DEVELOPMENT OF AN FE BIOFIDELIC FLEXIBLE PEDESTRIAN LEG-FORM IMPACTOR (FLEX-GT-PROTOTYPE) MODEL

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ABSTRACT

The Japan Automobile Research Institute and the Japan Automobile Manufacturers Association, Inc., have been developing a biofidelic flexible pedestrian legform impactor (Flex-PLI) since 2002, and its latest version is called Flex-GT-prototype.
Flex-GT-prototype has flexible construction like human lower limb and is equipped with many sensors to evaluate the severity of pedestrian lower limb injuries in multiple locations. In this study, an FE Flex-GT-prototype model was developed, and its fidelity to an actual Flex-GT-prototype was verified at various evaluation conditions.

INTRODUCTION

Test methods for assessing the pedestrian protection performances of motor vehicles in pedestrian-vehicle collisions (hereafter simply "pedestrian protection test methods ") were developed by EEVC (European Enhanced Vehicle-safety Committee), ISO (International Organization for Standardization) and IHRA (International Harmonized Research Activity) in the past. At the present, the Pedestrian Protection Informal Group belonging to the United Nations ECE/WP29/GRSP plays the central role in the development of international pedestrian protection test methods.

In these test methods, the pedestrian lower limb protection test method is designed to collide a leg-form impactor, simulating a human lower limb, against a car, and measure the intensity of impact on a leg-form impactor. Therefore leg-form impactors are required to be highly biofidelic (i.e. having a response-to-impact characteristic equivalent to that of the human leg) and to be highly injury-assessable (i.e. enabling to accurately estimate the severity of leg injury to realworld pedestrians). However, the conventional leg-form impactor "TRL-LFI" which was developed by Transport Research Laboratory (TRL) [1] cannot reproduce the bending deformation characteristics of the human long bones due to the rigid structure of long bones, and the bending characteristics of the TRL-LFI knee is more stiffer than the one of human knee. For these reasons the appropriateness of TRL-LFI as an assessment tool has been in question [2, 3].

From such a background, the Japan Automobile Research Institute and the Japan Automobile Manufacturers Association, Inc., started to develop a biofidelic flexible pedestrian legform impactor (Flex-PLI) in 2002 [3, 4], and its latest version is called Flex-GT-prototype. In this study, a computer simulation model which has high capability on reproducing the Flex-GT-prototype responses was developed. The model can be used for finalizing the Flex-GT leg-form impactor specifications and improving various car front technologies for pedestrian lower limb protection.

FE FLEX-GT-PROTOTYPE MODEL

Model Construction

Figure 1 shows the overall construction of Flex-GT-prototype and its computer simulation finite element model ("FE Flex-GT-prototype model"). FE Flex-GT-prototype model is based on the Flex-PLI 2004 model developed by Honda R&D Co., Ltd. [5]. The body construction of the FE Flex-GT-prototype model consists of the thigh, leg, and knee parts.

As shown in Figure 2(a), the FE Flex-GT-prototype model has similar constructions of the actual thigh and leg of the Flex-GT-prototype. Regarding the knee, the FE Flex-GT-prototype model also has similar construction of the actual knee of the Flex-GT-prototype, then employs bar elements to simulate the knee ligaments while Flex-GT-prototype employs cables and springs to serve as the knee ligaments, as shown in Figure 2(b).

As shown in Figure 3, the FE Flex-GT-prototype model has the similar construction of the flesh of Flex-GT-prototype, so as to add the deformation characteristics of flesh.

Measurement Items

Figure 4 shows the measurement items of Flex-GT-prototype. The strain which is generated at various points on the surface of each bone core under an impact is measured by strain gages to determine the bending moment applied to the thigh and leg. The elongation which is generated in the knee ligaments due to the bending and shear deformation of the knee is measured by potentiometers installed along the ligaments. The FE Flex-GT-prototype model was designed to produce strain of the bone core (convert to bending moments using dynamic 3-point bending simulation results) and elongation of the knee ligaments, then can compare the actual Flex-GT-prototype measurement values.

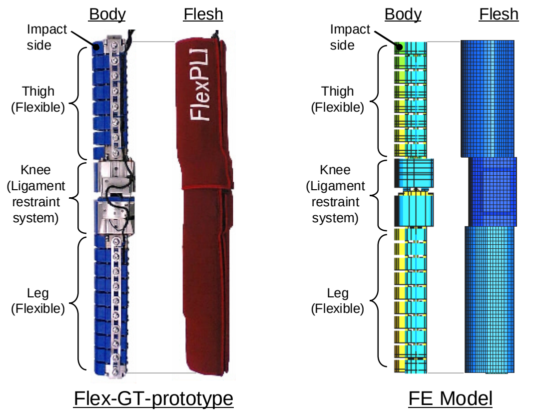


Figure 1. Overview of Flex-GT-prototype and FE Flex-GT-prototype model.

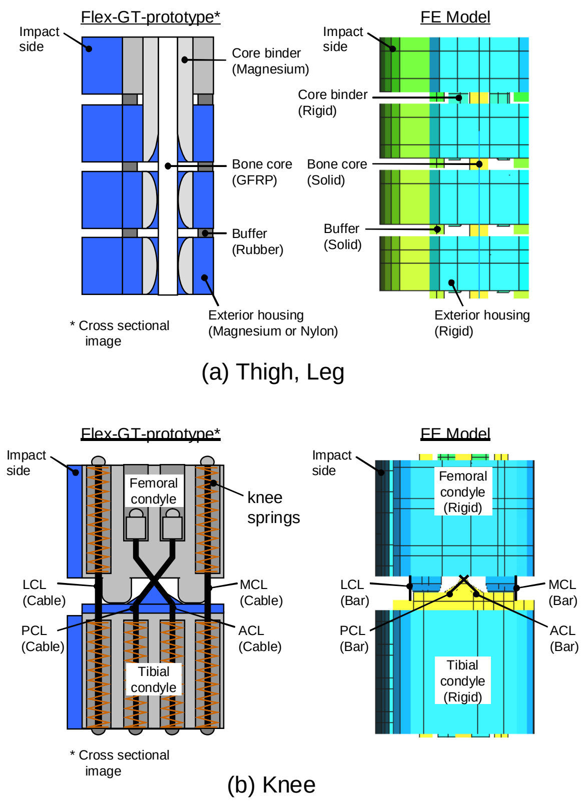


Figure 2. Body construction of Flex-GT-prototype and FE Flex-GT-prototype model.

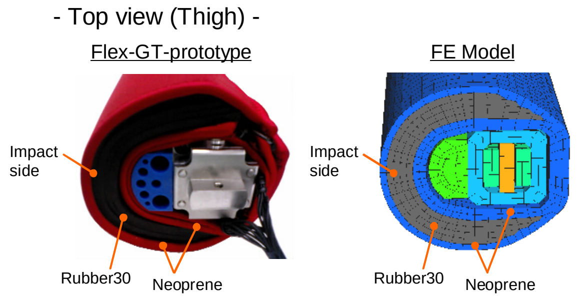


Figure 3. Flesh construction of Flex-GT-prototype and FE Flex-GT-prototype model.

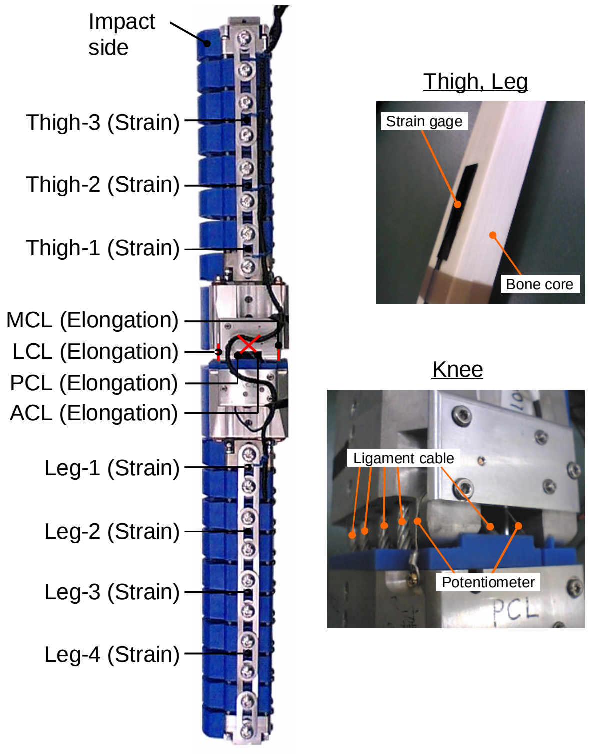


Figure 4. Measurement items of Flex-GT-prototype.

EVALUATION OF THE FE FLEX-GT-PROTOTYPE MODEL

The FE Flex-GT-prototype model was evaluated to verify its ability to simulate Flex-GT-prototype. The evaluation was conducted on the segmental models (Thigh, Leg, and Knee models), and the assembled model.

Evaluation of Segmental Models

Thigh and leg models

Figure 5 shows the dynamic 3-point bending simulation setup for evaluating the bending characteristics of the thigh and leg models. In this simulation, a solid ram was made to collide with the thigh or leg by free fall (Figures 6 and 7 shows the kinematics of thigh and leg 3-point bending), and the response characteristics of the thigh and leg models were compared with the experimental results of the Flex-GT-prototype thigh and leg.

Figures 8 and 9 compare the moment-deflection responses of the thigh and leg models with the experimental results of the Flex-GT-prototype thigh and leg in 3-point bending. The comparison indicates that, although the deformation characteristics of the thigh and leg models slightly vibrated in the early stage of deflection, the thigh and leg models both exhibited an overall deformation characteristic that is equivalent to the experimental results of the Flex-GT-prototype thigh and leg, respectively.

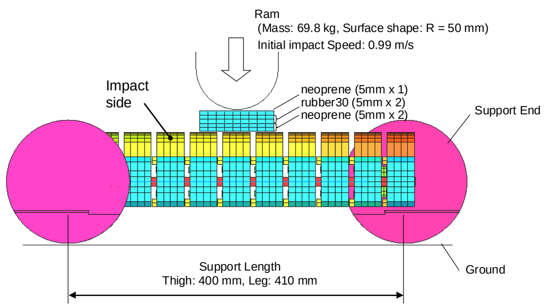


Figure 5. Dynamic 3-point bending simulation set up for thigh and leg of FE Flex-GT-prototype model.

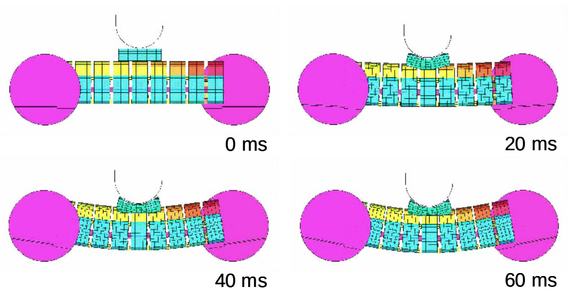


Figure 6. Thigh 3-point bending (Kinematics).

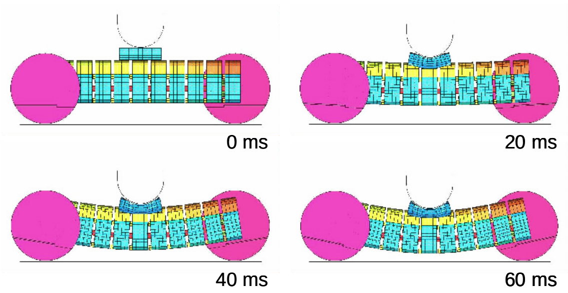


Figure 7. Leg 3-point bending (Kinematics).

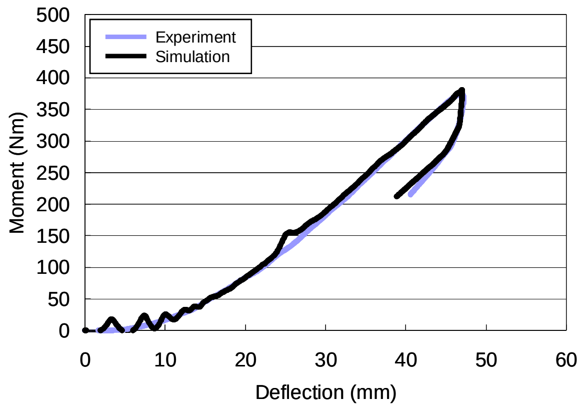


Figure 8. Comparison of moment-deflection response in dynamic thigh 3-point bending between experiment and simulation.

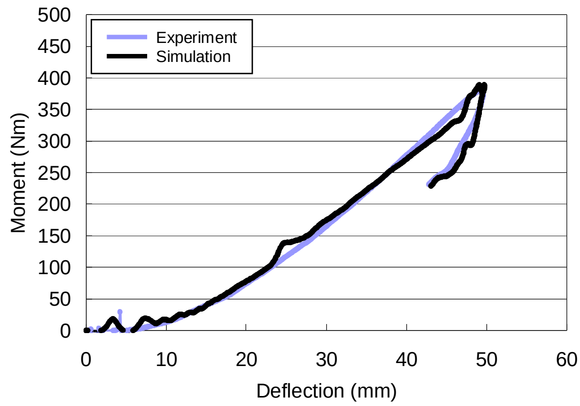


Figure 9. Comparison of moment-deflection response in dynamic leg 3-point bending between experiment and simulation.

Knee model

Figure 10 shows the dynamic 3-point bending simulation setup for evaluating the bending characteristics of the knee model. In this simulation, a solid ram was made to collide with the knee by free fall (Figures 11 shows the kinematics of knee 3-point bending), and the response characteristics of the knee model were compared with the experimental results of the Flex-GT-prototype knee.

Figure 12(a) compares the bending moment of the knee model with the experimental results of the Flex-GT-prototype knee in relation to the passage of time from the impact. Though containing some vibrations, the waveform of the knee model indicated an overall similarity to the experimental results of the Flex-GT-prototype knee.

Figure 12(b) compares the ligament elongation of the knee model with the experimental results of the Flex-GT-prototype knee in relation to the passage of time from the impact. The waveforms of the knee model indicated an overall similarity to the experimental results of the Flex-GT-prototype knee. Thus, the results reported in Figures 12(a) and 12(b) verify the equivalence of the knee model to the Flex-GT-prototype knee.

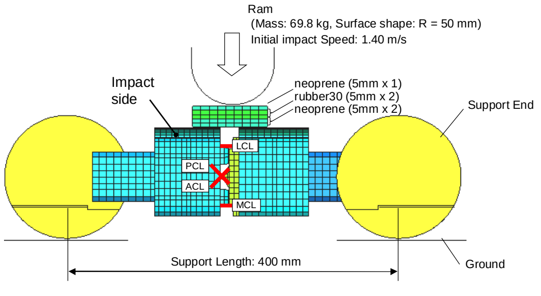


Figure 10. Dynamic 3-point bending simulation set up for knee of FE Flex-GT-prototype model.

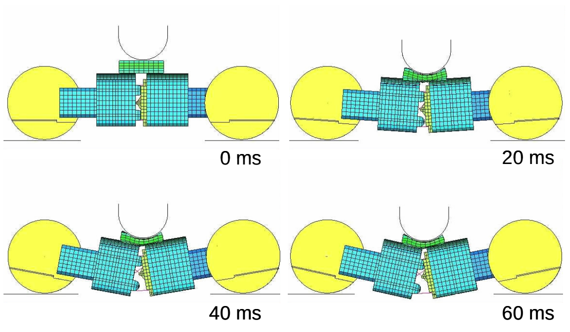
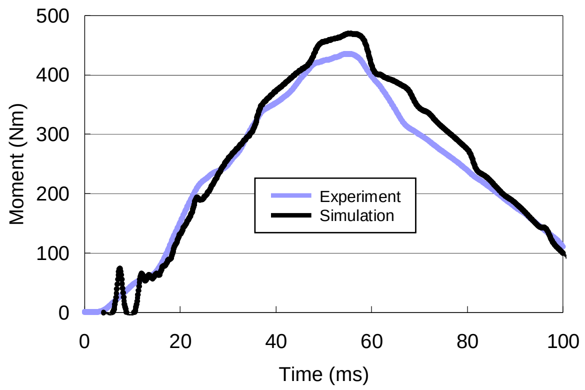
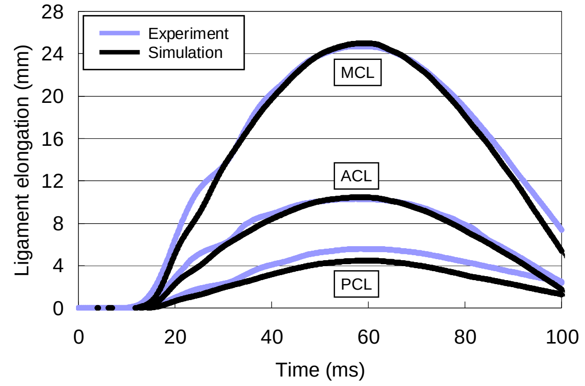


Figure 11. Knee 3-point bending (Kinematics).



(a) Moment



(b) Ligament elongation

Figure 12. Comparison of time history curve in dynamic knee 3-point bending between experiment and simulation.

Evaluation of Assembly Model

Assembly dynamic bending simulation

Figure 13 shows the dynamic bending simulation setup of the assembly model. In this simulation, the assembly model was made to collide with a rigid stopper by free fall from a revolutional joint with a one degree of freedom. Then, the response characteristics of the assembly model were compared with the experimental results of Flex-GT-prototype.

Figure 14 reports the waveforms and maximum values recorded by the assembly model at its various measurement points, together with the experimental results of Flex-GT-prototype. Although the waveforms of the assembly model slightly vibrated, they proved to be similar to the measured waveforms of Flex-GT-prototype. There was also a high degree of congruence between the simulation results and experimental results relating to the maximum value and the time at which the maximum value was generated.

The above comparative results verify that the FE Flex-GT-prototype model in the dynamic bending simulation gives responses equivalent to the responses of Flex-GT-prototype in its real calibration test.

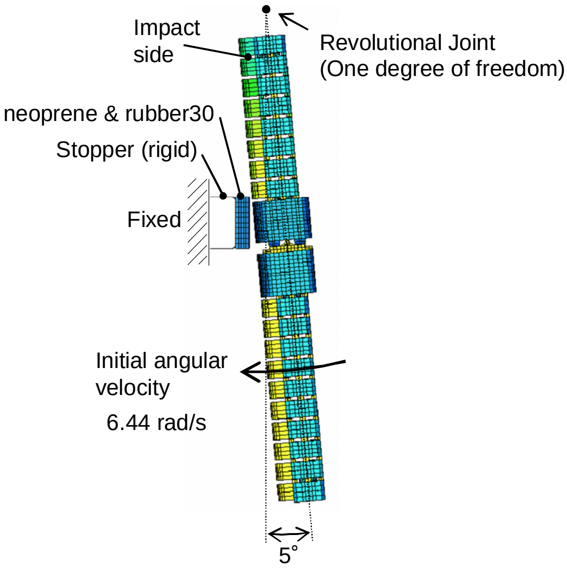
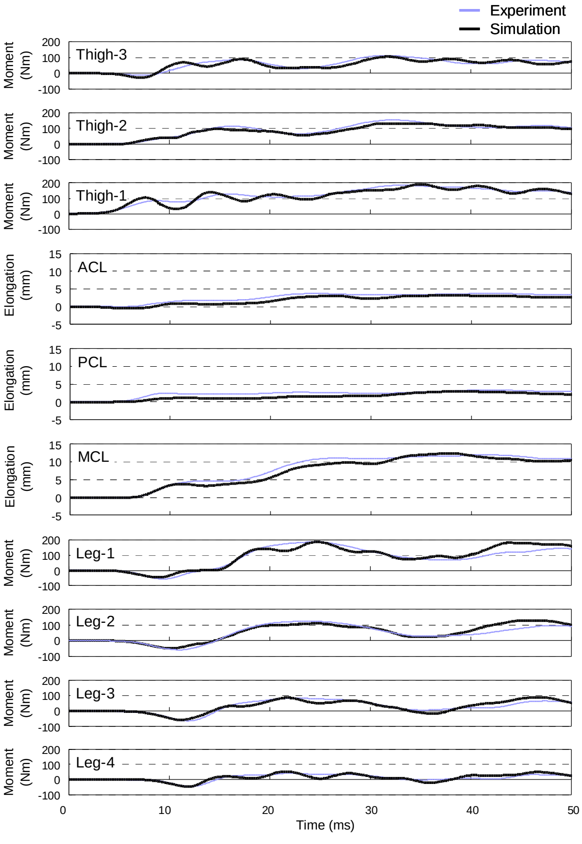
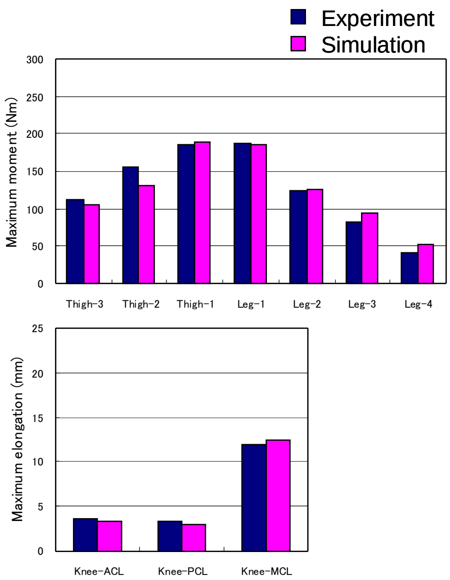


Figure 13. Dynamic bending simulation set up for FE Flex-GT-prototype model.



(a) Wave forms



(b) Maximum values

Figure 14. Results of dynamic bending simulation for FE Flex-GT-prototype model.

Simplified car collision simulation

Figure 15 shows the setup of a simplified car collision simulation. The FE Flex-GT-prototype model was made to collide with a simplified car model at an initial impact speed of 11.1 m/s. The simplified car model was composed of a BLE (bonnet leading edge) model, BP (bumper) model, and SP (spoiler) model each having shell elements for simulating the characteristics of automotive steel sheets. The responses of the FE Flex-GT-prototype model were compared with the experimental results of Flex-GT-prototype.

Figure 16 shows the behavior of the FE Flex-GT-prototype model in the simplified car collision test and the behavior of Flex-GT-prototype in an actual car collision test. It is evident that the FE Flex-GT-prototype model closely simulates the flexible behavior of Flex-GT-prototype when colliding with a car.

Figure 17 compares the response waveforms and maximum values of the FE Flex-GT-prototype model with the experimental results of Flex-GT-prototype. Both indicated a high similarity in waveform shape, maximum value and the time at which the maximum value was generated.

The above comparative results verify that the FE Flex-GT-prototype model in a simulated car collision test generates responses equivalent to the responses of Flex-GT-prototype in its real collision test with a car.

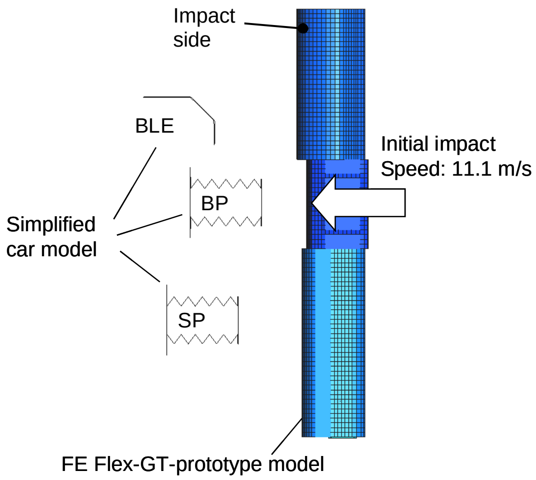


Figure 15. Collision simulation setup with Flex-GT-prototype and simplified car model.

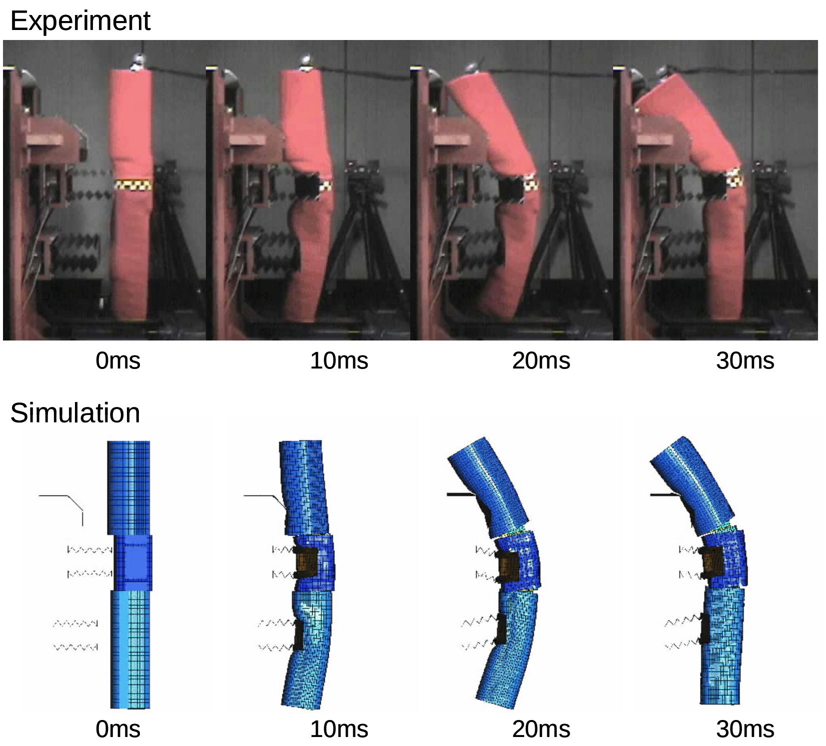
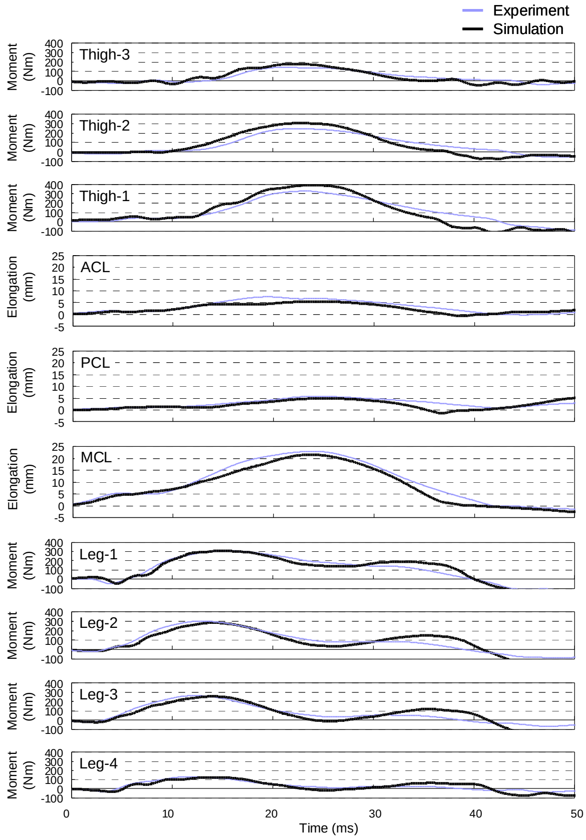
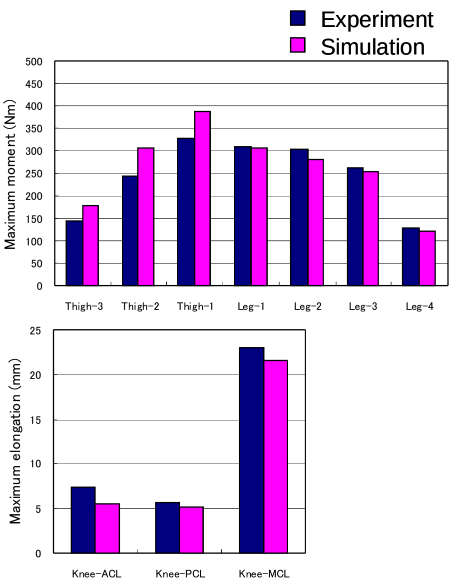


Figure 16. Collision simulation with Flex-GT-prototype and simplified car model (Kinematics).



(a) Wave forms



(b) Maximum values

Figure 17. Results of collision simulation with Flex-GT-prototype and simplified car model.

CONCLUSION

In the present study, a computer simulation model of the latest version pedestrian leg-form impactor, FE Flex-GT-prototype model, was developed, and its fidelity to an actual Flex-GT-prototype was evaluated.

Based on the evaluation results under the segmental level (thigh, leg, and knee parts) and assembly level loading conditions, it was verified the equivalence of the FE Flex-GT-prototype model to an actual one.

It is planned that this computer simulation model will be used in finalizing the Flex-GT leg-form impactor specifications and improving various car front technologies for pedestrian lower limb protection.

ACKNOWLEDGEMENT

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