Assessment of Motorcycle Helmet Chin Bar Design Criteria with Respect to Basilar Skull Fracture using FEM

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1 Abstract

Statistical studies showed that the chin bar of full-face helmets is the region with the highest number of impacts. In an Australian research, fifty percent of severe impacts took place to the front of the helmet and forty percent of these resulted in Basilar Skull Fracture (BSF). There are two standards, which include criteria for assessing the performance of the helmet's chin bar, Snell M2015 and ECE 22.05. These standards have developed some methods for testing the chin bar in order to protect the head from facial impact during motorcycle accidents, but they do not seem to consider head and neck injuries. The present work has utilized the finite element method to assess the Snell M2015 and ECE 22.05 criteria for chin bar design with respect to the injuries at the base of the skull. In the first step, the fem model has been mounted on a headform to simulate the chin bar test for both standards. In the next step, the Hybrid III dummy model has been coupled to the helmet to simulate the response of the whole body, in particular at head and neck connection, to the facial impact. Finally, the results obtained from the dummy model simulations have been utilized to assess if the standards could provide reasonable criteria for BSF. The simulations are performed with LS-Dyna and the focus of the assessment is about the injuries at the intersection between skull and spine.

2 Introduction

Motorcycle helmets have been studied from the middle of the 20th century in order to reduce head injuries [1]. Helmets are effective in mitigating and preventing contact injuries like skull fracture, but their role in injuries due to inertia is not as effective as their role in contact injuries [2]. Statistical studies showed that, the chin bar of the full-face helmet has the highest probability of impact. Almost 50% of the severe impacts took place to the front of the helmet, as shown in Figure 1, and 40% of them led to Basilar Skull Fracture (BSF) [3]. In addition, a clinical survey, which studied 100 patients, who were suffering from BSF, revealed that half of them were motorcyclists [5].
An Australian governmental project, which studied helmets with respect to BSF, proposed further investigation based on simulation in order to identify the effect of the helmet's chin bar stiffness on BSF [4]. Therefore, the present work is an attempt to assess the effect of the stiffness of helmet chin bar on the induced neck force, which is an indication for BSF [10, 11].

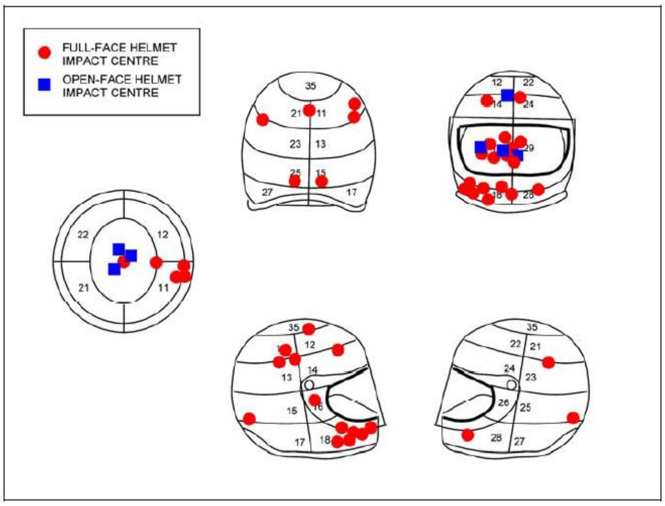


Fig.1: Approximate impact points for impacts on motorcycle helmets [4].

3 Helmet Chin Bar Tests Methods

There are two standards which prescribe some experimental tests for validating the chin bar of full-face helmets. These standards have been used to verify the models used in this work.

3.1 Snell 2015

In order to test a chin bar in accordance with Snell 2015, the helmet must be fixed on a rigid frame so that the reference plane is at 65±5º from the horizontal and the chin bar faces up, as shown in Figure 2. A mass of 5±0.2 Kg with a flat striking face of 0.01 m^2 minimum area shall impact the central portion of the chin bar with an impact velocity of 3.5 ± 0.2 m/s. After impact, the maximum downward deflection of the chin bar shall not be more than 60 mm and no component fails, which could cause a potential injury [6].

3.2 ECE 22.05

According to ECE 22.05 the helmeted headform shall be positioned with the angle of 65±3º above the flat anvil as shown in Figure 2. The drop height should be such that the impact velocity is 5.5 +0.15/-0.0 m/s. The measured acceleration of the headform‘s center of gravity must not exceed 275 g (g is gravity), and the calculated HIC_{36} shall not be more than 2400 [7].

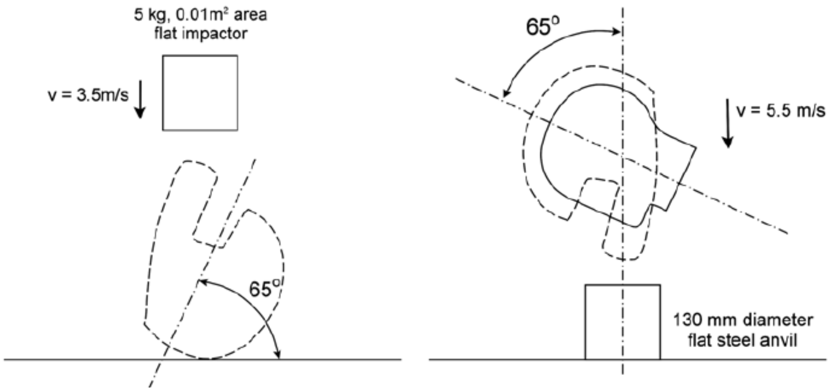


Fig.2: Chin bar impact test configuration for Snell 2015 (left) and ECE.22.05 (right) [4].

4 Basilar Skull Fracture (BSF)

Any fracture, which occurs exactly at the skull base or originate remotely from base of skull and propagates to the bones at the base of the skull, could be called Basilar Skull Fracture [4]. BSF occurs due to either direct impact or because of an impact remote from base of skull [8], like as a consequence of impact to facial bones [9]. BSF could occur due to mandibular impact without facial fracture [10] and motorcyclists are strongly susceptible to this type of impact during accidents [3] (Figure 3) but the helmet standards haven’t clearly addressed possible causes of BSF [4].
An experimental survey introduced the induced axial tensile load on Foramen Magnum because of mandibular impact, as an indicator of BSF [10, 11], so in the present work, the upper neck tensile load is considered as an indicator of BSK.

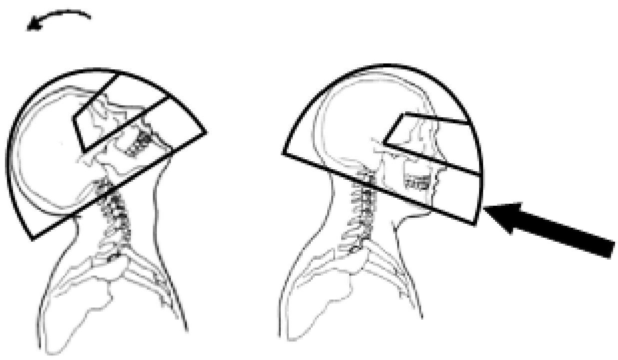


Fig.3: Neck extension during chin bar impact.

5 Finite Element Simulation

5.1 FE Model of Helmet

The Finite Element model of the AGV-T2 helmet, size 58 [13], manufactured by Dainese S.p.A. (a partner of the MOTORIST EU network), was numerically modified by changing the thickness of the chin bar, as illustrated in Table 1, to show the effect of its stiffness on the force induced at the upper neck section. The geometry file was provided by Dainese S.p.A. and imported in HyperMesh [16] to generate the fem model. The finite element simulations were performed using LS-Dyna 971.
The main parts of the helmet, which are involved in energy absorption, are composite shell and foam liner. 4-node quadrilateral shell elements were utilized to generate the FE model of the composite shell and 4-node tetrahedral solid elements for the liner discretization (Figure 4). The liner foam is made of EPS (Expanded Polystyrene) and the shell of composite laminates, which had different layup in different parts of the helmet. The crushable Foam and Laminated Composite Fabric material models were used for liner and shell, respectively [12, 15] and the material properties are described in [13]. The model of the helmet was used to simulate the impact attenuation test of ECE 22.05 [17], drop tests using a Hybrid III dummy [13 and 17] and oblique impacts using a Hybrid II headform [18]. The head linear and rotational accelerations predicted by simulations were in good agreement with the experimental data.

Fig.4: Helmet FE Model

The Model	Total Thickness of Chin Bar (mm)
Model Number I	0.445
Model Number II	0.465
Model Number III	0.485
Model Number IV	0.505
Model Number V	0.525

Table 1: Thickness of Chin Bar for Different Models

5.2 FE Model of the Hybrid III 50th Percentile Male

In the present work LSTC/NCAC Hybrid III 50th percentile male dummy model (LSTC.NCAC_H3_50TH.130528_BETA), shown in Figure 5, was used to represent the human body behaviour during the chin bar impact. This FE model was provided by Livermore Software Technology Corporation (LSTC: www.lstc.com) and was the last updated version of Hybrid III 50th Percentile model. Mohan et al. [14] validated this FE model and reported a reasonable correlation to the calibration tests in order to represent the behaviour of joints.

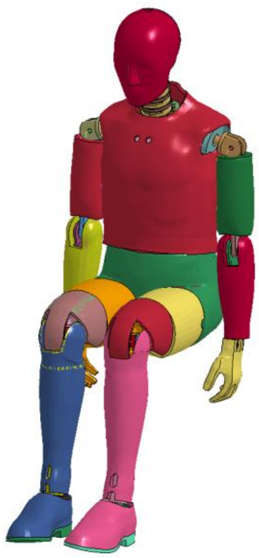


Fig.5: Hybrid III 50th Percentile Male FE Model.

6 Methodology

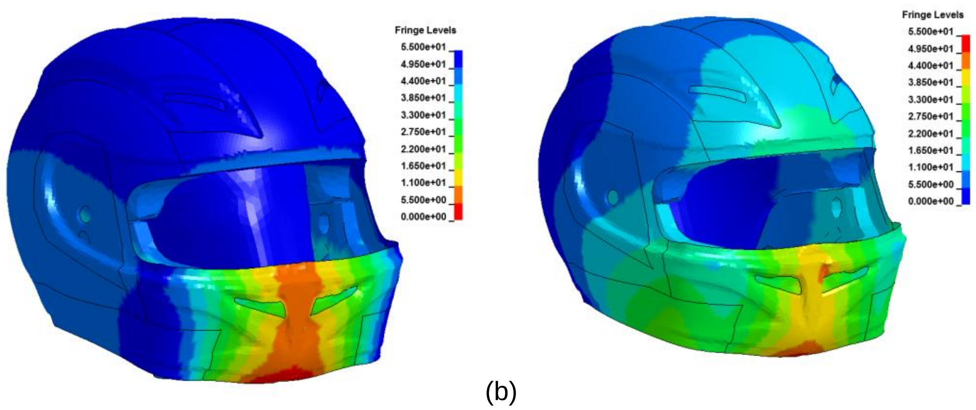
6.1 Simulation of Standard Tests

In the first step, the helmet model was modified as explained above, five different helmet models were obtained each charaterized by a different chin bar stiffness. Then the standard tests were carried out numerically for all models in order to check that all of them were still acceptable according to the same standards.

The result of ECE 22.05 and Snell 2015 are shown in Table 2, and it is depicted that all helmet models passed the virtual test. In addition, the contours of displacement for both standards, for one case, have been illustrated in Figure 6.

The Model	ECE 22.05		Snell 2015
	Maximum Head Acceleration (g's)	HIC	Maximum Displacement (mm)
Model Number I	173.95	530	56
Model Number II	162.17	522	54
Model Number III	136.24	480	53
Model Number IV	126.71	460	50
Model Number V	127.93	450	53

Table 2: The result of Simulation for Standard Tests



(a) (b)

Fig.6: The Contour of Displacement: (a) ECE 22.05, (b) Snell 2015.

6.2 Simulation of Coupled Models

In the next step, the obtained helmet models were coupled with the dummy model, as it is illustrated in Figure 7. Impacts of the helmeted dummy onto a flat anvil, were simulated for the different helmet models, to compare the load induced at the upper neck section.

Fig.7: Helmeted Dummy model impacting a flat anvil.

7 Results and Discussion

Table 3 shows the maximum neck tensile force, which is an indication for BSF due to facial impact, for all helmet models with different stiffness. It is obvious that the results in Table 2 are different from the results which are shown in Table 3, because of the effect of the body's inertia [13]. The contours of displacement for the helmet and the neck extension, for one of the helmet models, have been shown in Figure 8 for different time steps.

With considering the model number "I" as the reference, Figure 9 illustrates the variation of neck force and acceleration for different models.

Table 3 and Figure 9 illustrate that, changing the acceleration, which was due to change of chin bar stiffness, led only to slight changes in the neck force.

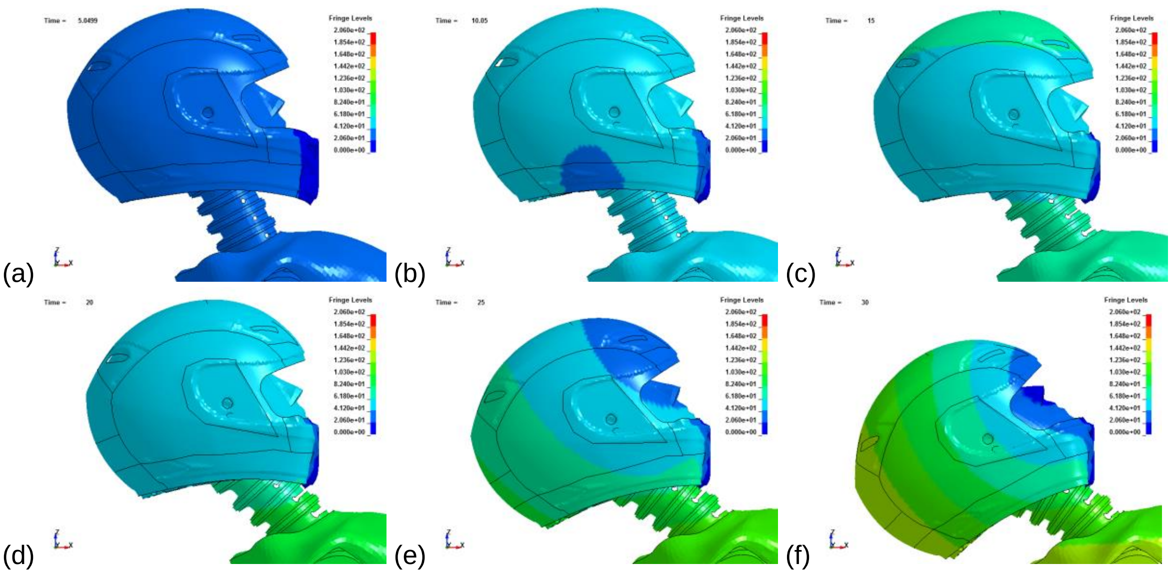


Fig.8: The Helmet displacements and the neck extension: a) t=5 ms, b) t=10 ms, c) t=15, d) t=20 ms, e) t=25 ms, f) t=30 ms

The Model	Total Thickness of Chin Bar (mm)	Maximum Head Acceleration (Gs)	Upper Neck Tensile Force (KN)
Model Number I	0.445	130.44	6.42
Model Number II	0.465	111.37	6.36
Model Number III	0.485	140.22	6.58
Model Number IV	0.505	133	6.56
Model Number V	0.525	101.22	6.73

Table 3: Maximum Neck Force and Maximum Head Acceleration

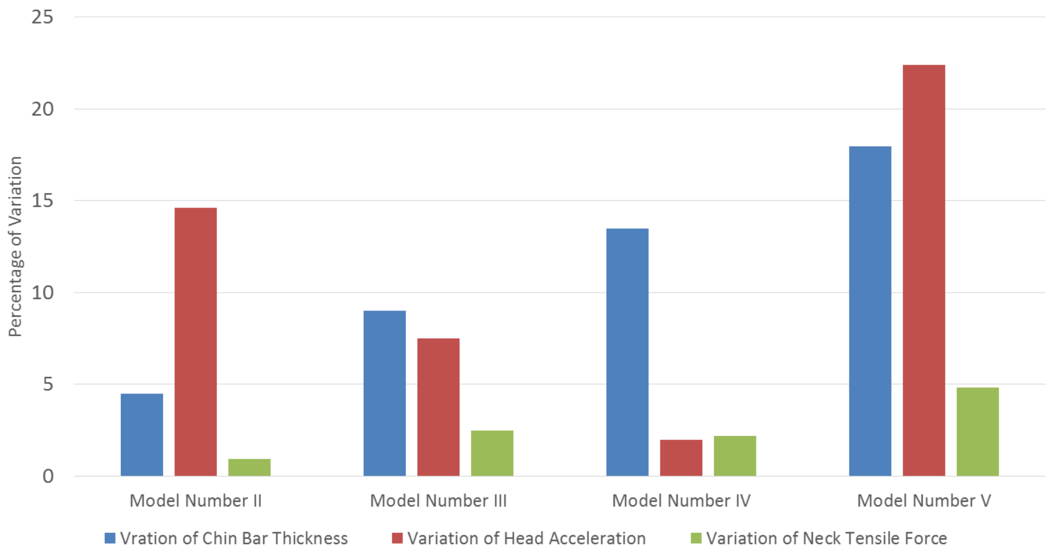


Fig.9: Variation of Acceleration and Neck Force for Different Chin Bar Stiffness

8 Conclusion

The present study aimed at clarifying the relationship between stiffness of the chin bar and tensile neck force.
Helmets with different chin bar stiffness, but all approved by current ECE.22.05 and Snell 2015 standards, were virtually tested coupled with a model of Hybrid III 50th percentile male dummy.
Simulations did not provide a clear trend of variation of the tensile neck force with the stiffness of the chin bar. Therefore, further investigations are required in order to verify the reliability of available chin bar design criteria for providing protection against BSF.
One of the possible limitations of present survey could be due to the use of the FE model of the dummy as the human body's surrogate, therefore more detailed model like THUMS [19] or experimental tests using cadavers are recommended in order to obtain more accurate results.

9 Acknowledgment

This work performed as a part of the research training network MOTORIST funded by a Marie Curie fellowship of the 7th framework programme of the EU under contract number FP7-PEOPLE-2013-ITN-608092. The authors would like to thank Dainese S.p.A. for providing the helmet's CAD model.

10 Literature

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