The Use of Finite Element Models in Automotive Regulations

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Introduction

Government safety regulations for the United States automotive industry are currently based upon the crash testing of vehicles and the subsequent analysis of crash test dummies measurements using injury criteria. There are different injury criteria for each part of the body: head, neck, thorax, lower leg, etc.

Current injury criteria usually use a simple calculation based on measurement at one point like peak deflection or peak force. From a biomechanical standpoint it would be ideal to information like stress or strain throughout the body part to predict injury. Techniques in computer modeling make it possible to monitor stress and strain in a model of the human body.

Models of each body part are loaded using information from crash test dummies. The model then predicts the response of the body part to the loading conditions. The flexibility and relatively low cost of running computer models make them a very useful method to improve injury prediction in crash tests for regulation. This paper discusses the requirements that computer models, specifically finite element models, should meet to be acceptable for use in regulation.

Requirements of Regulatory Models

There are three main requirements that should be met in models intended for use in regulation: a balance of complexity and solution speed, validation of the physical response, and the ability to differentiate between injury and non-injury. The first characteristic, a balance of complexity and solution speed, is very important for a model to be used in regulation. In the automotive industry, time is very valuable and models that require several hours to solve can be very costly for a company. Most current injury standards only require simple calculations of injury criteria; therefore, to minimize the impact, the solution time should be as short as possible.

One major benefit of using computer models is the ability to provide a more biomechanically-based injury assessment. However, the physical response of the model must be validated. This is done by simulating existing experiments that measure the physical response of a cadaver or volunteer and then comparing the recorded response to the modeled response. The experiments must be representative of loading conditions found during injury in an automobile.

Finally, injury criteria must be developed for a computer model used for automotive regulation. Experimental injury tolerance tests should be simulated. Measurements in the model are then correlated with experimentally observed injury. If there are multiple types of injuries that can occur to the same body part, several injury criteria can be created.

Example Models

Head and thorax models have been developed in conjunction with the United States Department of Transportation, National Highway Traffic Safety Administration (NHTSA) using the specifications described above.

The head model was developed as part of NHTSA's Simulated Injury Monitor (SIMon) program (Takhounts et al., 2003). The model (Fig. 1) was developed to predict three main types of injury diffuse axonal injury (DAI), contusions, and acute subdural hematoma (ASDH). The model uses a rigid skull which allows loading of the model using dummy head kinematics. To achieve a fast run time (under 2 hours for a 150ms run), a relatively simple four part design was chosen.

The model was validated for physical response. Two sets of experiments were simulated. One set was simulated to verify the motion of the brain relative to the skull during impact, an important component of DAI and ASDH type injuries. A second set was used to verify the pressure distribution on the skull, necessary value to predict contusions. The injury criteria were developed by simulating the scaled head kinematics of over 100 animal injury experiments and evaluating potential injury conditions using model measurements for each of the three injury types.

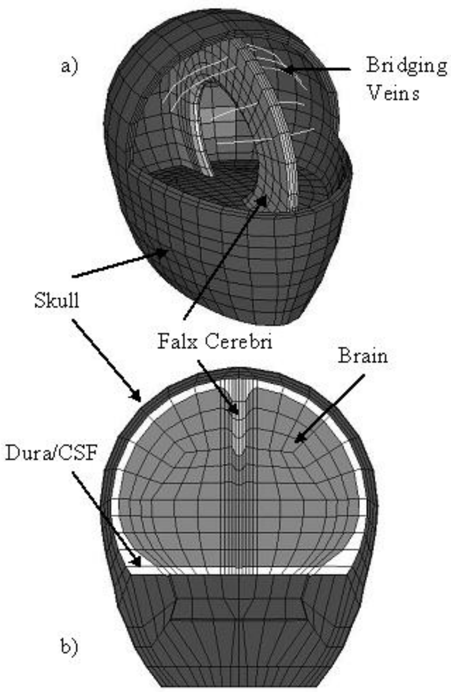

Figure 1: SIMon finite element head model a) cut-away view without brain, b) coronal slice.

The thorax model (Campbell et al. 2005) was developed as a tool to study the differences between restraint systems on thoracic injury and improve injury prediction from dummy chest deflection measurements. Rib fracture was found to be the primary injury of interest and a two-dimensional model (Fig 2) was determined to be sufficient to characterize that injury, allowing for a simple and fast model (less than 1 hour for a 60ms run).

The thorax model's physical response was validated using cadaveric pendulum impact experiments (Kroell et al., 1971, 1974). An injury criterion for rib fracture in the thorax was developed by simulating over 100 cadaver sled tests using chestband displacement data. Rib strain in the model was correlated with rib fracture to predict injury.

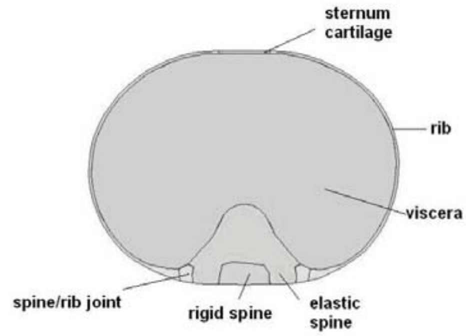

Figure 2: Thorax Finite Element Model

Conclusion

Computer models have been shown to be a potentially useful tool to improve the automotive regulation process. Measurements from crash test dummies can be used to drive computer models and simulate experimental impacts. Three important requirements were identified for computer models intended for use in automotive regulation: a balance of complexity and solution speed, validation of the physical response, and the ability to differentiate between injury and non-injury. The finite element models given as examples in this paper illustrate that these specifications can be used to create successful models with the potential for use in automotive regulations.

Bibliographic References

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