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SAFETY EQUIVALENCE OF APTA 8G AND GMRT 5G SEAT TESTS BASED ON HUMAN INJURY

SUMMARY

The Federal Railroad Administration (FRA) sponsored research conducted at the Volpe Center aimed to assess the safety equivalence of the passenger rail seat dynamic test requirements specified in the United States (US) APTA [1] and Great Britain (GB) GMRT [2] safety standards. In this study, Volpe Center researchers utilized finite element (FE) simulations to replicate crash tests with forward-facing commuter rail passenger seats and two Hybrid-III 50th percentile male (H3-50M) anthropomorphic test devices (ATDs).

The researchers conducted this study to address questions on the safety equivalency of the crash pulses specified in the two safety standards and the different requirements for injury criteria. Notably, the APTA seat standard uses a triangular 8g crash pulse, while the GMRT safety standard uses a less-severe trapezoidal 5g crash pulse. It is noteworthy that despite the less severe crash pulse, the GMRT standard imposes more stringent requirements for injury criteria overall.

BACKGROUND

Revenue seats in passenger railcars on the U.S. general railroad system are subject to the safety requirements described in the APTA seat standard. This standard requires seats to be tested in simulated collision conditions with instrumented ATDs to assess the seat integrity, human injury performance, and occupant compartmentalization.

In a preceding study, Volpe Center researchers used an FE model of the same commuter rail seat in the APTA injury seat test and compared the injury criteria for different sized occupants (50th percentile male, 5th percentile female, and 95th percentile male) [3]. That study discusses the validation of the commuter rail seat model using test data supplied by the manufacturer. Additionally, the researchers used the same commuter rail seat FE model to analyze the space requirements from the APTA seat structural integrity test [4]. In these previous studies, the commuter rail seat was designed to meet the APTA requirements, but not specifically the GMRT safety standard.

The current study uses the same commuter rail seat FE model to compare the APTA and GMRT injury seat tests, but additionally uses physical sled test data to compare the standards with a different commuter rail seat that was designed to meet the GMRT requirements. It should be noted that this research does not prove or disprove the compliance of these seats with the requirements in either the APTA or GMRT safety standards.

OBJECTIVES

The objective of the analysis is to compare the safety equivalence of the GMRT and APTA seat standards based on human injury. The APTA 8g crash pulse is more severe than the GMRT 5g crash pulse. However, the GMRT injury criteria are overall more stringent than the APTA injury criteria so it is not obvious if the standards result in approximately equivalent safety based on human injury.

METHODS

Two different seat designs were used to compare the safety equivalency of the APTA and GMRT seat standards based on human injury. Ideally, the seat standards would agree on whether a given seat design passes or fails the human injury requirements. If a seat met the requirements in one standard and failed requirements from the other standard, then the two safety standards would not be considered equivalent.

The two seat designs used in this study were 2-person commuter rail seats with a floor-mounted pedestal. However, the seat that was evaluated by FEA was designed to meet the APTA standard (US seat) and the seat that was evaluated by sled testing was designed to meet the GMRT standard (GB seat). Since the seat designs were different, the FEA and test results in the next section cannot be directly compared with each other.

Figure 1 shows an annotated snapshot of the FE model prior to impact. The FE model represents the forward-facing injury seat test for the APTA and GMRT safety standards. The researchers changed the velocity and acceleration applied to the FE model to represent the different crash pulses specified in the standards. The researchers removed the seat-back and seat-bottom foam cushions as they were not directly impacted to improve the simulation stability and reduce runtime.

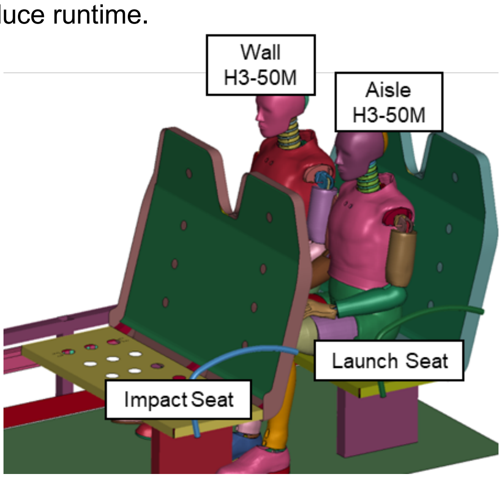

Figure 1. FE Model of Forward-facing Seat Test Prior to Impact with US Seat Design

A test lab in GB performed injury seat tests with the APTA 8g and GMRT 5g crash pulses with the setup of both tests being as close to identical as possible. The test lab collected injury data from the ATDs and provided a test report to the Volpe Center which was used to calculate normalized injury results.

The sled test lab also provided two exemplar test crash pulses with one meeting the APTA requirements and one meeting the GMRT requirements. Figure 2 shows the exemplar crash pulses with the APTA and GMRT crash pulse requirements overlaid for comparison.

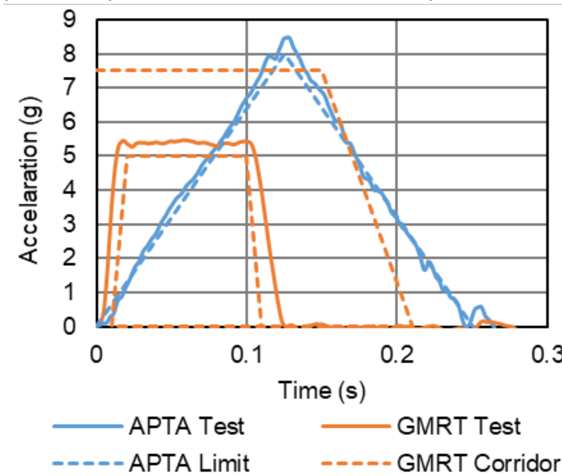

Figure 2. APTA 8g and GMRT 5g Crash Pulses

Table 1 shows the injury assessment reference values (IARVs) or performance limits for the APTA and GMRT seat injury tests. The GMRT IARVs are more stringent in many areas and highlighted in red.

Table 1. Injury Assessment Reference Values

Criterion	APTA	GMRT
Head Injury Criterion (HIC15)	700	500
Head Acceleration, 3 ms	-	80g
Neck Injury Criterion (Nij)	1	1
Neck Axial Tension	4.17 kN	4.17 kN
Neck Axial Compression	4.00 kN	4.00 kN
Chest Acceleration, 3 ms	60g	60g
Chest Compression	-	63 mm
Chest Viscous Criterion (VC)		1 m/s
Combined Thoracic Index (CTI)	-	1
Femur Axial Load	10.00 kN	5.7 kN†
Tibial Index (TI)	-	1.3
Tibia Compression	-	8.00 kN
Knee Slider	-	16 mm

† Femur axial load IARV linearly decreases from 5.7 kN to 4.3 kN when tibial index (TI) increases from 1 to 1.3

RESULTS

The human injury FEA results presented in this section are normalized by the IARVs in Table 1. Results greater than 1 would not meet the selected performance requirement, and values close to 0 indicate a very low likelihood of human injury.

Table 2 summarizes the normalized injury results from the FEA of the US seat. The FEA results are promising from a safety equivalency perspective because the injury requirements were met for both the APTA and GMRT evaluations.

Table 2. Normalized Injury Results from FEA of APTA 8g and GMRT 5g Seat Tests (US Seat)

Criterion	APTA FEA		GMRT FEA	
-	*Aisle*	*Wall*	*Aisle*	*Wall*
HIC15	0.37	0.38	0.15	0.19
Head Acceleration	-	-	0.47	0.48
Nij	0.49	0.50	0.27	0.25
Neck Tension	0.69	0.53	0.28	0.31
Neck Compression	0.07	0.07	0.08	0.07
Chest Acceleration	0.42	0.45	0.24	0.26
Chest Compression	-	-	0.08	0.08
Chest VC	-	-	0.01	0.01
CTI	-	-	0.20	0.20
Femur Load	0.36	0.44	0.65	0.64
TI	-	-	0.82	0.89
Tibia Compression	-	-	0.06	0.06
Knee Slider	-	-	0.59	0.68

For the head and neck regions, the APTA injury results were higher than the GMRT injury results. This may have been due to the more severe APTA crash pulse. The differences in crash pulses can also affect how the ATD's head hits the impact seat. A hard hit to a stiff part of the impact seat can result in high head and neck injury values. There can be large test-to-test variability in head and neck injury values to the chaotic nature of the ATDs being launched during the test. Additionally, the ATD seated on the wall side tended to have higher injury results because the wall seat is stiffer due to its attachment to the carbody wall.

In general, the GMRT leg injury results were higher than APTA. The researchers attribute this to GMRT using relatively more conservative IARVs for the legs. Tibias and knees also tend to have more direct impacts with passenger rail seats than femurs, so the resulting tibia and knee injury criteria tend to be higher. However, an argument can be made that leg injuries are typically not life-threatening but may affect an occupant's ability to egress.

Table 3 summarizes the normalized injury results from the testing of the GB seat. The test results are again promising from a safety equivalency perspective because the injury requirements were not met for both the APTA and GMRT evaluations. One additional finding from the tests was that the GB seat partially detached from its attachments with the APTA crash pulse but not the GMRT crash pulse; however, the partial detachment did not result in a failure of the test.

Table 3. Normalized Injury Results from APTA 8g and GMRT 5g Seat Tests (GB Seat)

Criterion	APTA Test		GMRT Test	
-	*Aisle*	*Wall*	*Aisle*	*Wall*
HIC15	0.66	1.23	1.10	1.64
Head Acceleration	-	-	1.06	1.19
Nij	0.35	0.55	0.74	0.35
Neck Tension	0.23	0.41	0.50	0.24
Neck Compression	0.12	0.06	0.23	0.14
Chest Acceleration	0.20	0.26	0.24	0.20
Chest Compression	-	-	0.00	0.00
Chest VC	-	-	0.00	0.00
CTI	-	-	0.16	0.13
Femur Load	0.34	0.42	0.68	0.75
TI	-	-	0.27	0.32
Tibia Compression	-	-	0.17	0.16
Knee Slider	-	-	0.13	0.27

The GMRT injury results were higher than the APTA injury results even though the GMRT results came from a less severe crash pulse. One possible explanation is that the GMRT crash pulse ramps up more quickly and can result in a higher secondary impact velocity with a short travel distance. Another possible explanation is the partial detachment of the seat during the APTA test.

CONCLUSIONS

This study showed evidence for safety equivalency of the forward-facing injury seat tests from APTA and GMRT based on human injury results. The FEA simulations of the US seat met the injury requirements for both APTA and GMRT. The tests of the GB seat did not meet the injury requirements for either APTA or GMRT. In both cases, the standards agreed on whether the seat met or did not meet the injury requirements. However, this study did not assess the equivalency of the structural integrity tests, which are also required by both standards, which utilize heavier 95th percentile ATDs. For example, a seat might meet the human injury requirements for both the APTA and GMRT standards, but it might only succeed compartmentalizing occupants in the GMRT structural seat test due to the difference in crash pulse severity.

FUTURE ACTION

Further study of passenger rail accident and test data is necessary to see if an 8g triangular or 5g trapezoidal crash pulse is most representative of real-world passenger train impacts. However, passenger rail accidents are rare, so this data may not be readily available. The researchers recommend that further sled tests be conducted to compare results from APTA and GMRT seat injury and structural integrity tests using identical passenger rail seats in each test.

REFERENCES

[1] American Public Transportation Association, "APTA PR-CS-S-016-99, Rev. 3.1 - Standard for Passenger Seats in Passenger Railcars," Washington, D.C., October 2023.

[2] Rail Safety and Standards Board, "GMRT2100 Issue 6.2 - Rail Vehicle Structures and Passive Safety," March 2023.

[3] Federal Railroad Administration, "Injury Finite Element Analysis of APTA Passenger Rail Seat Test," RR 23-07, May 2023.

[4] Federal Railroad Administration, "Finite Element Analysis of APTA Passenger Rail 8G Structural Seat Test," RR 23-06, May 2023.

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KEYWORDS

Crashworthiness, dynamic sled testing, ATDs, rail passenger safety, secondary impacts, finite element analysis.

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