Human Model for Real-world Vehicle-Pedestrian Impact Simulations

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Abstract: A mid-size male pedestrian was modeled in LS-DYNA. The model was validated extensively at component-level as well as at full body-level. The pedestrian model is intended to reproduce specific lower limb injuries in a typical pedestrian impact with a passenger vehicle, such as long bone fracture and knee ligament tear. The model may be used to assess vehicle performance in real-world vehicle-pedestrian impact events.

Keywords: pedestrian impact, human model, lower extremity injury

1 Introduction

Pedestrians represent the most vulnerable road users. Given an impact event, the probability for a pedestrian to be injured in a traffic crash is much higher than that for an occupant. Per NHTSA's 2005 statistical data [1], about 88% of vehicle-pedestrian impacts result in injuries whereas this ratio for occupants involved in vehicle-to-vehicle crashes is only 32%. This phenomenon may be explained by their rather different impact conditions, but also by the widely implemented occupant protection technology in modern vehicles, while pedestrian protection technology is just coming due to the relative new requirement. There exist some other inherent issues regarding pedestrian protection, including the direct exposure of a vulnerable human body to the impact of a broad variation of vehicle front-ends and the very severe secondary collision to the ground which are almost uncontrollable.

The Commission of European Communities (CEC) has proposed a directive that will require all new automobiles sold in the European Union to pass pedestrian acceptance tests by 2015. Similar initiatives are underway world-wide. The CEC pedestrian acceptance tests are component tests proposed by the Working Group 17 of European Enhanced-Safety Vehicles Committee (EEVC/WG17) [2]. They include: headform impactor (both child and adult) to bonnet top, lower legform to bumper, and upper legform to bonnet leading edge. These tests are designed to assess pedestrian protection performance of a given vehicle for specific injury modes under certain impact conditions in an objective, reproducible manner. The head injury threshold adopted is HIC (15) value less than 1000 for two third of the test area, which address the injury caused by linear acceleration. The leg injury criterion includes knee bending moment, knee shear displacement, and upper tibia acceleration, which focus on fracture trauma. The upper leg injury criterions are impact force and bending moment.

The EEVC component tests have provided a means to assess the pedestrian protection performance of a vehicle design in the laboratory environment. However, they could not be used directly to assess a real-world vehicle-pedestrian impact event. A mid-size male pedestrian model was developed in LSDYNA to supplement the EEVC component tests [3]. This paper presents the validation work for this pedestrian model with full scale Post Mortem Human Surrogates (PMHS) tests.

2 Method

The pedestrian model consists of a rigid skull, a Finite Element (FE) cervical spine model [4], a FE thorax model with solid organs [5], a rigid pelvis, a FE pelvic flesh model, rigid hands models, FE lower limb models [3], and rigid foot/shoe models (Figure 1). The model is 177 cm high and weighs 77.36 kg, which represents a mid-size male [6]. The model has 134,603 nodes and 126,848 elements.

The neck model includes the vertebral bodies, ligaments, and muscles (Figure 1a). The thorax model consists of the spine, the sternum and the cartilage, the soft tissues, the heart, the lung, the blood vessels, the muscles, the shoulders, and the arms (Figure 1b). A rigid pelvis was generated to connect the head/neck/thorax model to the lower limb model. The lower limb model consists of long bones, flesh, skin, major ligaments, menisci, patella, tendon, and joint capsule. The lower limb mesh was generated using a "structural mesh approach" (over 95% hexahedral elements) with good mesh quality. The material properties of bone, menisci, and tendon were obtained from published data and material tests were conducted to characterize ligaments, flesh, and skin.

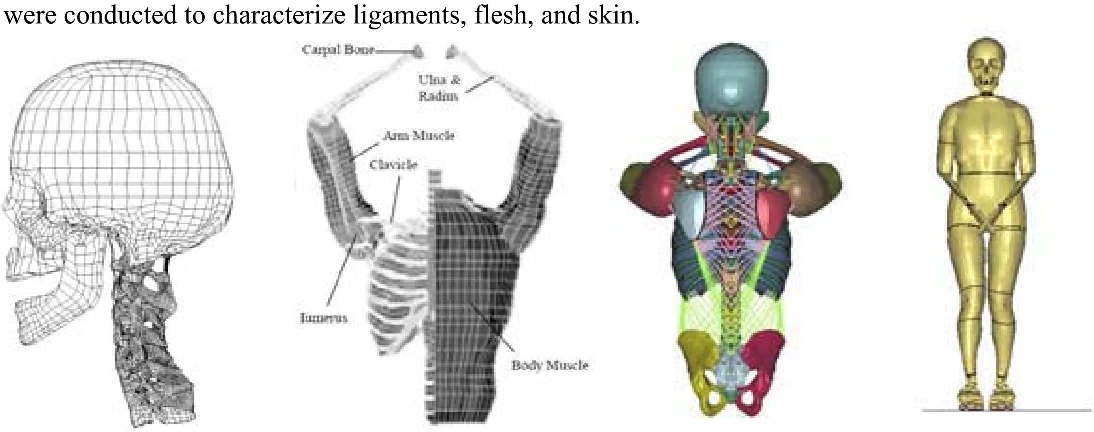


Figure 1 (a) Head/Neck model; (b) Thorax model; (c) Integrated head/neck/thorax with a rigid pelvis; (d) Full body pedestrian model.

Seven PMHS were tested in full-scale vehicle-pedestrian impact experiments under identical test conditions with a late-model mid-sized sedan. Tests were performed with the PMHS positioned laterally at the vehicle's centerline, in a mid-stance position, with the vehicle traveling at 40 km/h.

Vehicle-to-pedestrian impact tests were simulated in LS-DYNA (Figure 2). The model was set up as in the tests. The right (struck side) lower extremity was positioned behind the body and the left lower extremity was positioned in front of the body. A simplified vehicle buck model was given a 40 km/h initial velocity toward the pedestrian. Gravity was applied to the pedestrian. Proper contacts were defined between pedestrian body segments, between the pedestrian and the vehicle, and between the pedestrian and the ground.

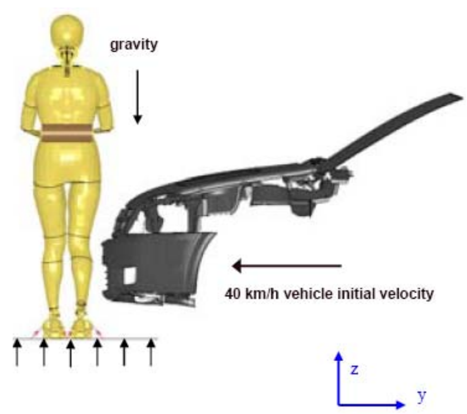


Figure 2 Vehicle to pedestrian impact simulations

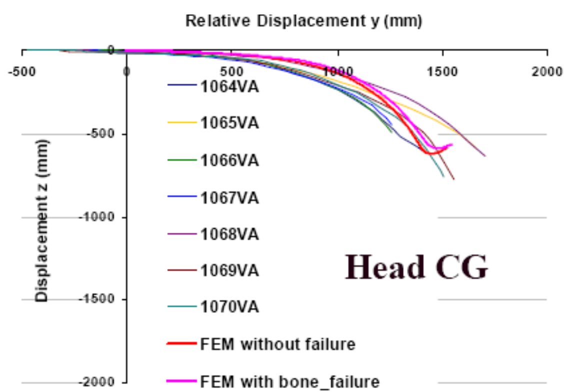
The time histories of nodal displacements corresponding to the photo targets in the tests were extracted from the simulations. Two simulations were run, one with bone failure defined and the other without bone failure defined. Maximum plastic strain was used in the model for bone fracture. The risks of ligament injuries were analyzed using the maximum tensile force in the ligaments in the simulations. The element elimination approach was not used for ligaments in current study due to the method's limitations.

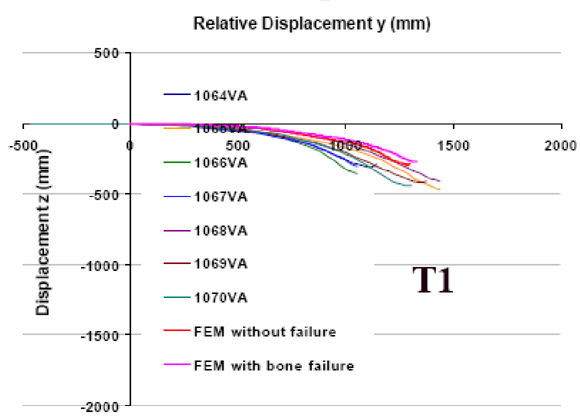
3 Results

The trajectories at the head CG, the T1, the pelvis, both femurs and tibias were compared to testing data (Figures 3 to 5). The head CG and T1 trajectories showed to be close to the lower bound of test data. Vertical displacement of the pelvis is much higher than the testing data. This is due to that pelvis fractures were not modeled in current simulation due to the rigid pelvic model. While bone fractures recorded in right leg reduce the vertical displacement of right lower limb, no effect was observed in the trajectories of the left limb.

A tibia fracture and a fibula fracture were observed in the right lower limb around 17 ms and 19 ms, respectively, in the simulation (Figure 6). The simulation result suggested that, during a 40kph car-to-pedestrian impact, the struck side leg is at the highest risk for bone fracture, the non-struck side has lower bone fracture risk, and both femurs are unlikely to be fractured. The model prediction is in good agreement with bone injuries observed in the car-to-PMHS impact tests, suggesting that the current pedestrian model might be used to predict bone fracture risks in car-to-pedestrian impacts.

In the pedestrian impact simulations, the risk of ligament injuries was analyzed using the maximum tensile force in the ligaments. The ligament forces recorded in the simulations showed higher injury risk in the left LCL. This is in good agreement with test data. However, since it did not use the element elimination option for the ligaments, the model can not predict the sequence of ligament rupture.





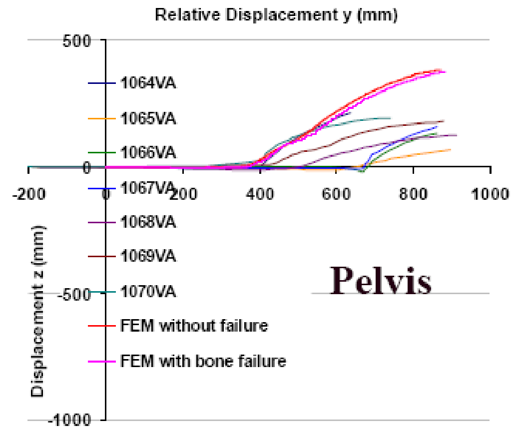


Figure 3 The head, T1 and pelvis trajectory comparisons

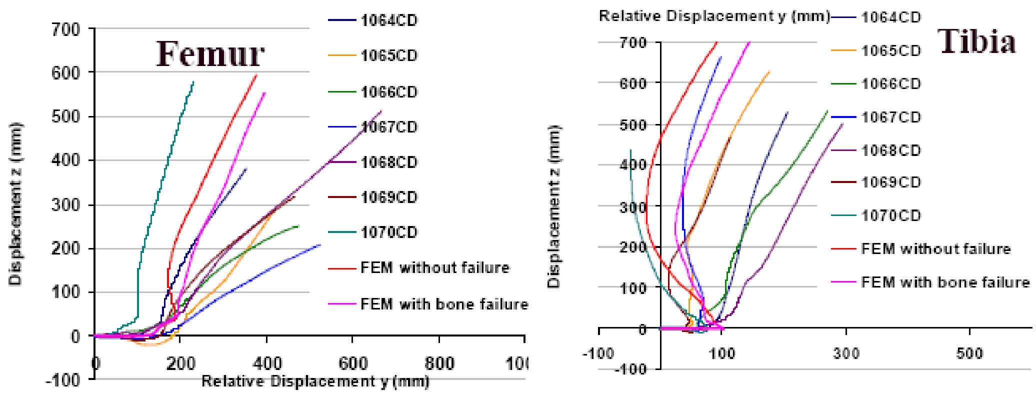


Figure 4 Right femur and tibia trajectory comparisons (struck side)

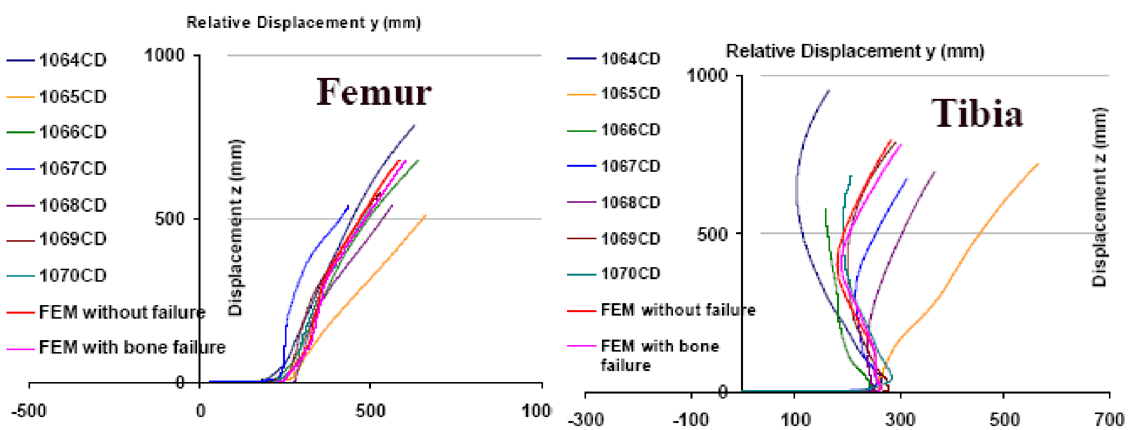


Figure 5 Left femur and tibia trajectory comparisons (non-struck side)

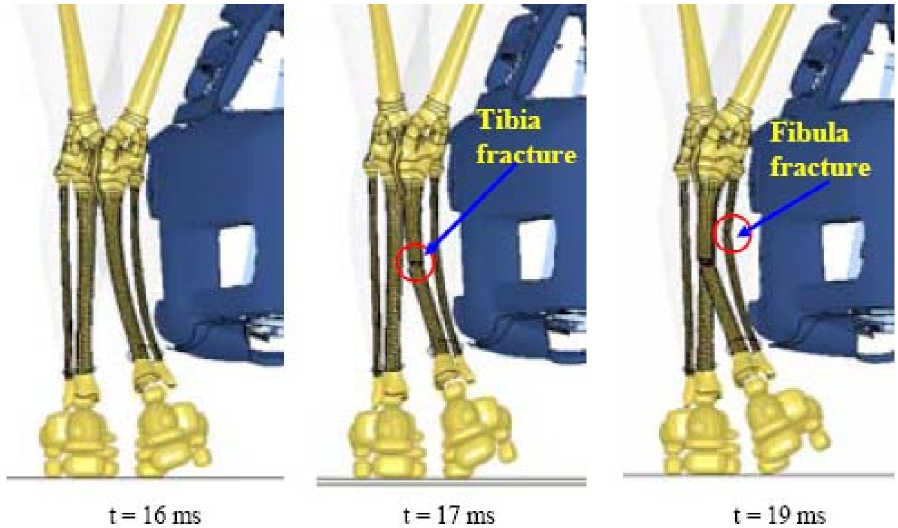


Figure 6 Right (struck side) tibia and fibula fractures in the simulations

4 Conclusions

A detailed full body mid-size male pedestrian model was validated. The model showed good agreement with tests specific to car-to-pedestrian loadings. The model correctly predicted the sequence of bone fractures observed in tests with injury values close to the leg tolerance data. The model also reproduced initial knee ligament tears in the non-struck side, and suggested that the strain rate effect on knee lateral bending is negligible.

Acknowledgments

This study is a joint effort between General Motors and University of Virginia. We acknowledge the contributions of Costin Untaroiu and Jeff Crandall from University of Virginia.

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