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Numerical Analysis on Dynamic Behavior of an Occupant in a Decelerating Automobile

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Abstract. In this paper, numerical analysis is conducted on dynamic behavior of an occupant in a decelerating automobile. The analytical model consists of a rigid-body LSTC Hybrid III dummy model sat on a seat that consists of rigid plates. Assuming a situation that a self-driving small-size bus is subjected to sudden decelerating acceleration, constraint of the dummy by a seat belt of an air bag is not considered. Both of the dummy and the seat are given same initial velocity with relatively slower range, then the velocity of the seat is decreased with a constant rate. The dynamic responses of the dummy are numerically calculated with the commercial software LS-DYNA. The motions of dummy are discussed under various values of decelerating acceleration and friction constants between seat and dummy.

1. Introduction

Recently development of self-driving cars advances more and more. One application of a self-driving car is transportation of elderly people for shopping or going to hospital with a small-size bus in a depopulated area [1]-[5]. In this usage of a self-driving small-size bus is expected to run with relatively slower speed, thus the occupants are supposed to be not constrained by a seat belt or an air bag. However, the self-driving bus also cannot avoid a sudden brake due to external factor such as a car driven by a man, bicycles, pedestrians and animals. To establish the occupant safety in a self-driving bus, it is required to prescribe the motion of occupant when the bus is subjected to a sudden decelerating acceleration and to know the limit of magnitude of the acceleration at which the safety of the occupant is ensured.

In this paper, numerical analysis is conducted on dynamic behavior of an occupant in a decelerating automobile. The analytical model consists of a rigid-body dummy model sat on a seat that consists of rigid plates. Assuming a situation that a self-driving small-size bus is subjected to sudden decelerating acceleration, constraint of the dummy by a seat belt of an air bag is not considered. Both of the dummy and the seat are given same initial velocity with relatively slower range, then the velocity of the seat is decreased with a constant rate. The dynamic responses of the dummy are numerically calculated and the motions of dummy are discussed under various values of decelerating acceleration and friction constants between seat and dummy.

2. Procedure of Analysis

Fig. 1 shows the analytical model of an occupant sat on a seat of a bus in this research. The bus is modeled by two seats placed in the direction of travel (x-direction) and a floor. The seats and the floor are modeled with rigid-body plates. The dimensions of the seats are chosen based on that of an existing small-size bus. A numerical rigid-body dummy model is positioned on the rear seat. The LSTC Hybrid III 50th Male dummy model is utilized in this research. The dynamic motion of the dummy is numerically calculated with the commercial software LS-DYNA. The dummy is subjected to the vertical gravitational acceleration in the negative *y*-direction. The contact and friction conditions are introduced between the dummy, the seats and the floor. The friction constants are selected as the following two cases: (1) μ_s=0.7, μ_d=0.5 and (2) μ_s=0.4, μ_d=0.2, where μ_s is the maximum static friction coefficient and μ_d is the dynamic friction coefficient. We assumed that the initial speed of the bus is 6.0 m/s (=21.6 km/h). In the calculation, initial velocity of the dummy is set to 6.0 m/s (=21.6 km/h) in the traveling direction that is same as the initial velocities of the seats and floor. First, the dynamic response of the dummy is calculated for the time duration of 1 s keeping the velocities of the seats and the floor constant. Then the velocities are decreased linearly with respect to time with the range of decelerating acceleration from a=1.2 m/s^2 to 12 m/s^2 that correspond to the decelerating time t_d=5 s and 0.5 s, respectively. After the velocities of the seats and the floor are vanished, the calculation is continued for 1 s keeping the seats and floor are stopped. An example of velocity profile of the seats and floor is shown in Fig. 2.

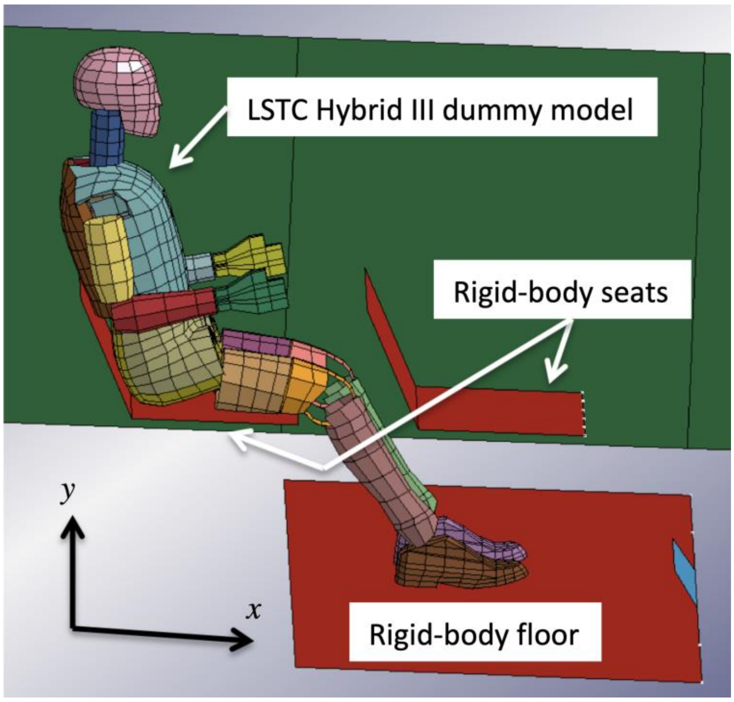


Fig. 1. Analytical Model of an Occupant Sat on a Seat

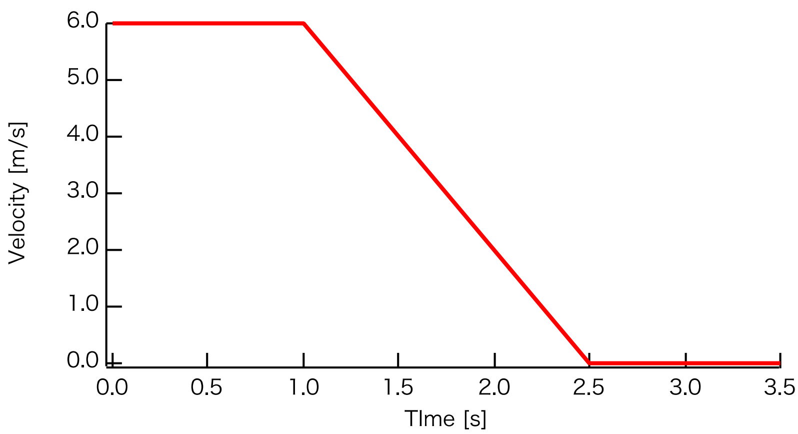
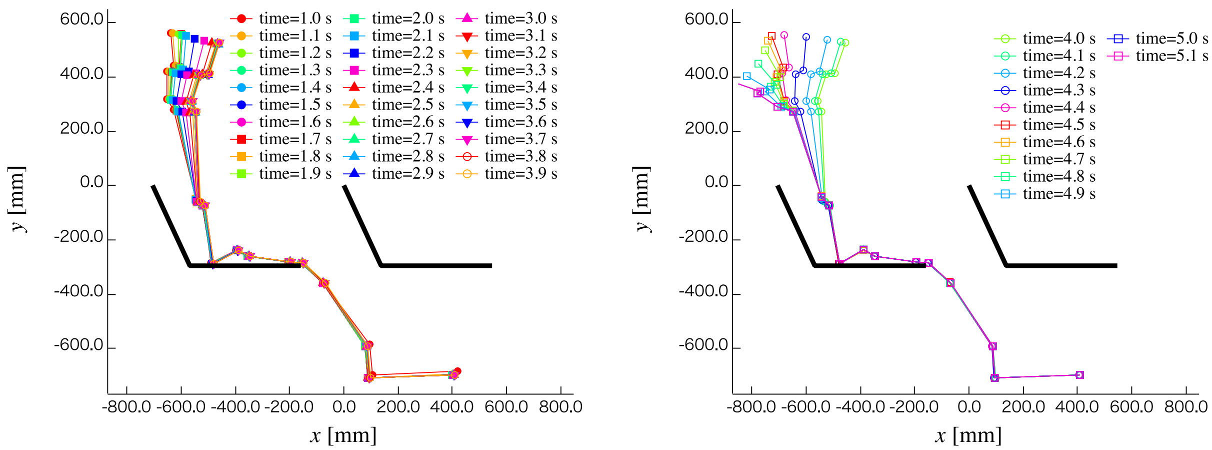


Fig. 2. An Example of Velocity Profile of Seats and Floor, a=4 m/s^2, t_d=1.5 s

3. Results and Discussion

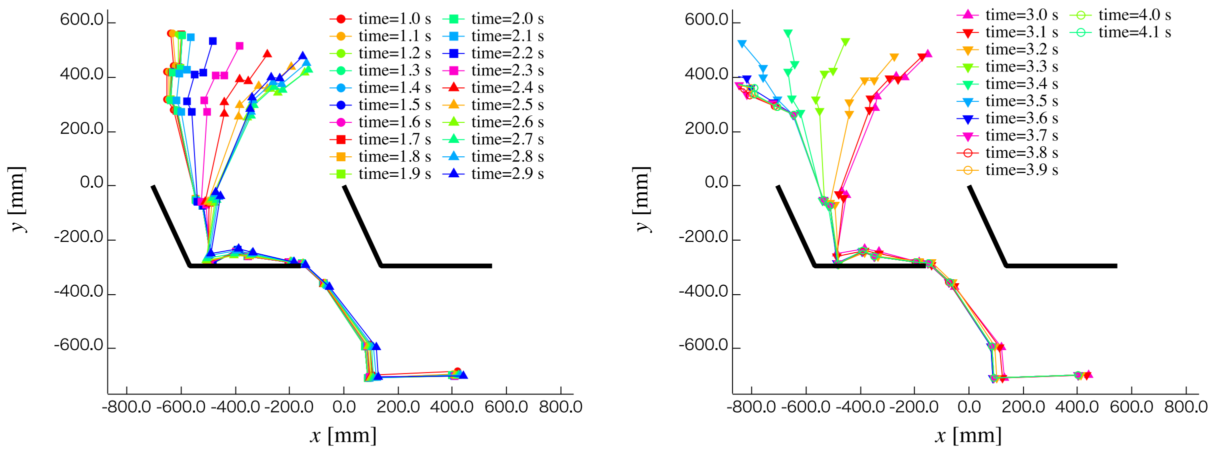
Figures from 3 to 7 show the snapshots of motion of the dummy model at the time interval of 0.1 s, under the friction constants μ_s=0.7, μ_d=0.5 in the *x*-*y* plane. In each figure, (a) shows the snapshots before and under deceleration, while (b) shows the snapshots after stopped. The dummy body is expressed by a broken line that connects from head to toes. The viewpoint is fixed on the seat.

Fig. 3 denotes the result under a=3 m/s^2, t_d=2.0 s. In this relatively long deceleration time, the lower body is almost fixed on the seat although the upper body slightly swings. Under a=6 m/s^2, t_d=1.0 s, the amplitude of the swing motion of the upper body increases due to the increase in the acceleration as shown in Fig. 4. When the acceleration is increased further to a=6.7 m/s^2, t_d=0.9 s, as shown in Fig. 5, one can see that the waist rises from the seat, which results in the larger forward tilting of the upper body. The collision of the dummy to the front seat is observed when the acceleration is increased to a=7.5 m/s^2, t_d=0.8 s as shown in Fig. 6. In Fig. 7, the result of the largest acceleration in this numerical example shows the other type of collision. Owing to the large acceleration, the whole body starts to slide on the seat, which results in the collision of the knee to the front seat. Then the upper body rotates towards the back of the front seat until they collide.



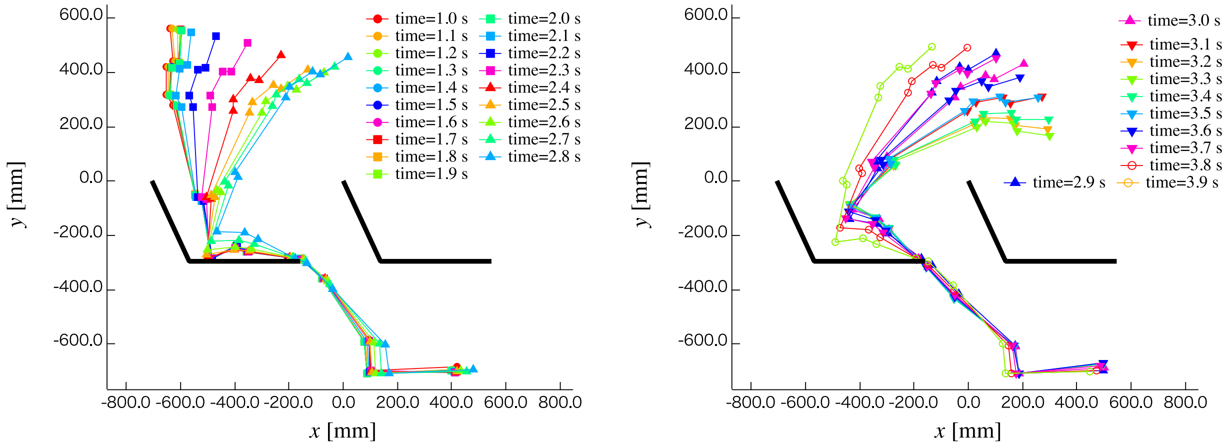
(a) Before and under Deceleration (b) After Stopped

Fig. 3. Snapshots of Motion of the Dummy Model, a=3 m/s^2, t_d=2.0 s, μ_s=0.7, μ_d=0.5



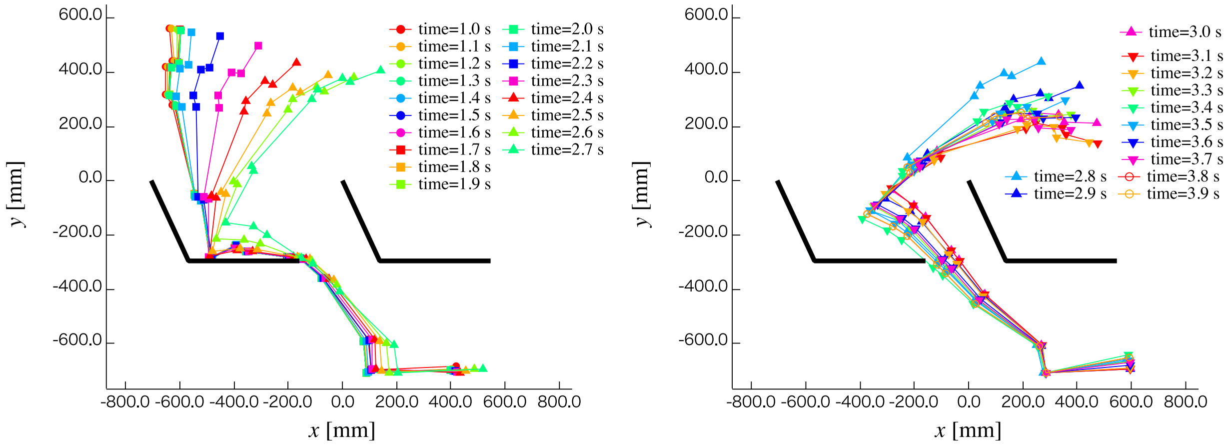
(a) Before and under Deceleration (b) After Stopped

Fig. 4. Snapshots of Motion of the Dummy Model, a=6 m/s^2, t_d=1.0 s, μ_s=0.7, μ_d=0.5



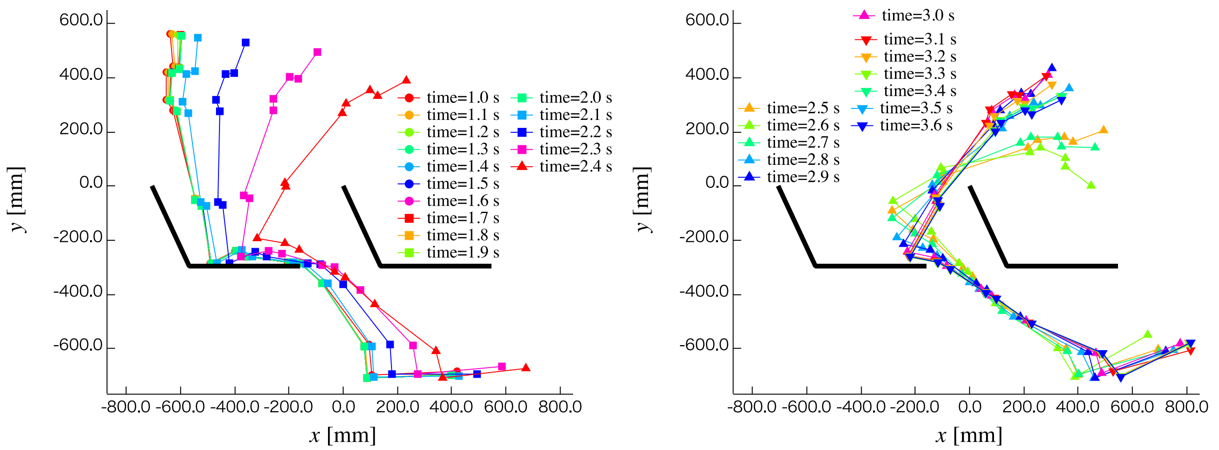
(a) Before and under Deceleration (b) After Stopped

Fig. 5. Snapshots of Motion of the Dummy Model, a=6.7 m/s^2, t_d=0.9 s, μ_s=0.7, μ_d=0.5



(a) Before and under Deceleration (b) After Stopped

Fig. 6. Snapshots of Motion of the Dummy Model, a=7.5 m/s^2, t_d=0.8 s, μ_s=0.7, μ_d=0.5

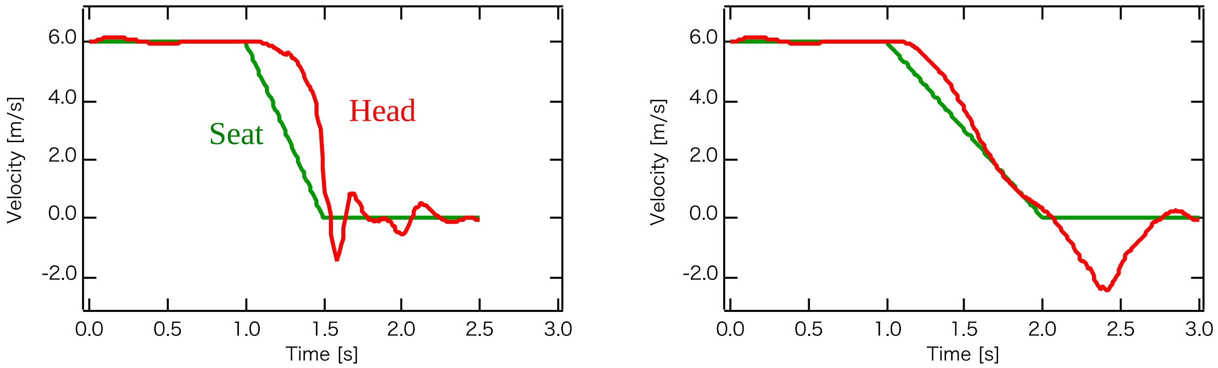


(a) Before and under Deceleration (b) After Stopped

Fig. 7. Snapshots of Motion of the Dummy Model, a=12 m/s^2, t_d=0.5 s, μ_s=0.7, μ_d=0.5

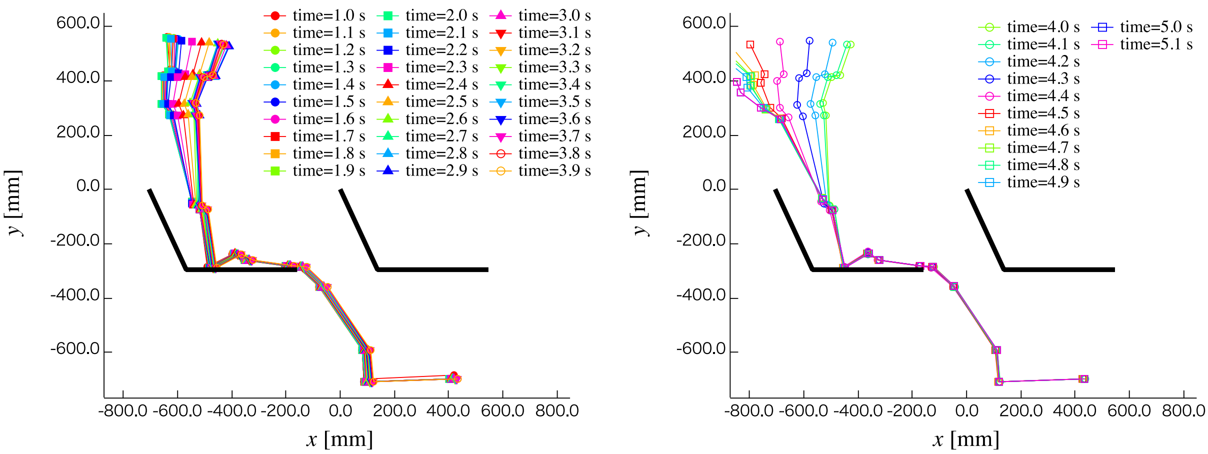
Figs. 8(a) and 8 (b) shows the time histories of velocities, in the direction of travelling, of head and seat under a=12 m/s^2, t_d=0.5 s and a=6 m/s^2, t_d=1.0 s, respectively. Fig. (a) shows larger deceleration in head velocity due to the collision compared to the result in Fig. (b).

Figures from 9 to 12 show the snapshots of motion of the dummy model under the smaller friction constants μ_s=0.4, μ_d=0.2. In this case, the slides of whole body on the seat can be observed even in relatively small acceleration. Therefore, collision of the dummy to the front seat, observed in Figs. 11 and 12 are similar to the result shown in Fig. 7; owing to the slide, the knee collides to the front seat first, then the upper body rotates and collides to the back of the front seat.



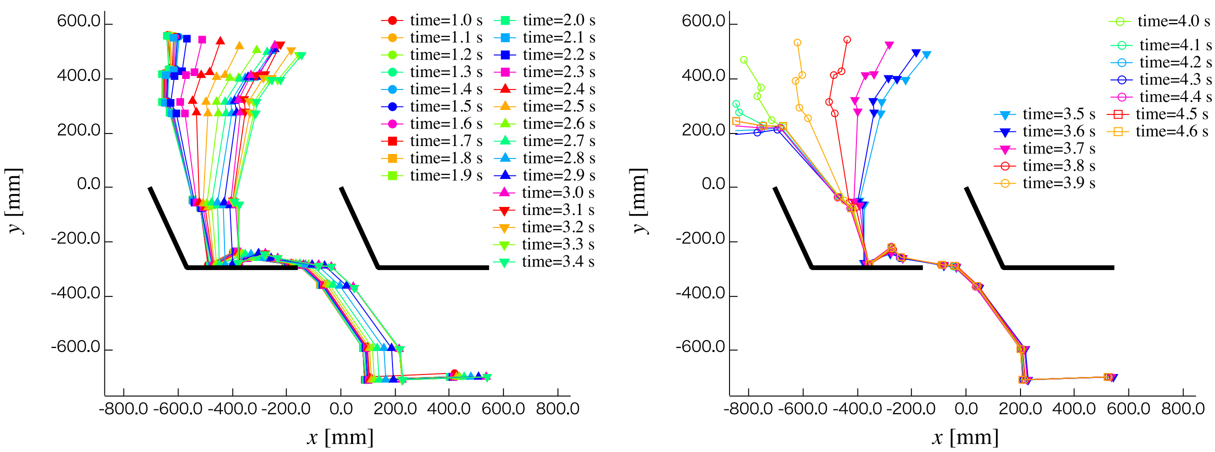
(a) a=12 m/s^2, t_d=0.5 s (b) a=6 m/s^2, t_d=1.0 s

Fig. 8. Time Histories of the Velocities of Head and Seat, μ_s=0.7, μ_d=0.5



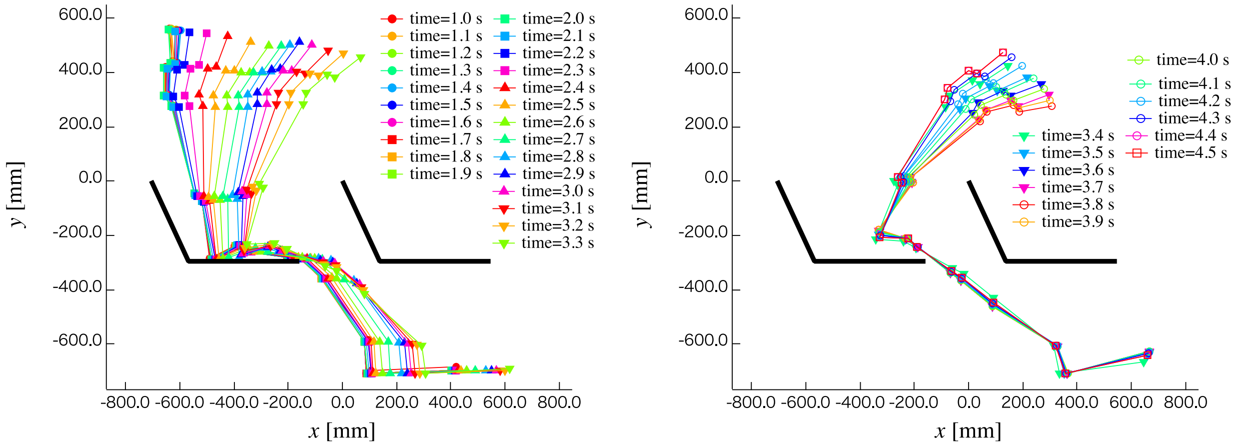
(a) Before and under Deceleration (b) After Stopped

Fig. 9. Snapshots of Motion of the Dummy Model, a=3 m/s^2, t_d=2.0 s, μ_s=0.4, μ_d=0.2



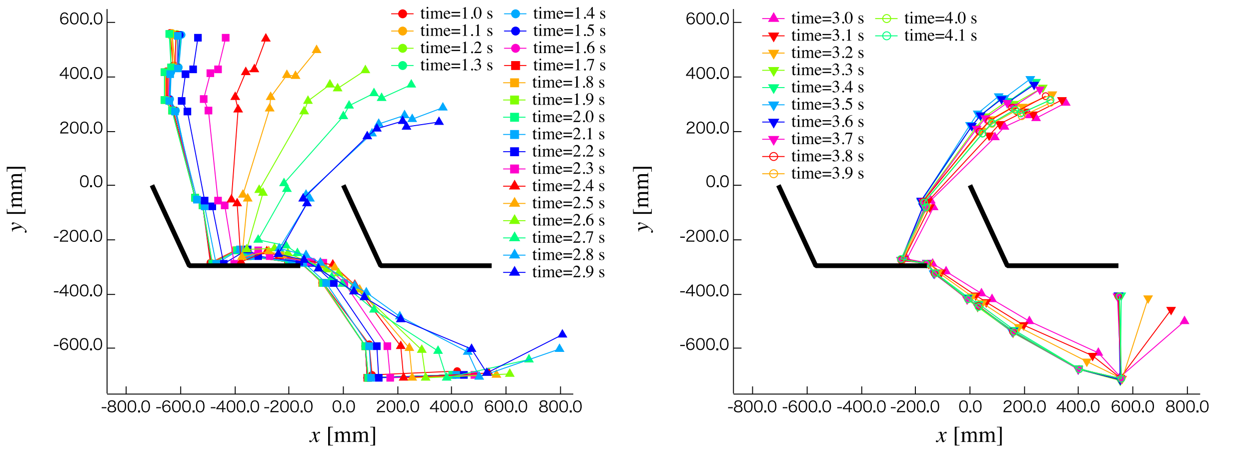
(a) Before and under Deceleration (b) After Stopped

Fig. 10. Snapshots of Motion of the Dummy Model, a=4 m/s^2, t_d=1.5 s, μ_s=0.4, μ_d=0.2



(a) Before and under Deceleration (b) After Stopped

Fig. 11. Snapshots of Motion of the Dummy Model, a=4.3 m/s^2, t_d=1.4 s, μ_s=0.4, μ_d=0.2



(a) Before and under Deceleration (b) After Stopped

Fig. 12. Snapshots of Motion of the Dummy Model, a=6 m/s^2, t_d=1.0 s, μ_s=0.4, μ_d=0.2

4. Conclusion

In this paper, numerical analysis is conducted on dynamic behavior of an occupant in a decelerating automobile. The dynamic responses of a dummy model sat on a seat are numerically calculated, which show the two types of collision of the dummy to the front seat depending on the combination of the acceleration and the friction constants between the dummy and the seat.

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