TKI>2016 XIV Konferencja Naukowo-Techniczna
TECHNIKI KOMPUTEROWE W INŻYNIERII

Numerical analysis of effort in cervical spine structures in the acceleration impulse

Agnieszka Mackiewicz[1], Grzegorz Sławiński[2], Agnieszka Kaczmarek-Pawelska[1], Romuald Będziński[1]

[1]Zakład Inżynierii Biomedycznej, Wydział Mechaniczny, Uniwersytet Zielonogórski
[2]Katedra Mechaniki i Informatyki Stosowanej, Wojskowa Akademia Techniczna
email: a.mackewicz@ibem.uz.zgora.pl, grzegorz.slawinski@wat.edu.pl, a.kaczmarek@ibem.uz.zgora.pl, r.bedzinski@ibem.uz.zgora.pl

ABSTRACT: The risk of threat to life and health of the crew increases, as a result of an explosion under a military wheeled armored vehicle. Examination of this accident in terms of the security of soldiers let to a complex analysis of the mutual interaction between the body of the soldier, seating and structural elements of the vehicle. As a result, shock wave impacts can cause **v**ibrations resulting from the construction of the vehicle and extreme acceleration of the passenger's body. This study attempts to analyze the impact of an explosion of an improvised explosive device (IED) under the military wheeled armored vehicle with the risk of cervical spine structures injuries of soldiers. The analysis was carried out using numerical methods in the LS-DYNA softwere and include the variable displacements values and acceleration recorded during the explosion. Studies are important in identifying overloads cervical spine during explosion under the armored wheeled vehicle type Rosomak. Based on these studies it is also possible to assess the destructive effects in the spine structures.

KEYWORDS: cervical spine, finite element analysis, dynamic overload, effort, wheeled armored vehicle

1. Introduction

Statistics from the military conflicts in 2001-2010 in Iraq and Afghanistan indicate that large number of the soldiers deaths were caused by the impact of explosives [1, 2]. Explosion under a military wheeled armored vehicle causes rapid acceleration of the body of a soldier, including his head. As a result, the stress and strain values on the structures of the spine increase to a value of tensile strength of tissues. The aim of study was to develop a numerical model, which would enable assessment of the impact impulse acceleration to the effort of the cervical spine structures. The model included the impact of the seats location and seat belts.

2. Methodology

The study was based on a dynamic numerical analysis in the LS-DYNA software using the explicit integration method to solve fast changing time problems. In the first step, of research a simplified geometry of the armored wheeled vehicle type Rosomak was prepared (Fig. 1) having the correct placement of the seats, in the range of assault designed for soldiers-passengers (P2, P3, P4, P5) and in the driver's compartment (P1).

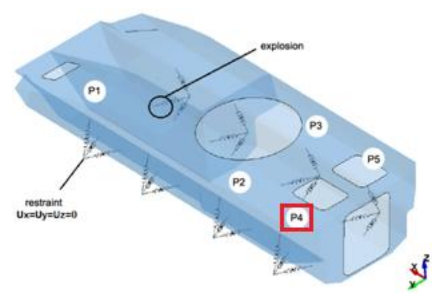

Fig. 1. Model of the Rosomak vehicle with the distribution of passengers-soldiers in a three-dimensional coordinate system (x- the direction of travel, y- perpendicular direction to the direction of travel, z – vertical direction)

The simulation of an explosion under the right front wheel of the vehicle was performed, to simulate the response of the vehicle as speed impulse of the floor – 10.7 m / s [3]. In the second step the impact of impulse wave to the human body was examined, in order to determine the location of the seat which is the most threatening. For every individual case variant with and without seat belt were tested. In the study a model of the body of a soldier in the form of a Hybrid III 50th Male Dummy was used. The results showed that the large displacement of the soldier's body appears in the case of location on the seat P4, which was the subject of further analysis. To determine the type of destructive changes in the structures of the P4 soldier's cervical spine, the model of cervical was prepared. The numerical model, consisted of vertebrae, intervertebral discs and skull with the brain. In the cervical spine model 4 ligaments: Anterior Longitudinal Ligament (ALL), Posterior Longitudinal Ligament (PLL), Ligamentum Flavum (FL), Interprinous Ligament (ISL) were modeled. (Fig. 2).

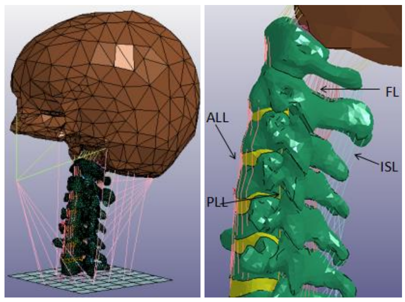

Fig. 2. Geometry of numerical model

The geometry of the cervical spinal structures generated based DICOM file with the CT scan. The material properties of cervical spine structures are summarized in Table 1.

Tabela 1. Materials properties [4-6]

Material	*E* [MPa]	*ν* [–]	ρ [g/mm3]
Vertebra bone	15000	0,22	0,002
Brain	20	0,49	0,0025
Skull	15000	0,22	0,0035
Nucleus pulposus	A=0,12 B=0,09	0,49	
Annulus fibrosus	A=0,56 B=0,14	0,48	
Ligaments	2-30		

3. Numerical modeling and simulation

In the study bone of the vertebrae, the skull and the brain were modeled with solid elements and declared them the linear-elastic properties. During the skull modeling doesn't take into account the geometry of the mandible which has been replaced by 3 beams elements. Intervertebral discs are the most flexible structures in the spinal column and have a significant impact to the stiffness of the whole column. In the model of intervertebral discs was separated into the structure of the nucleus pulposus and the annulus fibrosus. The nucleus pulposus and the annulus grounds were described by means of the hyperelastic material using Mooney-Rivlin [4]:

$$W = A(I-3) + B(II-3) + C(III^{-2}-1) + D(III-1)^2 \quad (1)$$

where:

$$C = 0{,}5A + B \quad (2)$$

$$D = \frac{A(5\nu-2)+B(11\nu-5)}{2(1-2\nu)} \quad (3)$$

I,II,III – invariant of the component of deformation tensor.

The acceleration was applied to the nodes plate below the vertebrae C7 in all directions. Changes in the value of these displacements were taken from the model of the Hybrid III 50th Male Dummy during the simulation.

4. Results and discussions

Injuries of the soldiers, passengers of the military vehicles are the result of the influence of the acceleration from vibrating floor, overturning and instability of the vehicle and the pressure from the explosion. Soldier P4 is exposed to the occurrence of cervical spine compression injuries associated with displacement in the Z direction of and hitting his head on the roof of the vehicle. The maximum value of the absolute displacement is observed in the X direction, which exposed the cervical spine to lateral bending. Values of the displacements in the X direction are four times lower when the soldiers have the belt in comparison to the test without the belt. The volume of displacement in the Y direction for the case with belt show the positive and negative values which indicates the possibility of flexion-extension, and taking into account the movement in the X direction also rotation-extension injuries of the cervical spine. In the studies were carried out analysis of the strain (figure 3) and the stress distribution volume in the structures of the cervical spine. The most destructive changes are located in the lower cervical spine segments, confirming the results obtained during the study by Levine (1994) [7]. The maximum deformation observed in the intervertebral discs structures of C5C6 and C6C7. Bambach studied the possibility of injury in the cervical spine during a collision the impact of the hitting head on the vehicle roof. The results obtained by Bambach are similar to the results obtained in the studies – the largest damage occurs at the C5-C7 level, due to the compression with back or lateral bending of the head. Bambach, reports that the most often it leads to: fractures of vertebral arch, dysfunction of articular facet, break off of the ALL and the PLL [8]. During the numerical simulation it was observed that it is possible that fracture of the spinous processes during hyperextension.

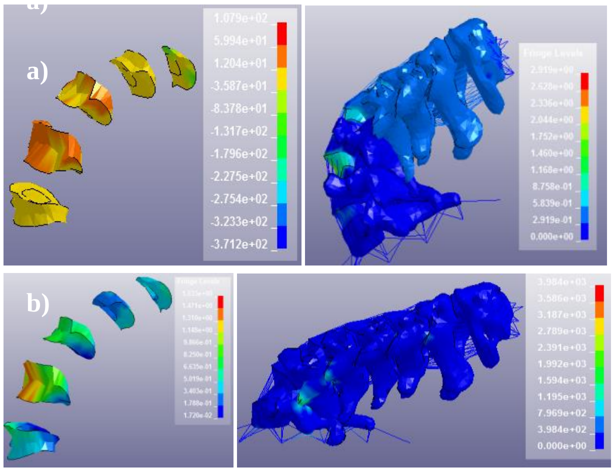

Fig 3. The strain distribution in the intervertebral discs and spine column: a) P4 without belts, b) P4 with belts

Ligaments were modeled with beams elements. In the case of the ligaments the values axial forces were determined and presented in Table 2.

Table 2. The values of the axial force in the ligaments [N]

	ALL	PLL	FL	ISL
P4 with belts	1718,2	113,1	10811,5	16154,7
P4 without belts	2874,6	78,7	4176,9	8633,8

For each ligament the values of the load was compared with experimental results. The study present that the ALL, FL and ISL are overloaded (table 2), which may indicate formation instability in the spinal column. This fact can be explained by the characteristic movement of the neck and head regarding to fixed seat belt on the body. As a result, movement occurs flexion of the column (stretching ISL and FL) which is followed extension (stretching ALL).

This investigation was supported by a research grant, as a part of the project DOBR-BIO4/022/13149/2013 financed by NCBiR.

References

[1] Belmont P.J., Schoenfeld A.J., Goodman G., *Epidemiology of combat wounds in Operation Iraqi Freedom and Operation Enduring Freedom:orthopaedic burden of disease*, J Surg Orthop Adv, 19,2–7, 2010.

[2] Krzystała E., Mężyk A., Kciuk S., *Analiza zagrożenia załogi w wyniku wybuchu ładunku pod kołowym transporterem opancerzonym*, Zeszyty Naukowe WSOWL, Nr 1 (159), 2011

[3] Nilakantan A., *Computational Assessment of occupant Injury Caused by Mine Blasts underneath Infantry Vehicles*, Int. J. Vehicle Structures & Systems, 1 (1-3), 50-5, 2009.

[4] Mackiewicz A., Banach M., Denisiewicz A., Będziński R., *Comparative studies of cervical spine anterior stabilization systems-Finite element analysis*, Clinical Biomechanics, Feb 32,72-79, 2016.

[5] Kleiven S., *A parametric study of energy absorbing foams for head injury prevention*, Royal Institute of Technology Sweden Paper Number 07-0385, 2009.

[6] Toosizadeh, N., Haghpanahi, M., *Generating a finite element model of the cervical spine: Estimating muscle forces and internal loads*, Scientia Iranica, 18, 1237–1245, 2011.

[7] Levine R.S., *Head and Neck Injury*, Society of Automotive Engineers, USA, 276, 1994.

[8] Bambach M.R., Grzebieta R.H., McIntosh A.S., Mattos G.A., *Cervical and thoracic spine injury from interactions with vehicle roofs in pure rollover crashes*, Accident Analysis and Prevention, 50, 34-43, 2013.