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DYNAMIC CRASH TESTING OF OPEN-BAY COMMUTER RAIL SEATS

SUMMARY

Engineers at MGA Research Corporation, (MGA) performed simulated dynamic crash tests using donated commuter rail passenger seats and two Hybrid-III 50th percentile (H3-50M) anthropomorphic test devices (ATDs). The tests were conducted to determine whether existing passenger seats comply with new requirements for open-bay seats, as described in the American Public Transportation Association's (APTA's) safety standard: APTA PR-CS-S-016-99 – Passenger Seats in Passenger Rail Cars, Revision 3 [1].

The test results indicate that at least one seat design of those tested to date complies with the performance requirements for the forward-facing human injury test in the open-bay configuration. The other seats could possibly satisfy the forward-facing human injury test requirements with minor modifications.

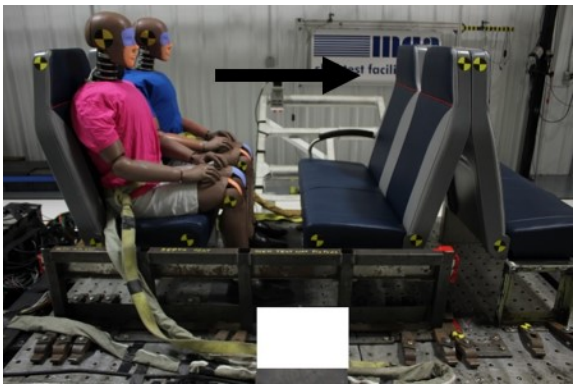

Figure 1. Pre-test Photo of an Open-bay Seat Test

BACKGROUND

Passenger seats in commuter rail trains are subject to the safety requirements described in the APTA seat standard. The original version of the standard was authorized in 1999. Revisions 1 and 2 were authorized in 2003 and 2010, respectively. Revision 3 is planned to be authorized and supersede the previous revisions in early 2021.

The APTA seat standard requires seat testing in simulated collision conditions with instrumented ATDs to evaluate the seat structural integrity, human injury criteria, and ATD containment/compartmentalization. Three dynamic sled tests with ATDs are required in the standard:

- Forward-facing human injury test with instrumented 50th percentile ATDs
- Rear-facing human injury test with instrumented 50th percentile ATDs
- Forward-facing structural integrity test with 95th percentile ATDs

The standard also requires static strength tests for seat components, lateral and vertical seat attachment tests, and flame and smoke emissions tests. The open-bay seat tests described here evaluated seats in accordance with only the forward-facing human injury test with 50th percentile ATDs, as a preliminary assessment of the potential for open-bay seats to comply with the new requirements. The forward-facing tests with 50th and 95th percentile ATDs are generally the most challenging tests.

Prior to Rev. 3, the APTA seat standard specified dynamic sled testing only with seats positioned in the row-to-row configuration, i.e.,

seats that face the same direction. Row-to-row seating has historically been the most common seating configuration in passenger trains. However, open-bay seats, i.e., pairs of seats that face one another without a table in between, have become popular in several regions. Some recent commuter car procurements have included cars configured with nearly all seats positioned in the open-bay configuration.

Forward-facing occupants in open-bay seats have a longer distance to travel before impact with the adjacent seat during an accident, when compared to occupants in row-to-row seats. The longer travel distance leads to an increase in the occupant's impact velocity and thus increases the risk of human injury. Revision 2 of the seat standard noted that evidence from accident investigations, dynamic sled tests, and computer analysis indicated that open-bay seats do not provide the same level of passenger protection as row-to-row seats or facing seats with an energy-absorbing table between the seats. Revision 2 does not preclude the use of open-bay seats, but it recommends that workstation tables (which comply with APTA table standard APTA PR-CS-S-018) be positioned between facing seats to compartmentalize passengers and minimize injury severity in the event of a collision.

Revision 2 of the seat standard does not explicitly address dynamic sled testing of open-bay seats. This deficiency permitted such seats to be used in revenue service without being subjected to safety testing that would be required for identical seats positioned in the row-to-row configuration. Revision 3 of the seat standard remedies this situation by requiring that all three dynamic sled tests with ATDs be performed with seats in the open-bay configuration if more than 50 percent of a car's passenger seating capacity is configured as open-bay seating.

Some rail industry groups have expressed concerns that open-bay seats may not comply with the proposed requirements, forcing a major redesign of their seats or reconfiguring their installations with fewer open-bay seats. To better understand this concern, the Federal Railroad Administration (FRA) has sponsored dynamic sled tests of four commuter seat designs (anonymously donated by seat manufacturers) which are or could be used in the open-bay configuration. For this research program, seats were tested in accordance with the forward-facing human injury test described in Rev. 3 of the APTA standard. The tests were performed by MGA in Greer, South Carolina. The seat manufacturers have not been identified to protect proprietary information.

Three of the four planned seat tests have been conducted to date, due to seat availability. The final test is planned for early 2021. A comprehensive FRA Technical Report will be published after all tests are completed, with pre- and post-test photos, time histories of the data channels, and a more thorough analysis of the results.

OBJECTIVES

These seats have been designed to comply with the APTA standard in the row-to-row configuration, but not specifically in the open-bay configuration. The objective of these tests was to determine if existing seats comply with the forward-facing 50th percentile human injury test requirements for open-bay seats in Rev. 3 of the seat standard. Particular concerns are related to head and neck injuries, loss of ATD compartmentalization, and seat component detachment. This research testing does not evaluate compliance of these seats with any other requirements in the APTA standard, which would be necessary for these seats to be in full compliance with Rev. 3.

METHODS

The dynamic sled tests were conducted in accordance with the requirements in Section 3.2.1 Forward-facing Human Injury Test in Rev. 3 of the APTA seat standard. Each sled test consisted of three pairs of commuter seats fastened to a simulated carbody structure, rigidly

secured to the test sled. Two Hybrid III 50th percentile male (H3-50M) ATDs were positioned in the rear forward-facing row of seats (see test setup above in **Figure 1**). Each ATD was instrumented to measure tri-axial head and chest acceleration, axial neck load, extension/flexion neck bending moment, and axial femur load. The sled was subjected to an 8g crash pulse, as depicted in **Figure 2**. The tests were documented using three high-speed video cameras as well as pre- and post-test photographs.

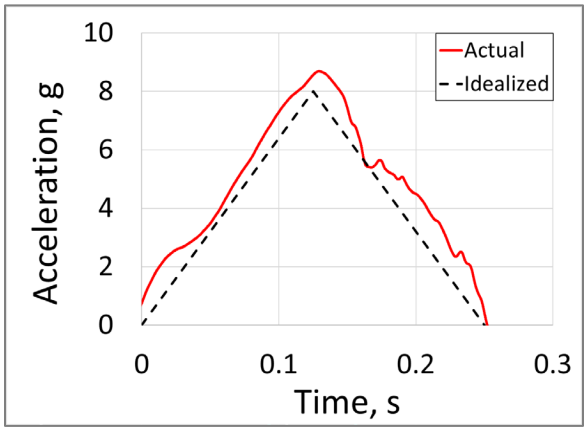

Figure 2. Test Crash Pulse

RESULTS

The measured injury results for each ATD in each test conducted to date are depicted below in **Table 1** (green indicates compliance; red indicates non-compliance). The 15 ms head injury criterion (HIC_{15}) was near the limit in each test and was exceeded for at least one ATD in Tests 2 and 3. The Nij criterion, a combination of axial neck force and extension/flexion neck bending, was also high or exceeded the criterion for most of the ATDs. Injury measurements for the head, neck, and femurs in the open-bay tests were roughly double those measured in tests of the same seats in the row-to-row configuration.

Table 1. Injury Results

Injury Criterion	Test 1		Test 2		Test 3	
	Aisle ATD	Wall ATD	Aisle ATD	Wall ATD	Aisle ATD	Wall ATD
$HIC_{15} \leq 700$	682	641	682	994	753	675
$N_{ij} \leq 1.0$	0.7	0.8	0.5	0.8	1.2	1.04
Axial neck tension (F_z) ≤ 4170 N	1679	582	681	836	641	833
Axial neck comp (F_z) ≤ 4000 N	1764	1752	1425	2441	2769	2890
Chest deceleration (3 ms) ≤ 60 g	18	19	19	14	27	25
Axial femur load ≤ 10000 N	5862	6368	2320	2514	6195	6073

Table 2 summarizes all requirements for each sled test. Only the seats in Test 1 complied with all the requirements. It is possible that modest design changes to the Test 3 seats could enable them to comply with all the test requirements. More extensive modifications to the seats in Test 2 may be required for compliance, such as a taller seatback to compartmentalize the ATDs.

Table 2. Results Summary

Additional Criterion	Test 1	Test 2	Test 3
Seats shall not detach			
Seat components shall not detach			
ATDs shall be compartmentalized			
All injury criteria within limits			

CONCLUSIONS

While it is encouraging that the Test 1 seats complied with the test requirements in the human injury test using 50th percentile ATDs, it remains to be seen if the seats will also comply with the test requirements in the structural integrity test, which uses 95th percentile ATDs. The additional mass and higher center of gravity of the larger ATDs will likely increase the seat back deformation of the facing seats, which may further jeopardize ATD compartmentalization. There are several other requirements in the APTA seat standard with which compliance must also be demonstrated, but the dynamic 8g tests are typically the most onerous.

The tests required in the APTA seat standard do not consider the situation in which ATDs are seated in both forward-facing and rear-facing seat pairs. This configuration would likely cause increased head and neck loads and

accelerations due to direct ATD-to-ATD impact, because of the increased rigidity of the ATDs' heads when compared to a relatively soft seat back cushion. This configuration is not required to be tested in the APTA standard because the ATDs are not designed to provide biofidelic results in direct contact; however, it is still a safety concern for rail operators when considering the widespread use of open-bay seats.

These test results provide useful information for seat manufacturers and rail operators interested in configuring railcars with open-bay seats that comply with industry safety standards. The results indicate that at least one open-bay seat design complies with the performance requirements for the forward-facing human injury test with 50th percentile ATDs.

FUTURE ACTION

A finite element model is currently being developed to simulate selected open-bay seat configurations, which will be validated using the test results. The model may be used to vary parameters such as the seat pitch and seat deformation behavior to evaluate their influence on the performance requirements, particularly ATD head and neck injury and compartmentalization. The model may also be used to evaluate the injury severity for different sized ATDs and characterize ATD-to-ATD contact with the addition of an ATD in the rear-facing seat.

REFERENCES

1. American Public Transportation Association. (2021). Passenger Seats in Passenger Rail Cars (APTA PR-CS-S-016, Rev. 3).

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