Occupant head injury assessment for bullet trains using dummy crash tests

Gongxun Deng, Ciaran Simms, Tuo Xu, Yong Peng, Zhixiang Li, Lin Hou,
Quanwei Che, Yangyang Yu, Zhixiang Liu

I. INTRODUCTION

Railway, especially high-speed railway, is an important mode of transportation. However, train collisions cannot be completely avoided and can potentially cause heavy casualties due to the train's high kinetic energy and the fact that passengers are unrestrained in their seats. The human head is the most vulnerable region in train collision impacts [1]. In addition to numerical simulation, which is an important tool to predict train occupant injury [2-3], the dummy crash test is a valuable means to reproduce the response of passengers during a collision [4-5]. The relationship between carriage interior design and occupant injury severity is not well established. This paper assesses the influence of a folding table and seat deflection on head injury severity during a low-severity frontal collision of a bullet train.

II. METHODS

An integration of finite element (FE) simulations and dummy sled tests was employed (Fig. 1). Firstly, the train crash pulse was obtained before the sled tests using FE simulations. A detailed FE model of an eight-car coupled bullet train was established, and its energy-absorbing structures were verified by impact experiments. The train-to-train crash simulation was performed according to the railway crashworthiness standard EN 15227 [6]. In train collisions, the first carriage of the moving train is the most severely affected vehicle of the whole train. Therefore, the acceleration time history of the first carriage was obtained from the FE train-to-train collision simulation. Secondly, to effectively reproduce the crash pulse by sled, the obtained crash pulse from FE simulation was simplified to the representative triangular pulse, see Fig. 1 and [7]. The sudden drop in the acceleration occurs when energy absorption is complete and the two trains have reached a common velocity.

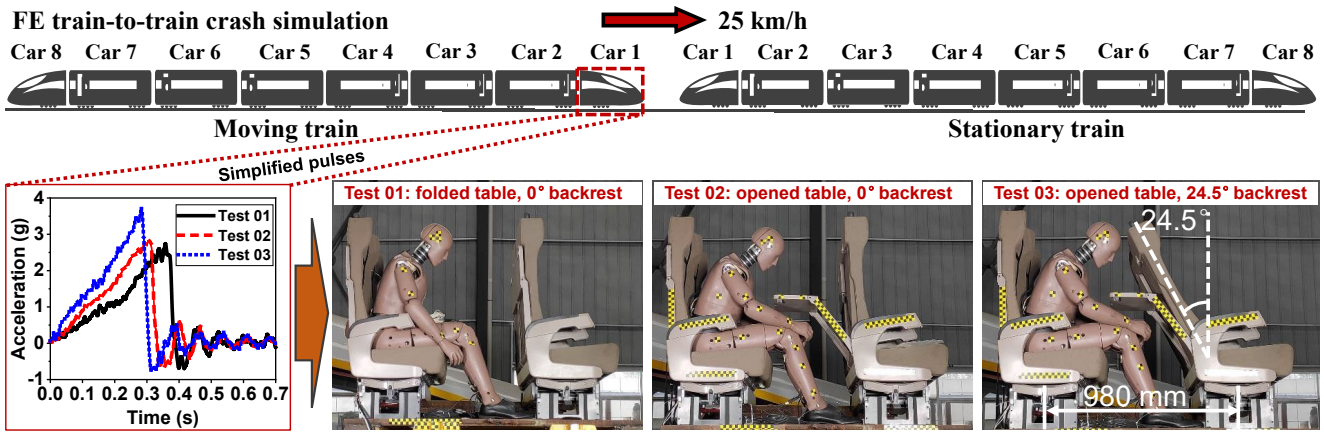

Fig. 1. Overview of the methodology for occupant injury analysis in bullet trains.

Three Hybrid III 50th Male dummy sled tests were performed at Train Collision Lab, Central South University, China (Fig. 1). The seats used in bullet trains were provided by the bullet train manufacturer, CRRC. Two parameters, including the foldable table and the maximum rotation angle (24.5°) of the seat backrest, were considered (Fig. 1). According to the interior layout of bullet trains in China, the longitudinal distance between two seats is 980 mm. In train collisions, passengers may be projected long distances from their seats because they are not restrained by seat belts or airbags. Here, to avoid damage to the dummy after it falls from the seat, a loosely fitting two-point seat belt was used that did not interfere with the dummy seatback contacts. Two high-speed cameras were employed to record dummy kinematics over the full trajectory. Dummy head acceleration was measured by a triaxial accelerometer and HIC_{15} (Head Injury Criterion) was calculated to assess the dummy head injury.

Y. Peng (e-mail: yong_peng@csu.edu.cn; tel: +86-073182655374) is a Professor and G. X. Deng, T. Xu, Z. X. Li and L. Hou are PhD candidates, all in the School of Traffic & Transportation Engineering at Central South University, China. C. Simms is a Professor in Biomechanics at Trinity College Dublin, Ireland. Q. W. Che, Y. Y. Yu and Z. X. Liu are Senior Research Engineers, all in CRRC Qingdao Sifang Co., Ltd., China.

III. INITIAL FINDINGS

Figure 2 depicts a sample sequence of dummy kinematics at different timings and phases. In general, the occupant motion in bullet train collisions can be categorized into three stages: slide phase, contact phase, and rebound phase. In the first phase, the occupant moves forward, towards the seatback in front, due to the vehicle impact deceleration. Subsequently, the occupant hits the frontal seat. Finally, the occupant rebounds after the occupant compression reaches its maximum value. t_0 is the first train collision time, t_1 is the first dummy-frontal seat impact time, and t_2 is the first rebound time. The collision ends at t_3.

Figure 3 shows head resultant accelerations and HIC_{15} values. The maximum head resultant accelerations for the three tests are 30 g, 25 g and 15 g, respectively, and these are much higher than the peak train deceleration. Nonetheless, the HIC_{15} values for the three tests are very low: 17, 13 and 4, respectively, due to the soft seatback design. The duration windows for HIC_{15} of the three tests are 9 ms, 8 ms and 15 ms, respectively.

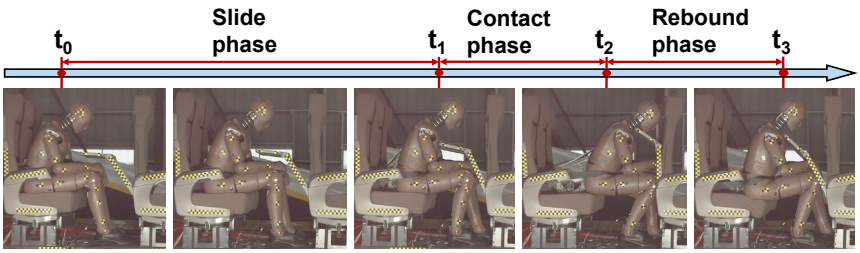

Fig. 2. Occupant kinematics processes for test 02.

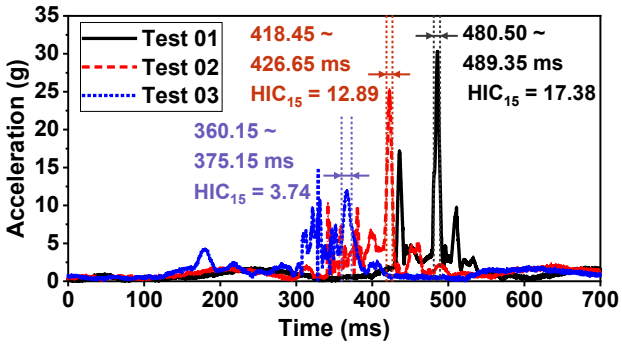

Fig. 3. Occupant head impact injury assessment.

IV. DISCUSSION

This study is the first series of dummy crash tests of seated occupants in bullet trains to take place in China. The kinematic response of the whole dummy can be divided into several critical moments and three stages that are common to all tests. However, in test 03 the head makes first contact with the seat in front due to the small longitudinal distance between the head and the frontal seat backrest (Fig. 1: 24.5° backrest in test 03), while the occupant body (excluding the head) makes first contact with the seat in front for the other two tests. The maximum head acceleration is moderate and its duration is short, resulting in very low HIC_{15} scores. In addition, the head peak acceleration and HIC_{15} of test 03 are obviously less than for the other two tests, and the duration window for HIC_{15} is larger than for the other two tests. The reason is that the backrest of the seat in front for test 03 is adjusted to the maximum angle (24.5°), which causes the gas spring (i.e., pneumatic energy absorber) of the seat adjustment to absorb a lot of the occupant energy and the frontal seat backrest to be 'softer'.

The crash pulses used in the dummy sled tests are from the FE train-to-train collision simulation according to the railway crashworthiness standard EN 15227. The crash pulses with about 3 g peak value are moderate impacts due to the low impact speed (approx. 25 km/h) and the integrated multi-stage energy-absorbing devices. The low HIC_{15} results demonstrate that a bullet train equipped with multi-stage energy-absorbing devices can protect unrestrained passengers during low-speed frontal collisions specified by the railway crashworthiness standard. However, the occupant's head impact injury may be severe in higher-speed crashes and future study should focus on this. This work is also valuable to verify the numerical model of bullet train seats.

V. ACKNOWLEDGEMENTS

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