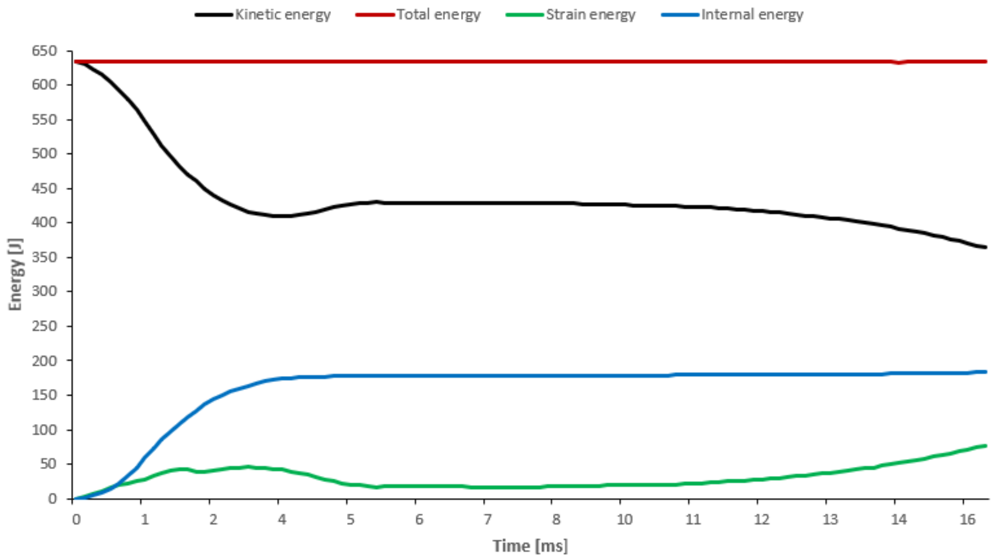

Fig. 9. Energy distribution graph [J]

5. CONCLUSIONS

The initial simulation proved that the helmet structure remained undamaged in such exaggerated conditions, what was the main aim of this project. The analysis showed that this facemask construction is not susceptible to such forces. Basing on this particular example one could make a statement that the face of the player is completely safe behind these bars.

Thanks to the reference point it was possible to determine and analyze the rotational and longitudinal accelerations that act on the head. However, the values cannot be taken into further consideration because the simulation did not reflect a possible field collision. What is more, the inflatable padding, head and brain model was omitted as it was not the focus of this research. The padding would definitely limit the values as their job is to absorb energy.

This knowledge proved that further research should be conducted to analyze the accelerations and their effect on brain tissues. It is necessary to provide a research based on real collision in which players suffered head injury. Additionally, implementation of different energy absorbers inside the helmet should be considered.

Such a research will have huge influence on helmet design. The coaches might include the results during their theoretical meetings with players considering their health.

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WSTĘPNA SYMULACJA NUMERYCZNA KASKU DO FUTBOLU AMERYKAŃSKIEGO

Streszczenie: Artykuł ma na celu zaprezentowanie wstępnej analizy zderzenia dwóch kasków do futbolu amerykańskiego. Główny nacisk został położony na zbadanie czy kratka kasku nie zostanie uszkodzona przez takowe zderzenie. Dodatkowo został umieszczony punkt masowy, który reprezentuje masę głowy. Dzięki temu jest możliwość zbadania przyspieszeń rotacyjnych działających na mózg zawodnika. W tym celu został stworzony model dyskretny (obliczeniowy) kasku. Badanie jest przeprowadzone z użyciem prawdziwego kasku – Riddel Revolution oraz przy użyciu doświadczenia jednego z autorów.

Słowa kluczowe: Futbol Amerykański, kask, Metoda Elementów Skończonych, zderzenie