NUMERICAL STUDY OF EOD HELMET UNDER BLAST LOADINGS

B. Valverde-Marcos[1], J. Antona-Makoshi[2], M.Rodríguez-Millán[1]

[1] Department of Mechanical Engineering at University Carlos III of Madrid, Spain.

[2] Japan Automobile Research Institute, Japan.

Introduction

Nowadays, in military conflicts and in terrorist attacks, the number of victims injured and deceased due to the use of explosive devices such as weapons represents a significant percentage worldwide. IEDs (Improvised Explosive Devices) are the leading cause of death among troops in armed conflicts.

The need arises to protect the troops against explosions, especially the trained personnel attempting bomb disposal. The equipment used by this staff is known as a bomb suit or Explosive Ordnance Disposal (EOD) suit, that is used in order to reduce the injury if the devices explodes. This equipment is made up of different pieces: a helmet, a jacket (with chest and abdominal aramid plates), trousers and cooling and communication systems.

The protection that the helmets offers (often made in aramid fibers) is usually evaluated in terms of Intracranial Pressure or strain in different parts of the brain.

In this study, a numerical finite model of helmet was developed in order to evaluate helmet use limits, using a validated head finite element model.

Objetives

- Develop a finite element model able to determinate the response of a EOD helmet in a explosive event.
- Compare the injuries in the head of the helmet operator to different loads at a specific distance, with and without the helmet.
- Use the Head Injury Criterion (HIC) in order to define the amount of explosive charge that personnel trained to disarm explosive devices are able to withstand before death, using and not using the helmet.
- Evaluate the volume of brain exposed to strains that cause brain damage, with and without the helmet.

Numerical Model

The EOD helmet model was based in the antibomb suit used by Guardia Civil (from Spain). It was composed of five parts: the shell, made by composite aramid fiber (Kevlar); the visor, made by transparent polycarbonate 22 mm thick; the closed cell rubber, which joins the visor with the helmet; and the interior foams, that are divided in a hard and a soft foam. The mechanical properties was described in [1,2,3,4].

The FE model of human head was development and validated by J. Antona-Makoshi in [5] and it is composed of: the brain (and its different parts), skull, skin and neck.

The explosive charges were modelled using a hybrid CONWEP-ALE technique. This method avoids the modelling of the fluid medium between the explosive and the target and eliminates the physical modelling of the explosive. The simulation was developed with 0.050, 0.075 and 0.100 kg of TNT loads for 10 ms. In all cases the explosive was at 0.681 m from the system head-helmet, in the midplane. The distance value was selected from *NIJ Standard 0117* and adapted to an only head case (not full body).

Head Injury Criterion (HIC)

Configuration	TNT load (kg)	HIC	Reduction (%)
Head without EOD helmet	0.050	1235.0	-
	0.075	2968.0	-
	0.100	5552.0	-
Head with EOD helmet	0.050	61.9	**94.99**
	0.075	170.3	**94.26**
	0.100	352.7	**93.65**

The Head Injury Criterion (HIC), developed by Versace in [6], was used for calculate the probability of traumatic brain injury. It is based in translational acceleration (in *g*) of centre of gravity of the head and its duration. The HIC is a global head injury criterion widely utilised for vehicle safety evaluation and it is able to be related to the Abbreviated Injury Scale (AIS) by means of probability curves.

Configuration		AIS1 (%)	AIS 2 (%)	AIS 3 (%)	AIS 4 (%)	AIS 5 (%)	AIS 6 (%)
0.050 kg of TNT	EOD helmet	100	96	73	32	7	0
	No EOD helmet	2	1	0	0	0	0
0.075 kg of TNT	EOD helmet	100	100	100	100	100	99
	No EOD helmet	16	6	2	0	0	0
0.100 kg of TNT	EOD helmet	100	100	100	100	100	100
	No EOD helmet	54	20	6	2	0	0

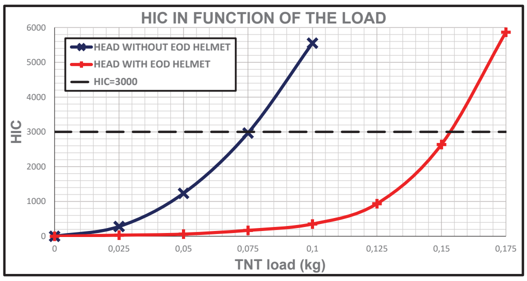
EOD helmet reduced the risk of head injury for 0.050 and 0.075 kg of TNT to a very low severity and, for 0.100 kg of TNT, minimizing a certain death (HIC≥3000) to an AIS 2 level of injury.

$$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2,5}(t_2 - t_1)\right\}_{max}$$

For the distance between load and target recommended by the *NIJ Standart 0117:*

- 0.075 kg of TNT load caused the death of the antibomb personnel without the EOD helmet.
- 0.150 kg of TNT load caused the death of the antibomb personnel using the EOD helmet.

In addition, HIC f(TNT load) has non-linear relation.



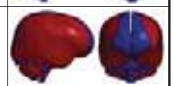
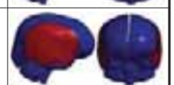
Strains at the brain

To analyze the injury derived from the principal strains in the brain tissue, the injury criteria developed by Zhang et al. [7] was used. If the brain undergoes principal strain greater than 0.24 occur, a mTBI will appear with a probability of 80%.

Configuration	TNT load (kg)	Max. Prin. Strain	Time (ms)	Reduction (%)
Head without EOD helmet	0.050	0.8495	2.02	-
	0.075	1.0648	2.14	-
	0.100	1.1824	2.14	-
Head with EOD helmet	0.050	0.2936	4.65	**65.44**
	0.075	0.4002	4.44	**62.42**
	0.100	0.5419	4.12	**54.17**

The EOD helmet moves the region affected by max. prin. strains slightly upward on the lateral zone of the frontal lobe.

The percentage of cerebral volume (of a total of 1201.04 cm^3) that is subject to strains above the threshold of 0.24 was analyzed. It has been proven that brain damage was concentrated in the outer area of the brain, in the cerebral cortex. EOD helmet reduced the affected brain volume a 98.81%, a 99.27% and a 95.36%, respectively.

Configuration	TNT load (kg)	Affected brain volume (cm^3)	(%)	(red colour)
Head without EOD helmet	0.050	78.32	6.52	
	0.075	183.69	15.29	
	0.100	277.64	23.12	
Head wit EOD helmet	0.050	0.15	0.01	
	0.075	1.34	0.11	
	0.100	12.87	1.07	

Conclusion

- EOD helmet reduced HIC value about 94%. At the distance recommended by *NIJ Standard 0117*, the critical TNT loads were 0.150 and 0.075 kg with and without helmet, respectively.
- The most strain (using and not using EOD helmet), was located in frontal cortex, in its lateral zone, and was reduced 60% (on average). The injured cerebral volume has been reduced about 98%.

References

[1] L. Zhang, R. Makwana y S. Shama: *Frontiers in Neurology,* vol. 4 (art. 88), p. 12, 2013.
[2] Q. H. Shah: International Journal of Impact Engineering, vol. 36, nº 9, pp. 1128-1135, 2008.
[3] J. A. Loya-Lorenzo, J. Aranda-Ruiz, M. Rodríguez-Millán y K. Miroir: VI Congreso Nacional de I+D en Defensa y Seguridad, Valladolid, 2018.
[4] L. Zhang, R. Makwana y S. Shama: Frontiers in Neurology, vol. 4 (art. 88), p. 12, 2013.
[5] J. Antona-Makoshi: Vehicle Safety Division, Department of Applied Mechanics, Chalmers University of Technology, Gothenburg, Sweden, 2016.
[6] J. Versace: 15th Stapp Car Crash Conference, Coronado, EE.UU., 1971.
[7] L. Zhang y K. H. Yang: Journal of Biomechanical Engineering, vol. 126, nº 2, pp. 226-236, 2004.

Acknowledgements

The authors acknowledge the Ministry of Economy and Competitiveness of Spain and FEDER program under the Project DPI2017-88166-R for the financial support of the work; and Marcos Rodríguez-Millán thanks the Spanish Ministry of Education, Culture and Sports for the professor's mobility program José Castillejo's 2018 grant (CAS18/00292).