# THE IDENTIFICATION OF DAMPING AND STIFFNESS PARAMETERS OF A DRIVER MODEL ON THE BASIS OF CRASH TESTS

**Marek Jaskiewicz, Tomasz Stanczyk**

*Kielce University of Technology, Faculty of Mechatronics and Machine Building*
*Aleja Tysiaclecia Panstwa Polskiego 7, 25-314 Kielce, Poland*
*tel.:+48 413424285, 413424336, fax: +48 413448698,*
*e-mail: m.jaskiewicz@tu.kielce.pl; stanczyk@tu.kielce.pl*

***Abstract***

*The following paper presents the identification of damping and stiffness parameters of a man model on the basis of crash tests conducted in PIMot. The frame analysis of the film with a registered crash test was conducted. On the basis of this analysis there were prepared the characteristics of horizontal and vertical displacements in time function and a movement trajectory for each part of the dummy. Theses characteristics were used in an identification procedure. The values of identified parameters were stipulated in the work. The correctness of obtained results has been illustrated by the comparison of results of tests and a computer simulation conducted with the use of a dynamic man model and identified parameters' values. Obtained results were used to conduct simulations which show the influence of an age weakened muscle structure of a man (manifested with the decrease of the values of damping and stiffness parameters) onto the man movement during a crash. Additionally it has been illustrated the conformity of obtained test results through the presentation of frames of the film from the test with a model outline from computer simulation. Conducted simulations demonstrate that more serious injuries during car crashes with elderly people may be caused not only by a age decreasing man body strength.*

***Keywords:*** *passive safety, crashes, parameter identification, protection, head injuries*

## 1. Introduction

The increasing number of road accidents, where approx. 50% [4,10] comprise head-on collisions, persuaded car manufacturers to design equipment, which better and better protects drivers and passengers [6]. New concepts are being [3,5] worked out to increase safety levels of people in cars. A widely seen development of air bags and safety belts in recent years, has led to a significant decrease of upper and lower limb, trunk and head injuries [9], while in this context, one may observe a relative increase of upper spine and skull base injuries. One of the solutions to decrease the level of these body parts' injuries is to promote a correct adjustment of headrests and the concept of active headrests. The results presented in the following paper are a part of the bigger work [1], which aimed at the assessment of protective effectiveness of active headrests [2]. In order to do that, it was essential to work out a dynamic man model, in a sitting position, protected with seat belts and the identification of this model's parameters. A drawn-up model and identified parameters were used to build a computer simulation program of man body behaviour during a car crash.

## 2. Experimental tests

A crash test of a Hybrid II dummy was conducted at the Automotive Industry Institute. It has been recorded with a camera of 2500 frames per second. The film was made available to the authors of the following study. The film was processed in such a way that after a post-frame analysis of the whole test, 100 frames were selected which allowed for precise characterisation of all dummy movement phases. The measuring analysis of film frames enabled to work out X(t) and

Y(t) displacement characteristics and the movement trajectory for each part of the dummy, which corresponds particular model solid. A detailed description of the methodology of characteristics has been stipulated in paper [1].

### 3. The identification of damping and stiffness parameters of a model

The built dynamic driver model for car crashes is a discrete model with 13 degrees of freedom. It is a man-driver model, seated in a car seat and fastened in seat belts. Particular solids of a model correspond 11 isolated body parts of a man: head, neck, upper, middle and lower trunk, arm, forearm, hands, thighs, shins and feet. Assumptions formulated in detail, a model structure and movement equations have been presented in papers [1] and [7].

A full model description requires the knowledge of three parameter groups:

- geometric parameters (dimensions of particular body parts and mass centre coordinates),
- inertia parameters (mass and moment of inertia),
- characteristics of spring-damping elements (linear damping and stiffness coefficients).

The values of geometric parameters have been estimated on the basis of own anthropometric tests [8]. To estimate mass centre coordinates and inertia parameters, literature recommendations found their application here. These two groups of parameters are relatively easier to estimate.

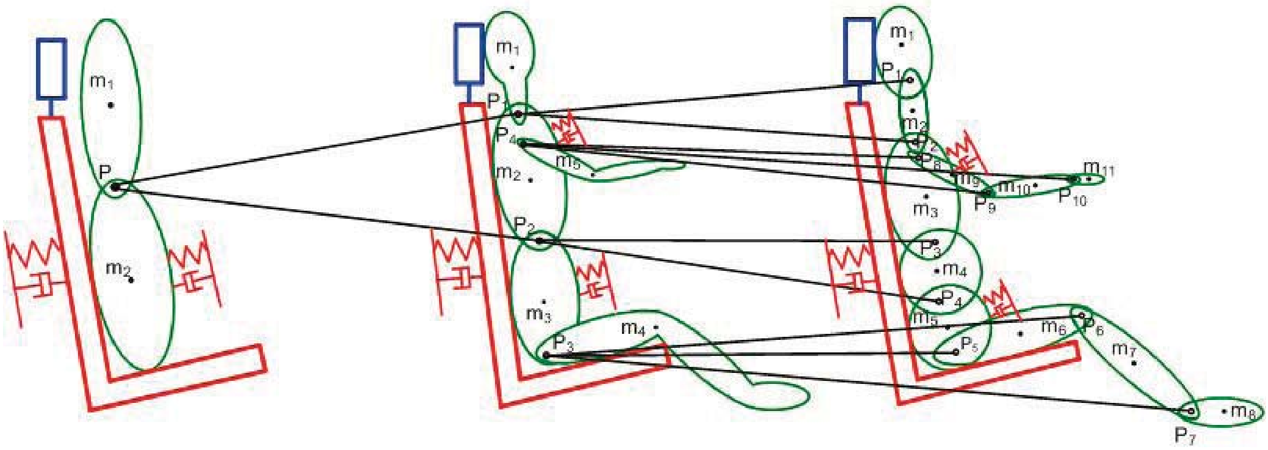


*Fig. 1. The illustration of parameter identification of damping and stiffness with the use of 3 models of different complexity levels: a) a model with 3 degrees of freedom, b) a model with 7 degrees of freedom, c) a model with 13 degrees of freedom*

The issue which is more difficult, however, is the identification of damping and stiffness parameters of a model. The model is characterised by 10 angular damping and stiffness coefficients of joints which are between model solids and four damping and stiffness coefficients, which characterise linear translation: shoulder and hip parts of a seat belt, seat rest and air bag. Simultaneous identification of 28 parameters is a difficult issue and it may lead to incorrect (from the point of view of mechanical interpretation) results. That is why, a special procedure of parameter identification has been prepared. The identification has been conducted in three phases, with the use in case of first two, previously prepared models with 3 and 7 degrees of freedom, and finally in case of the third one, a final model with 13 degrees of freedom. The idea of conducting the identification has been illustrated in Fig. 1. A detailed description of the procedure is present in paper [1].

A formal result of the conducted identification, in the form of obtained values of damping and stiffness coefficients, has been presented in Table 1.

*Tab. 1. The chart of identified values of damping and stiffness coefficients of a driver model*

| Joint (spring-damping element) | | Parameter k [Nm/rad] [N/m]* | Parameter c [Nms/rad] [Ns/m]* |
|---|---|---|---|
| head-neck | P1 | 18.00 | 9.50 |
| Neck – upper trunk part | P2 | 19.50 | 11.00 |
| Upper trunk part – middle trunk part | P3 | 47.50 | 30.00 |
| Middle trunk part – lower trunk part | P4 | 32.50 | 21.00 |
| Lower trunk part - thigh | P5 | 32.00 | 21.50 |
| Thigh - shin | P6 | 27.50 | 17.00 |
| Shin - foot | P7 | 19.00 | 10.50 |
| Upper trunk part - arm | P8 | 24.50 | 11.50 |
| Arm - forearm | P9 | 16.50 | 7.50 |
| Forearm - hand | P10 | 11.50 | 6.50 |
| Shoulder belt (upper) | pas1 | 29000* | 1100* |
| Hip belt (lower) | pas2 | 36000* | 1800* |
| Car seat rest | op | 80000* | 4200* |
| Air bag | pod | 40000* | 3100* |

For the purposes of testing practice, the fact of obtaining an identification result is not as important as its quality. A main measure of the quality is the conformity of computer simulations conducted with the use of identified parameter values with the test results. The comparison of computer simulation with tests for particular model solids will be shown on the following graphs – Figures 2 to 7. It is worth remembering that this conformity is not only dependent on identification results but also on adequacy of a prepared model. In such a case, the assessment has to include these two actions. Fig. 2 present graphs on horizontal and vertical head and neck displacement in time function, whereas Fig. 3 – the trajectories of body parts' movement.

On (x) displacement graphs, one may see: following positive displacements, a phase of negative displacements of head and neck, and consecutive phases of minor positive and negative displacements. On the trajectory graphs, it may be visible by the existence of consecutive minor and minor forward and backward deviation loops. It is the result of the fact that in a crash test (see Fig. 8), a car seat was not equipped with a head rest. Such a situation is quite different from a typical car situation, however from the identification point of view is more favourable as it enables to realize a wider movement range, which causes more precise identification.

Displacement routes in time shown in Fig. 2 and 3 and the trajectories permit to assess highly the conformity of routes obtained in computer simulation and the test. The maximum displacement forward in x direction (big loop), obtained in simulation is, by 3.9% for a head and 1.8% for a neck, smaller than in the test, while the maximum displacement in y direction (big loop) is by 5.3% for a head and 6.1% for a neck bigger than in the test.

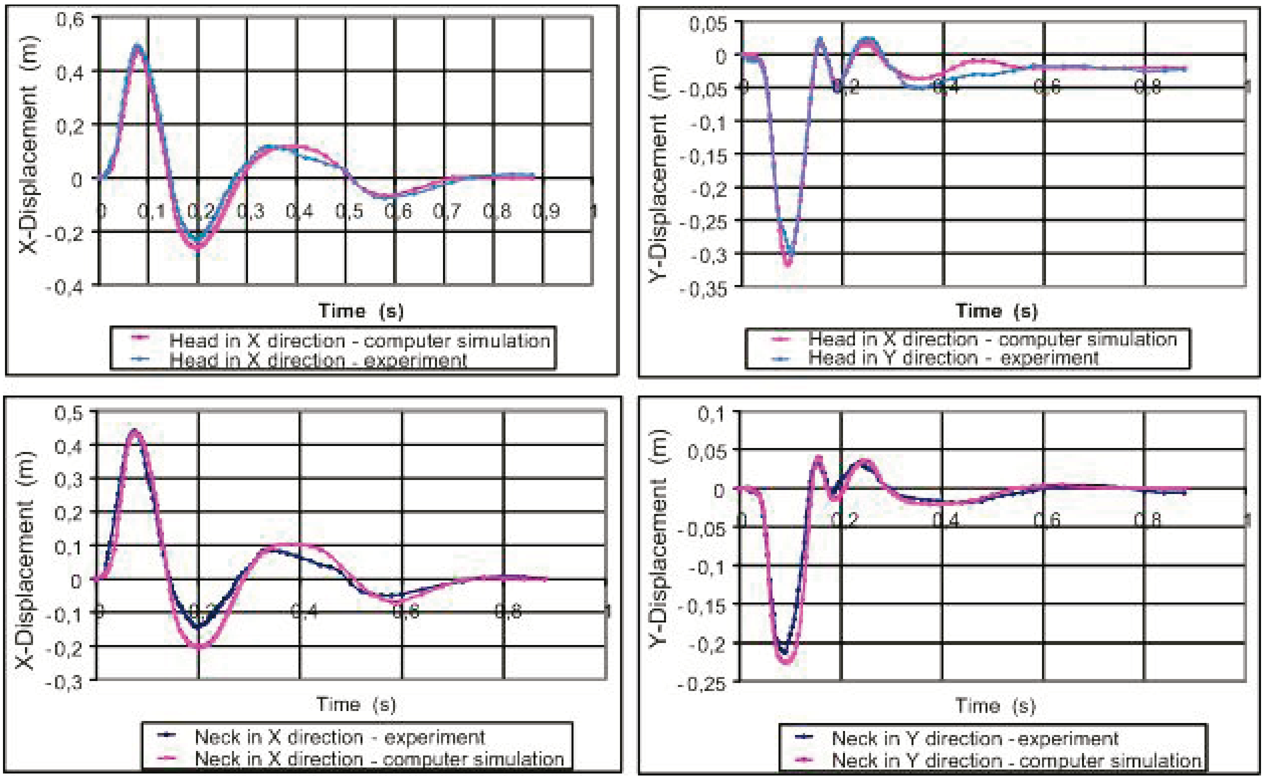



*Fig. 2. The comparison of test results and the computer simulation of horizontal head and neck displacements*

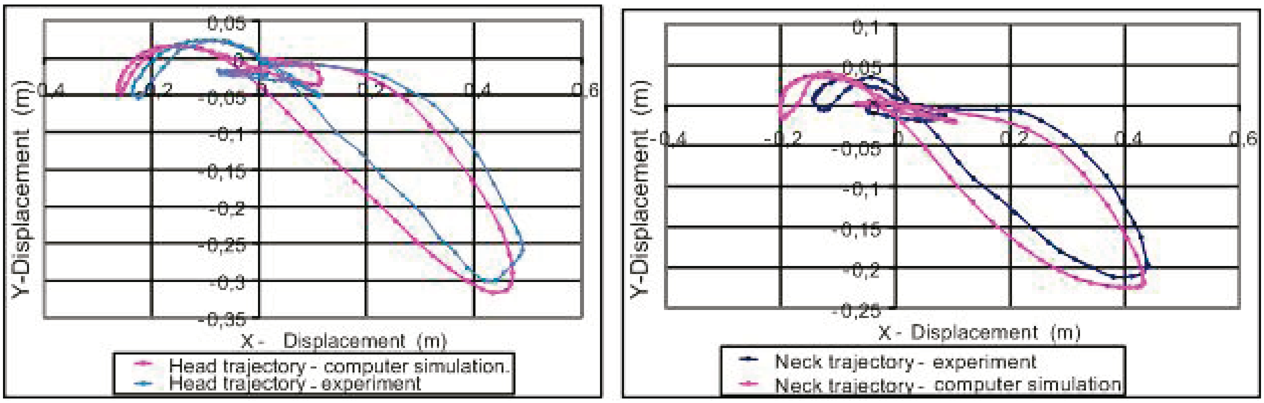



*Fig. 3. The comparison of head and neck trajectories obtained in tests and computer simulation*

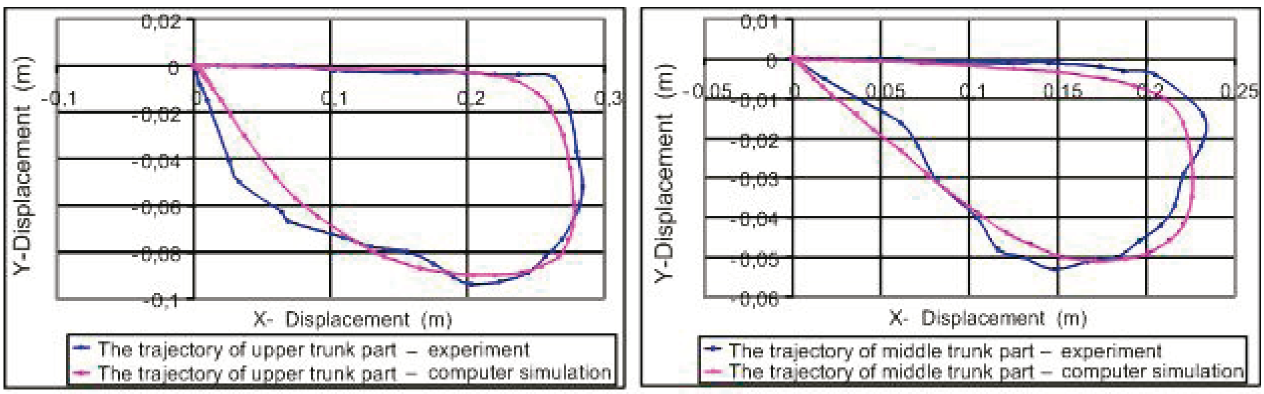



*Fig. 4. The comparison of the movement trajectories of upper and middle trunk parts obtained in tests and computer simulation*

From the point of view of the usefulness to simulation assessment of the head rest protective functioning, the most important issue is the conformity of head and neck displacements. However, on account of the possibility to use a drawn-up model for other applications, it is essential to obtain a good level of conformity for other body parts. Further comparisons will be illustrated solely on the trajectory examples. Full set of graphs of horizontal and vertical displacements in time function has been presented in paper [1]. Fig. 4 shows upper and middle trunk trajectories.

Since in the test as well as in the simulation, a lower trunk part performed only horizontal displacement, in relation to that part of the body, instead of a trajectory, the route of this displacement in time function was shown in Fig. 5.

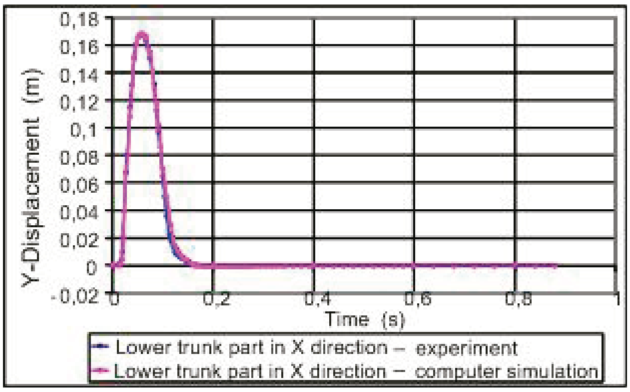



*Fig. 5. The comparison of lower trunk part displacement obtained in tests and computer simulation*

The graphs illustrated in Fig. 4 and 5 show that also in case of displacements of particular part of the trunk, the computer simulation demonstrates high conformity level with the test. In the computer simulation, slightly smaller values are obtained for x as well as y directions. The maximum forward displacement in x direction is by 2.1% for an upper trunk part and by 2.6% for a middle part smaller than in the test, where in y direction by 4.3% for an upper trunk part and by 3.8% for a middle trunk part smaller than in the test. In case of a lower trunk part, the maximum displacement in x direction is by 0.02% smaller than in the test.

Fig. 6 and 7 show limb movement trajectories. At the same time, in case of legs, illustrations were limited to show only thigh and shin trajectories, where in case of hands, it was limited to the presentation of arm and forearm movements.

So as in case of legs' movement, the maximum displacements obtained in the simulation are slightly smaller than in the test. For a thigh, the differences of maximum displacements amount respectively to: in x direction – 4.06% and in y direction – 0.01%, whereas for a shin: x – 4.1%, y – 3.5%.

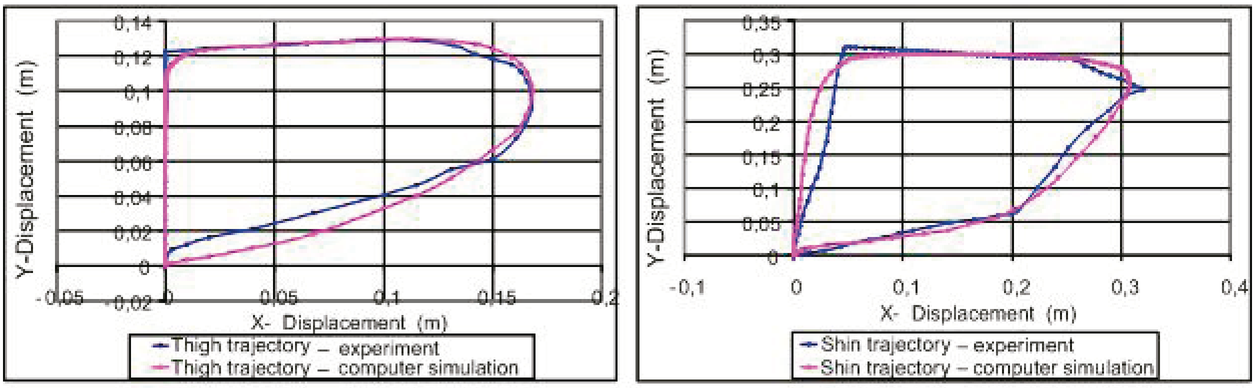



*Fig. 6. The comparison of thigh and shin trajectories obtained in tests and computer simulation*

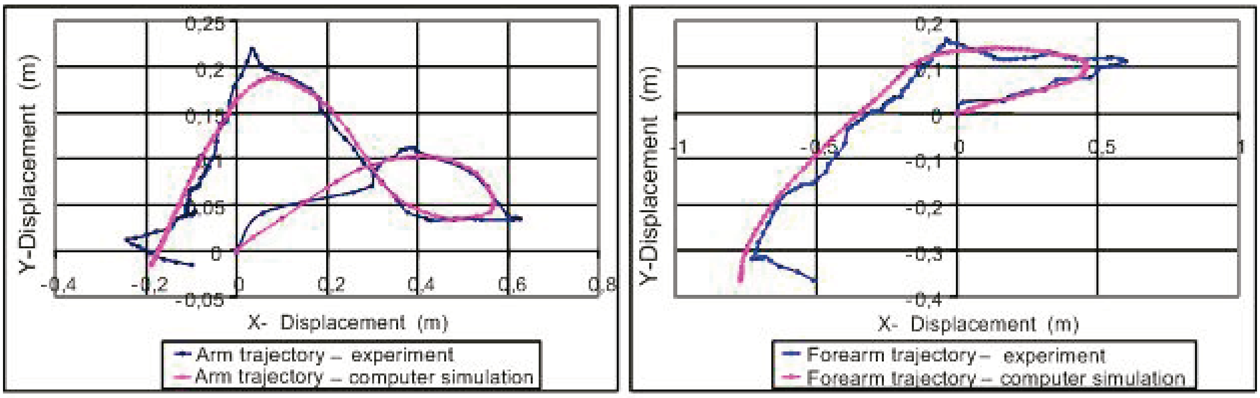
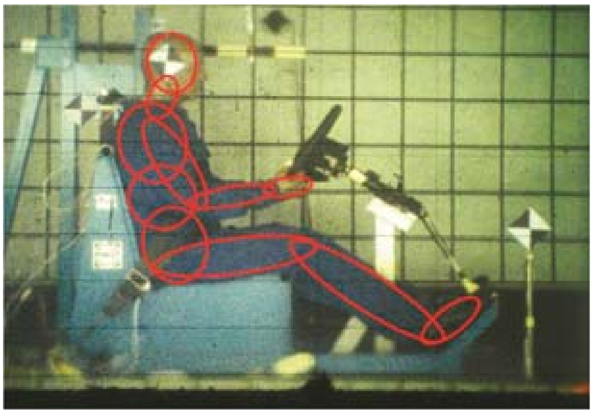



*Fig. 7. The comparison of arm and forearm movement trajectory obtained in tests and computer simulation*

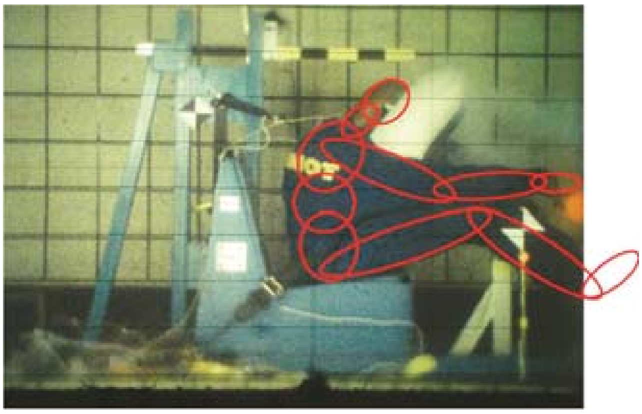
The biggest amount differences are present in case of a hand simulation. Relatively high values of a relative mistake of displacements occur only locally. Where, at the same time, a general movement character demonstrates a good similarity. The maximum forward displacement in x direction is by 9.4% for an arm and 23.9% for a forearm smaller than in the test, and the maximum displacement in y direction relatively smaller by: 14.3% for an arm and 10.6% for a forearm.

Additionally, to illustrate the conformity of obtained results with the test, Fig. 8 presents frames of the film from the test in selected movement phases with a model outline in the same time moments. A particular location of the model was achieved in a computer simulation for identified parameter values.

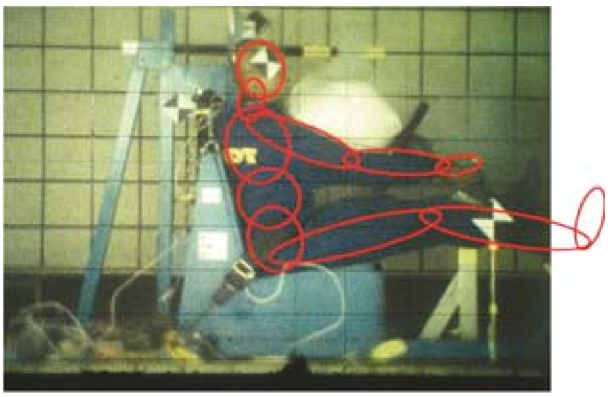
Taking into consideration model complexity (13 degrees of freedom) and the number of parameters describing the model – overall 88 parameters, it is needed to state that the conformity of computer simulation and test results is high.



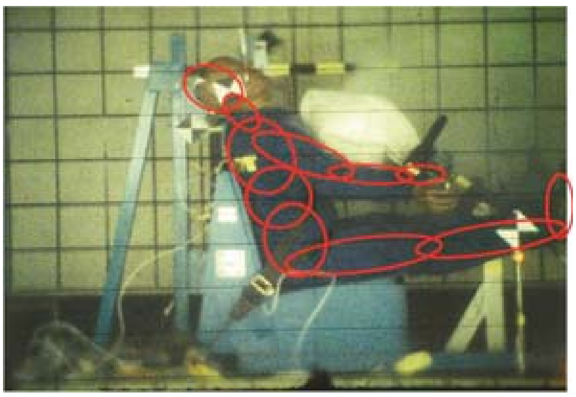
*a) initial movement phase: t = 0 s.*



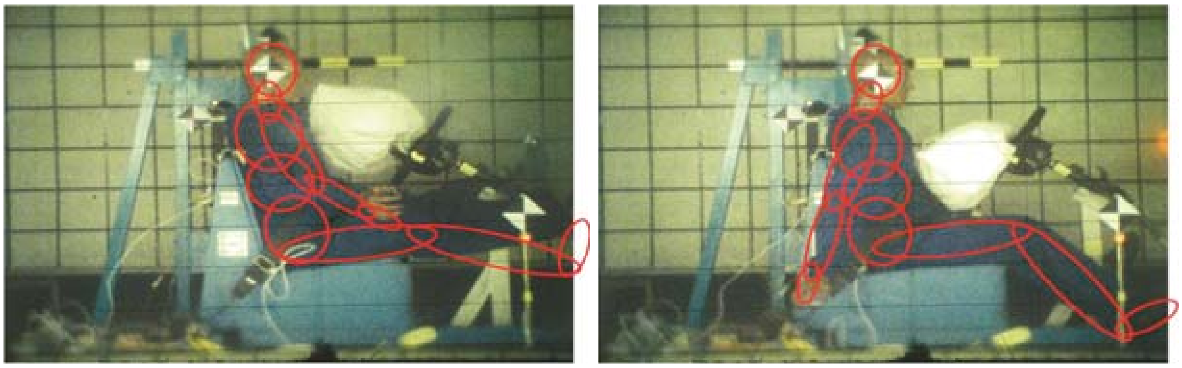
*b) maximum displacement to the front: t=0,08 s*



*c) return movement – trunk in output position: t = 0,148 s*



*d) maximum displacement to the back: t = 0,196 s*



*e) repeat return of trunk to output position: t = 0.276 s* *f) final movement phase: t = 0.88 s*

*Fig. 8. The comparison of tests and computer simulation*

## 4. The simulation of human body movement with a weakened muscle structure

During safety tests, a typical approach have been tests for a 50 centile man with extreme estimations – the tests for a 95 centile man and 5 centile woman. In this way an adjustment of safety elements to people of particular height and weight is checked. However, it is similarly important to check another factor. Experts dealing with car accident analysis know a lot of cases, in which in the same road conditions, a young person survived or suffered minor injuries, whereas such loads occurred fatal for an elderly person. It has been due to the fact that along with age the muscles, which keep the person's position and protect internal organs, become weaker.

The weakness of a man muscle structure causes that man body displacements in the same conditions are bigger. Thus, not only decreased strength but also greater displacements (for instance greater bends of neck spine) will cause more dangerous injuries in case of older people.

Therefore, the authors of the following paper recognize as particularly important to try to assess a body behaviour during a crash according to an age. Even if the behaviour assessment was approximate, then with a careful and well-thought-out selection of model parameters, the obtained results may have high research and practical value. The identification of geometric and inertia parameters has been conducted on the basis of own anthropometric measurements for different age groups [3]. A more difficult task though, was to assess damping and stiffness parameters. There are numerous publications from the scope of forensic medicine dealing with lower resistance of the elderly people to injuries. However, in this case the description language is different. It is impossible to find the mechanical parameters of a man body such as damping and stiffness coefficients.

Being directed by various literature information, some pre-arranged values that characterise the weakness of a muscle structure were applied to illustrate the issue. Four age groups were distinguished: the first – to 30 years of age; the second one: 30-40 years of age; the third: 40-50 years of age and the fourth one – above 50 years of age. As the base, there were adopted identified values of damping and stiffness coefficients illustrated in table 1. It has been recognized that these values characterise the first age group (to 30 years of age). In relation to the remaining age groups, it has been assumed that in the following age groups damping and stiffness parameters decrease by 15 per cent, i.e. to 85 per cent for the second group (30-40), 70 per cent for the third group and 55 per cent for the fourth group – above 50 years of age. Acting this way, we were able to come closer to real physical properties of elderly people. These estimations need to be treated with care, as some publications indicate, such a weakness may even be greater.

The results of a body movement simulation during a crash, conducted with the above-mentioned assumptions, have been presented in Fig. 9-12. In these figures have been shown movement trajectories of particular male parts of the body during a head-on collision for individual age groups.

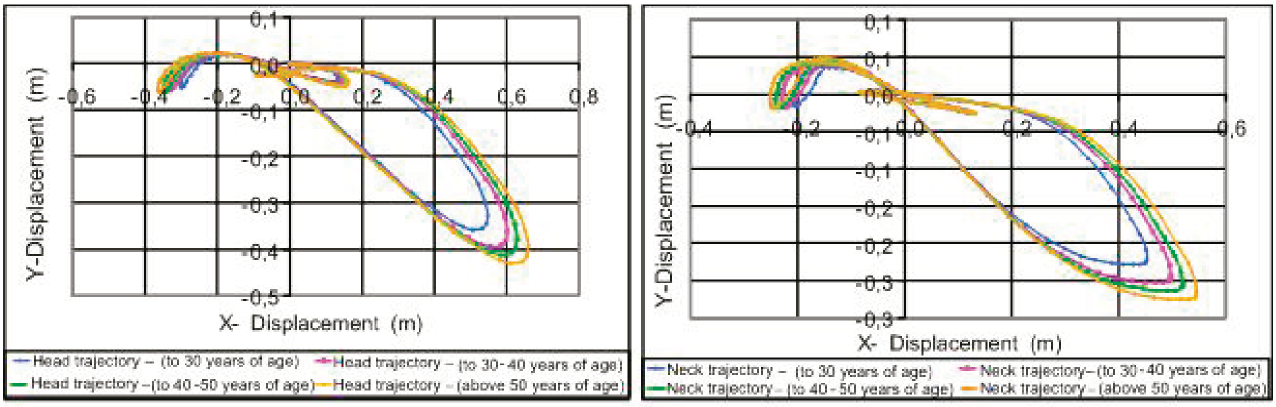



*Fig. 9. The movement trajectory of male heads and necks in four age groups*

Presented results show that the biggest differences of displacement values occur in case of a head and a neck. This means a very strong bend of neck spine. The differences of maximum horizontal displacements to the front between the first and fourth age group amount to approx. 19.2% for a head as well as a neck. In case of vertical displacements, maximum differences between the first and fourth age group amount to 18.6% for a head and neck.

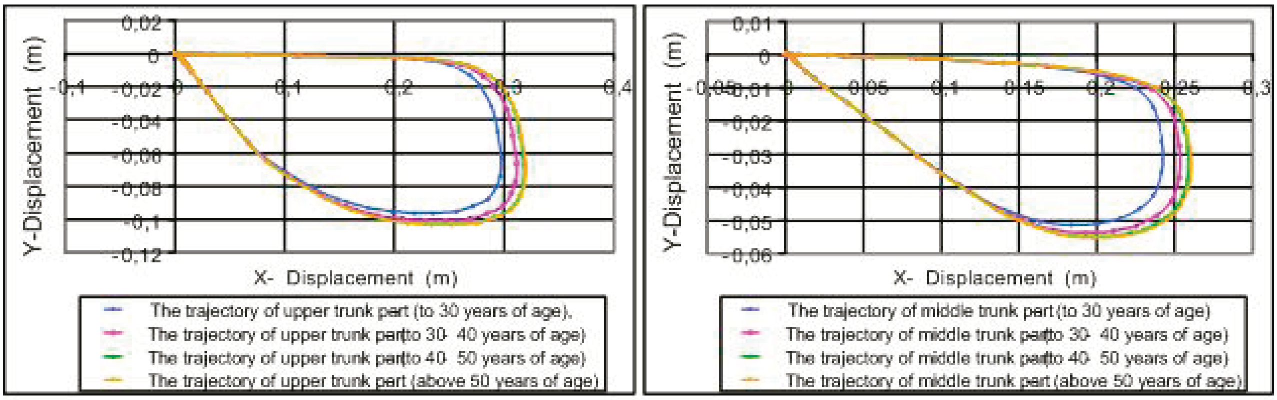



*Fig. 10. The movement trajectory of male upper and middle trunk parts in four age groups*

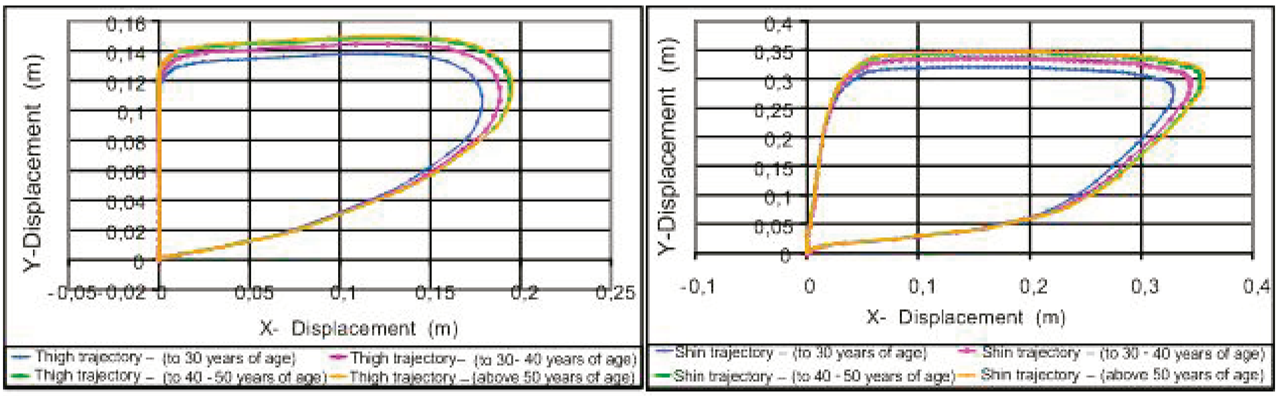



*Fig. 11. Male thigh and shin movement trajectories in four age groups*

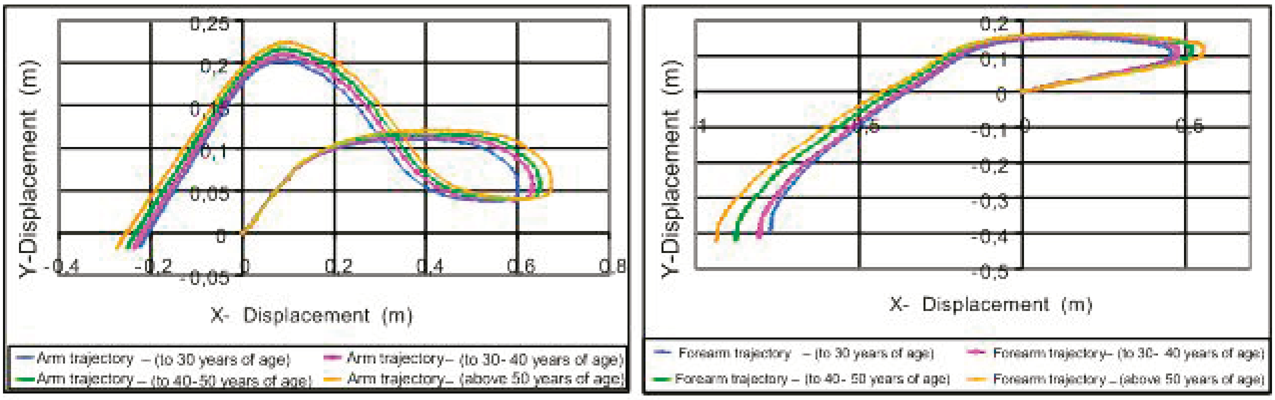



*Fig. 12. The movement trajectory of male arms and forearms in four age groups*

With absolute values this means the difference in head displacement to the front (big loop) in x direction by 12 cm and in y direction by 8cm, whereas movement to the back (small loop): in x direction by 7 cm and y direction by 1cm. As it is known that along with age, a neck spine movement range also decreases, greater displacements may mean its injury. Taking into consideration forwarded results, this should be perceived as a considerable threat.

The differences of trunk displacements between extreme age groups (Fig. 9) are smaller and amount, for upper and middle trunk part (for displacements in both x and y directions), approx. 7.2%. Furthermore, hand and leg displacement differences shown in Fig. 10 and 11 for extreme age groups are smaller than the diversification of head and neck displacements.

## 5. Summary

The following paper presents the identification of damping and stiffness parameters of a man-driver model, seated in a car seat and fastened in seat belts. Identification has been facilitated by a film documentation from PIMot (the Automotive Industry Institute) of a crash test, filmed by a high-speed camera. On the basis of 100 selected film frames, time routes of displacements have been determined for particular body parts in x and y directions. These routes were used in the identification procedure.

The correctness of obtained results has been illustrated through the comparison of tests and computer simulations, conducted with the use of a dynamic man model and identified parameter values. Obtained results were used to conduct simulations which illustrate the influence of the age weakened man muscle structure (manifested by the decrease of damping and stiffness coefficient values) on a body movement during a collision.

Conducted simulations demonstrate that more serious injuries during car crashes with elderly people may be caused not only by a age decreasing man body strength. Bigger displacements, caused by the weakness of a muscle structure, (in particular heads and necks) may contribute greatly to the occurrence of serious injuries in this group of drivers and passengers.

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