## Head Injury Analysis of the Seated Occupant in Urban Rail Train Collision

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## I. INTRODUCTION

In recent years, the urban traffic situation in China is faced with great pressure, due to the fast urbanisation process. Especially, the existing traffic systems in large and medium-sized cities are becoming one of the bottlenecks of sustainable social development. Urban rail transit is an effective way to relieve urban traffic pressure, realise urban sustainable development and reduce urban pollution. With the increasing volume and speed of urban rail vehicles, it is urgent to propose effective measures to improve the safety level of occupants. At present, passive protection is still an important way to reduce occupant injuries [1-4]. It is, therefore, of great practical significance to evaluate the passive safety level of urban railway vehicles.

In order to ensure the safety of occupants during train collision, the European Union conducted a number of projects between 1990 and 2007, including [5-7], to study passive safety technology in trains. The Federal Railroad Administration and the Volpe National Transportation Systems Center studied the crashworthiness of rail vehicles through simulation and experiment. They used dummy models to evaluate the protection level of newly designed chairs and tables in the real railway vehicle crash test [8-9]. Through the above studies, they concluded some measures to improve the safety level of occupants [10-11]. In order to ensure the safety of occupants in collision accidents, Britain has carried out a series of secondary collision studies on occupant and occupant compartment structures in vehicles. Aiming to improve the safety of vehicle interiors in collision accidents and use the interiors to reduce occupant casualties, the crashworthiness of railway trains, but mainly on the crashworthiness of the vehicle body structure. Nevertheless, the ultimate goal of passive safety protection of train structures is to protect the safety of occupants. In contrast, few efforts were devoted to occupant secondary collision. It is thus very necessary to study the safety of occupants in secondary collisions from the perspective of the internal structure of the train body.

#### **II. METHODS**

In this paper, a finite element method was used to study the responses of dummies during secondary collision. A nonlinear finite element software LS-DYNA was used to simulate the collision process between train and occupant. The calculation was carried out in supercomputer centre in Wuxi, China.

So far, only the crashworthiness standard AV/ST9001 provides a criterion for evaluating the collision injury of railway occupant. In the AV/ST9001 B3.1, it is said that ATD Hybrid III representing a 50<sup>th</sup> percentile male should be installed in each seating position when testing for passenger injury resulting from seats [12]. The Rigid-FE Hybrid III dummy models developed by Livermore Software Technology Corporation (LSTC) are based on the physical Hybrid III adult dummies [13]. The Rigid-FE Hybrid III 50<sup>th</sup> percentile male dummies were studied in the paper. The overall composition of the dummy can be roughly divided into three parts: head and neck, body and limbs, as shown in Fig. 1. The bones of the neck, spine, pelvic and limbs are rigid. The muscles of the limbs are made of elastic materials. The dummy's head, ribs and lumbar vertebrae are modeled with viscoelastic materials. The soft tissue at the knee, the chest muscle tissue, abdomen and buttocks are made of low-density foam materials. Overall, the dummy is semi-deformable.

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IRCOBI Asia 2020



Fig. 1. Hybrid III 50<sup>th</sup> Fast Dummy.

An urban rail vehicle was used for finite element modelling, mainly including the chassis, side wall, end wall, roof and coupler and draft gear, as shown in Fig. 2. The vehicle had 1,106,726 shell elements, 5,908 solid elements, 32 beam elements, and a total of 991,799 nodes. The coupler and draft gear was simulated using beam elements. This subway vehicle was made of high-strength aluminum alloy material. The PIECEWISE\_LINEAR\_PLASTICITY material model in LS-DYNA, namely the No. 24 material model, was adopted. The material parameters are shown in Table I.



Occupant - vehicle coupling model was established. For convenience of analysis, occupants were numbered 1 - 6, as shown in Fig. 3. The seats of No. 1 occupant and No. 6 occupant were longitudinally arranged, while other occupant seats were horizontally arranged. No. 1 occupant and No. 6 occupant sit perpendicular to the train moving direction. No. 2 occupant and No. 3 occupant sit in the same direction as the train, while No. 4 occupant and No. 5 occupant sit in the opposite direction of the train.

≥13

Elongation (%)

≥8

≥7



Fig. 3. Occupant - vehicle coupling model.

Railway vehicles are classified into crashworthiness design categories, according to European Standard EN 15227 [14]. Urban vehicles, classified as C-II, are designed to operate only on dedicated rail infrastructure. EN 15227 specifies that a metro train with an initial speed of 25 km/h hits the other stationary identical metro train

which has no braking. It is more time-consuming to calculate the collision model with two trains. To improve the calculating efficiency, rigid-wall which is reported to be widely used in many related references was used to replace the stationary train in the EN 15227 [15]. In this paper, the scenario where a train crashing a rigid-wall at 12.5 km/h was equivalent to that Standard EN15227 specifies.

When the train crashed the rigid wall, automatic single contact was set in the collision area of the car body. And the self-contact friction coefficient was set to 0.2. Surface to surface contact was set between the train wheel and the track, and the friction coefficient was set to 0.001. The friction coefficient between the occupant's sole and the floor was 0.49, and the friction coefficient between the rest of the occupant's body and the carriage was 0.3 [16]. The whole model applied gravity, and the track was constrained.

In the crashworthiness standard [12], an investigation was undertaken into establishing the number of recorded injuries to specific body regions that could be attributed to seats. The head, neck, legs and arms accounted for 30%, 28%, 20% and 14%, respectively, indicating that it is more necessary to investigate the head injury, compared with the other injuries.

The maximum injury criterion of head specified for seat testing using a Hybrid III ATD shall be 500 [12]. In this paper, the extensive head injury evaluation index HIC36 was selected to evaluate the occupant injury, which represented the maximum value of HIC within any 36 ms, as shown in Eq. (1).

$$HIC_{36} = \max\left(t_2 - t_1\right) \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt\right)^{2.5}$$
(1)

where,  $t_1$  and  $t_2$  are the initial and termination points of the integral respectively, and the time interval  $t_2 - t_1$  is less than 36ms. a(t) is the time curve of the resultant acceleration at the centre of the head of the occupant, g (s).

#### **III. INITIAL FINDINGS**

The head acceleration time curves of the six occupants are shown in Fig. 4, where the No. 1 occupant's head contacted the door frame at 0.17 s and the peak acceleration was 58 g; No. 2 occupant's head contacted the door frame at 0.3 s and the peak acceleration of the head was 63 g; No. 3 occupant's head contacted the front seat at 0.23 s and the peak acceleration was 69 g. The peak acceleration of the head of these three occupants were relatively high. When the head of the No. 6 occupant contacted with the handrail at 0.62 s, the peak acceleration was 17.8 g, and the head acceleration of No. 4 occupant and No. 5 occupant were relatively low.





The head injury values  $HIC_{36}$  of occupants at different positions are shown in Table 2. Among them, the head injury index value  $HIC_{36}$  of No. 3 occupant was the largest, while the head injury index value  $HIC_{36}$  of No. 4 occupant and No. 5 occupant were the minimum. That is, the occupant's head injury is the minimum when the occupant sits in the opposite direction of the train.

			TABLE II			
HIC <sub>36</sub> OF OCCUPANTS AT DIFFERENT POSITIONS						
occupant	1#	2#	3#	4#	5#	6#
HIC <sub>36</sub>	53	71	120	1	1	14

# **IV. DISCUSSION**

In this study Hybrid III 50<sup>th</sup> percentile male dummies were selected to investigate the head injuries. Through the analysis of the head injuries of occupants in six different positions inside an urban rail vehicle, it was found that the head was injured the least when 50<sup>th</sup> percentile male dummies were in the opposite driving direction of the train. This result can provide recommendations for the occupants to choose their seats when boarding trains. In this paper, only the head injury of the occupant was analysed, and the neck, chest, legs and other injuries of the occupant should be further analysed.

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