11TH INTERNATIONAL CONFERENCE
BIOMDLORE 2016
OCTOBER 20–22, 2016, DRUSKININKAI, LITHUANIA
BIOMDLORE.VGTU.LT

eISSN 2345-0630
ISBN 978-609-457-959-2
eISBN 978-609-457-958-5
DOI: 10.3846/biomdlore.2016.09

Numerical modelling of the forklift tip-over to test effectiveness of the safety components

Marcin Milanowicz[1], Paweł Budziszewski[2], Krzysztof Kędzior[3]
[1, 2, 3] Central Institute for Labour Protection – National Research Institute, Poland
E-mails: [1] *marmi@ciop.pl (corresponding author),* [2] *pabud@ciop.pl,* [3] *krked@ciop.pl*

(Received 22 March 2016; accepted 17 May 2016)

Abstract. Forklift overturning with its operator is the most common and dangerous type of an accident involving internal transport. The forklifts are equipped with safety components to avoid, or reduce the effects of forklift tip-over. However, there is very few information on the effectiveness of such systems. The aim of the research was to evaluate their effectiveness with the use of numerical simulation. The study relied on carrying out numerical simulations of forklift overturning with its operator. Active human body model was used in the research. Human body output parameters, e.g. forces and accelerations of the head and neck were used to estimate injuries sustained by an operator. The effectiveness of the safety components was assessed on the basis of estimated injuries.

Keywords: numerical simulation, injuries criteria, Madymo, accident analysis, multibody dynamics, numerical human body model.

Introduction

About 100 000 forklifts is registered in Poland. According to the data of the National Labour Inspectorate, Poland, every year there is an average of 90 accidents involving them. As a result of these accidents nearly 100 people are injured (out of which approx. 10–15 deaths) [1]. The most common and dangerous type of an accident involving internal transport is forklift overturning with its operator inside. This might be caused by turning a corner too fast, having an unbalanced load, driving onto a curb, or transport the load raised too high. New forklifts are equipped with an active or passive safety systems to avoid, or reduce the effects of forklift tip-over. Older forklifts (without safety systems) must be retrofitted with the safety components available on the market. However, there is very few information on the effectiveness of such systems. Studies on the safety components effectiveness, with the use of numerical modelling, were conducted in Central Institute for Labour Protection – National Research Institute (CIOP-PIB), Poland. The effectiveness was assessed on the basis of estimated injuries. The methodology and results of the research are described in the article.

Methods

The study relied on carrying out numerical simulations of the forklift overturning with its operator inside. Study was carried out with the use of the Madymo package [2]. A model of the accident site, consisting of the numerical models of: forklift; human body; ground and safety components, was developed (Fig. 1). The simulation was performed for several different configurations include three speeds: 0 km/h; 13.5 km/h and 23 km/h. The overturning forklift model was validated based on experimental results [3] for 0 km/h, [4] for 13.5 km/h and based on real-life accident reconstruction [5] for 23 km/h.

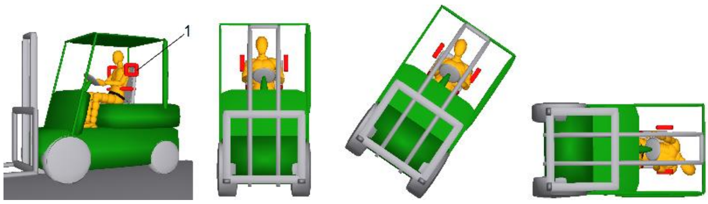

Fig. 1. Simulation model. 1 – example of safety component: seat wings model

For each test configuration forklift model was equipped with the following safety components: two-, three-, four-point seatbelts (2B, 3B, 4B), support structure to maintain the operator in the seat so-called seat wings (SW) (Fig. 1), seat armrest (SA) structure to prevent falling out of the forklift cab, in the form of additional door bar (D) and safety helmet for operator (H). Models of 2B, 3B, 4B were taken from Madymo database; models of SW, SA, D were developed as rigid bodies; H model was developed as multibody one and validated; described in [6]. Active human body model, based on Pedestrian model available in the Madymo database [7], was used in the research (model retains the position recommended by forklifts producers and responds to external forces acting on it by mapping the human reaction and behaviour). To activate human model a kinematic excitation is used. In the Madymo package, it is possible to pre-set motion (in this case – rotational motion in joints simulating human joints) in a kinematic joints by introducing a function defining the behaviour of the angle over time [8]. Model was developed and validated based on experimental results described in [4]. The effectiveness of the safety components was evaluated on the basis of the potential injuries of the head and neck sustained by a forklift operator (the more protection, the less severity of injuries).

Results

Results of the simulation, each time contain the following data: animation showing kinematics of an overturning forklift; injury criteria for head and neck. For head HIC 15 ms (Head Injury Criterion) was used and for neck shear/axial forces, measured in upper cervical spine, were used to evaluate potential injuries. Evaluated injuries of head and neck were transfer to Abbreviated Injury Scale (AIS) using tables from [9] (tables 13, 14 for head; 15, 22 for neck). Where for AIS: 1 – minor injuries; 2 – moderate injuries; 3 – serious injuries; 4 – severe injuries; 5 – critical injuries; 6 – maximum injuries; 9 – not further specified [10].

Fig. 2. The AIS results for different safety components and velocities

Results in AIS scale in order from most to less effective safety components are shown in Figure 2. Results are shown for each safety components configuration and for three forklift velocities. The last results labelled NO REST are for forklift without safety components.

Conclusions and discussion

As the results show, in most cases, the effectiveness of the safety components decreases with increasing velocity. A two-point seatbelt (2B, Fig. 2), uses as only safety component, does not fully protect the operator from life-threatening injuries. However, 2B significantly reduce the probability of serious injuries in connection with other safety components, e.g. SW+2B; H+2B. The most effective safety component are seat wings while lap seatbelt is fastened (SW+2B). In the case when the seatbelt is not fastened (SW) there is a high probability of hitting operator's head on the forklift ceiling. A very effective solution is to use four-point seatbelt (4B). However, this solution is impractical because the belt limits the movement of the operator during manoeuvring. Three-point belt is a solution as effective as four-point belt only if the forklift overturns the side on which shoulder belt attachment is fixed. Otherwise, the operator will not be maintained by a shoulder belt and there is a high probability of hitting his head on the ground (3B). Structures to prevent falling out of the forklift cab, in the form of additional door bar (D and D + 2B), effectively protect the operator from falling out when, e.g. cornering at high speed but only in cases when do not come to overturn. However, if it comes to overturn, there is a high probability of suffering severe life-threatening injuries.

Similar studies are conducted in different research centres all over the world. Usually these are experimental studies using ATD (anthropomorphic test device) crash test dummies, e.g. [4] using numerical simulation, e.g. [3]. The use of numerical simulation has many advantages, among others it enables testing of many different safety components and scenarios. Thereby, selection of optimal safety solution is possible. Furthermore, knowledge of the course of this type of accidents can be used to train forklift operators in the field of Occupational Safety and Health procedures. Moreover, the use of an active model of the human body enabled the modelling of the human responses - in this case the behaviour recommended by the forklift producers and operators training centres. The human response taking into account in this type of research is an innovation. Based on the French Institute for Research and Security (INRS, France) results [4] an active human body model was developed by CIOP-PIB. The use of active models is another step to improve the accuracy of simulation results.

Acknowledgements

This paper has been based on the results of a research task carried out within the scope of the third stage of the National Programme "Improvement of safety and working conditions" partly supported in 2014–2016 – within the scope of state services – by the Ministry of Labour and Social Policy (Poland). The Central Institute for Labour Protection – National Research Institute (Poland) is the Programme's main co-ordinator.

References

[1] *Informacja Państwowej Inspekcji Pracy* [online]. 2013. Rada Ochrony Pracy [cited 20 March 2016]. Available from Internet: http://rop.sejm.gov.pl/1_0ld/opracowania/pdf/material60.pdf

[2] *Madymo Theory Manual Release 7.5*. 2013. Helmond: TASS International.

[3] Rebelle, J.; Mistrot, P.; Poirot, R. 2009. Development and validation of a numerical model for predicting forklift truck tip-over. Vehicle system dynamics, *International Journal of Vehicle Mechanics and Mobility* 47(7): 771–804. http://dx.doi.org/10.1080/00423110802381216

[4] Rebelle, J. 2015. Use of a modified HYBRID III 50th dummy to estimate the effectiveness of market restraint systems for forklift truck drivers, *International Journal of Crashworthiness* 20(4): 348–369. http://dx.doi.org/10.1080/13588265.2015.1015362

[5] Milanowicz, M.; Budziszewski, P. 2013. Numerical reconstruction of the real-life fatal accident at work: a case study, in *Lecture Notes in Computer Science*. Vol. 8026. Ed. by V. G. Duffy. Berlin Heidelberg: Springer-Verlag, 101–110. http://dx.doi.org/10.1007/978-3-642-39182-8_12

[6] Milanowicz, M. 2012. Development of the numerical safety helmet model for reconstruction and prevention of the accidents in the work place, *Mechanik* 7: 537–545.
[7] *Madymo Human Body Models Manual Release 7.5*. 2013. Helmond: TASS International.
[8] Milanowicz, M. 2015. *Numerical modelling of occupational accidents caused by falls from a height. PhD Thesis*. Warsaw: Central Institute for Labour Protection – National Research Institute.
[9] *Occupant protection & egress in rail systems* [online]. 2006. EURailSafe [cited 1 May 2016]. Available from Internet: http://www.eurailsafe.net/subsites/operas/HTML/appendix
[10] *Abbreviated Injury Scale (AIS) 2005 – update 2008*[online]. 2008. Association of the Advancement of Automotive Medicine [cited 1 May 2016]. Available from Internet: http://www.aaam.org/