Coupled experimental versus numerical helmet evaluation under multidirectional impact

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1 INTRODUCTION

It is well known in the scientific community that head rotational acceleration is an essential factor leading to diffuse brain injury or commotion, Reference [1]. Several attempts exist in the literature in order to develop new helmet test methods that include the tangential loading of the helmet at the time of impact Reference [1]. However, despite these efforts no standard exist today that considers the oblique helmet impact and assesses the helmet performance under complex linear and tangential impact. The reason may be that no multidirectional brain injury criteria exist.

The present paper presents a multidirectional coupled experimental versus numerical helmet protection assessment method and its application to a set of existing bicycle helmets.

2 MATERIAL AND METHODS

This section presents the methodology applied in the present paper, i.e. the definition of a multidirectional helmet test method and finally the application of the method to a set of 10 existing bicycle helmets.

2.1 Coupled experimental versus numerical test method

In order to asses the helmet protection capability there is a need to define realistic impact conditions based on accident data, to involve a relevant headform with adequate 6D kinematic instrumentation and finally to involve advanced brain FE modeling in order to integrate tissue level injury criteria under complex brain acceleration. Once defined the robustness of the method will be assessed, by focusing on one helmet. For the robustness control, the oblique impact have been conducted five times on five helmets and the brain injury risk has been computed separately for each impact.

2.2 Evaluation of a set of bicycle helmets

Once defined the new helmet test method will be applied to a set of ten existing bicycle helmets. For each helmet type, six helmets are considered and a special designed test matrix enables it to conduct each of the linear and oblique impacts three times. For each helmet results are expressed in terms of maximum axon strain (MAS) and in terms of brain injury risk, by computing each impact with the brain FE model according to the new experimental versus numerical test method.

3 RESULTS

Results are exposed in terms of novel helmet test method definition and robustness evaluation. Further results report a full multidirectional evaluation of helmets against biomechanical based brain injury.

3.1 Helmet test method and robustness

The helmets are evaluated in order to assess their protection capability under linear and tangential impact.
For the linear impact the velocity is 5.45 m/s against a flat anvil. However in order to control the pure linearity of the impact, a Hybrid III headform fitted with rotational acceleration is used for this tests. The 6D linear accelerations under front, occipital and lateral impact are be recorded versus time.
Several accident investigations proved that current head impact angles are between 30° and 60°. On the other hand it is well known that head angular acceleration is leading to brain injury. For the new tangential impact test it is suggested to submit the helmet, fitted on a fully instrumented Hybrid III headform to significant tangential loading in order to evaluate its ability to dissipate rotational energy. It is believed that an impact against an anvil inclined at just 30° would mainly compress the foam. At the other extremity, if the anvil angle is 60°, the helmet would mainly slide along the anvil. Therefore it is suggested to fix the anvil angle at 45° and to conduct three impacts as shown in figure 1. This tangential test conditions conducts effectively to a foam shearing and in turn permits the evaluation of the protection capability of the helmet under a combined linear and tangential loading. Suggested impact velocity for these impacts is 6.0 m/s.

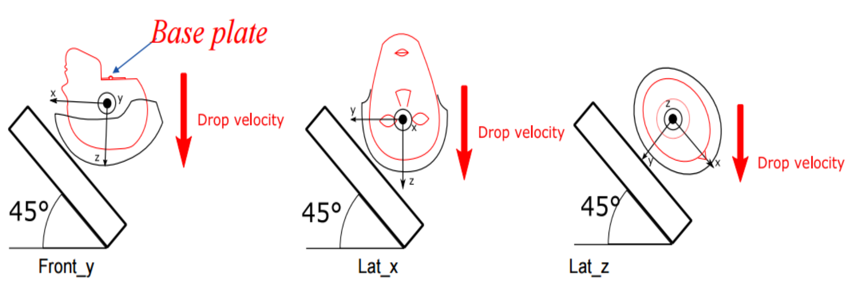

Figure : Illustration of the tangential helmet test impact conditions.

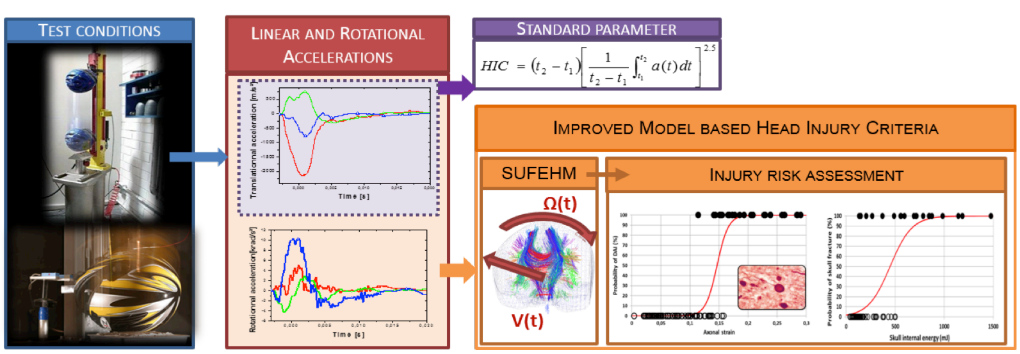

Figure 2 : Illustration of the coupled experimental versus numerical helmet test method.

For the linear and the tangential test, it is suggested to introduce the 6D linear and rotational acceleration into the Strasbourg Universtity FE Head Model (SUFEHM) as shown in figure 2, in order to assess the brain injury risk in a more realistic way. The SUFEHM is an advanced brain model that includes a heretogeneous hyperviscoelastic and anisotropic brain constitutive law, which enables it to compute the maximum axon strain for a given impact. This model has been used extensively for the simulation of over 100 real world head trauma in order to derive tissue level brain injury criteria. It has been shown in Sahoo et al. (3) that a moderate brain injury (AIS2) occurs for a maximum axon strain (MAS) od 15%.
The robustness of both the experimental and the numerical step of the proposed method showed that for a given helmet and impact direction the spead out of maximum linear and rotational acceleration as well as MAS was under 8%.

3.2 Evaluation of a set of ten bicycle helmets

Results are reported in terms of histograms, which show the maximum axon strain (MAS) and injury risk for each impact situation and for each of the ten helmets. Concerning the linear impacts, it appears that about one third of the helmet lead to MAS of about 0.07 which corresponds to a very lon risk of injury, one third show a MAS close to 0.15 with an injury risk of 50% and one third show critical protection with a MAS of about 0.25 which corresponds to an injury risk of 100%.
Concerning the oblique impacts it is interesting to observe that the protection capability of the helmets strongly depends on the impact direction. For impacts leading to rotation around the antero-posterior (X) direction, nearly all helmets protect adequatel. For the impact leading to rotation arounf left-ryght(Y) direction, half of the helmet only offer an acceptable protection with a brain injury risk under 50%. Finally when the impact leadr to rotation around the vertical axis nearly all helmet lead to an injury risk of 50% to 100%.

4 CONCLUSIONS

A multidirectional bicycle helmet test method is proposed where 6D headform acceleration versus time curves is recorded during linear and oblique impact tests. This 6D head kinematic is considered as the input of a brain computational model that calculates the maximum axon elongation in order to assess the brain injury risk.

The coupled experimental versus numerical test method has been applied to a set of 10 existing helmets and demonstrated that helmets show very different brain protection capabilities. Further this study shows that the most critical impact for all helmets is the oblique impact that leads to rotation around the vertical Z axis. This study is a step towards the proposal of new standards and can be used for helmet rating in the context of consumer information tests.

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5 REFERENCES

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