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THREE DIMENSIONAL ANALYSES OF SEAT BELT AND DRIVER IN CASE OF SUDDEN BRAKING

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RESEARCH ARTICLE

ABSTRACT: A seat belt is a vehicle safety device designed to secure the occupant of a vehicle against harmful movement that may result during a collision or a sudden stop. In recent years, serious and fatal accidents have decreased in number. The reason is that more and more people begin to understand the importance of using safety belts. When driver makes a sudden stop, the speed from the car causes driver to hit the seat belt with significant force. That force saves life, but can leave passenger with bruises, scrapes and fractures. In this paper the influence of different force values on the abdomen of the driver by the seat belt is analyzed. As a result, the different speed values of the car, due to sudden braking, give different values of force which the seat belt acts on the driver.

KEY WORDS: driver, injury, vehicle, finite element method

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TRODIMENZIONALNA ANALIZA POJASA I VOZAČA U SLUČAJU IZNENADNOG KOČENJA

REZIME: Sigurnosni pojas je sigurnosni uređaj vozila dizajniran da osigura putnika u vozilu od štetnog kretanja koje može nastati tokom sudara ili iznenadnog zaustavljanja. Poslednjih godina broj teških i fatalnih nesreća se smanjio. Razlog je taj što sve više ljudi počinje da shvata važnost korišćenja sigurnosnih pojaseva. Kada vozač naglo zaustavi, brzina od automobila dovodi vozača o značajnog udara u sigurnosni pojas. Ta sila spašava život, ali može ostaviti putnika modricama, ogrebotinama i lomovima. U ovom radu analiziran je uticaj različitih vrednosti sile na abdomen vozača pomoću sigurnosnog pojasa. Kao rezultat toga, različite vrednosti brzine vozila, usled naglog kočenja, daju različite vrednosti sile koje sigurnosni pojas deluje na vozača.

KLJUČNE REČI: vozač, povreda, vozilo, metoda konačnih elemenata

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1. INTRODUCTION

Traffic accidents are a major source of fatalities and serious injuries [1]. The major cause of car occupant fatalities in car accidents is head injuries which occurs when vehicle passengers are thrown out through the windshield or when they collide with the vehicle seat or dashboard. Based on research the World Health Organization [2] injury in road traffic crashes is expected to become the third most important cause of the global burden of injuries/diseases by 2020. More than 1.25 million people die each year as a result of road traffic accidents. Globally, road traffic crashes are a leading cause of death among young people, and the main cause of death among those aged 15–29 years (Figure 1).

Based on all the research, a lot of effort has been invested to change the awareness of drivers and all passengers in vehicles. The most important form of passenger protection in the car is the use of the seat belt. Seat-belts limit the movement of vehicle occupants in the event of a crash in order to reduce the force that currently operates on the passenger in the vehicle. Wearing a seat-belt reduces the risk of a fatality among drivers and front-seat occupants by 45–50%, and the risk of minor and serious injuries by 20% and 45% respectively. In the case of passengers in the rear seat, the use of seat belts reduces fatal and serious injuries by 25% and minor injuries by up to 75% [3]. Over time, there is progress and development of awareness about the application of good laws in the binding of seat belts, but still only half of the country's world has adopted a good seat-belt laws. About 4.8 billion people, from 105 countries have seat belts in the back seat.

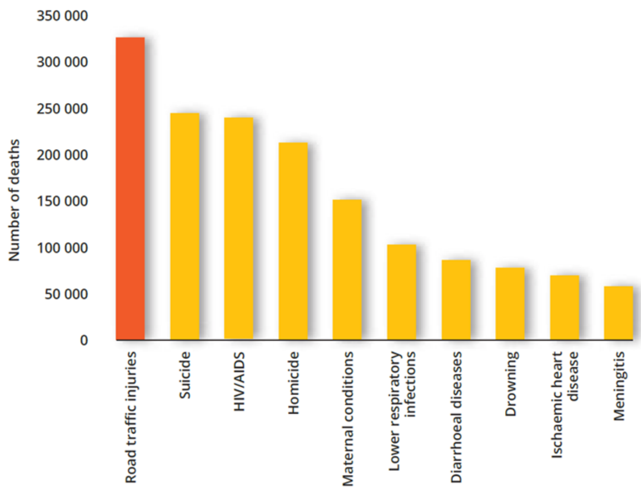


Figure 1. The most common causes of death of young people under 30 years [2]

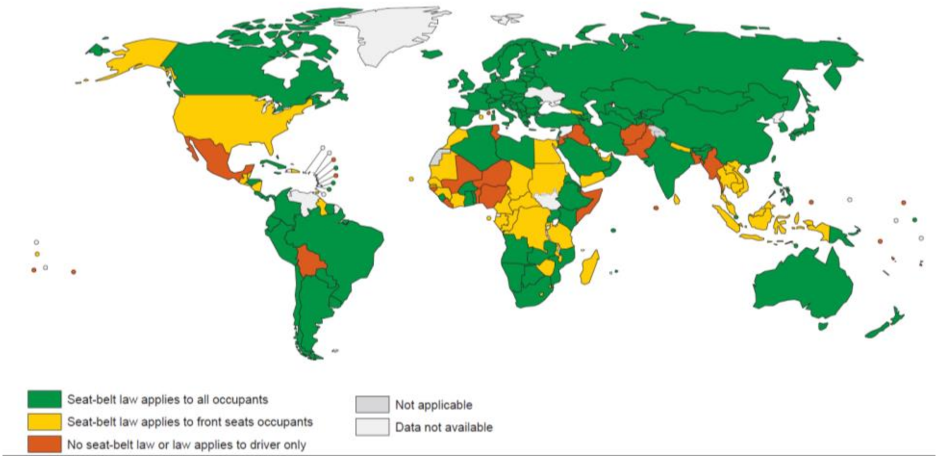
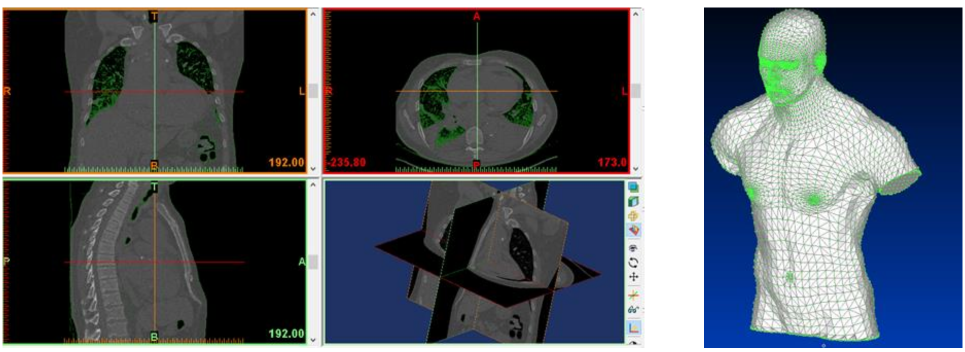


Figure 2. Seat-belt laws in the world

Experience from developed countries indicates that the use of seat belts is one of the most effective ways to reduce road accident fatalities [4, 5]. In this paper, using numerical simulations, it has been shown that the force of the sudden braking extends through the torso of an adult male person, previously tied to the safety belt.

2. MATERIALS AND METHODS

The finite element model of a human torso was developed using the CT scans. The high resolution CT data were read into Mimics 14.0 ((Materialise Inc., Leuven, Belgium) visualization software, where the images were segmented by thresholding to obtain 3D model (Figure 3).



a) b)

Figure 3. The process for the 3D FE model: a) CT scan and 3D reconstruction of the CT scans, and b) meshing of the 3D FE model

The whole FE torso model was divided into two parts, including thoracic and abdominal soft tissues and thoracic cage (Figure 4). In this paper, the aim was to examine the values of the load on the chest, and the pressure forces, so we did not take into account the human internal organs.

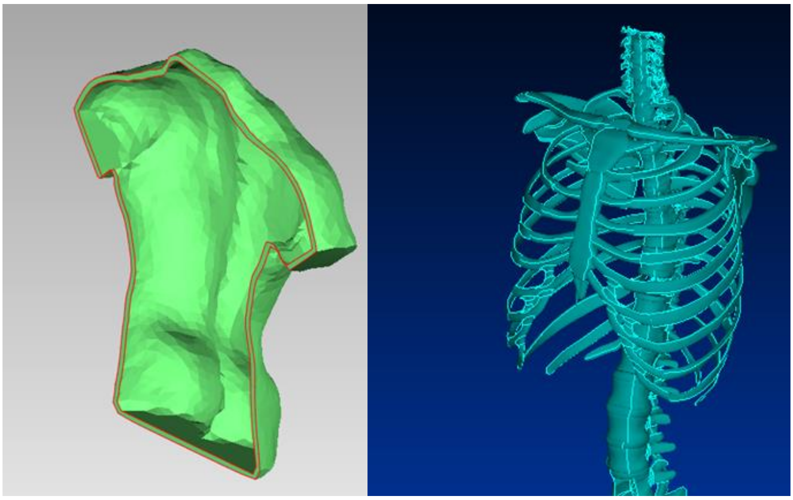


Figure 4. Finite element model of the human torso with tissue and thoracic cage

The material properties assignment is detailed in Table 1.

Table 1. Material properties of used materials

Parts	Material type	Parameters	Reference
Rib (cortical)	Elastic	ρ = 2.0 g/cm^3, E = 11.5 GPa, μ = 0.3	[6]
Rib (trabecular)	Elastic	ρ = 1.0 g/cm^3, E = 0.04 GPa, μ = 0.45	[6]
Tissue	Elastic	ρ = 1100 kg/mm^3, E = 10 MPa, μ = 0.3	[7]

In this paper the model of an adult man weighing 85 kg, height 180 cm was used. Three cases of speed of car movement and sudden shock of an irreversible obstacle were analysed. The speed of the car was 40, 50 and 60 km/h. Also, the driver used the seat belt. According to [9], the following force values applied to the driver were used: 24.7 kN, 38.5 kN and 55.5 kN, for 40, 50 and 60 km/h, respectively.

One of the basic principles of continuum mechanics is the principle of virtual work. Starting from the equilibrium equations [8] by applying the boundary conditions can be equal to the virtual work of internal and external forces:

$$\delta W_{\text{int}} = \delta W_{ext} \tag{1}$$

Virtual work of the previous equation in matrix form can be written as:

$$\delta W_{\text{int}} = \int_V \delta \mathbf{e}^T \boldsymbol{\sigma} dV \qquad \delta W_{ext} = \int_V \delta \mathbf{u}^T \mathbf{F}^V dV + \int_{S^\sigma} \delta \mathbf{u}^T \mathbf{F}^S dV + \sum_i \delta \mathbf{u}^T \mathbf{F}^{(i)} \tag{2}$$

Applying the principle of virtual work and the constitutive relations for linear elastic material in matrix form

$$\boldsymbol{\sigma} = \mathbf{Ce} \tag{3}$$

and by applying the concept isoparametric interpolation [9] in the finite element, on the basis of which the coordinates and displacements at any point within the element is

$$\mathbf{x} = \mathbf{NX} \qquad \mathbf{u} = \mathbf{NU} \tag{4}$$

we can write the equation of equilibrium finite elements:

$$\mathbf{KU} = \mathbf{F}_{ext} \tag{5}$$

where **K** is element stiffness matrix, **B** - strain relation matrix - displacements at the nodes, which contains excerpts interpolation function, **C** - elastic constitutive matrix, **e** = BU - matrix deformation, **U** - displacements at the nodes, **X** - coordinates of nodes, **N** - matrix of interpolation functions, $\mathbf{F}_{ext}$ - external forces in the element nodes.

In the linear analysis of solids a basic assumption is that the moving solids are infinitesimally small and that the material is linearly elastic. Also, the assumption is that the nature of the boundary conditions remains unchanged under the action of external loads. Under these assumptions, the equations of equilibrium are derived for finite element structural analysis. Equation (5) is related to the linear analysis of solids because the moving U is linear function of external forces $\mathbf{F}_{ext}$. In the case when displacement is not linearly dependent of the load, nonlinear analysis is applied.

In the linear analysis, the assumption that the displacement must be small is applied in calculating the stiffness matrix and force vector because all the volume integrals are applied to the original volume of the finite elements. Also, the matrix **B**, which relates strain and nodal displacement is constant for each element and is independent of the displacement element nodes. For a linear elastic material is assumed that the constitutive matrix is constant. Fixed boundary conditions are also the default in the linear analysis.

3. RESULTS

Numerical simulation was performed using the Ansys software package 14.5. Three cases of speed of car movement and sudden shock were analyzed. The speed of the vehicle was 40, 50 and 60 km/h. Following force values applied to the driver were used: 24.7 kN, 38.5 kN and 55.5 kN, for 40, 50 and 60 km/h, respectively. Figure 5 represent the results of the first simulation.

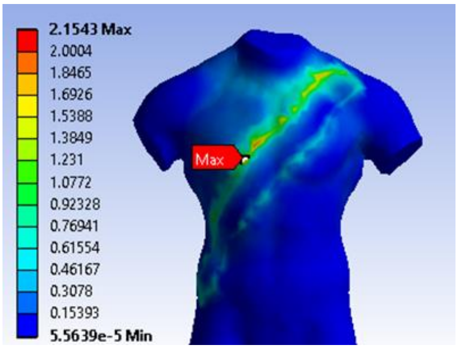


Figure 5. The numerical result of the von Misses stress when a force of 24.7 kN was applied on the chest part

The result of this simulation shows that the highest stress occurs on the chest part, due to the influence of the belt, where the maximum value was 2.15 MPa. Figure 4 and 5 shows the stress distribution for the remaining cases.

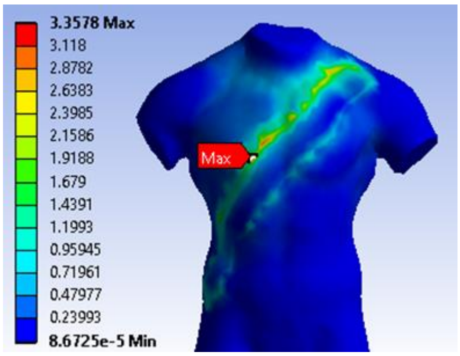


Figure 6. The numerical result of the von Misses stress when a force of 38.5 kN was applied on the chest part

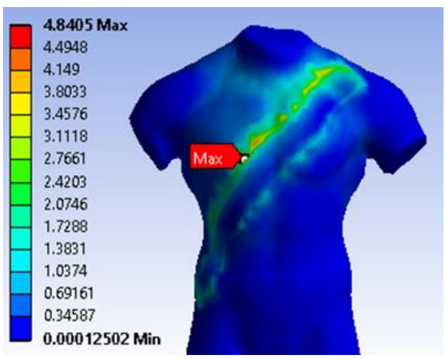


Figure 7. The numerical result of the von Misses stress when a force of 55.5 kN was applied on the chest part

From the previous figures, Figure 6 and Figure 7, it can be concluded that the maximum value of the stress is always in the chest. The highest stress values of the last two measurements are 3.35 and 4.84 MPa, respectively. It can be concluded that the dependence of force and stress is rather linear (Figure 8).

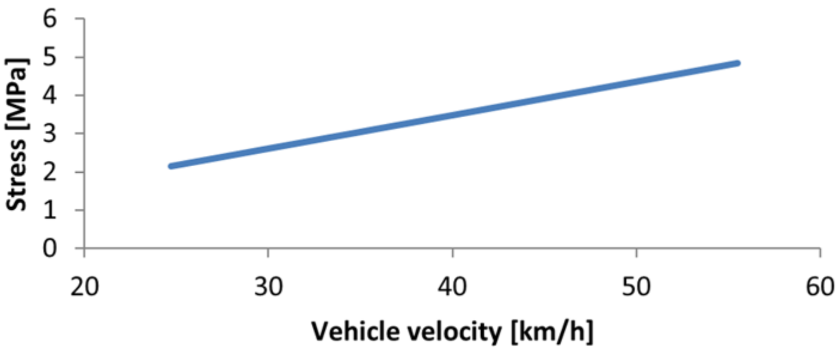


Figure 8. A diagram of the dependence of force and stress generated on the body of the model

4. CONCLUSIONS

Previous section shows the research results of the numerical simulation driver interactions and seat belts during a sudden impact on a fixed obstacle. Numerical simulations were done using Ansys 14.5 was used. Finite element model of the human torso with tissue and thoracic cage was used. Three cases of speed of car movement and sudden braking of an irreversible obstacle were analysed. The speed of the car was 40, 50 and 60 km/h. Also, the driver used the seat belt. The following force values applied to the driver were used: 24.7 kN, 38.5 kN and 55.5 kN, for 40, 50 and 60 km/h, respectively. The results of this study show where the greatest pressure on the human body was during sudden braking. The largest load zone is the upper part of the chest, where the values of the von Misses stress reach the highest values of 4.84 MPa, for the speed of a car of 60 km/h.

The direction of future research will be to investigate how internal organs suffer from sudden pressure, as well as the way the shifts affect them.

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