Development of the FLEX-PLI GTR Regulated Borderline© FE model

Pradeep Mohan, Chirag S. Shah

I. INTRODUCTION

Pedestrian safety has posed new challenges and serious concerns in traffic accidents in recent years. The lower limb was found to be the most frequently injured body region with AIS 2+ level injuries in about 33% of cases worldwide with significant socioeconomic impact [1][2].

In 1998, the European Enhanced Vehicle-Safety Committee (EEVC) proposed a test procedure to assess protection to the lower extremity of a pedestrian during a collision [3]. A leg-form Impactor composed of rigid long bones was utilized in this procedure. In recent years, a more biofidelic leg-form impactor know as **FLEX**ible - **P**edestrian **L**eg-form **I**mpactor (FLEX-PLI) has been developed to address pedestrian safety regulatory requirements representing an average adult male right side leg. As opposed to the leg-form impactor with rigid bone parts, the FLEX-PLI is more biofidelic especially for its long bone parts, which have human-like bending characteristics [4]. The FLEX-PLI also provides extended injury assessment capabilities, including long bone bending moment at multiple locations and knee ligament elongations in comparison to other pedestrian leg-forms [4]. Several iterations of the FLEX-PLI hardware under direction of the FLEX-PLI Technical Evaluation Group (FLEX-TEG) resulted in the latest FLEX-PLI Global Technical Regulation (GTR) regulated hardware adapted in Europe and Japan for the pedestrian safety regulatory requirements.

As with any safety devices, the FLEX-PLI GTR hardware has variability in performance coming from the hardware itself due to materials and manufacturing and the environment in which it is applied. To account for the hardware variability, acceptance corridors are defined. These acceptance corridors depicts the range in which the hardware must fall to be approved for subsequent testing applications.

The typical FE model of the FLEX-PLI GTR Regulated hardware can only produce one response/output (standard or nominal) within the acceptance corridors. Any specific trend for a specific hardware for example higher or lower value of any specific output will result in large discrepancies between test and the standard FE model as shown in Fig. 1 between blue line (standard FE model response) and the grey line (test) data curves. To minimize this discrepancy a novel approach has been developed to optimize the FE model performance to accurately match the test curve as shown in Fig. 1 between red line (optimized FE model) and grey (test) data curves. The objective of current study is to describe development of the method or process to accurately capture the hardware variability. The outcome is the FE model referred hereafter as FLEX-PLI GTR Regulated Borderline© finite element (FE) model. This model is capable of matching each individual hardware response accurately so the hardware trends can be captured. This ensures that the FE model used to simulate with a specific hardware testing can have a minimum discrepancies between the FE model and the hardware to begin with. The advantage of this method is reduced error margins between the FE model and hardware testing as the model is customized to match a specific hardware.

II. METHODS

State of the art FE model referred hereafter as the standard (or nominal) model of the latest FLEX-PLI GTR Regulated hardware has been developed and validated against a variety of loading conditions to ensure the desired performance. The model consists of three regions: femur, knee and tibia (Fig. 1). Both femur and tibia regions have segmented structures with bone cores in the center to provide necessary bending characteristics. The femur bone core has three and tibia bone core has four locations to measure bending moments.

Pradeep Mohan is working as General Manager at Humanetics Innovative Solutions India Private Limited (E-mail: pmohan@humaneticsatd.com Phone: +91-80-6781 9645). Chirag S. Shah is working as Project Manager at Humanetics Innovative Solutions, Inc. (USA).

The knee comprised of elongation measurement capabilities for the four major ligaments: anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL) and lateral collateral ligament (LCL). The complete hardware is wrapped with neoprene and rubber layers to represent the flesh (Fig. 1). The four tibia moments and elongations of the ACL, PCL and MCL are implemented for injury assessment for the regulatory requirements.

The standard model predicts nominal response and has limitation of realizing the hardware performance trends within the certification range. To capture the trend of a specific hardware, the feature called borderline has been developed as add on to the standard nominal FE model. User can enter the peak signal values from one of the certification loading conditions for all the seven injury channels and the borderline feature will optimize the model response of matching the certification test data within 2% accuracy for the signal peak values. Unlike the standard model, the performance/behavior of the borderline model changes based on the user input to match a specific hardware trends.

III. INITIAL FINDINGS

The inverse certification results from the model for two extreme signal peak values of MCL are presented as an example to explain the concept and functionality of the borderline feature. Fig. 2 shows when the hardware has a performance trend of producing higher or lower MCL elongations due to materials and manufacturing. The optimized model after implementing the borderline feature can capture both the high and low MCL trend accurately while the standard model showed larger discrepancies.
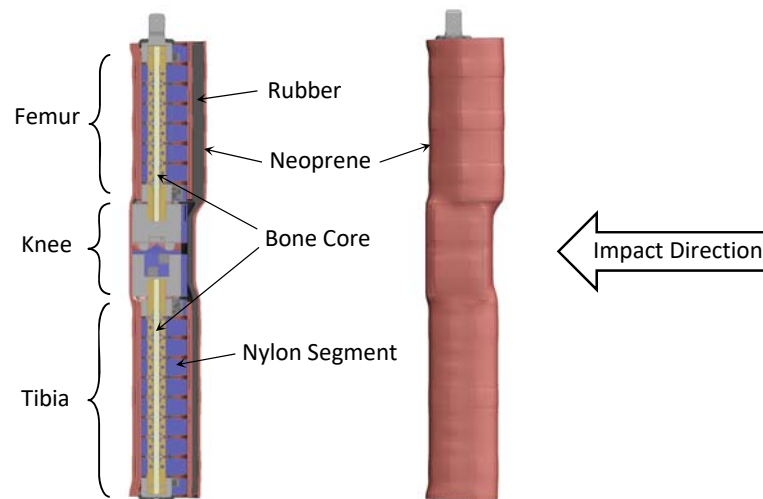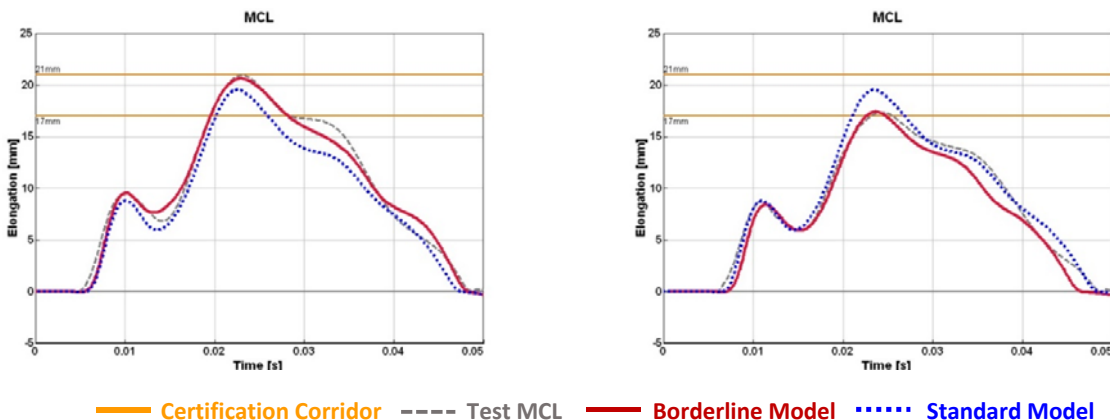

Fig. 1: FLEX-PLI GTR (Regulated) FE Model

Fig. 2: Borderline FE model feature for capturing the high and low MCL hardware performance trend

IV. DISCUSSION

Hardware performance variability is inevitable. The standard nominal model can predict only one response despite hardware variability. The FLEX-PLI GTR regulated borderline model can be customized to match individual hardware response based on the inverse certification test. The borderline model is capable of predicting the FLEX-PLI hardware variation from certification to vehicle like cases. Environment variability is not within the scope of the FLEX-PLI GTR regulated borderline model. The borderline feature can be used with or without the hardware certification data. However, user is cautioned for application of this feature for any values not coming from the actual hardware inverse certification test and the consequential results of the model.

V. REFERENCES

[1] Mizuno Y. (2005) "Summary of IHRA Pedestrian Safety WG Activities – Proposed Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars", Paper No. 05-0138, ESV.

[2] Konosu A. (2008) "Development of Flexible Pedestrian Legform Impactor (FLEX-PLI) and Introduction of FLEX-PLI Technical Evaluation Group (FLEX-TEG) Activities", http://www.sae.org/events/gim/presentations/2008konosul.pdf, SAE Government/Industry meeting.

[3] European Enhanced Vehicle-safety Committee: EEVC Working Group 17 report (1998). "Improved test methods to evaluate pedestrian protection afforded by passenger cars".

[4] Konosu A. and Tanahashi M. (2005) "Development of a biofidelic Flexible Pedestrian Leg-form Impactor (FLEX-PLI 2004) and Evaluation of its biofidelity at the Component and at the Assembly Level", SAE paper No. 2005-01-1879.