Investigation of the Effect of Non-Struck-Side Lower Limb on Pelvic Kinematics for the Development of Pedestrian Pelvis Impactor

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I. INTRODUCTION

During the development of a pedestrian pelvis impactor (PPI) to enhance pelvis protection when hit laterally in car-to-pedestrian accidents, Isshiki *et al.* [1] conducted a sensitivity analysis using a human body model (HBM) to identify the lower limb regions that needed to be represented to address pelvic loading and injury mechanisms. This was achieved by removing the upper body, simplifying the pelvic geometry and replacing the non-struck-side lower limb with a concentrated mass at the acetabulum. However, some differences in pelvic rotation were identified in a specific load case. This would result in an inaccurate pelvic loading representation due to the difference in the loading direction to the pelvis. As the pelvis injury metrics measure lateral-medial loading, it would be crucial to represent pelvic rotation around the anterior-posterior and vertical axes, in addition to the accurate representation of the lateral-medial load. The non-struck-side lower limb potentially influences pelvis rotation in these two directions, in addition to the lateral-medial loading, due to the inertial load transmitted to the pelvis via the acetabulum.

This study investigates the effect of the non-struck-side lower limb on pelvic rotation and pelvic injury metrics in car-to-pedestrian impacts in order to further clarify the key elements that need to be represented for an accurate estimation of pelvic loading.

II. METHODS

A total of nine car-to-pedestrian impact simulations were conducted to investigate the effect of the non-struck-side lower limb on pelvic rotation. As shown in Fig. 1, three SCMs (Sedan SCM, SUV-Low SCM, SUV-High SCM), representing different geometry and stiffness of car front-ends adopted from [1], were employed to simulate impacts against three different HBMs. These HBMs were: (1) a full-body HBM [2]; (2) a model created by removing the upper body and replacing non-struck-side lower limb with a concentrated mass (Model-A); and (3) a model with the concentrated mass positioned 100 mm lateral to the hip joint relative to Model-A (Model-B). Model-B was devised as a tentative technical solution to better represent the pelvic rotation and injury metrics of the full-body HBM. The time history of the three components of the section force at the acetabulum on the non-struck side were recorded relative to the coordinate system affixed to the pelvis to identify how the non-struck-side limb and its substitutes interact with the pelvis. The time history of the pelvic rotation angle about x-axis and the sacroiliac joint force were also quantified to investigate how the change in the interaction influences the pelvic rotation and the injury metric.

III. INITIAL FINDINGS

Figure 2 shows the time history of the three components of the force transmitted through the acetabulum on the non-struck side, pelvic rotation angle about x-axis and sacroiliac joint force for the nine combinations of the three HBMs and the three SCMs. For all three SCMs, Model-A showed reduction of z-component of the force, while well maintaining y-component of the force, except the Sedan SCM. The same trend was confirmed for Model-B. The rotation angle of Model-A increased significantly for the Sedan and the SUV-Low SCM, suggesting that the force applied from the non-struck-side limb to the pelvis generates moment about the x-axis, which reduces pelvic rotation. This increase was found to be diminished with Model-B specifically for the SUV-low SCM, where the moment of inertia of the concentrated mass about the centre of gravity of the pelvis was increased by the offset. Despite the reduction in z-component of the hip joint force for the SUV-High SCM, the changes of the pelvic rotation angle with the SUV-High SCM were much smaller than those with the other

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two SCMs. The sacroiliac joint force of Model-A decreased significantly for the Sedan and the SUV-Low SCM, while the decrease was diminished with Model-B, specifically with the SUV-low SCM. This opposite trend to that of the pelvic rotation is deemed reasonable, given that the pelvic rotation reduces the y-component of the forces applied to the pelvis (reaction force from the non-struck-side limb and contact force from a car) that primarily act in the direction of car travel. In the impact against the SUV-High SCM, where the pelvis is directly engaged by the car front-end, the sacroiliac joint force increased with the substitutes of the non-struck-side limb, while the magnitude of the pelvic rotation was small. This trend cannot be explained solely by the pelvic rotation.

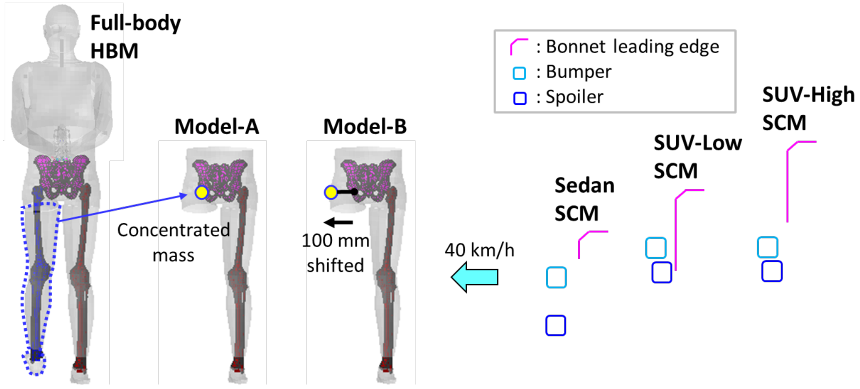

Fig. 1. Simulation conditions and appearance of the full-body human body model (HBM), Model-A, Model-B and the simplified car models (SCMs).

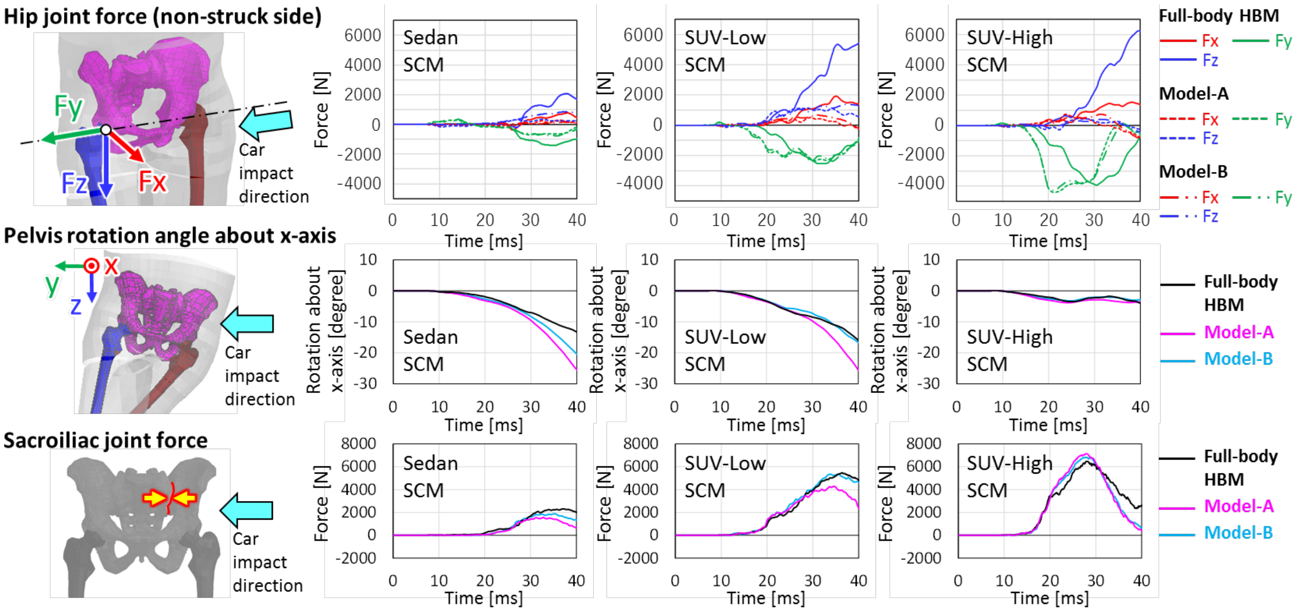

Fig. 2. Time histories of hip joint force, pelvic rotation about x-axis and sacroiliac joint force.

IV. DISCUSSION

In impacts without direct engagement of the pelvis by the car front-end, this study revealed that the non-struck-side lower limb affects the pelvic injury metric by applying a substantial force to the pelvis and changing pelvic rotation, suggesting that it is essential to accurately represent the influence of this force. An exemplar solution to increase the moment of inertia of the pelvis about x- and z-axis succeeded in representing this influence in such impact configurations, specifically with SUV-low SCM. However, Model-B still showed differences in the pelvic rotation and the sacroiliac joint force for the Sedan SCM, which suggests that some other loading mechanism to the pelvis may still be missing, in addition to the load applied from the non-struck-side lower limb. Further investigation is needed to clarify the factors for the differences.

V. REFERENCES

[1] Isshiki, T., *et al.*, IRCOBI, 2019.

[2] Kikuchi, Y., *et al.*, SAE Technical Paper, 2008.