

Flex-PLI Application to High-Bumper Vehicles - Optimization of Supplemental Weight

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ABSTRACT

The Flexible Pedestrian Legform Impactor (Flex-PLI) was developed to evaluate the risk of pedestrian lower extremity injuries. However, it has been pointed out that the post-crash kinematics of the Flex-PLI differs from those of a human body when it is hit by high-bumper vehicles. This paper describes the feasibility of applying the Flex-PLI to a wide range of vehicle types by adding a supplemental weight. The following aspects are discussed in this regard:

- A human body finite element (FE) model analysis shows that the upper body of the Flex-PLI is not involved in tibia and knee ligament injury indexes in the first contact with a high-bumper vehicle.
- A rigid bar model is introduced and its rotational energy ratio is formulated. The rotational energy ratio is employed to evaluate the post-crash kinematics of the Flex-PLI and a human leg model.
- The feasibility of adding a supplemental weight to the Flex-PLI with regard to the bumper height is discussed.

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INTRODUCTION

The Flexible Pedestrian Legform Impactor (Flex-PLI) was first developed by the Japan Automobile Manufacturers Association, Inc. (JAMA) and the Japan Automobile Research Institute (JARI) in 2002. It simulates the flexible motion of the human lower extremities. Its biofidelity has been validated and its post-crash kinematics has also been examined [1,2,3,4,5,6].

However, it has been pointed out that the Flex-PLI kinematics is not always consistent with those of a human body when it is struck by a high-bumper vehicle. Lack of weight corresponding to the upper part of the human body causes the Flex-PLI to be thrown ahead of the vehicle. A previous study proposed adding a supplemental weight to the top of the Flex-PLI to make it applicable to high-bumper vehicles [7].

This paper presents a theoretical solution to optimize the supplemental weight for the Flex-PLI to make its post-crash kinematics matches that of a human body. A human body finite element (FE) model developed by JAMA and JARI was used to simulate human body kinematics [8,9,10].

At the first stage of this study, the kinetic energy history of the human FE model was observed on a part-by-part basis. This was done for both a sedan and a sport utility vehicle

(SUV) in order to examine which parts of the human body should be selected as the counterparts of the Flex-PLI.

At the next stage, a rigid-body kinematics model was employed to estimate the initial movement of the Flex-PLI and a human leg FE model. A supplemental weight for addition to the Flex-PLI was optimized to make the rotational energy ratio match that of the human leg model.

By optimizing the mass and the height of the supplemental weight, the rotational energy ratio of the Flex-PLI is made equal to that of the human leg model. A single combination of optimum mass and height is proposed. The feasibility of adding the supplemental weight in accordance with the bumper height is also discussed in the final part of this paper.

REAL-WORLD BUMPER HEIGHT

The relative height of the pedestrian center of gravity (COG) and the vehicle bumper height are decisive factors affecting post-crash human kinematics [11]. Figure 1 is a histogram of the bumper height, summed up from 534 vehicles in the pedestrian accident database of the National Automotive Sampling System Pedestrian Crash Data Study (NASS-PCDS) [12]. The PCDS categorizes the vehicles into four body types:

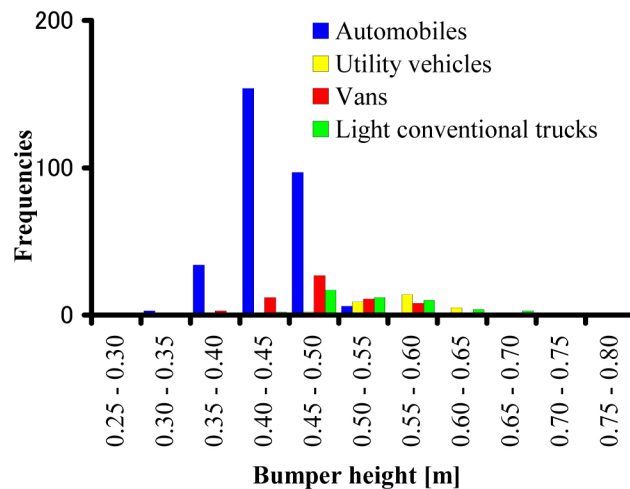


Figure 1. Distribution of bumper heights.

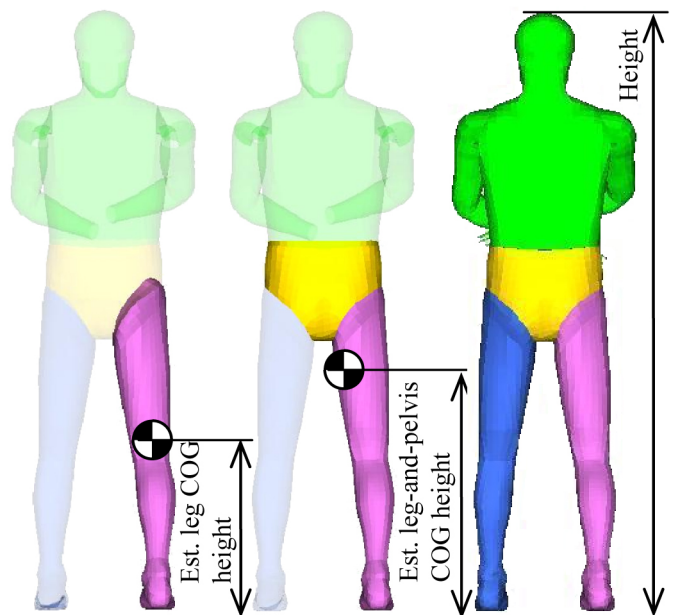
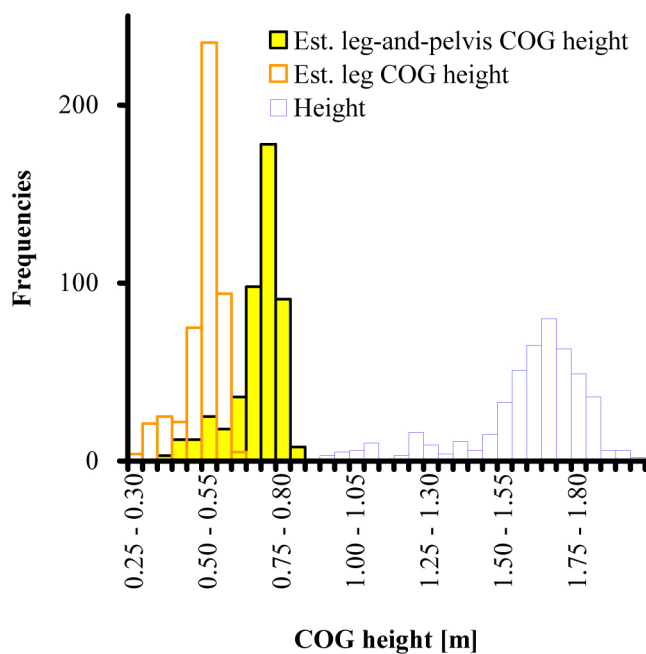


Figure 2. Human COG heights

- Automobiles
- Utility vehicles (< 4,536 kg GVWR)
- Van-based light trucks (< 4,536 kg GVWR)
- Light conventional trucks (pickup style cab, < 4,536 kg GVWR)

The automobile category has the largest population, however, other high-bumper vehicles have a more widely scattered range of bumper heights.

Figure 2 is a histogram of the human height and COG height. The human height data are drawn from the NASS-PCDS. The leg-and-pelvis and the leg COG heights are

estimated in proportional to those of the FE model referred to in a latter section. The leg COG heights of the pedestrians shown by the orange bars range generally from 450 mm to 600 mm. The distributions of the leg-and-pelvis COG heights of the pedestrians are shown by the solid yellow bars. Sixty-six percent of them range from 0.65 to 0.80 m

It is observed that bumper heights in the real world are generally lower than that of the average human leg-and-pelvis or the average leg COG heights.

KINETIC ENERGY

Figures 3 (a) and (b) are examples of pedestrian crash FE models. Figure 3 (a) illustrates a model of an adult male

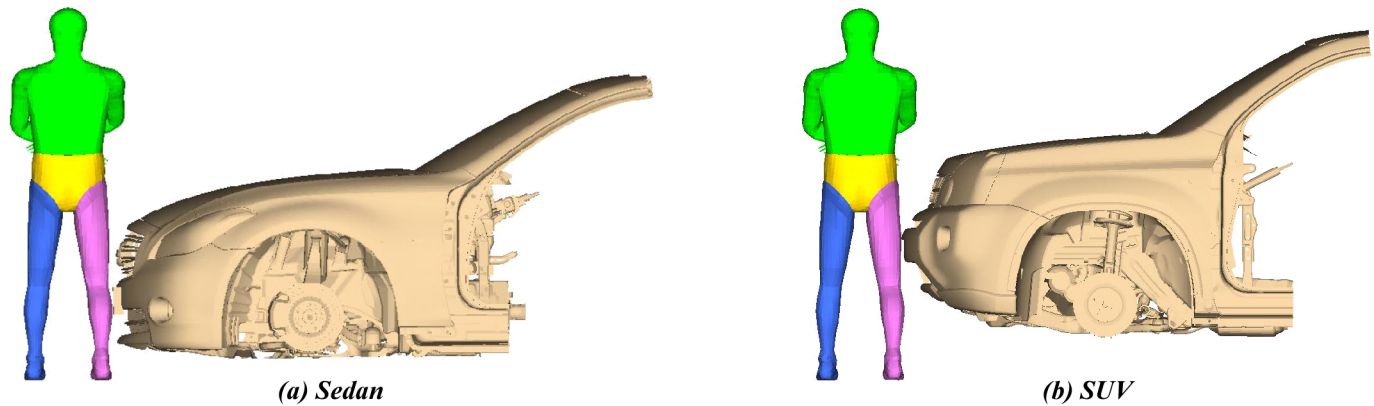


Figure 3. Human FE simulation models

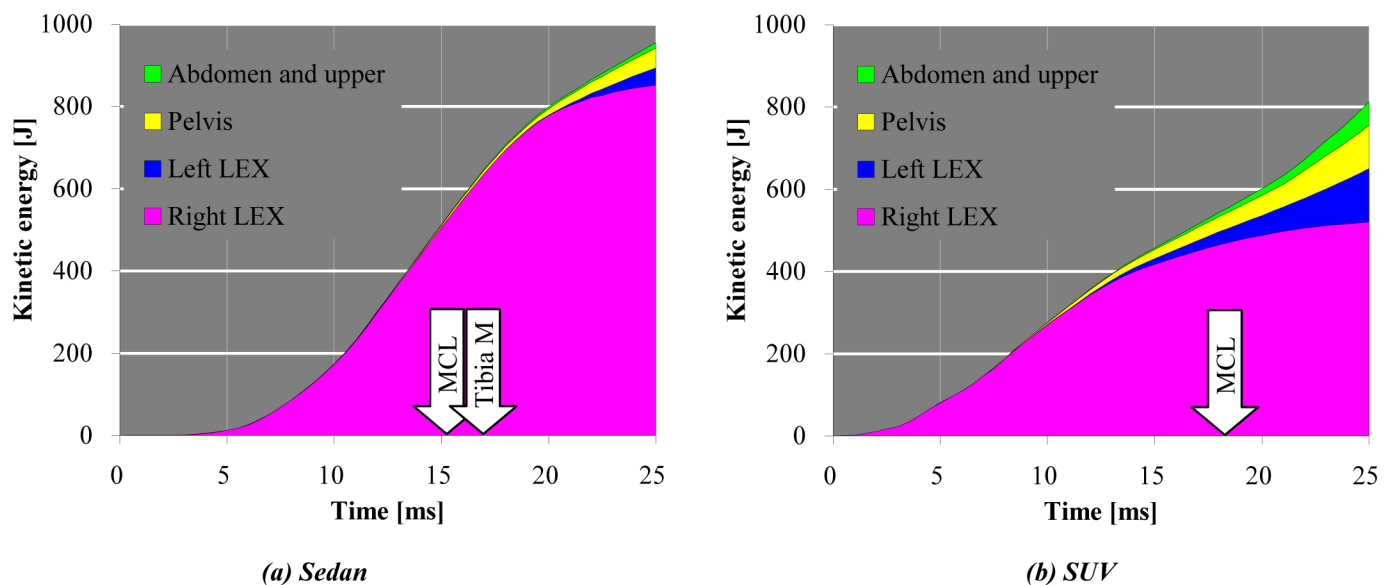


Figure 4. Kinetic energy of body parts

human and a sedan, and (b) is for an SUV. The adult male pedestrian model was developed by JARI (Japan Automobile Research Institute) under the supervision of JAMA (Japan Automobile Manufacturers Association, Inc.) in 2010.

The FEM calculations are conducted using crash simulation software, PAM-CRASH.

Figures 4 (a) and (b) show histories of the kinetic energy of human body parts, calculated from a 40-km/h frontal crash simulation. Figure 4 (a) is an example of a sedan and 4 (b) is for an SUV. The solid arrows in the graphs illustrate the time when the corresponding injury indexes reach their first peak values.

At the first contact with the bumper of the vehicle model in this case, the right side (facing to the vehicle) leg of the human model starts to move. The pelvis of the human model with the sedan in (a) starts to move at around 15 ms. Figure 4 (a) shows that the kinetic energy of the right leg is dominant when the injury index of the medial collateral ligament

(MCL) elongation and the tibia bending moment reach their maximum values. The pelvis and above move very little before the injury indexes reach their peak values.

On the other hand, the pelvis of the human model with the SUV in (b) starts to move at around 10 ms. not only the right leg but also the pelvis is affected when the injury indexes reach their peaks. High-bumper vehicles cause the upper part of the human body to move earlier than low-bumper vehicles.

These results lead to the rigid bar modeling in the next section. For sedan type vehicles, the leg facing to the vehicle matters for the injury indexes of the same leg. On the other hand, in SUV cases, the pelvis should be included for the lower extremity injury risk evaluations.

The rest of the whole human body also works as inertial forces. But it is confirmed by simulation basis that their effects are negligible, as far as the lower extremity injury indexes are concerned.