Relation between Secondary Impact Velocity and Behaviour of Longitudinal-Seat Passenger in Railway Collisions

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I. INTRODUCTION

Railway passengers do not have seat belts; therefore, they are thrown forward in the event of a frontal collision. Thus, a possibility exists that passengers on longitudinal seats would be projected to a significant distance and could collide at high velocity with interior fixtures. Based on sled tests simulated by the UK Railway Group Standards GM/RT2100, a previous study applied acceleration pulses to passengers on a longitudinal seat and found that the most severe injuries occurred for passengers seated second and third-closest from the bench-end partition [1]. Other studies claim that a higher secondary impact velocity (SIV) correlates positively with the more severe passenger injuries [2-4]. Thus, decreasing SIV is vital to decrease the severity of injuries to passengers in general.

Numerical simulations are useful for obtaining effective case studies concerning SIV. In 2015, we proposed a numerical simulation method with $\leq 3\%$ error of SIV to reproduce sled tests for passengers seated third-closest from the bench-end partition [5]. In this method, HIC (Head Injury Criterion) was overestimated due to vibration of head acceleration. The present study uses this method to examine how SIV relates to passenger behaviour which means translating and leaning to the bench-end partition in the event of a frontal collision.

II. METHODS

The numerical simulation allows us to investigate how initial seating position and passenger behaviour affect the SIV. The parameters of the numerical simulation are acceleration pulse and distance from bench-end partition. The European Committee for Standardization EN 15227 requires that in the event of a railway collision at a velocity of 36 km/h, the mean impact acceleration in the survival spaces be limited to 5 G [6]. As done in a previous study focusing on transverse seats [7], the present study adopts rectangular and triangular acceleration pulses with mean accelerations of 5 G. We assume that SIV correlates with the integrated acceleration pulse. The acceleration pulses were varied in duration to vary their integration value. The technical report of the European Rail Industry (UNIFE) for interior passive safety in railway vehicles mentions that the lower limit of duration of acceleration pulses is 100 ms and the upper limit is 160 ms [8]. The durations used herein are 80, 100, 120, 140 and 160 ms. Figure 1 shows several acceleration pulses. The distances from the bench-end partition are 200, 400, 600, 800, 1000, 1200 and 1400 mm. A distance of 600 mm separates a passenger seated second-closest from the bench-end partition and 1000 mm separates a third-closest passenger. ES-2 facet dummy model (Ver. 3.1) was used. The coefficient of friction was 0.9.

Next, to compare the SIV for equal integrated acceleration pulses, we numerically simulated a collision assuming the condition of varying jerk. The duration of acceleration is 160 ms; Figure 2 shows the acceleration pulses. The acceleration peaks occur at 20, 40, 60, 80, 100, 120 and 140 ms. The distance between passenger and partition is 1000 mm, which means that the secondary impact occurs after the acceleration pulse.

Finally, we examine a countermeasure to suppress the dummy model’s behaviour and to reduce the SIV. The countermeasure comprises installing armrests. A shape of the armrest is a box that is 50 mm wide. The armrest heights are 50, 100, 150, 200, 250 and 300 mm. Initially, the dummy model is 600 mm from the bench-end partition.

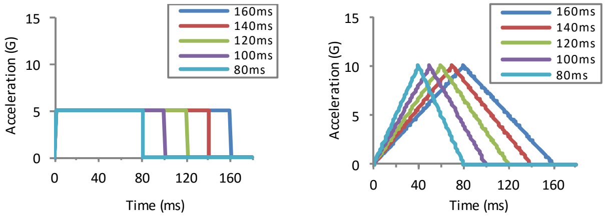

Fig. 1. Acceleration pulse (left: rectangle, right: triangle).

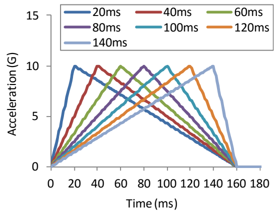

Fig. 2 Acceleration pulse for varying jerk.

III. INITIAL FINDINGS

Figure 3 shows the initial posture of the dummy model and the posture at the time of secondary impact. Figure 4 shows SIV as a function of distance from partition. The SIV is the greatest for the initial position of 600 mm and for accelerations of 80 and 100 ms. However, the SIV is the greatest for the initial position of 800 mm and accelerations

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lasting longer than 120 ms. The initial position of 800 mm would be between the second and third-closest seats from the partition. Within 600 mm in Fig. 4, the triangular acceleration pulses yield greater SIV differences (as opposed to rectangular acceleration pulses). For example, Fig. 5 shows the SIV difference for an acceleration that lasts 160 ms. A bench-end partition that is 600 mm from the passenger gives a different SIV. We have presumed that the dummy model's behaviour affects the SIV. Figure 6 shows a scatter diagram of SIV in the case of a rectangular acceleration pulse. The dispersion in SIV is large, even for equal integrated acceleration pulses. The same tendency occurs for triangular pulses. The error between SIV and the integrated acceleration pulse is distributed from -4.6 to 3.8 m/s.

Figure 7 shows SIV as a function of jerk. When jerk is 0.07 G/s (peak is at 140 ms), the SIV is 10.4 m/s. Moreover, when jerk is 0.5 G/s (peak is at 20 ms), SIV is 11.4 m/s. In this way, we find that the SIV varies with jerk even if the integrated acceleration pulses at the time of secondary impact are equal.

The SIV ratio for each armrest condition has been calculated and normalised to the SIV without an armrest (Fig. 8). With the 200 mm armrest, which is generally regarded to be the standard armrest height, the normalised SIV is 61% for a 100 ms acceleration. The normalised SIV is 79% for a 160 ms acceleration. For a 160 ms acceleration and a 300-mm-high armrest, the SIV almost halved (48%).

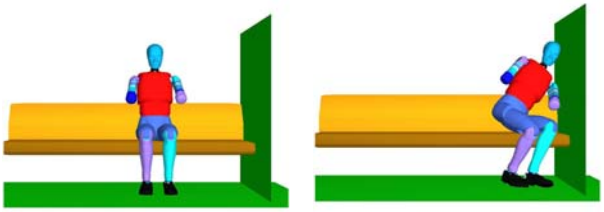

Fig. 3. Initial dummy position and position at moment of secondary impact.

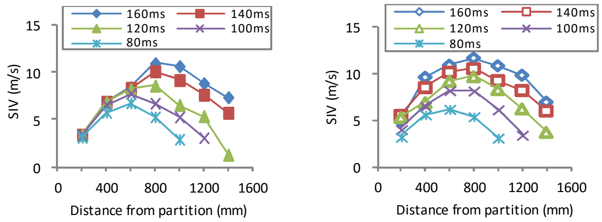

Fig. 4. SIV as a function of distance from partition [rectangles (triangles) are for left (right)].

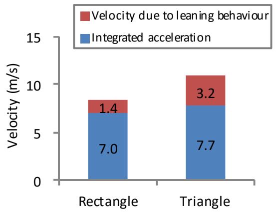

Fig. 5. SIV for 160 ms acceleration pulse at initial position of 600 mm.

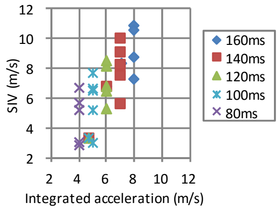

Fig. 6. Scatter diagram of SIV vs integrated acceleration (Rectangle).

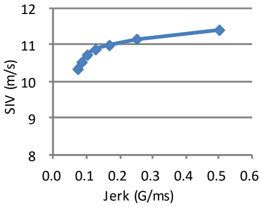

Fig. 7. SIV as a function of jerk.

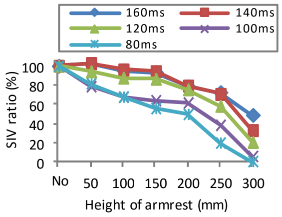

Fig. 8. Effect of armrest: SIV as a function of armrest height for various acceleration-pulse durations.

IV. DISCUSSION

The differences that appear in the Fig. 5 are attributed to the influence of the dummy model's leaning behaviour. The SIV is the sum of the integrated acceleration and the velocity due to the leaning behaviour. At 600 mm from the bench-end partition (which is the case in the Fig. 5), because the SIV for a rectangular acceleration pulse is 8.4 m/s and the integrated acceleration at secondary impact is 7.0 m/s, the velocity due to the leaning behaviour is 1.4 m/s. Furthermore, because the SIV for a triangular acceleration pulse is 10.9 m/s and the integrated acceleration at secondary impact is 7.7 m/s, the velocity due to the leaning behaviour is 3.2 m/s. In other words, the difference in SIV due to rectangular and triangular acceleration pulses is 2.5 m/s. Thus, the difference in velocity due to the leaning behaviour is 1.8 m/s. The results indicate that 72% of the difference in SIV results from the velocity due to the dummy model's leaning behaviour.

Correlation between SIV and integrated acceleration is examined in Fig. 6. The coefficient of correlation is 0.70 (0.73) for rectangular (triangular) pulses, which is insufficient to estimate SIV only with integrated acceleration.

We thus conclude that not only the acceleration pulse but also passenger behaviour must be considered to properly determine the SIV.

V. REFERENCES

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