Development of a Human Model for Numerical Simulation of Railway Collisions

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Dummy models for impact simulation have only been able to assess impact from one direction. Some models are able to evaluate frontal impact, while others can evaluate side impact or rear impact. When evaluating collision safety, separate dummy models are employed depending on whether the dummy models are parallel to the direction of travel or perpendicular. In addition, it is difficult to evaluate the interior fixtures of Japanese railway vehicles because the physiques of dummy models are based on Westerners. Therefore, a human model with a Japanese physique was developed to evaluate various situations in railway vehicles.

Keywords: safety, ergonomics, railway collision, numerical simulation, interior fixture

1. Introduction

As well as countermeasures for active safety, countermeasures for passive safety have been studied in the fields of automobile and aviation safety. In the railway industry, research to mitigate the severity of injuries has been conducted in Europe and the United States. EN15227 [1] and CFR238 [2] prescribe crashworthiness requirements for railway vehicle bodies. On the other hand, there is no crashworthiness requirement in Japan, despite JIS E 7106 [3] providing a standard for static body strength. Therefore, requirements need to be developed in order to reduce injuries, and to this end it is important to evaluate onboard safety in the event of a collision.

The impact phase is divided into two parts. One part is the collision between the railway vehicle and an external object, which is called the “primary impact.” The other is the collision between a passenger and an interior fixture, which is called the “secondary impact.” This study focuses on secondary impacts.

The severity of injuries depends on the acceleration pulse caused by the primary impact, the characteristics of interior fixtures, the initial position of passengers, inter alia. Physical impact tests were conducted to clarify the relationship between these factors and severity of injury [4]. Physical tests reproduce accident conditions by using an acceleration pulse with a sled, onto which the dummy and interior fixtures are placed. The conditions and the number of physical tests which can be carried out are restricted because of cost. Numerical collision simulations are thus used to perform parametric studies efficiently, overcoming the constraints of physical tests. The numerical simulations performed on computers replicated physical tests by using interior fixture models and dummy models [5].

Various dummy models are used in numerical simulations (Fig. 1). The structure of a dummy model used for frontal impact is different to that used for lateral impact. Standing dummy models are used to evaluate injuries to pedestrians. Dummy models suitable for collisions are employed in the field of automobile crash research. However, it is difficult to cope with the diversity of passenger postures in the field of railway crash research. In addition, there is the problem of using dummy models with Western physiques in Japanese safety assessments. The secondary impact collision positions of such models are different from those of Japanese people. Therefore, a human model with a Japanese physique was developed so that it could be used in numerical simulation of railway collisions in Japan.

2. Developing a human model with a Japanese physique for railway collisions

Finite element human models have been developed in the field of automobile crash research to precisely evaluate potential damage to a human body. This study proposes a human model for railway collision based on the H-Model [6] made by ESI Software et al. Figure 2 shows the characteristics of the developed human model used in this study.

2.1 Characteristics of H-model

An assessment of injuries to the head and chest is important to evaluate damage to passengers that could be fatal. However, the structure of a dummy model’s chest is different to that of a human body’s chest. Dummy models have chest structures that can only evaluate the level of injury that would be caused by an impact from one direction. The human model can evaluate all the impact directions that occur in railway vehicles. The human model for railway collision was based on the H-model, whose chest structure is the same as a human body. The characteristics of
Customizing the physique of the H-model to that of a Japanese adult male is important as it will allow the interior fixtures of Japanese railway vehicles to be evaluated.

2.2 Customization of posture

The H-model has skin, flesh, bone and organs, the same as the actual human body. The skin and the bones are made of shell elements. The rib cage has 12 pairs of ribs made of beam elements. Its structure can be changed due to impact from any direction. The flesh and organs are made of solid elements. The connections of the backbone and limb joints are rotational. A part of solid element of the shoulders, pelvis and knees has been removed, enabling the H-model to change its posture, for example from standing to sitting.

2.3 Customization of physique

The physique of a Japanese adult male was investigated to create a Japanese human model. Two data sources were used. One was data from about 3500 Japanese males aged between 20 and 79, published by the Research Institute of Human Engineering for Quality of Life in Japan from 2004 to 2006 [7]. The other was the results of the national census taken in 2005 [8]. Since it is expected that the ratio of elderly persons among railway users will increase in the future, it was assumed that the age group for railway users was 20-79. With regard to the average height and weight of that age group, the Japanese adult male physique was approximately 169 cm for 66 kg.

The height and weight of the H-model were adjusted to meet this physique. The number of nodes was approximately 19,000 and the number of elements was 22,000.

2.4 Confirming the precision of the developed human model

The results of the simulation analysis were compared with results of human chest impact tests performed in the United States in order to confirm the precision of the proposed human model [9]-[13].

The results of the frontal chest impact simulation are shown in Figs. 3 and 4. Chest displacement and force exerted on the impacting object were measured. The diameter of the impacting object was 150 mm for a weight of

Fig. 2 Characteristics of developed human model

Fig. 3 Frontal chest impact simulation

Fig. 4 Test and simulation results of frontal chest impact
23 kg. The impacting object collided with the center of the chest of the dead human bodies at speeds of 4.3 m/s and 6.7 m/s. The test results had corridors because of individual differences. Figure 4 shows the relationship between force and chest displacement in previous tests and in the simulation with the developed human model. From these results, it was confirmed that the simulation results were within the upper and lower limits of the previous test results.

The results of the lateral chest impact simulation are shown in Figs. 5 and 6. The impacting object collided with the side of the chest of the dead human bodies at speeds of 4.3 m/s and 6.7 m/s, i.e., at the same speed as in the frontal impact tests. Figure 6 shows the time history of the force exerted on the impacting object in the tests and in the simulation. From these results, it was confirmed that simulated results were within the upper and lower limits of the previous test results.

The human model precisely reproduced the characteristics of the human body for frontal and lateral impacts, enabling chest impacts to be evaluated from all directions.

3. Injury evaluation for the developed human model

Railway injury evaluations were conducted with the developed human model.

3.1 Injury evaluation of a transverse table seat

(1) Simulation conditions

The dummy model for frontal impact and the human model were seated on a transverse seat, facing the front, the side, and at an oblique angle. A simulation in which the chest collided with the table was performed. Figure 7 shows the initial position on the transverse seat in relation to the table. The table was rigid, with a width of 360 mm, a thickness of 20 mm, and a height of 800 mm. The impact velocity was 3 m/s. The injury evaluation index indicates the maximum chest displacement in the dummy model and human model.

(2) Results

Figure 8 shows the behavior of the frontal impact dummy model and the human model. The chest of both models collided with the table. Figure 9 shows the maximum chest displacement. The maximum chest displacement of the dummy model was lower than that of the human model when the impact was from the side and from an oblique angle. It is believed that the dummy model underestimated side and oblique impact.

3.2 Injury evaluation with impact from several directions

(1) Simulation conditions

There is a possibility that a passenger could be thrown, colliding with several interior fixtures and receiving injuries from several directions. A simulation in which the human model collides with interior fixtures 1 and 2 consecutively, was conducted. The human model was in a standing position. Figure 10 shows the initial position of the standing human model. The interior fixtures 1 and 2 were rigid. The accident scenario was a train colliding with large motorcar on a railroad crossing at a speed of approximately 50 km/h. Injury evaluation indices indicate the maximum point of front and side chest displacement in the human model.

(2) Results

Figure 11 shows the behavior of the human model. Figure 12 shows the maximum chest displacement with front and side impact. Chest displacement during frontal impact was at its maximum when the human model collided with interior fixture 1. Chest displacement during side impact was at its maximum when the human model collided with interior fixture 2. A human body would collide with handrails or other passengers in an actual train vehicle; therefore, impact would come from several direc-
direction of train collision

(a) Frontal impact dummy model   (b) Human model

Fig. 7 Initial position on transverse seat in relation to table

Direction of train collision

(a) Frontal impact dummy model   (b) Human model

Fig. 8 Behavior 90 ms after colliding with table

Direction of train collision

Table
Transverse seat
Floor
Frontal

Fig. 9 Maximum chest displacement of dummy model and human model

Frontal impact dummy model
Human model

Table
Transverse seat
Floor
Frontal

Obliqueness

Fig. 7 Initial position on transverse seat in relation to table

Fig. 8 Behavior 90 ms after colliding with table

Fig. 9 Maximum chest displacement of dummy model and human model

Frontal impact dummy model
Human model

(1) Simulation conditions
The difference in behavior caused by difference in physique was evaluated by comparing the secondary impact position of a human model with a Japanese physique, with that of an American model. Figure 13 shows the initial position of the human model on a transverse seat. The seat’s pitch was 960 mm. The transverse seat and the input acceleration pulse were the same as in the previous section. The height of the head impact was adopted as the evaluation index.

(2) Results
Figure 14 shows the behavior of a human model with a Japanese physique on a transverse seat. The knee and head of the human model collided with the back of the
Fig. 10 Initial position of standing human model

Fig. 11 Behavior of standing human model

Fig. 12 Maximum chest displacement for each direction

Fig. 13 Initial position of a human model with a Japanese physique on a transverse seat
transverse seat. The behavior was the same as for the human model with an American physique. Figure 15 shows the height of head impact. The height of the Japanese model was 40 mm lower than that of the American model. In general, a transverse seat has a table fastening fixture near the place where head impact occurs (Fig. 16). The severity of head injuries could thus be decreased by installing table fastening away from the place of impact. A human model with a Japanese physique enables the evaluation of interior fixtures with Japanese train passengers.

4. Conclusions

In this study, a human model with a Japanese physique was developed to evaluate passenger injuries in railway vehicles, which is difficult with dummy models. The characteristics of the human model are as follows:

- Its posture can be changed from standing to sitting.
- It can be used to evaluate impact from all directions.
- It has a Japanese physique, with a height of 169 cm for a weight of 66 kg.

Simulations with the human model were performed to evaluate passenger injuries under railway vehicle conditions. From the results, it was confirmed that the human model can assess safety in train collisions.

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