PEDESTRIAN IMPACT: THE EFFECT OF PEDESTRIAN MOTION ON HEAD CONTACT FORCES WITH VEHICLE AND GROUND

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ABSTRACT

There has been considerable development of car design to reduce pedestrian injury severity and thus the role of the ground impact in causing severe head injury has come to the fore. A Madymo model is used to examine the relative severity of the road and vehicle impacts and the effect of pedestrian motion before impact. Results show head impact locations on the vehicle are predictable but their severity varies with pre-impact stance. In contrast, head-ground impact is highly variable. The ground stiffness results in high contact forces, but the delta V for ground impact is less severe than the vehicle impacts, showing a higher momentum change in the latter.

Keywords: pedestrians, impact variability, head injury

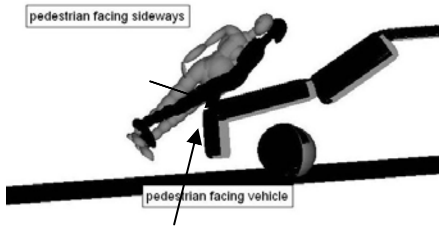
A 1980's study of real world pedestrian accidents concluded that at higher impact speeds, head injuries were primarily due to vehicle rather than road impact, whereas at low speed the ground impact increases in importance (Lestrelin et al, 1985). Considerable development of car fronts has now occurred to reduce aggressiveness to pedestrians and as new ECE test requirements are implemented, the role of the pedestrian-ground impact in head injury arises. This paper examines the vehicle/head and head/ground impacts, compares their severity and evaluates the effect of pedestrian motion prior to car contact and the influence of low level vehicle braking. Finally, a real world case study is used to show that pedestrian initial stance and speed can have a substantial effect.

METHODS

A simplified model of a production vehicle with contact surfaces was created and the Madymo 50th percentile male pedestrian model (Coley et al, 2001) was configured for wrap-type impacts with initial positions (1) standing facing the vehicle, (2) standing facing sideways (3) moving sideways. Figure 1 shows the setup. The influence of minor postural alterations such as left/right leg placed rearward and pre-impact transverse velocity (0-6ms^{-1}) was investigated. Three vehicle impact speeds were implemented (5, 10 and 20 ms^{-1}) to represent low, medium and high speed vehicle/pedestrian impacts. The pedestrian/vehicle friction was set to 0.2, pedestrian/ground friction was 0.58 (Wood et al, 2000]) Damping was not included in the contacts. Minor alterations to the model hip and ankle stiffness were required to prevent gimbal lock. A fixed level of braking of μ=0.75 was implemented. The ground was modelled using a linear force–penetration function adapted from (Hassan et al, 2003), while the vehicle surface descriptions were adapted from the Madymo vehicle database (2004) and the pedestrian head contact characteristic provided in the Madymo pedestrian model was utilised, see figure 2. It is therefore important to note that the results are comparative rather than quantitative predictions.

RESULTS

Vehicle/Pedestrian Contact : Figure 3 shows that, as expected, there is an increase in head/vehicle contact force with increasing speed together with a reduction in time to head contact. However, there is also a significant dependency of head impact load on initial stance of the pedestrian. At all speeds the highest impact loads occur in cases where the pedestrians is facing the vehicle, while an initial sideways posture results in the lowest head impact load. This is a result of the lower effective radius of rotation about the bonnet leading edge in the front/back orientation compared to the side/side cases. Therefore, as expected, the head contact force for the 45 degree rotation cases lie in between the facing forwards and facing sideways cases. Note: at 5ms^{-1} head contact occurs with the bonnet rather than the windscreen.



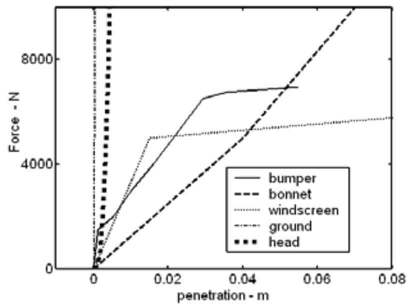


Figure 1: Model configuration

Figure 2: Contact characteristics

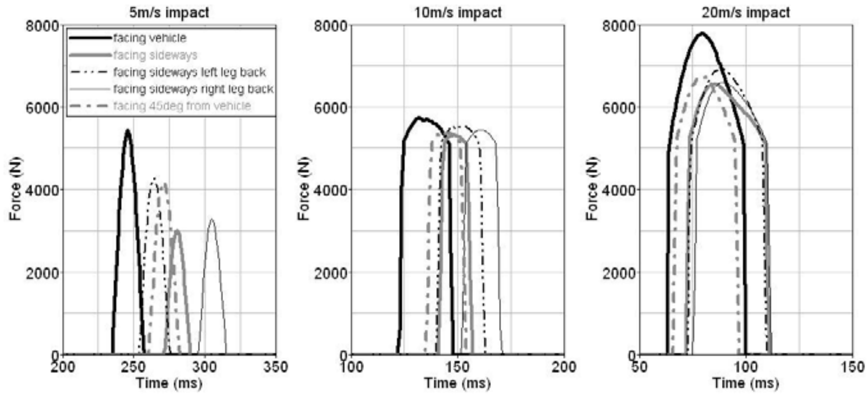


Figure 3 : postural alterations effects on vehicle/head contact force

The influence of leg position is very significant: when the non-struck leg lags behind, the pedestrian rotates about his/her vertical axis so that bonnet/windscreen contact occurs with the back of the head, while the reverse holds when the struck leg lags behind. The magnitude of the contact force is also variable at all three impact speeds, but especially at 5m/s-1 where the effect is nearly 20% for left leg back compard to right leg back. Within each speed category, the trends are consistent, but in real collisions local variations in bonnet/windscreen stiffness will partially mask this phenomenon.

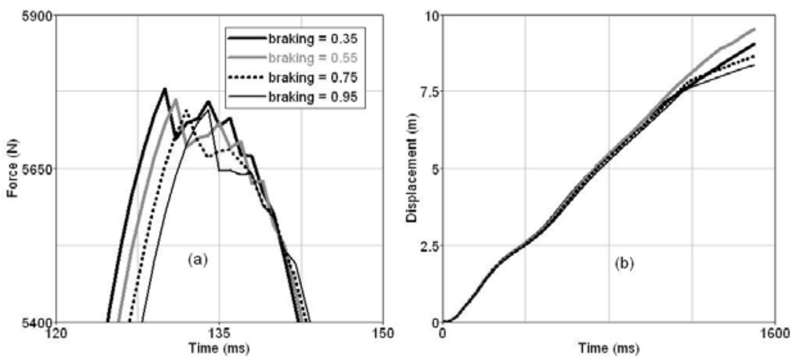


Figure 4. Braking effect on pedestrian head contact force (a) and total throw distance (b)

When facing the vehicle, head impact occurs earlier and the vehicle has therefore braked less,but this has little effect on the head contact force for the braking rates tested (μ =0.35-0.95) at 10m/s pre-impact vehicle speed. In contrast, this braking level does effect the total throw distance.

Pedestrian/ground contact: Figure 5 shows the predicted variation in pedestrian ground contact forces due to alteration in pedestrian pre-impact stance. By contrast with the vehicle contact, it is clear that the timing and peak magnitude of the ground contact is almost random with respect to the initial conditions. This is because the severity of the head ground contact is strongly affected by shielding of other body parts in some cases.

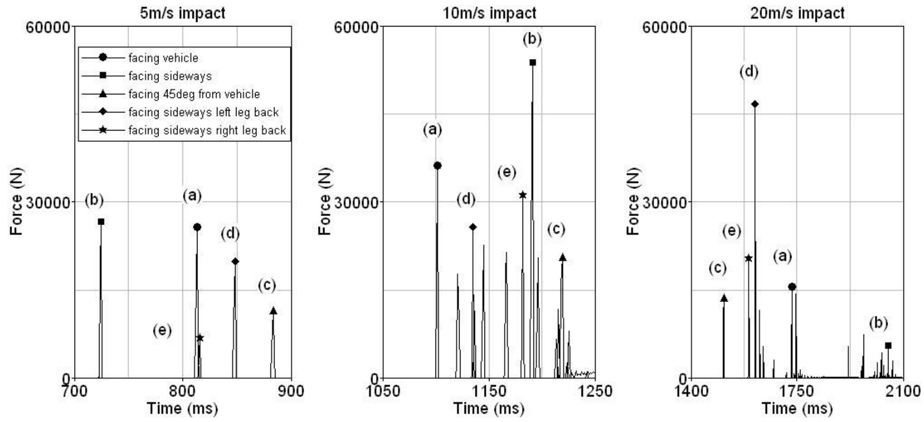


Figure 5 postural alteration effects on ground contact forces

The absolute magnitudes of both vehicle and ground contact loads are influenced by the head stiffness. However, since the same head characteristic is used for both, the relative effects of these can be assessed. Previous research on head injuries has shown that peak force or acceleration alone are insufficient to predict injury, as duration of loading is important. Furthermore, different kinds of head injuries are associated with different loading patterns. Therefore the duration Δt of the contact force and the head velocity change (Δv) during Δt for both the vehicle/head and vehicle/ground contacts are compared, see figure 6. It can be seen that for each impact speed the peak load in the ground contact is far higher than the vehicle head contact, but the associated momentum change is much lower. HIC values are not presented here as that method has been shown to be an oversimplification of head injury severity.

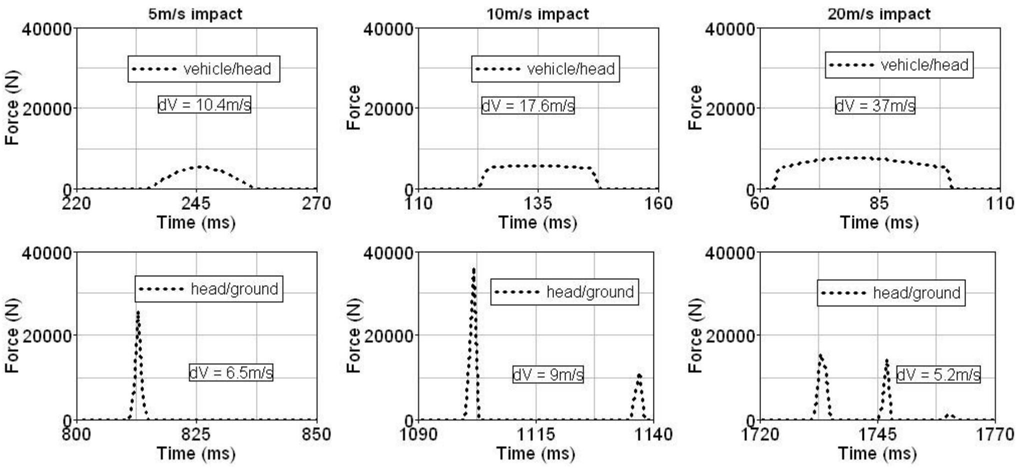


Figure 6: Contact forces and velocity changes for vehicle/head contact (top row) versus head/ground contact (bottom row) for initial stance of pedestrian facing vehicle (50ms window)

Pedestrian pre-impact velocity: It is well known that in cases where the pedestrian has a transverse velocity, subsequent movement can be significantly altered. Figure 7 shows that the head contact load from the vehicle is also significantly affected. The subsequent head ground contacts are, as before, highly variable and not shown as no pattern can be readily identified.

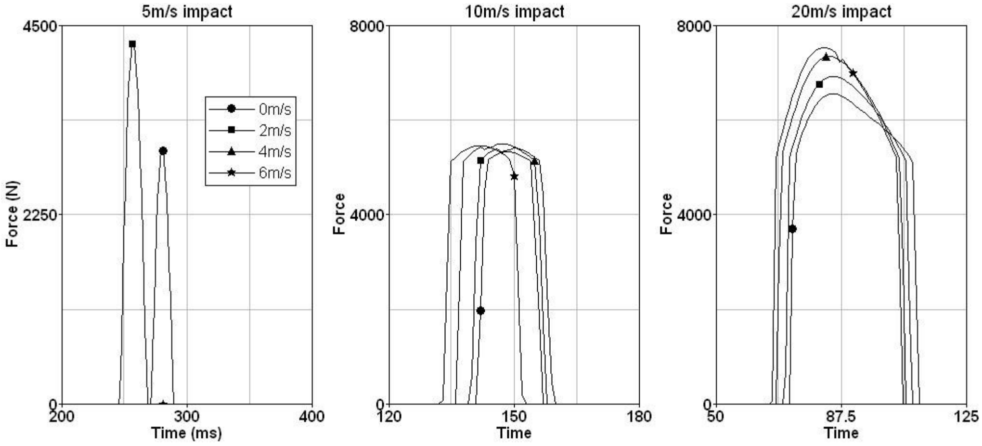


Figure 7 Influence of Pedestrian pre-impact velocities on vehicle head contact force

Case Study**:** To illustrate the variability, the following case is presented: a 14 year old girl running across a rural road was struck by a midsized car at about 20m/s. She suffered serious head injuries, but the only damage on the vehicle were twin indentations between the front grill and the bonnet corresponding to leg contact. Reconstruction was performed using the Madymo 5th percentile female model and a transverse speed of the girl varying from 0-6m/s. However, using any of the pre-impact stances described earlier, the vehicle/head contact absent in the real crash occurred in all simulations. The head contact with the vehicle could only be avoided if she was running diagonally away from the vehicle with a substantial forward tilt. The simulation subsequently showed a significant head impact with the road.

CONCLUSIONS

The initial pedestrian stance orientation has a significant measurable effect on the vehicle/head contact force. For the pedestrian/ground contact, very large and almost random variations in contact force occur as a result of different body parts absorbing the ground impact. Head contact with the ground results in higher forces acting over a shorter duration than the vehicle head contact force.

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