Research on the Submarining Injuries of Occupants in Large-angle Sitting Postures

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Abstract. With the development of automotive automation technology, large-angle seat are gradually becoming popular and have revolutionized the traditional sitting posture of vehicle occupants, posing challenges to the vehicle occupant protection performance. To evaluate the submarining risk of occupants and the injury characteristics in normal and large-angle sitting posture, and the improvement measures for preventing submarining of occupants in large-angle sitting posture, this study conducts a comparative analysis of kinematic posture and submarining risks of occupants in normal and large-angle sitting posture, studies the movement trends and injury characteristics of occupants in large-angle sitting posture, as well as the improvement measures for preventing submarining, based on the THUMS50 model that can meet the requirements of large-angle sitting posture. The results show that: compared with the normal sitting posture, the seat backrest has a larger inclination angle in the large-angle sitting posture. In this posture, the occupant is in a semi-reclining state. During the collision, the pelvis is more likely to move forward, thus resulting in submarining. When submarining occurs to occupants in the large-angle sitting posture, the head, abdomen, and pelvis move forward to a relatively large extent, resulting in greater injuries to the head and abdomen compared with the normal sitting posture. Increasing the seat cushion tilt of the large-angle seat can disperse the load concentrated on the abdomen to various parts such as the cervical spine, chest, and lumbar spine, effectively alleviating the submarining of occupants in the large-angle sitting posture.

Keywords: Large-angle seat; THUMS50; occupant sitting posture; backrest angle; seat cushion tilt.

1. Introduction

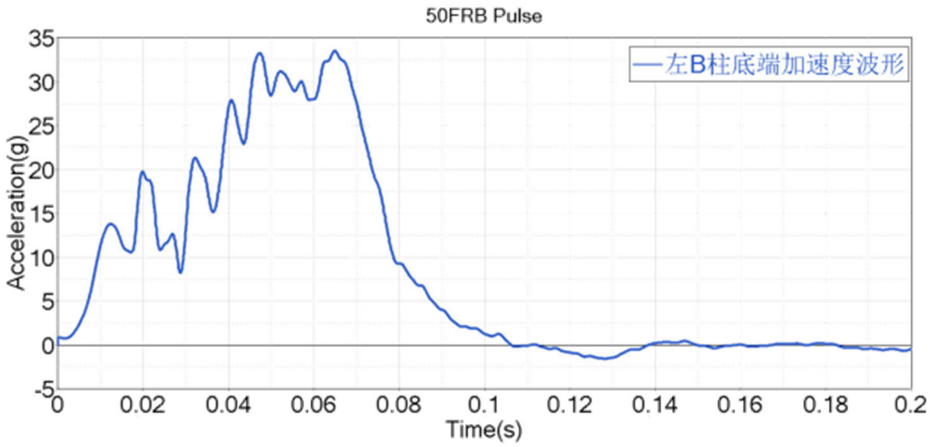
The development of automotive autonomous driving technology and the popularization of large-angle seats have made it possible for vehicle occupants to change from the traditional driving or riding posture to various comfortable sitting posture. However, changing the sitting posture may reduce or even invalidate the protection performance of the restraint system originally designed for the traditional sitting posture, which poses a greater challenge to the vehicle's passive safety performance[1].

The current restraint system mainly consists of a three-point seat belt with fixed points respectively fixed on the B-pillar, floor, and seat, as well as the driver's airbag installed in the center of the steering wheel and the front-passenger airbag inside the dashboard. In the large-angle seat sitting posture, seat torso angle causes the dummy's torso to move backward, losing contact with the seatbelt. At the same time, it increases the initial distance between the head and the airbag, potentially affecting the interaction time and protection effect between the head and the airbag [2]. In addition, in the large-angle seat sitting posture, the inclined backrest and raised leg rest may make the occupant's lumbar spine and pelvis more likely to move forward during a collision, resulting in submarining [3-4]. This also leads to excessive lumbar force and abdominal pressure. Therefore, it is very necessary to evaluate the impact of the large-angle sitting posture on the occupant protection performance.

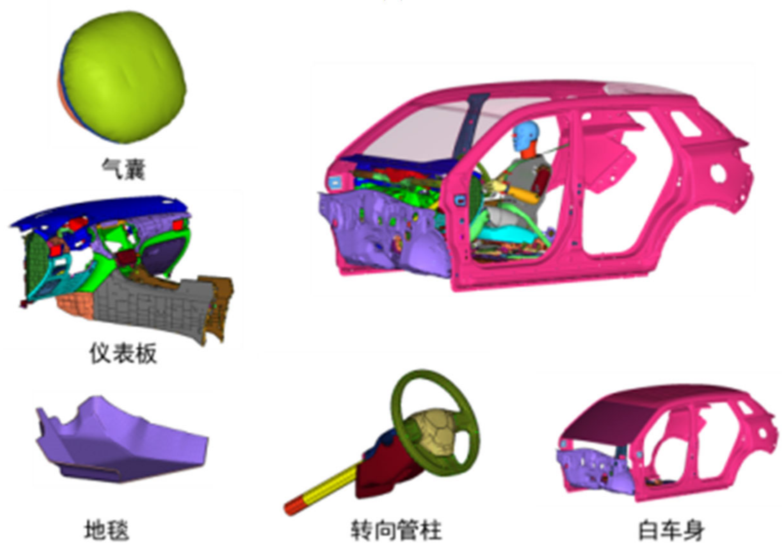
In addition, the current Anthropomorphic Test Devices (ATDs), whether physical or simulation-based, are designed for traditional sitting posture and cannot meet the requirements of various sitting postures of large-angle seats. Therefore, research on the protection performance of vehicle restraint systems for large-angle sitting postures can currently only be carried out through virtual simulation using Human Body Models (HBMs). In this study, the THUMS50 model, which is widely used in the industry, was selected to research the kinematic posture and injury characteristics of occupants in traditional and large-angle sitting posture. The submarining risks of occupants were analyzed comparatively, and improvement measures were proposed for the submarining.

2. Introduction to the Model

This paper takes the driver-side restraint system model under the 50km/h full width frontal rigid barrier impact test (FRB) condition of a certain vehicle model as the research basis to study the large-angle seat structure.



(a)

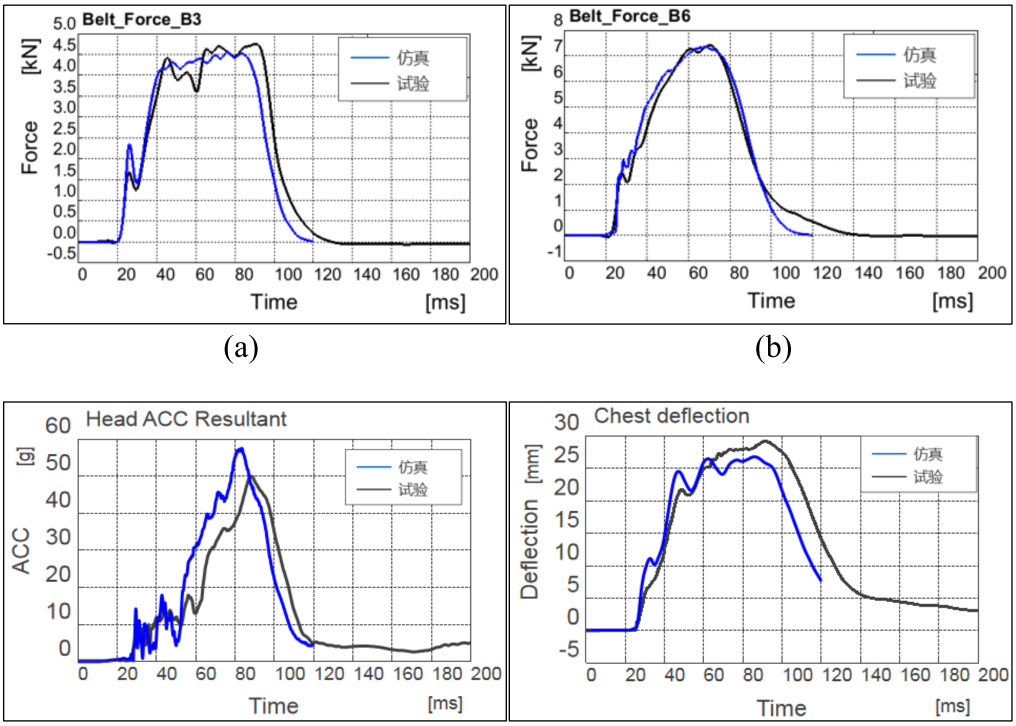


(b)

Figure 1. The driver's restraint system model (a) Acceleration waveform at the bottom of the left B-pillar, (b)Restraint system sub-model and its composition

Figure 1 (a) shows the acceleration curve at the bottom of the left B-pillar in the FRB test of this vehicle model. It is extracted and the boundary condition in the X-direction is applied through the BOUNDARY PRESCRIBED MOTION dyna keyword and input to the corresponding position of the sled-tested bare vehicle body to simulate the motion of the bare vehicle body in the full-vehicle test.

Figure 1 (b) shows the simulation model of the restraint system on the driver's side, which is mainly composed of components such as a Hybrid III 50th Male Dummy, a body in white, a carpet, three pedals (accelerator, brake, and footrest), a steering column, dashboard, airbags, seat belts, and seats. These components are connected together rigidly.



(a) (b)

(c) (d)

Figure 2. Results of the dummy injury values between the test and simulation of the model (a)Shoulder belt force, (b)Lap belt force, (c)Head ACC resultant, (d)Chest deflection

The simulation model of the driver's restraint system with the Hybrid III 50th male dummy has been verified against the full-vehicle test. Figure 2 shows the comparison of the dummy injury value curves between simulation and the full-vehicle test, mainly including the performance of the seat belt force, as well as the head acceleration, chest deflection, and chest acceleration of the Hybrid III 50th dummy.

As can be seen from Figure 2, the kinematic posture and injury value curves of the Hybrid III 50th dummy in the simulation and the test are basically the same, which proves the effectiveness and usability of this model.

3. Simulation Settings

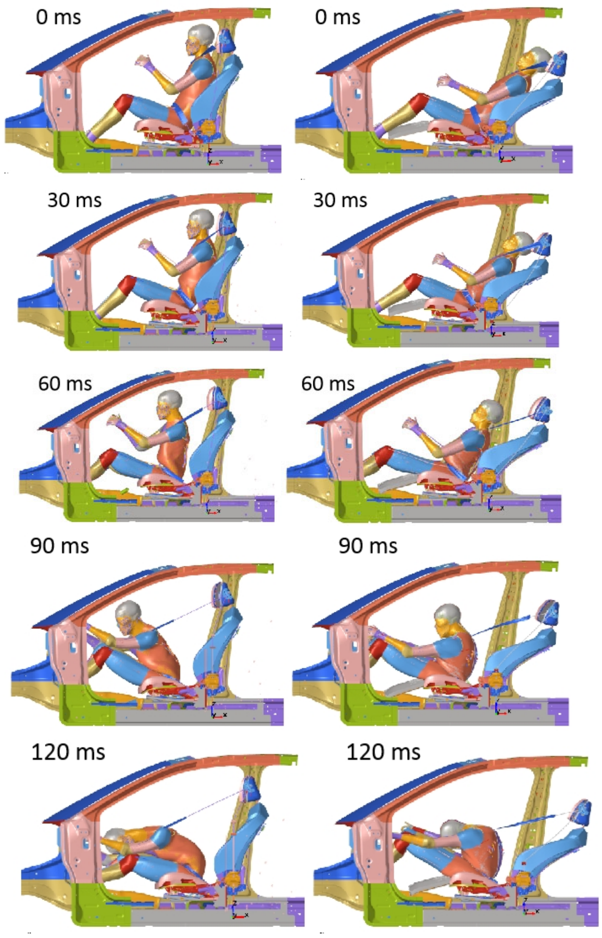
In this study, the seat settings for the normal sitting posture are as follows: the seat cushion tilt is 16 degrees, and the backrest angle is 23 degrees. The settings for the large-angle seat are as follows: the seat cushion tilt is 16 degrees, and the backrest angle is 55 degrees. The settings for the large-angle seat with anti-submarining function are as follows: the seat cushion tilt is 24 degrees, and the backrest angle is 55 degrees.

Simulations of three conditions are carried out: the first is that the occupants in the normal sitting posture, the second is that the occupants in the large-angle sitting posture, and the third is that the occupants in the large-angle sitting posture with anti-submarining measures.

In all three conditions, there are no airbags, and the same seat belts are used. The acceleration waveform in Figure 1 is adopted for the simulations.

4. Comparison of Occupant kinematic posture between Normal and Large-Angle Sitting posture

Figure 3 shows the comparison of the kinematic posture of occupants in normal and large-angle sitting posture. Figure 4 shows the movement curves in the X-and Z-directions of the marked points on the heads and pelves of occupants under the normal and large-angle sitting posture. By comparing the kinematic posture and trajectory curves of the dummy's head and pelvis, it can be found that, compared with occupants in the normal sitting posture, occupants in the large-angle sitting posture have an obvious tendency to move forward and downward with their heads and pelves. Especially after 60 ms, the forward and downward movement trends of the heads and pelves of occupants in the large-angle sitting posture become more intense, and an obvious submarining occurs.



normal sitting posture   large-angle sitting posture

Figure 3. Comparison of occupant kinematic posture

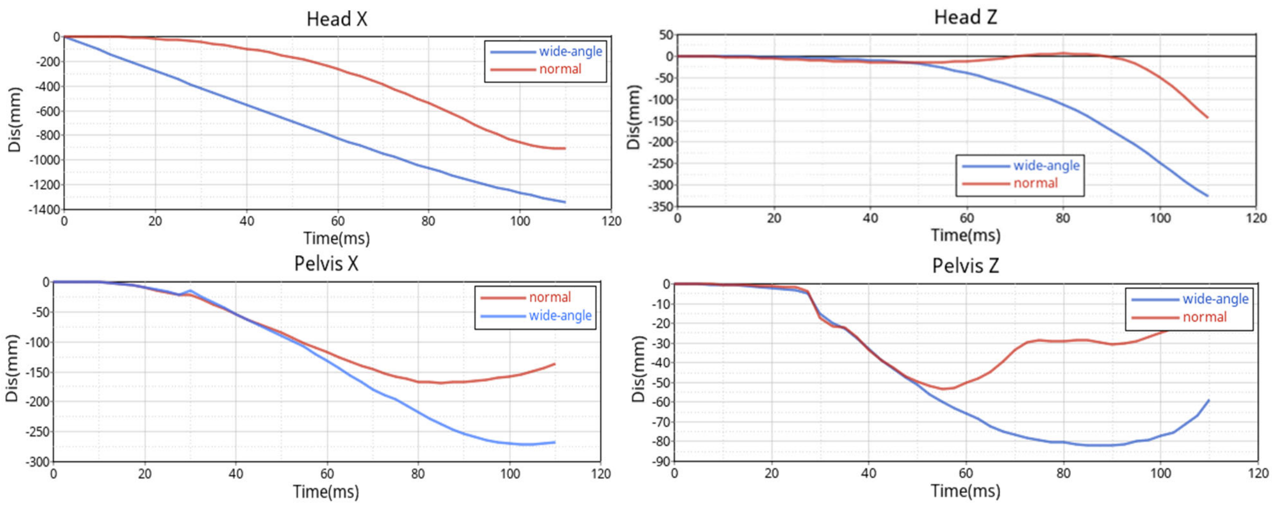
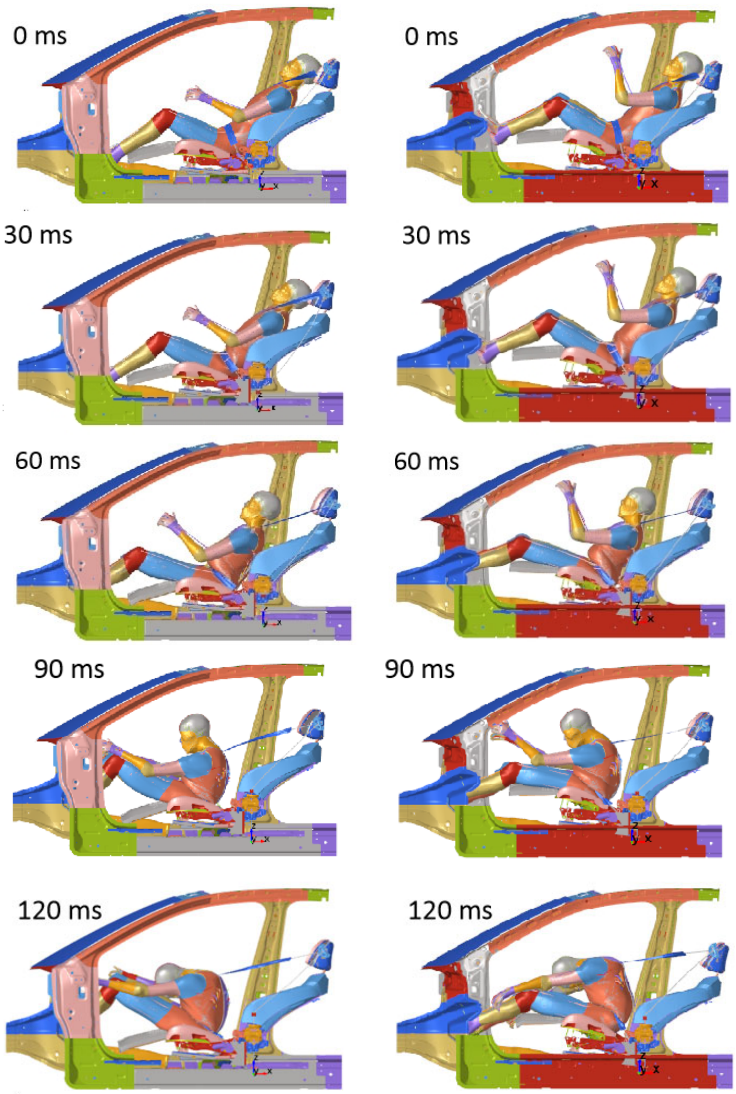


Figure 4. Movement curves in the X-and Z-directions of the marked points on the head and pelvis (a)Head movement in the X-direction, (b)Head movement in the Z-direction, (c) Pelvic movement in the X-direction, (d)Pelvic movement in the Z-direction

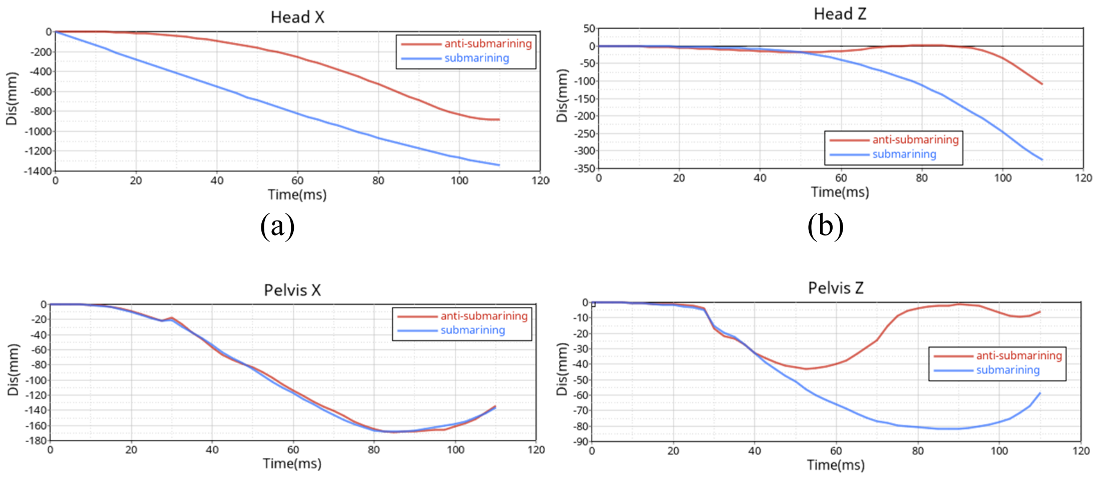
5. Comparative Analysis of Occupant Injuries of Occupants in Large-Angle Sitting posture with Occupants in Anti-Submarining Large-Angle Sitting posture

To improve the submarining of occupants in large-angle sitting posture, this study increases the large-angle seat cushion tilt. Figures 5 and 6 show the kinematic posture and trajectory curves of occupants in large-angle sitting posture with normal seat cushion tilt (submarining) and increased seat cushion tilt. It can be found that when the seat cushion tilt is normal, compared with the case of increased seat cushion tilt, the heads and pelves of occupants in large-angle sitting posture move forward and upward more vigorously, and the submarining trend is more obvious. Increasing the seat cushion tilt can effectively alleviate the submarining of occupants in large-angle sitting posture.



Normal seat cushion tilt   Increased seat cushion tilt

Figure 5. Comparison of occupant kinematic posture

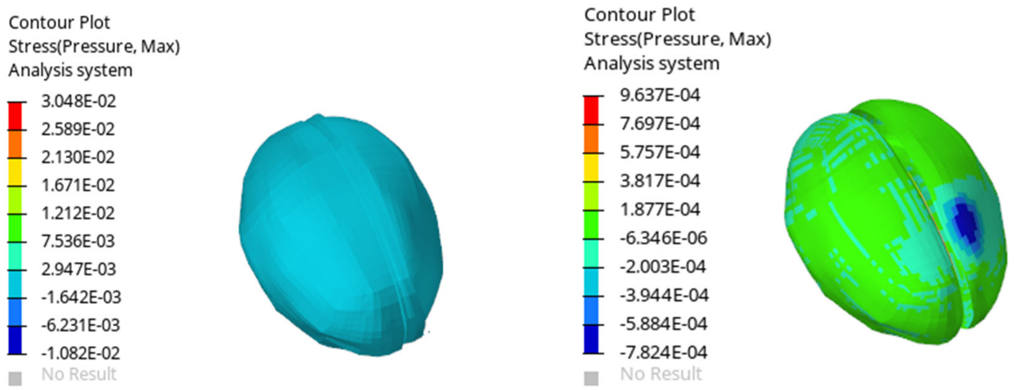


(a) (b)

(c) (d)

Figure 6. Movement curves in the X-and Z-directions of the marked points on the head and pelvis (a)Head movement in the X-direction, (b)Head movement in the Z-direction, (c) Pelvic movement in the X-direction, (d)Pelvic movement in the Z – direction

In the simulation, the injury indicators such as intracranial pressure, plastic stress of the cervical vertebrae, plastic stress of the chest ribs, plastic stress of the lumbar vertebrae, plastic stress and strain of the abdomen of occupants in large-angle sitting posture under two conditions (normal seat cushion tilt and increased seat cushion tilt) are extracted for comparative analysis.

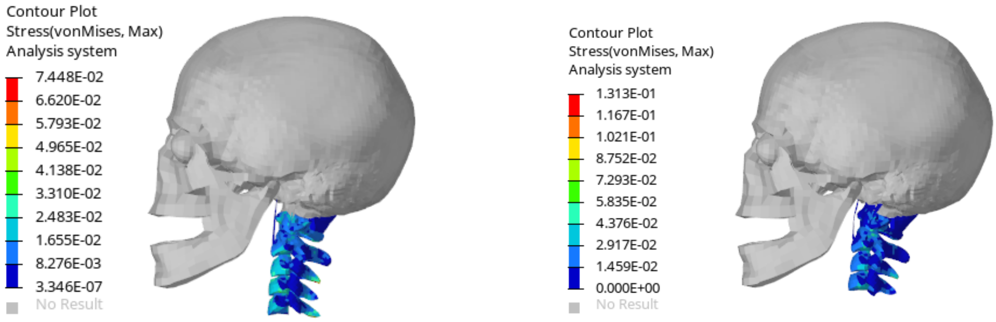


(a) (b)

Figure 7. Intracranial pressure distribution(a) Normal seat cushion tilt, (b) Increased seat cushion tilt

For head injuries in the THUMS model, they are mainly evaluated by intracranial pressure and skull stress values. Since this study only explores the influence of the large-angle sitting posture on occupant protection performance and does not consider or explore the influencing factors of the steering wheel and airbags, the head load is mainly affected by the neck tension load, and the skull damage is relatively small. Therefore, only intracranial pressure is considered for head injuries. The intracranial pressures of occupants under the two conditions are shown in Figure 7. The maximum intracranial pressure under the condition of normal seat cushion inclination is 74.48 MPa, and the maximum intracranial pressure under the condition of increased seat cushion tilt is 9.64 MPa.

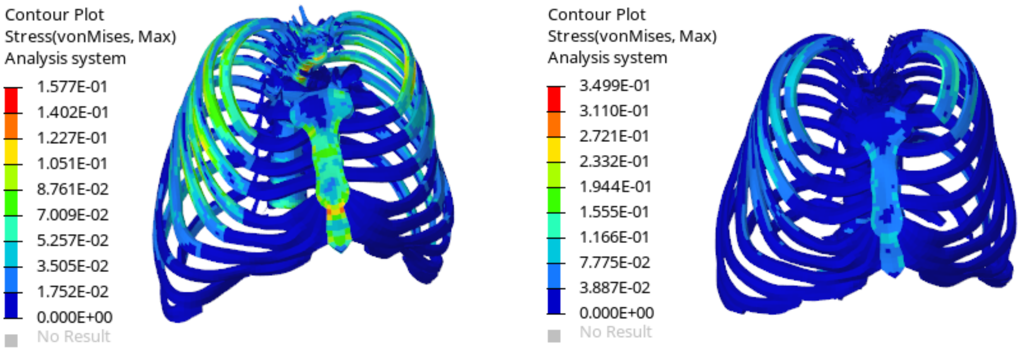
The plastic strains of the occupants' cervical vertebrae under two conditions are shown in Figure 8. For the normal seat cushion tilt, the maximum value is 74.48 Mpa. For the increased seat cushion tilt, the maximum stress on the dummy's cervical vertebrae is 131.3 Mpa.



(a) (b)

Figure 8. Plastic Stress of Cervical Vertebrae (a) Normal seat cushion tilt, (b) Increased seat cushion tilt

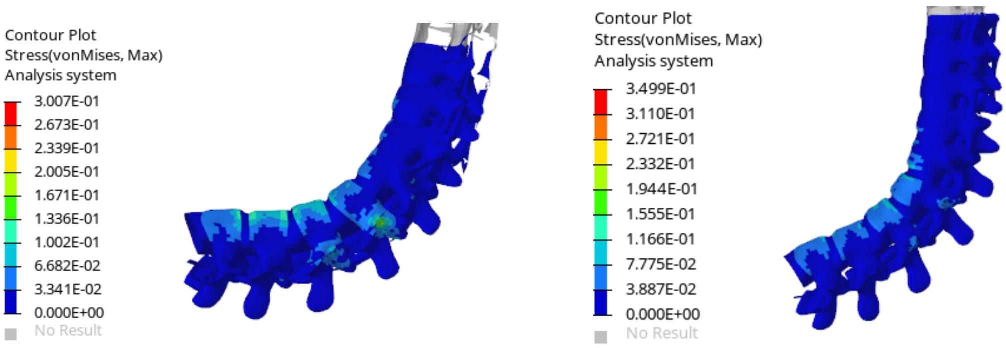
The plastic stress of the occupants' chest ribs under two conditions is shown in Figure 9. For the normal seat cushion tilt, the maximum stress is 157.7 Mpa. For the increased seat cushion tilt, the maximum stress of the dummy's chest ribs reaches 349.9 Mpa.



(a) (b)

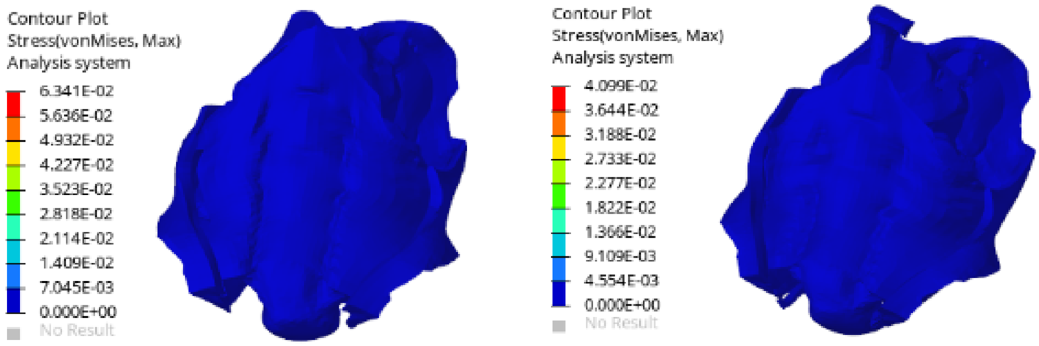
Figure 9. Plastic Stress of Chest Ribs (a) Normal seat cushion tilt, (b) Increased seat cushion tilt

The plastic strains of the occupants' lumbar vertebrae under the two conditions are presented in Figure 10. For the normal seat cushion tilt, the maximum value is 300.7 Mpa. For the increased seat cushion tilt, the maximum stress of the dummy's lumbar vertebrae is 349.9 Mpa.



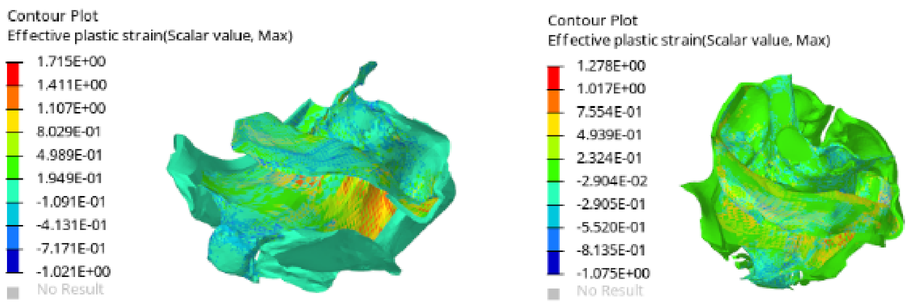
(a) (b)

Figure 10. Plastic Stress of Lumbar Vertebrae (a) Normal seat cushion tilt, (b) Increased seat cushion tilt



(a) (b)

Figure 11. Plastic Stress of the Abdomen (a) Normal seat cushion tilt, (b) Increased seat cushion tilt



(a) (b)

Figure 12. Plastic Strain of the Abdomen (a) Normal seat cushion tilt, (b) Increased seat cushion tilt

The plastic stress and strain of the occupants' abdomen under the two conditions are shown in Figures 11 and 12. For the normal seat cushion tilt, the maximum stress is 63.41 Mpa and the maximum plastic strain is 1.715. For the increased seat cushion tilt, the maximum stress of the dummy's abdomen is 40.99 Mpa and the maximum plastic strain is 1.278.

By comparing the injury conditions of the occupants' head, neck, chest, and abdomen under normal and increased seat-cushion tilt for a large-angle sitting posture, it is found that the submarining is more serious in the normal seat-cushion tilt . The collision load is mainly concentrated on the abdomen, resulting in relatively large plastic stress and strain in this area. When the seat-cushion tilt is increased, the plastic strain and stress of the occupants' abdomen decrease significantly, while the plastic stress of the cervical vertebrae, chest, and lumbar vertebrae increases. This indicates that raising the seat-cushion tilt can disperse the collision load concentrated on the abdomen to the cervical vertebrae, chest, and lumbar vertebrae, effectively alleviating the submarining tendency of the occupants.

6. Conclusions and Prospects

Based on the calibrated model of the driver's restraint system under the 50 km/h full width frontal rigid barrier impact test of a certain SUV model, this paper conducts a comparative analysis of the kinematic posture of occupants in normal sitting posture and large-angle sitting posture, as well as the kinematic posture and injury conditions of occupants under normal seat-cushion tilt and increased seat-cushion tilt for large-angle sitting posture. The main conclusions are as follows:

(1) Compared with occupants in normal sitting posture, occupants in large-angle sitting posture show a more obvious forward-downward movement trend of the head and pelvis. In the event of a collision accident, occupants in large-angle sitting posture are more prone to submarining.

(2) For the large-angle sitting posture, increasing the seat-cushion tilt of the large-angle seat to a certain extent can alleviate the submarining of occupants in large-angle sitting posture to a certain degree.

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