Factors Influencing Pelvis Rotation of THOR 50M and THOR 5F during Frontal Impact

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I. INTRODUCTION

The seat belt is a key element in restraint systems for occupant protection. If the lap belt slips off the anterior edge of the pelvis and intrudes into the abdomen (submarining), it can result in serious injuries. During frontal impact the pelvis of an occupant rotates rearward in many cases, and the belt-pelvis angle significantly influences the occurrence of submarining [1]. The belt-pelvis angle varies depending on the size of occupants and their seated postures [2-3]. Additionally, in rear-seat sled tests conducted using THOR 5F by NHTSA (Test No. 11098, 11099, 11100), submarining occurred in slouched postures. In this study, to understand pelvis rotation during impact, finite element (FE) simulations were conducted using THOR (50M, 5F) and THUMS (50M, 5F) models, and the force and moment applied to the pelvis were examined.

II. METHODS

FE simulations of sled tests were conducted for rear-seat occupants (THOR 50M, THOR 5F, THUMS 50M and THUMS 5F) using the deceleration pulse of a small car from a full-frontal impact test at 50 km/h. The occupant models were seated in the rear seat using a standard 3-point seat belt without force limiter and pretensioner. In addition to the linear motion of the pelvis, Euler's equations of motion were applied to the pelvis rotation around the principal axis of inertia of the pelvis with the origin at the pelvis centre of gravity (COG) as follows:

$$m\frac{dv_i}{dt} = \sum F_{pi}, \qquad I_i\frac{d\omega_i}{dt} - \left(I_j - I_k\right)\omega_j\omega_k = \sum N_{pi} \qquad (i,j,k = 1,2,3;\ p = 1,\dots,n) \tag{1}$$

where i, j, k is the principal axis number, p is the force number, v_i is the velocity of the pelvis COG, ω_i is the angular velocity of the pelvis, m and I_i is the mass and the inertia of the pelvis, while $F_{pi}$and N_{pi} is the force and moment acting on the pelvis. The forces and moments transmitted from the femur and lumbar spine to the pelvis were obtained from the joint constraint forces (hip joint, lumbar spine), and the forces and moments generated by flesh around the pelvis were calculated using the contact forces (ASIS, ischium, coccyx, flesh). The rotation around the lateral axis of the pelvis was examined whereby a negative moment corresponds to forward rotation.

III. INITIAL FINDINGS

THOR (50M, 5F) and THUMS (50M, 5F) exhibited comparable kinematics with a slight tilt of the torso and rearward rotation of the pelvis (Fig. 1). The pelvis angle of THOR 50M and 5F consistently increased over time, indicating rearward pelvis rotation, with an angle change of 36.0° in THOR 50M and 35.8° in THOR 5F (Fig. 2).

In the THOR 50M and 5F models, the linear and angular accelerations of the pelvis are accurately described in terms of forces and moments by Eq. (1). Figure 3 shows all components of the moment-time history around the lateral axis of the pelvis. The lap-belt force exerted on the ASIS, lumbar spine force and hip joint force contributed to the rearward rotation of the pelvis (positive moment), whereas the flesh, coccyx and lumbar spine (bending moment) exerted a forward rotation (negative moment). In the initial phase of impact, the lap-belt force primarily induced the pelvis rearward rotation. In the latter phase of the impact, the lumbar spine (bending moment due to torso flexion) as well as the coccyx exerted a substantial influence on stopping the rearward pelvis rotation. Additionally, the tension of the shoulder belt on the shoulder caused the lumbar spine to exert a downward force on the pelvis, thereby contributing to the rearward rotation of the pelvis in the latter phase.

In the latter phase of impact, seat cushion deformation by the ischium and coccyx was observed for both THOR and THUMS (Fig. 4). Specifically, the contact force on the coccyx was 9.7 kN and 4.1 kN for THOR 50M and 5F, respectively, whereas the cross-sectional force of the sacrum (S4) of THUMS 50M and 5F was 1.8 kN and 0.8 kN,

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respectively. Despite the smaller forces acting on the coccyx and sacrum in THUMS compared to THOR, it was evident that the force exerted on the coccyx and sacrum by the seat cushion effectively contributed to preventing the rearward rotation of the pelvis in both THOR and THUMS models.

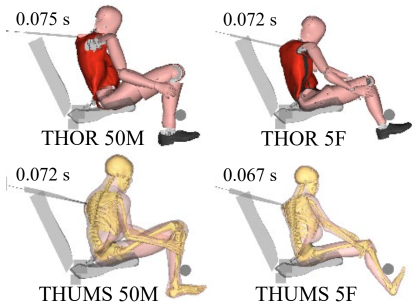


Fig. 1. Kinematic behaviour (time: max. pelvis displacement).

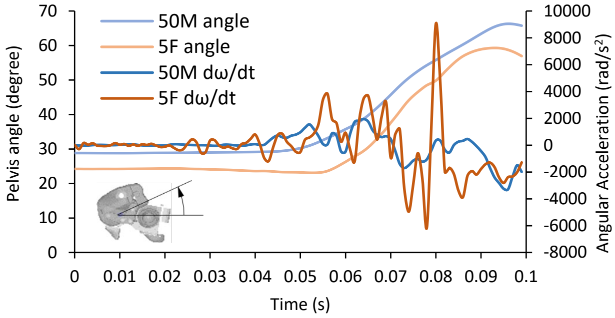


Fig. 2. Pelvis angle and angular acceleration of THOR.

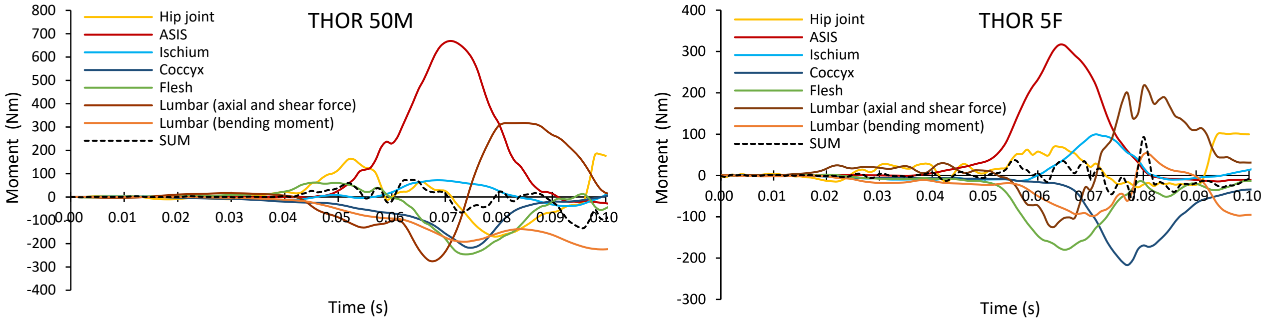
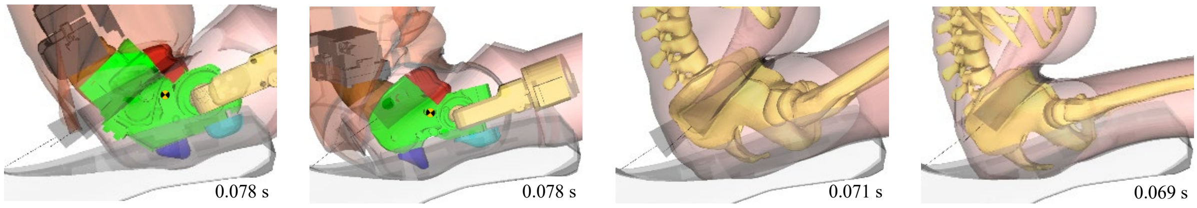


Fig. 3. Moment acted on the pelvis for THOR 50M (left) and 5F (right).



(a) THOR 50M (b) THOR 5F (c) THUMS 50M (d) THUMS 5F

Fig. 4. Condition of the pelvis at maximum coccyx force.

IV. DISCUSSION

In this study, it was shown that various forces influenced pelvis rotation. The coccyx of THOR 50M and 5F, which interacted with the seat cushion, counteracted pelvis rearward rotation. For THOR 5F, coccyx force affected pelvis motion significantly in the final phase of impact, while for THOR 50M it affected the pelvis motion in the middle phase, with a lesser effect on pelvis rearward rotation. This difference arises from variations in coccyx geometry. The coccyx of THOR 5F is positioned posteriorly to the pelvis COG, effectively preventing pelvis rearward rotation. In contrast, the coccyx of THOR 50M is positioned closer to the pelvis COG, resulting in a lesser effect on pelvis rotation compared to THOR 5F (Fig. 4). Hybrid III, lacking the coccyx, likely relies on the ischium contact force and the lumbar spine bending moment to control the pelvis rearward rotation. Thus, anti-submarining seat designed based on THOR might differ from those designed based on Hybrid III.

Although a certain amount of force was applied to the sacrum in THUMS, it remains unclear whether the coccyx and sacrum function effectively to prevent rearward rotation of the pelvis in humans. In sled tests using PMHS, sacrum fractures were reported [4], suggesting that substantial force was applied to the sacrum. Thus, it will be necessary to determine the thresholds of coccyx and sacrum fractures. Additionally, individual variations in the curvature and length of the coccyx and sacrum were observed from CT images [3]. Considering the effect of these individual differences will also be necessary for the development of anti-submarining seats.

V. REFERENCES

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