Application of a FE Human Model to the Simulation of Motorcycle Accidents Involving Roadside Barriers

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Abstract: It has numerously been pointed out in the literature what hazard roadside barriers constitute for a motorcyclist that is sliding on the road after falling. For more than 20 years efforts have been undertaken in order to develop measures for injury mitigation in case of an impact of the body onto the barrier. Even impact-test procedures have been developed for the assessment of the efficacy of such countermeasures. However, the biomechanical knowledge available in this field is relatively little compared to other fields of passive safety. This work is aiming at enlarging this knowledge by an insight into injury mechanisms using crash simulation.

The Finite-Element model HUMOS2 is applied to the simulation of human-body impacts onto roadside barriers. This includes a PMHS test as well as reconstructed accidents. The description of injury mechanisms, which had been reported for these body impacts onto roadside barriers, by means of numerical simulation is demonstrated. This is intended to extend the available methods for further developments in this field.

The HUMOS2 model has been developed in the automotive environment, but the potential for applications to other constellations, like injuries caused by barrier parts, is shown. The limits of the model in such an application are also discussed. The presented methodology can be used when biomechanically valid impact tests with crash-test dummies are to be developed for the assessment of safety features of roadside barriers.
Keywords: motorcyclist , roadside barriers, simulation

1 Introduction

Occupants of powered two-wheelers can, unlike car occupants, rather easily contact obstacles in the road environment in the course of an accident. Roadside furniture thus represents potential impact objects for the rider. This applies in particular to safety barriers.

It has numerously been pointed out in the literature what hazard roadside barriers constitute for a motorcyclist that is sliding on the road after falling. For more than 20 years efforts have been undertaken in order to develop measures for injury mitigation in case of an impact of the body onto the barrier. Even impact-test procedures have been developed for the assessment of the effectiveness of such countermeasures.

Such procedures either imply the use of an impactor [BASt, 1993] or a crash test dummy [Bouquet et al., 1998; Buerkle and Berg, 2000; CIDAUT, 2005]. Biomechanical measurements are used for the evaluation of the effectiveness of a tested device. The dummies as well as the applied biomechanical limits are nearly completely transferred from crash testing in the automotive sector without any modification. A reason for that may be that the available basis of experimental investigations is small compared to automotive passive safety.

Attempts have been shown in the past to apply numerical simulation in addition to impact testing for gaining insight into the problem of motorcyclists' impacts onto roadside barriers [Sala and Astori, 1998; Berg et al., 2005]. Those investigations have implied numerical models of dummies, whereas this paper describes the application of a human model to the simulation of the above-described impacts.

The impact of a motorcyclist onto a roadside barrier can occur in two scenarios. Either the occupant is still on the two-wheeler in a position close to normal riding posture, or the rider has been separated from the bike. For the latter case an impact configuration, which is suitable for the investigation of injury mitigation, can be found from reviewing literature and analysis of in-depth accident data [Peldschus, 2005]. In this configuration the rider slides into the barrier laying on his back with the head forward. The rider's velocity vector constitutes an angle of around 30 degrees with the tangent of the barrier. The longitudinal axis of the occupant is thereby either aligned with the velocity vector or with the barrier tangent. The injuries which are to be expected in such an impact configuration are to the head, neck, thorax and upper extremities (including the shoulder) mainly.

2 Methods

For the investigations presented in this paper the numerical human model HUMOS2 (human model for safety), which was developed within two European research projects, has been applied. HUMOS2 is a Finite-Element model for crash simulation and exists for three different codes. In this case the PAMCRASH version of the model was used. The geometry of the model was obtained from scanning slices of a post-mortem frozen human body. The model was scaled to represent the 5th, 50th and 95th percentiles of the european population. Of these, the 50th percentile was used for the work described in this paper. The numerical model consists of about 84000 elements and 60000 nodes. More than 500 material descriptions and more than 170 contact definitions are contained in the model. The material descriptions have mostly been developed on an experimental basis.

The HUMOS2 model has been extensively validated. The loading of the model in the validation aimed at reproducing conditions that are typical for car occupants as for instance shown in [Merten 2006] for lateral loading to the thorax. From the validation with impact directions in several body axis a potential applicability to other loading configurations can be derived. For the work described in this paper loading of the upper extremity, the thorax/shoulder region and the neck was simulated.

The simulation of the loading to the upper extremity was based on experimental work by Schueler et al. [Schueler et al., 1985]. In that work the impact of occupants of powered two-wheelers onto roadside barriers was investigated using post-mortem human surrogates (PMHS). These were projected with a velocity of about 32 km/h to the post of a metal roadside barrier. The slightly abducted upper arm thereby hit the post. Figure 1 shows the impact configuration. The model of the post was a so-called sigma post. Its horizontal cross-section resembles the shape of the letter sigma.

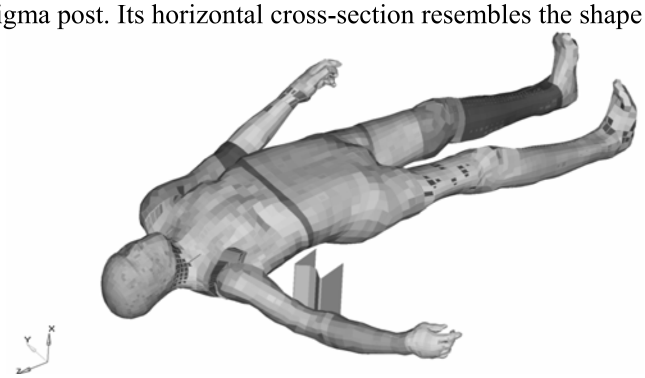

Figure 1 Impact of upper extremity to sigma post

The body height of the PMHS in the test was nearly identical to the height of the 50th percentile HUMOS2 model, whereas the mass of the PMHS exceeded that of the numerical model by 10kg. The post was modeled as an undeformable body. Movement of the post was supressed in the simulation. This represents the assumptions that deformation is virtually only to the human body and that the post was properly fixed to the ground for the experiment.

A loading of the shoulder/thorax region was simulated using a accident reconstruction by Schueler et al. [Schueler et al., 1984, number 4]. In the described accident a motorcyclist impacted a roadside barrier upon separation from his bike. The barrier was hit near the end of the installation, where the guardrail is approaching the ground. Thus an underpassing of the rider could be excluded. Instead, a contact between the rail and the human body had to be assumed. The guardrail was impacted at its most compliant part in the middle between two posts. The connections of the rail to the nearest barrier posts was modelled as fixed in space. The simulated impact speed of 27.5 km/h was taken from the accident reconstruction data and represents the median of the indicated interval.

Apart from a skull base fracture that was not considered for the simulations, the rider suffered from a serial rib fracture at the right side involving ribs 3 through 8, fractures of the clavicle and scapula, and fractures to the coccyx and the left femur. Furthermore the rider sustained internal injuries as pneumothorax, pneumopericard and liver rupture. The injuries are concentrated in the right side of the thorax. It was aimed at demonstrating how these injuries could have been caused by certain impact configurations. Figure 2 shows such a simulated impact configuration. The angle between the barrier tangent and the velocity vector of the human body was 45 degrees according to the reconstruction data. This set-up was simulated once with sliding along the barrier in the direction to the feet (feet-forward) and once with sliding along the barrier in the direction to the head (head-forward).

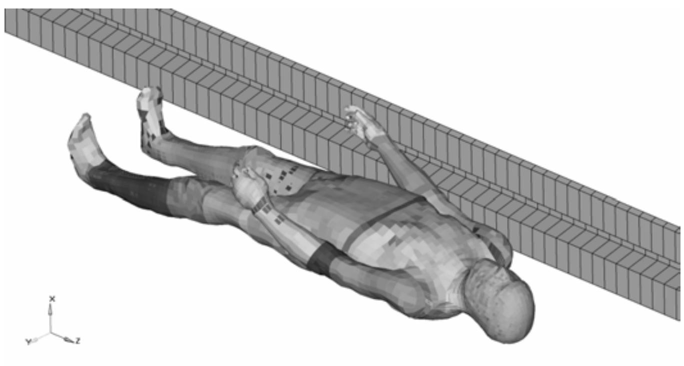

Figure 2 Impact onto barrier rail – straight position

Another simulated variant is displayed in figure 3. The set-up is similar to the feet-forward one, only the human model is positioned in a less straight manner. This resembles a more tensed rolling/sliding position and this configuration is derived from the sitting HUMOS model. This simulation is aiming at investigating the influence of the position of the upper arm with respect to the thorax in the injury causation.

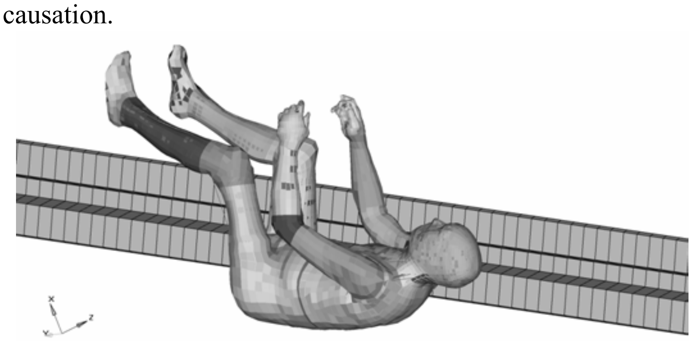

Figure 3 Impact onto barrier rail – tensed position

For the simulation of these impact configurations the rib material was used without modelling of material failure and element elimination. The evaluation of the loading and potential rib fractures was performed by quantitative strain analysis.

3 Results

Upper extremity

Figure 4 shows the strain distribution in the cortical bone of the humerus shortly after the impact. The local stress/strain concentration leads to failure of the bone and elimination of shell elements. Figure 5 shows the the state of that bone at the end of the simulation. The distance between the first eliminated elements and the humerus head is 194.4 mm.

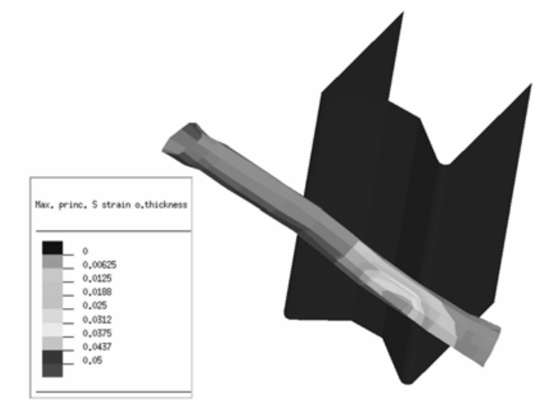

Figure 4 Strain contour at cortical humerus bone shortly after impact

Figure 5 Cortical humerus bone at end of simulation

Thorax/shoulder

The impact of the human model to the rail of the barrier is depicted in figure 6. In this case the sliding along the barrier is with the head forward. The pictures shows the state 30 ms after the first contact. The local peak strains as measured over the whole simulaion time are given in figure 7. The impacted side of the rib cage (right side) is shown from an interior view along with the clavicle. The upper left result is from the simulation with sliding along the barrier in the direction to the head (head-forward), the upper right one from the feet-forward configuration. The lower left result is from the tensed position. The highest strain are measured in the frontal axillar line. The highest values are seen for the feet-forward configuration for ribs 5 through 9. Slightly lower values are seen for the head-forward configuration, with a more evenly distributed loading on all ribs. No clearly defined local maxima can be observed for the tensed position. The values for the clavicle are however the highest for this case.

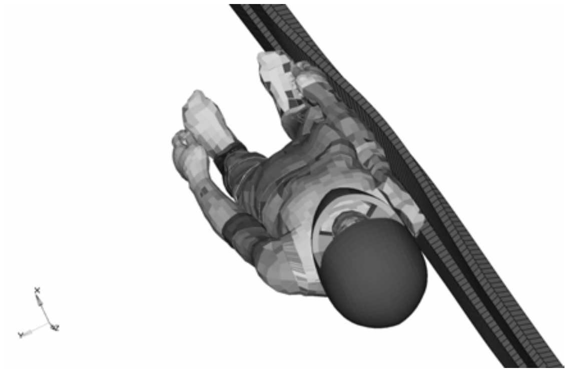

Figure 6 Impact onto barrier rail

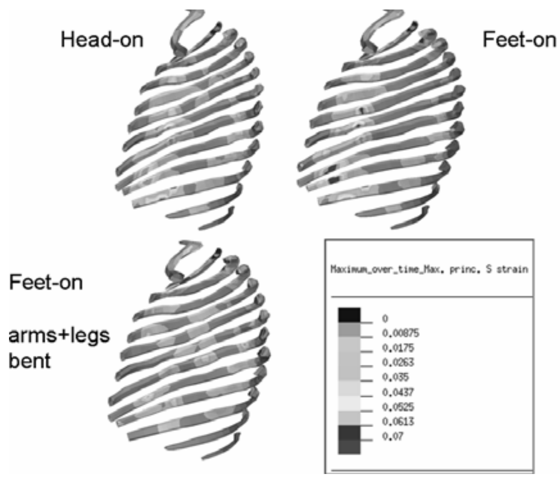

Figure 7 Maximum strains for ribs and clavicle

4 Discussion

The material failure in the humerus bone upon impact onto a sigma post resembles the cross break observed in the PMHS test. The fracture was documented with a distance of 20 cm to the shoulder joint in the experiment. This is well in concordance with the 194.4 mm which were measured for the simulation. This relatively isolated loading of a single bony structure can well be depicted with the HUMOS2 model.

The loading of the thorax/shoulder region according to the reconstruction of the accident could generally be described by means of simulation. However, there remains some uncertainty with respect to injury causation due to the complexity of the described accident. The simulations shown in this paper represent only a few of the possible positions, orientations of the body and most importantly contact partners, which are potentially causing injuries.

According to the presented simulation results a rib serial fracture seems most likely for the configuration with sliding along the barrier in the direction to the feet (feet-forward). The tensed position, in which the upper arm is not placed laterally to the thorax and intruding it by the loading caused by the impact, seems unlikely to have caused such a rib serial fracture.

The modelling of the clavicle (elastic deformation only) and the scapula (non-deformable body) presently limit the possibilities of injury simulation. Thus the mechanism of lateral loading of the rib cage after fracture of the clavicle can not be depicted.

5 Conclusions

The numerical human FE model HUMOS2 was successfully applied to the simulation of impacts of a human body to roadside barriers. This simulation technique can depict injury mechanisms. In order to be able to describe the loading to the body as in the analysed accident more precisely the modelling of clavicle and scapula has to be looked at in further detail. Particularly the failure of the clavicle is critical for such simulations. The applicability of the described method to the analysis of injuries to head and neck requires the use of a validated helmet model.

The possibilities to apply the presented method in the simulation of accidents of powered two-wheelers are not only limited by the quality of the models. They are also subject to the availability of appropriate input data for the simulation. The well described boundary conditions in a PMHS test prove to be far more favourable than complex accident kinematics.

The basic experimental research on this topic is very limited. The knowledge on impacts of occupants of powered two-wheelers onto roadside barriers can potentially be extended by the application of the described simulation method. It could be used to analyse the behaviour of dummies in the development of impact-test procedures as mentionned above. This could lead to the development of impact tests which are based on a better biomechanical basis than those found in this field today.

6 Acknowledgement

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