Studying the Effects of Front-end Impact-absorbing Member using Reduced Order Modelling

Patcharadanai Vichachang, Julaluk Carmai

I. INTRODUCTION

Finite element (FE) simulation has become a prevalent approach in the engineering field for investigating complex problems. However, such simulations can be computationally expensive, especially when dealing with a large nonlinear model. Parametric studies or optimization problems require many cases, hence high computational cost. In this study, a combined FE and model reduction technique was introduced to address the time-consuming issue of the FE simulations and to encourage parametric studies. A reduced order model (ROM) can be established from the FE simulation data. Essentially, a ROM is a mathematical model that leverages training and validation data to enable accurate prediction of output values based on an amount of set of inputs [1]. Despite its potential, the application of ROMs in the context of pedestrian-vehicle collisions has not been widely explored. Pedestrian safety is one concern of car manufacturers and there have been attempts to mitigate pedestrian injury during crash. One approach is to modify the bumper or front-end design. Introducing aluminium foam (Al-foam) to the front-end structure as an impact absorber can enhance the energy-absorbing capability. To study the design variations of the front-end energy-absorbing member, several simulations would be needed. But, as noted, the FE simulation is time-consuming. Therefore, a combined FE and model reduction technique was employed. The present paper aimed to study the effect of the front-end impact-absorbing member design parameters on the pedestrian head injury criteria (HIC) using ROM-based FE simulation.

II. METHODS

Car-pedestrian collision FE model

A Toyota Yaris 2010 FE model [2] was modified by adding mass to represent the battery weight in an electric vehicle. In addition, an upper and a lower impact-absorbing members were introduced to the original car model as shown in Fig 1. They were made of Al-foam and installed at two locations: one above the bumper beam, the other below the bumper beam. The original bumper beam material was changed from steel to Al-foam. In this study, three design variables with three levels each, including the bumper beam thickness, the position (B) where the maximum thickness (A) of 120 mm was located and the thickness (C) of the lower absorbing member with a constant height (D) of 92 mm, were considered. This led to twenty-seven data in the design space. The bumper beam thickness was varied by 5 mm, 10 mm, and 20 mm. Position (B) of the upper absorbing member varied in three locations including 0 (center of width W), +30 mm above the center and -30 mm below the center, as shown in Fig. 1. The thickness (C) of the lower member was set to be 112 mm, 122 mm, and 155 mm. Total Human Body Model for Safety (THUMS) was modified in a walking posture according to Euro NCAP's protocol Technical Bulletin 024 (TB024) [3]. The pedestrian-vehicle collision model was then set up by placing THUMS in front of the vehicle, as shown in Fig. 2. The car impact speed was 40 km/h [4].

Development of a ROM for car-pedestrian collision

A predictive model was established based on a model reduction technique proposed by Kayvantash [5]. The reduced order modelling consists of a learning step and a predictive step, as is the case for a supervised learning algorithm. For the learning step, the proper orthogonal decomposition (POD) algorithm was employed to decompose the original data set from the physical reference frame onto a new set of basis with special and useful properties. For the predictive step, the new space-time responses were reconstructed from two interpolated uncouple fields using the Kriging method for the spatial interpolation. Fig. 3 shows the development process of the ROM. The left block shows the process of obtaining the training and test data, which were provided by the FE

P. Vichachang (e-mail: s6409093800025@email.kmutnb.ac.th) is a MEng student in and J. Carmai is an associated Professor of Mechanical and Automotive Engineering at the Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand.

simulations. The Latin Hypercube Sampling (LHS) approach was employed to sample the data points. Twelve data points were selected and split into 9 training data and 3 test data. The 4-fold cross-validation was performed to test the performance of the predictive model. The validated ROM was then used to generate more data, as illustrated in the right block of Fig. 3., based on variations of input variables including the bumper beam thickness, the position B of the maximum thickness of the upper member, and the thickness of the lower member.

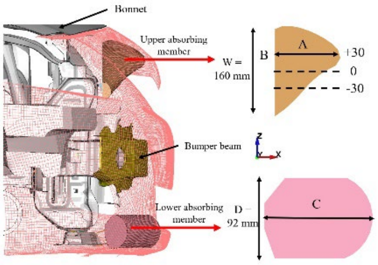

Fig. 1. Location of Al-foam impact-absorbing member at the front-end of the vehicle.

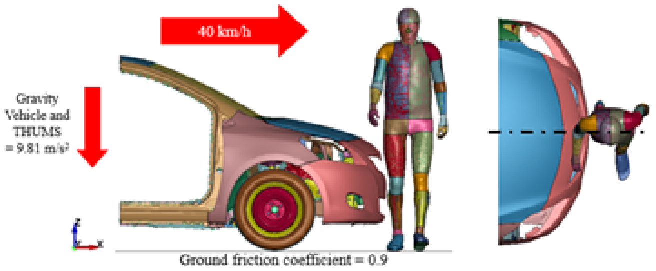

Fig. 2. Vehicle-pedestrian collision FE model.

III. INITIAL FINDINGS

The performance of ROM model was tested using the 4-fold cross validation. The HIC predicted by the ROM was compared with the finite element calculation. The mean absolute percentage error (MAPE) was calculated for each fold, and the average cross-validation error was 4.5%. The best model which had the lowest MAPE was selected. Fig. 4 shows the comparison of HIC obtained from the FE simulations and the selected ROM. Each point deviated within ±2.5% corridor. This validated ROM was then used to predict the HIC. Fig. 5 presents a 3D contour plot of the HIC at various sets of input design variables. It can be observed that introducing absorbing members to the front-end bumper affected the HIC value. The upper body rotated around the first impact point between the tip (B) of the upper member and the lower extremity. This resulted in an increased contact time with the lower extremity and a decreased head impact velocity in Z direction, leading to a decrease in HIC. When position B was closer to the bonnet, the HIC decreased due to the slower rotation of the upper body, resulting in a lower head impact velocity. The bumper beam and the thickness of the lower member had a slight effect on the HIC.

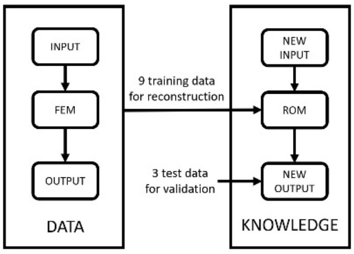

Fig. 3. ROM development process.

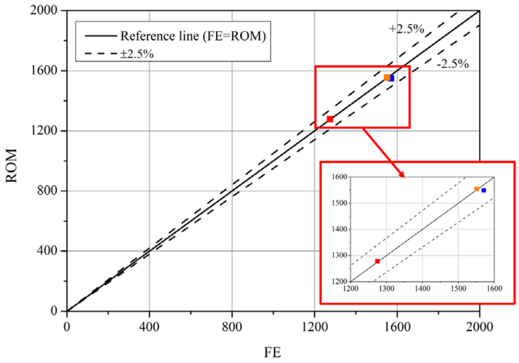

Fig. 4. Comparison of HIC between FE calculations and ROM predictions.

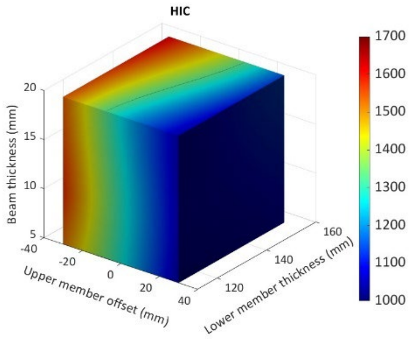

Fig. 5. Relationship between input design variables and the HIC predicted by ROM.

IV. DISCUSSION

A ROM for pedestrian-car collision was established based on FE simulation results. The predictive performance of the ROM was deemed acceptable with small errors. However, it is important to note that a limitation of this ROM is its assumption of a linear change in HIC between the input variable values. The validated ROM was then utilized to predict the HIC for various sets of input variables. Through this analysis, it was observed that the upper absorbing member had a strong influence on the HIC.

V. REFERENCES

[1] Kayvantash, K., *et al.*, *SAE Int J*, 2018.
[2] Wachirut, K., *et al.*, *Int ESV*, 2015.
[3] Euro NCAP, Technical Bulletin 024, 2019.
[4] Euro NCAP, Testing Protocol, 2017.
[5] Kayvantash, K., LS-DYNA User Forum, 2018.