

External Biofidelity Evaluation of Pedestrian Leg-Form Impactors

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ABSTRACT

Current state-of-the-art vehicles implement pedestrian protection features that rely on pedestrian detection sensors and algorithms to trigger when impacting a pedestrian. During the development phase, the vehicle must “learn” to discriminate pedestrians from the rest of potential impacting objects. Part of the training data used in this process is often obtained in physical tests utilizing legform impactors whose external biofidelity is still to be evaluated. This study uses THUMS as a reference to assess the external biofidelity of the most commonly used impactors (Flex-PLI, PDI-1 and PDI-2). This biofidelity assessment was performed by finite element simulation measuring the bumper beam forces exerted by each surrogate on a sedan and a SUV. The bumper beam was divided in 50 mm sections to capture the force distribution in both vehicles. This study, unlike most of the pedestrian-related literature, examines different impact locations and velocities. The results show how the Flex-PLI and the PDI-1 exert greater forces on the bumper beam than the THUMS, while the PDI-2 produced bumper beam forces similar to the THUMS. The PDI-2 is often used to represent the Hardest To Detect (HTD) surrogate in pedestrian detection assessments. These results indicate that the PDI-2 produces bumper forces similar to what would be produced by a 50th percentile male, suggesting that an alternative means may be needed to evaluate HTD scenarios. These results also suggest that the Flex-PLI or the PDI-1 are likely to produce bumper forces greater than would be produced by contact with a human. Studies with different vehicle and pedestrian sizes would be needed to fully understand the impactors’ performance.

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INTRODUCTION

Pedestrian related accidents are a global concern accounting for 22% of the fatalities worldwide. These numbers increase in low income countries where pedestrian fatalities can reach over 50% of all road related fatalities [1]. Since 2003 law makers and consumer groups [2] have developed test procedures to evaluate pedestrian crashworthiness, seeking to drive the field to reduce injuries and fatalities. Modern state-of-the-art vehicles aim for enhanced protection levels by using active devices. These vehicles implement active pedestrian protection features (i.e. pop-up hoods, pedestrian airbags, etc.) in an effort to mitigate injuries in case of accident. These pedestrian protection devices rely on pedestrian detection sensors (i.e. accelerometers, fiber optic and pressure sensors, etc.) and algorithms to trigger when impacting a pedestrian.

Throughout the development phase, the vehicle must “learn” to discriminate pedestrians from other potential impacting objects such as animals, stones, walls, vehicles, shopping carts, traffic cones, etc. During the learning process, a series of fire and non-fire scenarios sensor readings (training data) is fed into a machine learning software that eventually generates the firing algorithm to be implemented in the electronic control unit of the vehicle (ECU).

As in any machine-learning-generated code, the quality of the training data is key to generate the desired system response. Feeding the algorithm with unrealistic or non-biofidelic data would cause the system to misbehave. Although a number of computational models (human body models, non-fire impacting objects, etc.) are available for the OEMs to generate the needed training data, part of this data is often obtained in physical tests utilizing impactors whose external biofidelity is still to be evaluated. The ability of these impactors to exert human-like loads on the pedestrian detection sensors is key for the success of the discrimination learning process.

Some of the most commonly used impactors are the Flex-PLI, PDI-1 and PDI-2. The Flex-PLI is a leg-form impactor design to predict injury in pedestrian impacts [3], [4]. Both the PDI-1 and PDI-2 were designed and developed to excite the sensing system in a human-like manner. The first is intended to represent a 6 year-old pedestrian [5] while the latter is intended to be the hardest-to-detect surrogate (HTD) [6], i.e. to generate the lowest trigger signal on the pedestrian detection system. These impactors are not only used by manufacturers to set-up their sensing systems but also by consumer groups [7] to test them. This fact adds a particular issue since the manufacturer is pushed to utilize these physical impactors as valid surrogates regardless of their biofidelity levels, potentially undermining real world pedestrian detection.

Very little literature has been published regarding the external biofidelity of these impactors, i.e. their ability to exert human-like loads on the vehicle. Furthermore, the available literature is often limited to one impact point, one impactor and one velocity [8]. Further evaluation of the external biofidelity of pedestrian leg-form impactors is needed. The present study evaluates the external biofidelity of Flex-PLI, PDI-1 and PDI-2 and their suitability for the evaluation of pedestrian detection systems.

METHODS

Four different surrogate Finite Element (FE) models (Academic THUMS Version 4.01, Humanetics FLEX_PLI-2.0.2, PDI-1 and PDI-2) and two vehicle FE models (sedan and SUV) were utilized in this study to evaluate the impactors' external biofidelity. The simulations were conducted in LS-DYNA mpp s R7.1.1

THUMS

The AM50 THUMS pedestrian FE model (version 4.01) was acquired from LSTC. THUMS is a human FE model developed by Toyota Motor Corporation and Toyota Central R&D Labs., Inc. The model aims to simulate human body kinematics and injury responses of a 50th male with a height of 175 cm. The total number of element is around 2,000,000 in the current version [9]. Its validation includes femur, tibia and fibula bending, dynamic toe impact, pelvic impact and knee shearing and bending among others. Although there is no study addressing its external biofidelity explicitly, some of the results from the knee shearing and bending show good external biofidelity [10].

THUMS was positioned 30 mm above the ground to account for shoe height [11], in the stock posture (standing with its legs side by side) facing the left side of the vehicle. No tissue failure was defined. THUMS is used as a reference to assess the external biofidelity of the impactors.

Flex-PLI

The Flex-PLI is an impactor intended to represent a 50th percentile male leg [3], [4]. This impactor has been designed to predict injury in pedestrian impacts and is used by different consumer groups to assess injury and evaluate the performance of the pedestrian detection sensors [7]. Unlike its predecessor, the Transport Research

Laboratory legform (TRL), the Flex-PLI is composed of individual lumped masses connected by a central deformable core. The knee consists of two metal blocks representing distal femur and proximal tibia with a urethane layer between them. Medial and lateral collateral ligaments and anterior and posterior cruciate ligaments are represented by extendable wires. The Flex-PLI is instrumented to measure femur and tibia moments as well as knee acceleration and ligament elongation. The validation of this impactor includes: thigh and leg bending, knee bending and shearing, tibia load and MCL elongation among others [3], [4]. To our knowledge, no work has been published evaluating its external biofidelity.

The Flex-PLI [12] was positioned in two different locations: one matching THUMS's knee height and a second one matching Euro NCAP impactor height [7].

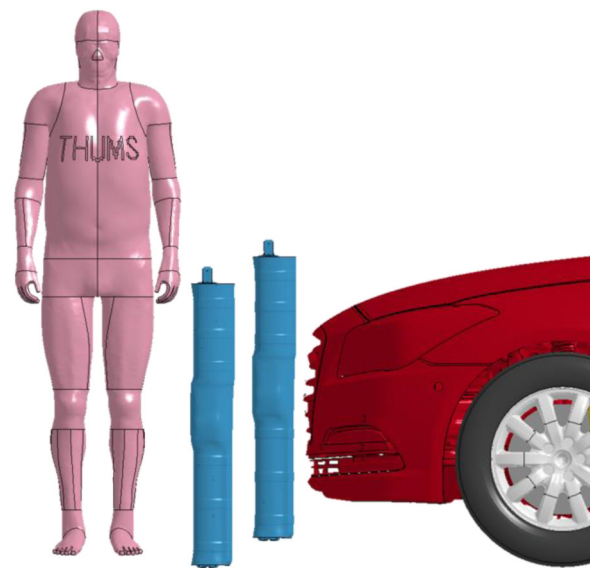


Figure 1. THUMS, Flex-PLI at THUMS's knee position and Flex-PLI at Euro NCAP position in front of sedan

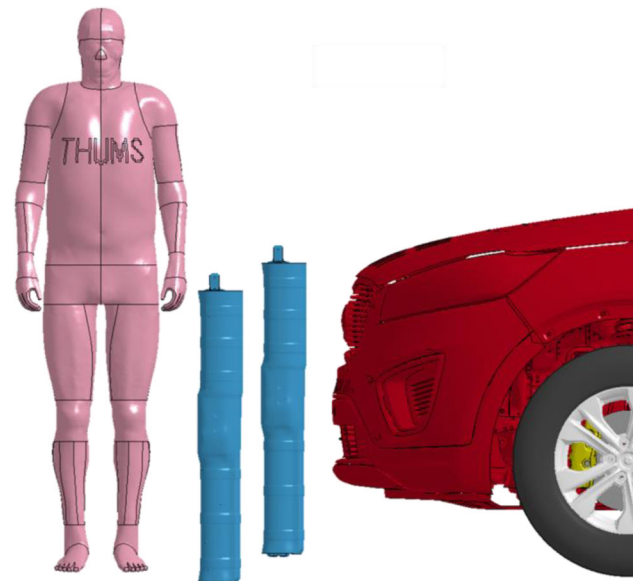


Figure 2. THUMS, Flex-PLI at THUMS's knee position and Flex-PLI at Euro NCAP position in front of SUV

PDI-1 and PDI-2

The PDI-1 is a pedestrian impactor intended to replicate loads on the vehicle comparable to a 6 year old dummy [5]. The PDI-2 is a pedestrian detection impactor intended to represent the worst case of the lower trigger level, or Hardest To Detect surrogate (HTD) in velocities ranging from 20 to 40 km/h [6]. Both impactors were design to realistically excite the pedestrian detection systems of the vehicle.

The PDI-1 and PDI-2 were positioned at ground height, according to their standard testing protocols [8].

Table 1. Surrogate mass and center of gravity height

Surrogate	Mass [kg]	Center of Gravity [mm]
THUMS	73.5	1045
THUMS's leg	10.9	563
PDI - 1	9.9	654
PDI - 2	6.73	650
Flex-PLI	12.9	511
Flex-PLI Euro NCAP	12.9	599

Table 1 shows the information regarding the mass and Center of Gravity (CoG) of the different surrogates. Information about THUMS's leg (isolated from the rest of the body) is also provided as a base for impactor performance evaluation.

Vehicles

The vehicle models in this study are simulation models utilized by Hyundai Motor Company (HMC) in their development phases. The selected vehicles include a sedan and a SUV with weights of 2050 and 2070 kg respectively.

Since most of the pedestrian detection systems include a bumper beam sensor (pressure, fiber optic, etc.), the study evaluates the external biofidelity of the different impactors by measuring the forces exerted on the bumper beam. The contact between the bumper beam and the rest of the vehicle was divided in 50 mm sections to capture not only total forces but also the distribution of those forces along the bumper beam.

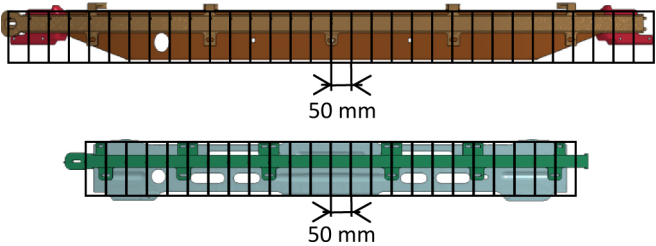


Figure 3. Sedan and SUV bumper beam section division for bumper beam force measurement

Simulation Set-Up

Simulations were conducted with the different surrogates at different impact locations and velocities (Table 2). The impact location is labeled using the distance from the impacting point to the center of

the vehicle in millimeters and the letter L indicating that the impact happens on the left side of the vehicle. The impact locations were chosen to match the center of the vehicle, its long member and the end of the bumper beam.

In the case of impactor simulations, the velocity was set by imposing an initial velocity to the impactor while in case of simulations with THUMS, the velocity was set by initial velocity and prescribed velocity on the vehicle model.

Table 2. Simulation matrix

Vehicle	Impact Location	Velocity [km/h]
sedan	Center line (000L)	25
sedan	435L	40
sedan	701L	25
SUV	Center line (000L)	25
SUV	498L	40
SUV	579L	25

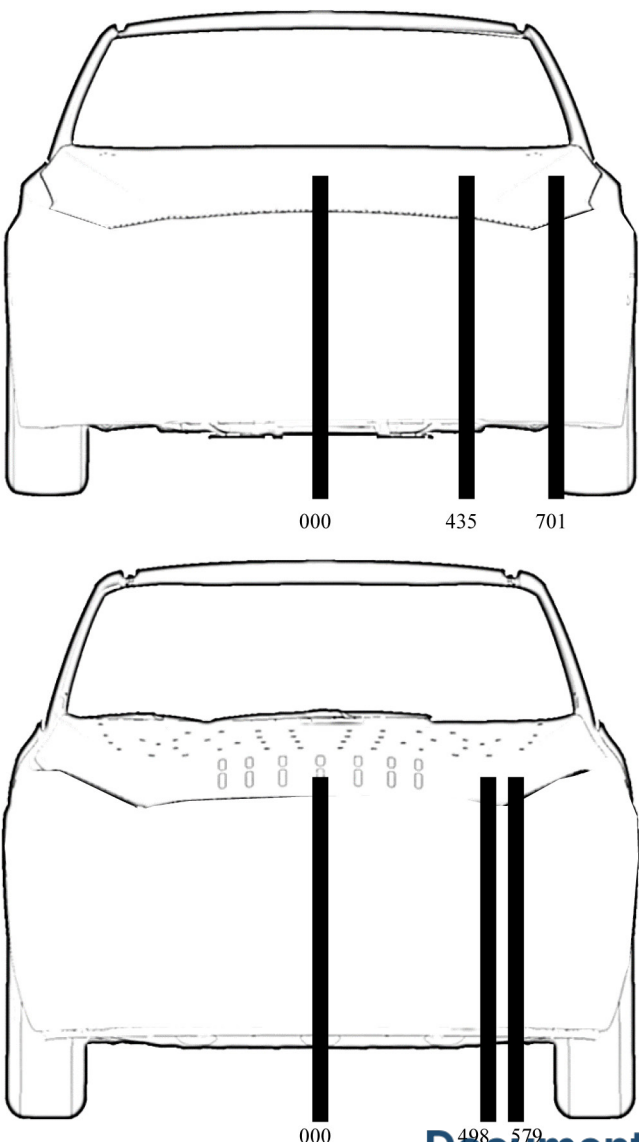


Figure 4. Sedan and SUV impact locations