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

Numerical analysis of the human body motion and under explosion

Piotr W. Sielicki[1], **Tomasz Gajewski**[1]

[1]Institute of Structural Engineering, Poznan University of Technology
email: piotr.sielicki@put.poznan.pl, tomasz.gajewski@put.poznan.pl

ABSTRACT: This paper presents the numerical results of analysis of the behavior of the human body under blast wave loading. This loading was generated by a condensed charge mass of 0.8 kg of explosive. The detonation point was located 1 meter from the dummy obstacle. The mass of TNT charge was cubic and initiated centrally. The blast wave propagation was generated using the coupled numerical design, including Eulerian and Lagrangian descriptions for both domains, i.e. air and the charge. The main goal of this work is to present the actual behavior of the human body motion and blast wave pressures for organs caused by the rapid pressure wave. In addition, the civilian safety criteria presented in official standards were fixed according to the results.

KEYWORDS: explosion, human safety, body motion,

1. Introduction

Blasts, also known as explosive waves, have harmful effects on health when they act directly upon the human body. Victims of blast injury suffer from multiple effects spread over the body region. One of the major lethal causes is elevated air-pressure on particular organs, such as eardrums, lungs and the brain.

Since explosive materials were invented many centuries ago, humans have experienced explosive effects caused by military or civilian attacks, either accidentally triggered in industrial processes or daily life. In military conflicts, due to their efficiency, armies have adapted explosive materials as a common medium and long-range weapon (from hand grenades to range missiles). For this same reason, for many decades and all over the world bomb attacks have been the main weapon for terrorists. On the other hand, history is full of examples of industrial explosions caused by accident, negligence, incompetence or deliberate action. World literature, for instance [3,9], depending on blast injury cause, classifies the following groups of injuries: primary, secondary, tertiary and quaternary.

2. Numerical Modeling

Creation of a complete and fully detailed mathematical description of the human body with medical state-of-art knowledge will be impossible for many years to come. Some difficulties include individual variability, complex and constantly remodeling materials and lack of robust nondestructive testing methods of biological tissues. However, for many engineering purposes, it is possible to build numerical models of the human body, which with satisfactory accuracy, would represent the desired features of the human body.

For the purposes of the paper, the simplified numerical model of behavior of the human body was built to investigate the influence of blast waves on the kinematics of the human body. The main aim was to obtain a model capable of reproducing realistic kinematics of the body subjected to air pressure waves and the pressure of surrounding air volume. Therefore, a human model with limbs and head was recreated as a system of fourteen connected components (head, trunk, arms, forearms, hands, thighs, lower legs and feet). Each part in finite element code was modeled as a rigid body. The limbs and head were linked to the trunk by joints with implemented nonlinear mechanical behavior and were limited according to the body physics. Body characteristics, both geometrical (e.g. dimensions, diameters, volume) and physical (mass, density), were crucial to obtain correct body motion.

The model mimicked a medium-sized male with height equal to 1.79 m (an average men height in Poland [5]) and mass of 84.8 kg. The finite element triangular mesh was constructed based on the geometry of the Hybrid III dummy. For many years, use of Hybrid III in the testing of human safety in car accidents was the golden standard in the automobile industry. Therefore, physical characteristics of a human, such as mass and moments of inertia, were taken from [4], where a Hybrid III model was tested. The nonlinear constitutive joint behavior of the human body model was proposed on the basis of the paper [4], where Hybrid III experimental curves of joints were presented.

Joint constitutive characteristics should be deter-mined carefully, as their validity provides proper human body motion. Hence, the joint behavior model was developed to simplify measured data of motion in a particular anatomical joint. The measurements of angle of rotation versus the moment of resistance to motion can be described by the mathematical formulation with unknown embedded parameters. The model proposed in the paper is expressed by the formula:

$$f(x) = \begin{cases} -\infty & x \le \alpha_{min} \\ a\dfrac{(x-d)^7}{10^9 b} + c & x \in (\alpha_{min};\alpha_{max}) \\ \infty & x \ge \alpha_{max} \end{cases} \quad (1)$$

where f and x are the moment of resistance to motion and rotation angle, respectively. Parameters a, b, c and d are calibrated from angle-moment relation for a particular joint in the sagittal, frontal or transverse plane of the human body. The parameters create non-linear relation, a and b scales function, c moves it up and down, and d moves it left and right. αmin and αmax are boundaries of rotation angles. According to the model, when rotation in joint x reaches αmin and αmax values, the moment of resistance to motion rapidly rises to minus infinity or infinity, respectively, and further rotation in the joint is impossible.

The behavior of the joints of separate dummy components based on the properties are presented in [1,4]. It should be noted that a position with 0 angles in particular joints describes an example of a straight standing position (according to [1]). Here, rest standing position is analyzed; therefore, some initial limb positions are not equal to 0. Complex joints are modeled as the superposition of two or three motilities in particular planes. For instance, shoulder joints allow rotation of the upper arm against the trunk in sagittal, transverse and frontal plane.

Further examples are presented in Figure 1 in an example of the movement range in a shoulder joint for the sagittal plane.

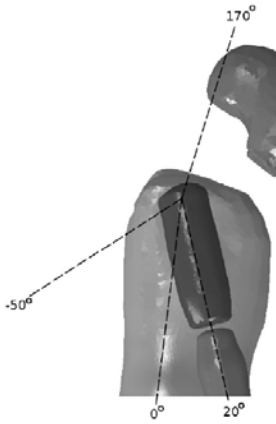

Figure 1. Motion range in the sagittal plain for a shoulder joint (side view). The reference, a straight standing human position, equals 0°, minimal angle equals -50° and maximal angle equals +170°, in rest standing position the position angle is +20°

3. Results and Conclusions

The experiment presented in the paper analyzes overpressure curves for the most vulnerable organs in the primary injuries group, i.e. eardrums and lungs. The curves are demonstrated in Figure 2, where overpressures for eardrums (green line) and lungs (red line) are plotted.

The overpressures for eardrums were calculated in the perpendicular distance of 0.05 m from the head surface for both sides (left and right eardrums). However, since both eardrum curves perfectly overlay for the overpressures and slightly differ for the under pressures, only one curve is presented. The overpressure peak equals 530 kPa and is reached in 1.03 ms after detonation.

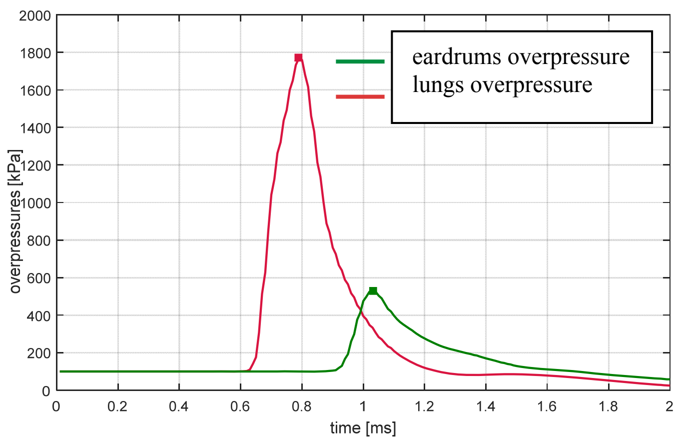

Figure 2. Air overpressure curves in time domain acting on ears (green) and lungs (red) of the dummy model for 0.8 kg of TNT charge.

The presented FE analysis presents a tool for assessing human body kinematics under explosion blast wave. Blast overpressures were presented for a human head and chest.

In future studies, the differentiation of mass of TNT charge will be checked, as well as the distance from the charge or human position (side or rear explosion). Further model extensions should be devoted to a development damage model of human joints, which could significantly expand the area of application.

References

[1] International standard orthopedic measurements. Technical report, the American Association of Orthopedic Surgeons.

[2] Goumtcha A.A., Thoral-Pierre K., and Roth S. Biomechanical model of the thorax under blast loading: A three dimensional numerical study. International Journal for Numerical Methods in Biomedical Engineering, 30(12):1667-1678, 2014.

[3] Yeh D.D. and Schecter W.P. Primary blast injuries - an updated concise review. World Journal of Surgery, 36(5):966-972, 2012.

[4] I. Kaleps, R. P. White, Jr., R. M. Beecher, J. Whitestone, and L. A. Obergefell. Measurement of Hybrid III dummy properties and analytical simulation data base development. Technical report, Harry G. Armstrong Aerospace Medical Research Laboratory, 1987.

[5] Z. Kulaga, M. Litwin, M. Tkaczyk, I. Palczewska, M. Zajaczkowska, D. Zwolinska, T. Krynicki, A. Wasilewska, A. Moczulska, A. Morawiec Knysak, K. Barwicka, A. Grajda, B. Gurzkowska, E. Napieralska, and H. Pan. Polish 2010 growth references for school-aged children and adoles-cents. European Journal of Pediatrics, 170(5):599-609, 2011.

[6] Dong L., Zhu F., Jin X., Suresh M., Jiang B., Sevagan G., Cai Y., Li G.,and Yang K.H. Blast effect on the lower ex-tremities and its mitigation: A computational study. Journal of the Mechanical Behavior of Biomedical Materials, 28:111-124, 2013.

[7] Esposito L., Clemente C., Bonora N., and Rossi T. Modelling human eye under blast loading. Computer Methods in Biomechanics and Biomedical Engineering, 18(2):107-115, 2015.

[8] Salimi Jazi M., Rezaei A., Azarmi F., Ziejewski M., and Karami G. Computational biomechanics of human brain with and without the inclusion of the body under different blast orientation. Computer Methods in Biomechanics and Biomedical Engineering, page 10, 2015.

[9] Zara R. Mathews and Alex Koyfman. Blast injuries. The Journal of Emergency Medicine, 49(4):573-587, 2015.

[10] Sielicki P.W. Masonry Failure under Unusual Impulse Loading. Publishing House of Poznan University of Technology, 2013.

[11] Sielicki P.W. and Stachowski M. Implementation of sapper-blast-module rapid prediction software for blast wave properties. Central European Journal of Energetic Materials, 12(3):473-486, 2015.

[12] Rigby S.E. and Sielicki P.W. An investigation of TNT equivalence of hemispherical PE4 charges. Engineering Transactions, 4(62):423-435, 2014.

[13] Tan X.G and Przekwas A.J. A computational model for articulated human body dynamics. International Journal of Human Factors Modelling and Simulation, 2(1), 2011.

[14] Tan X.G., Przekwas A.J., and Gupta R.K. A fast running model for skeletal impact biomechanics analysis. Proceedings of the ASME 2015 International Mechanical Engineering Congress Exposition, 2015.

[15] Mazurkiewicz L., Malachowski J., Baranowski P., and Damaziak K. Comparison of numerical testing methods in terms of impulse loading applied to structural elements. Journal of Theoretical and Applied Mechanics, 51(3):615-25, 2013