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RESEARCH RESULTS

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FINITE ELEMENT MODEL VALIDATION OF THOR-50M ATD FOR APTA TABLE TEST

SUMMARY

The Federal Railroad Administration (FRA) sponsored Volpe Center researchers to validate a publicly available finite element (FE) model of the Test device for Human Occupant Restraint 50th Percentile Male (THOR-50M) anthropomorphic test device (ATD) in LS-DYNA. The model used selected data from a series of 28 pendulum impact tests [1] to the ATD's chest and abdomen. The researchers performed the model validation for future FE analyses of dynamic 8g sled tests with fixed workstation tables per the "Fixed Workstation Tables in Passenger Railcars" safety standard [2] from the American Public Transportation Association (APTA) APTA-PR-CS-S-018-13, Rev. 2 (S-018).

The results of the THOR-50M pendulum impact FE model validation showed an average agreement rating of "good" as defined in ISO/TS 18571:2014 "Road vehicles — Objective rating metric for non-ambiguous signals."

BACKGROUND

Passenger rail accident investigations motivated FRA research on occupant protection strategies for passengers seated at workstation tables. FRA sponsored occupant protection research at the Volpe Center that offered recommendations for workstation table crashworthiness performance requirements.

The 8g sled test evaluates the structural integrity and energy absorption capabilities of passenger workstation tables, compartmentalization of ATDs, and the injury criteria resulting from simulated collision conditions. The APTA table standard has two different options for crashworthiness testing:

- **Option A** requires a THOR-50M ATD (validated in this study) or a Hybrid-III Rail Safety (H3-RS) ATD (validated previously [3]) in the forward-facing wall seat in a dynamic sled test.
- **Option B** allows Hybrid-III 50th Percentile Male (H3-50M) ATDs to be used in forward-facing seats but requires an additional destructive quasi-static test of the workstation table.

The ATDs used in crashworthiness tests are surrogates for actual human occupants. Chest, upper abdomen, and lower abdomen standardized pendulum impact tests are used to evaluate the biofidelity of ATDs by comparing them with test data from post-mortem human surrogates (PMHS), ensuring they have humanlike responses. Additionally, pendulum tests can identify "dead zones," locations where instrumentation may not accurately measure deformation. Lastly, the pendulum impact tests are useful for FE model validation of the ATDs because the test conditions are well-controlled and an instrumented rigid impactor is used.

Figure 1 shows a snapshot from one of the 28 pendulum impact tests compared with the corresponding FE model.

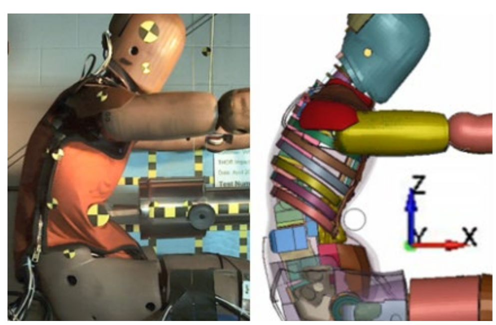

Figure 1. Side Snapshot at 60 ms in a Pendulum Test (Left) and FE Model (Right)

OBJECTIVES

The objective of the parametric tests was to validate the publicly available FE model of the THOR-50M ATD for use in future analyses of dynamic workstation table sled tests. The THOR-50M FE model has already been validated for automotive collisions, as demonstrated in its user manual.

METHODS

Researchers positioned the THOR-50M ATD FE model (version 2.7.0) in a slouched position wearing its jacket on a rigid floor in LS-DYNA. The researchers represented the pendulum impactor as a rigid cylinder with its motion constrained to 1 degree-of-freedom. The diameter of the cylinder, impact height, mass, and initial velocity were varied to match the average measured conditions from sets of 2-3 repeated tests.

The team compared test and model results for:

1. pendulum impact **force** calculated as longitudinal acceleration (x-direction in Figure 1) multiplied by pendulum mass,
2. **internal displacement** transducers (IR-TRACCs) in the x-direction (compression), and
3. **external penetration** in the x-direction calculated as the relative displacement between the pendulum and the T12 spine accelerometer on the THOR-50M ATD.

The 28 pendulum impacts consisted of tests to evaluate (1) lower abdomen biofidelity, (2) impact height sensitivity, (3) lower chest impact speed sensitivity, and (4) upper abdomen impact speed sensitivity. The three lower abdomen biofidelity tests were not included in the model validation for reasons described in the Results section.

The researchers used publicly available software, CORA v4.0.4 from Partnership for Dummy Technology and Biomechanics (PDB), per ISO/TS 18571:2014 to calculate a rating (R) for the agreement of the FE model with the test results. Table 1 shows the rating scale.

Table 1. ISO-TS-18571:2014 Rating (R) Scale for CORA

Poor	Fair	Good	Excellent
R ≤ 0.58	0.58 < R ≤ 0.8	0.8 < R ≤ 0.94	0.94 < R

RESULTS

Figure 2 shows a comparison of peak pendulum impact force versus internal compression for the speed sensitivity tests on the lower chest and upper abdomen. Researchers used three speeds for each impact location resulting in higher peak pendulum force and external penetration as speed increased. Two tests were conducted for each impact condition. The lower chest IR-TRACCs measured the internal compression for the lower chest impacts (colored blue), and the abdomen IR-TRACCs measured the compression for the upper abdomen (colored orange). The lower chest impact model underpredicted the initial stiffness of the ribs resulting in higher peak compression values (i.e., the blue squares are to the right of the triangles). The upper abdomen impact model had a softer response for all speeds (i.e., the orange squares are to the right of the triangles).

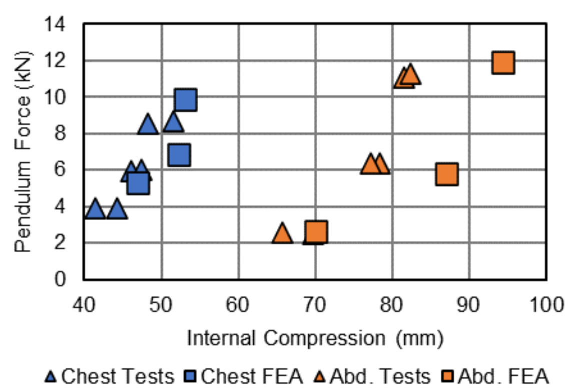

Figure 2. Peak Pendulum Force versus Internal Compression for Lower Chest and Upper Abdomen Speed Sensitivity Impacts

Figure 3 is the same as Figure 2 except the x-axis is now externally measured penetration by accelerometers instead of internally measured compression by displacement transducers. The lower chest impact model had a stiffer response than the tests at all speeds (i.e., the blue squares are above and to the left of the triangles). The upper abdomen impact model had a softer response for the higher speeds (i.e., the orange squares are to the right of the triangles).

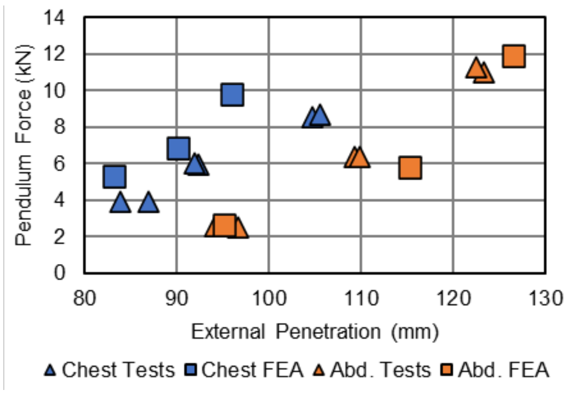

Figure 3. Peak Pendulum Force versus External Penetration for Lower Chest and Upper Abdomen Speed Sensitivity Impacts

Figure 4 shows peak pendulum force versus impact height. Error bars denote standard deviation (n=3) in the repeated tests. The model predicted a pendulum force that was three times higher than the test with the lowest impact height due to rigid contact with the ATD's pelvis (see Figure 6).

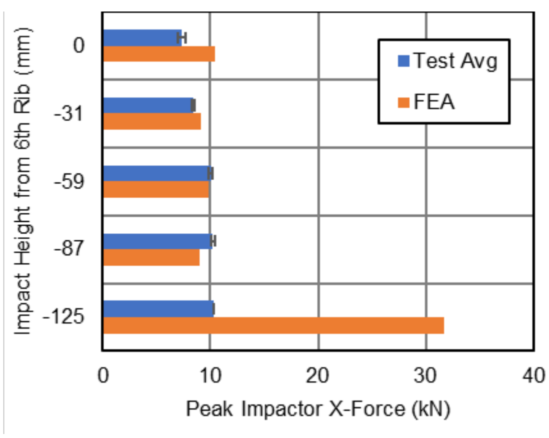

Figure 4. Peak Pendulum Force versus Impact Height

Figure 5 shows peak internal compression and external penetration versus impact height. Error bars denote standard deviation (n=3) in the repeated tests.

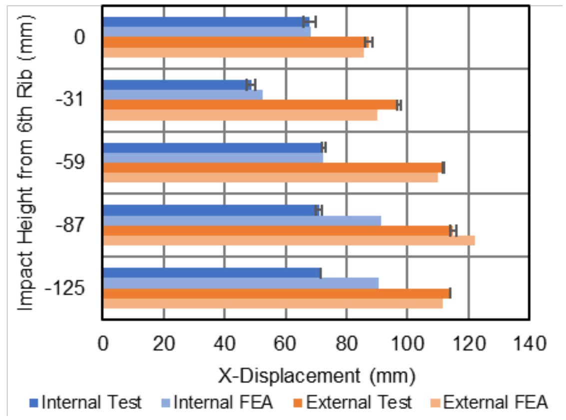

Figure 5. Peak Internal Compression and External Penetration versus Impact Height

Table 2 summarizes the ISO/TS 18571:2014 CORA scores of the FE model for the different impact heights.

Table 2. ISO/TS 18571:2014 (CORA) Scores

Pendulum Impact Height	Force	Int. Comp.	Ext. Pen.
6th Rib IR-TRACC	0.911	0.954	0.979
7th Rib	0.937	0.793	0.942
28 mm below 7th Rib	0.954	0.660	1.000
38 mm above Abd. IR-TRACC	0.846	0.824	0.965
Abd. IR-TRACC	0.801	0.965	0.998

The external penetration scores were all rated "excellent." The internal compression (IR-TRACC) scores were rated "fair" to "excellent" and worsened when the impactor was positioned further away from impacting in line with the sensors. One possible explanation is the difficulty in capturing the position of the pendulum relative to the stiff ribs and soft abdomen foams. The force measurements were rated mostly "good" or "excellent" except when the pendulum impacted the lower abdomen, resulting in a "fair" rating. This was due to the interaction between the rigid impactor and pelvis (as shown in Figure 6). The FE model predicted a hard impact between the rigid parts resulting in a spike in pendulum acceleration; however, the exact positioning of the ATD's lumbar spine did not result in a direct impact during the physical test. The three lower abdomen biofidelity tests also resulted in this discrepancy and were not included in the model validation.

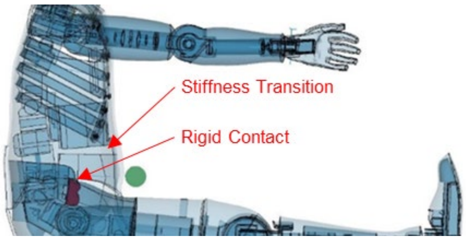

Figure 6. Side View of THOR-50M FE Model Annotating Regions without "Good" Scores

CONCLUSIONS

The researchers achieved an average rating of "good" per ISO/TS 18571:2014 for the THOR-50M model validation using 25 out of 28 pendulum impact tests. The lack of "excellent" rating agreement from the FE model indicates the need to continue physical compliance testing in the APTA table standard while model improvements are advanced. However, the researchers found the validation of the THOR-50M FE model to be similar to a previous study on the H3-RS ATD [3].

FUTURE ACTION

Validated FE models of the THOR-50M and H3-RS ATDs will be used for further research on safety equivalency of the different possible test configurations in the APTA table standard.

REFERENCES

[1] Eshraghi, S., Gondek, J., & Severson, K. (2020). Abdomen Impact Testing of the THOR-50M Anthropomorphic Test Device (Report No. DOT/FRA/ORD-21/08). Federal Railroad Administration.

[2] American Public Transportation Association (October 2022). Fixed Workstation Table in Passenger Rail Cars (in APTA PR-CS-S-018-13, Rev. 2).

[3] Eshraghi, S., Severson, K., Hynd, D., & Perlman, A. B. (2018). Finite Element Model Validation of the Hybrid-III Rail Safety (H3-RS) Anthropomorphic Test Device (ATD). Proceedings of the ASME 2018 International Mechanical Engineering Congress & Exposition, Paper No. IMECE2018-87736.

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KEYWORDS

Crashworthiness, pendulum impact testing, anthropomorphic test device, ATD, rail passenger safety, secondary impacts, crashworthy tables

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