Simulation of Various LSTC Dummy Models to Correlate Drop Test Results

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Abstract

Hybrid III Anthropomorphic Test Dummy (ATD) is primarily validated for frontal impacts from physical sled tests in an automotive incident but not for a military vehicle incident related to mine blast vertical impacts. Vertical drop tests were conducted using Hybrid III 50th percentile ATD. The purpose of conducting these tests was to identify which LSTC dummy model shows the best correlation with the test results. This paper presents the modeling correlation between LSTC's 50th percentile RIGID, FAST, and DETAILED dummy models. A rigid seat without seat cushion was used in the drop tests so the surroundings the dummy interacted with during the test were very predictive. A total of three drop tests from the same drop height were completed to ensure consistency and repeatability of the test data. The simulation was correlated to the test data for occupant responses.

Introduction

Hybrid III Anthropomorphic Test Dummy (ATD) is primarily validated for frontal impacts from physical sled tests in an automotive incident but not for a military vehicle incident related to mine blast vertical impacts. It is common for military vehicle mine-blast protected seat developers to use Hybrid III ATD to conduct full-scale drop tests and simulations, thus, injuries associated with vertical loading conditions can be evaluated and understood. Whether to use the Hybrid III ATD is a right choice or not is beyond the scope of this paper. There are three different dummy models publicly released by LSTC to represent physical Hybrid III ATD in a computer model. Vertical drop tests were conducted using Hybrid III 50th percentile ATD. The purpose of conducting these tests was to identify which LSTC dummy model shows the best correlation with the test results.

LSTC Dummy Models

The 50th percentile dummy models discussed in this paper include RIGID, FAST, and DETAILED dummy models (Figure 1). The FAST dummy is a derivative of the previous RIGID dummy in which all external materials are deformable, for example, materials for the arms, legs, and shoes. The development of the DETAILED dummy is given in [1]. The DETAILED dummy was validated and showed good correlation to the sled test. Table 1 lists the number of nodes and elements for each dummy model.

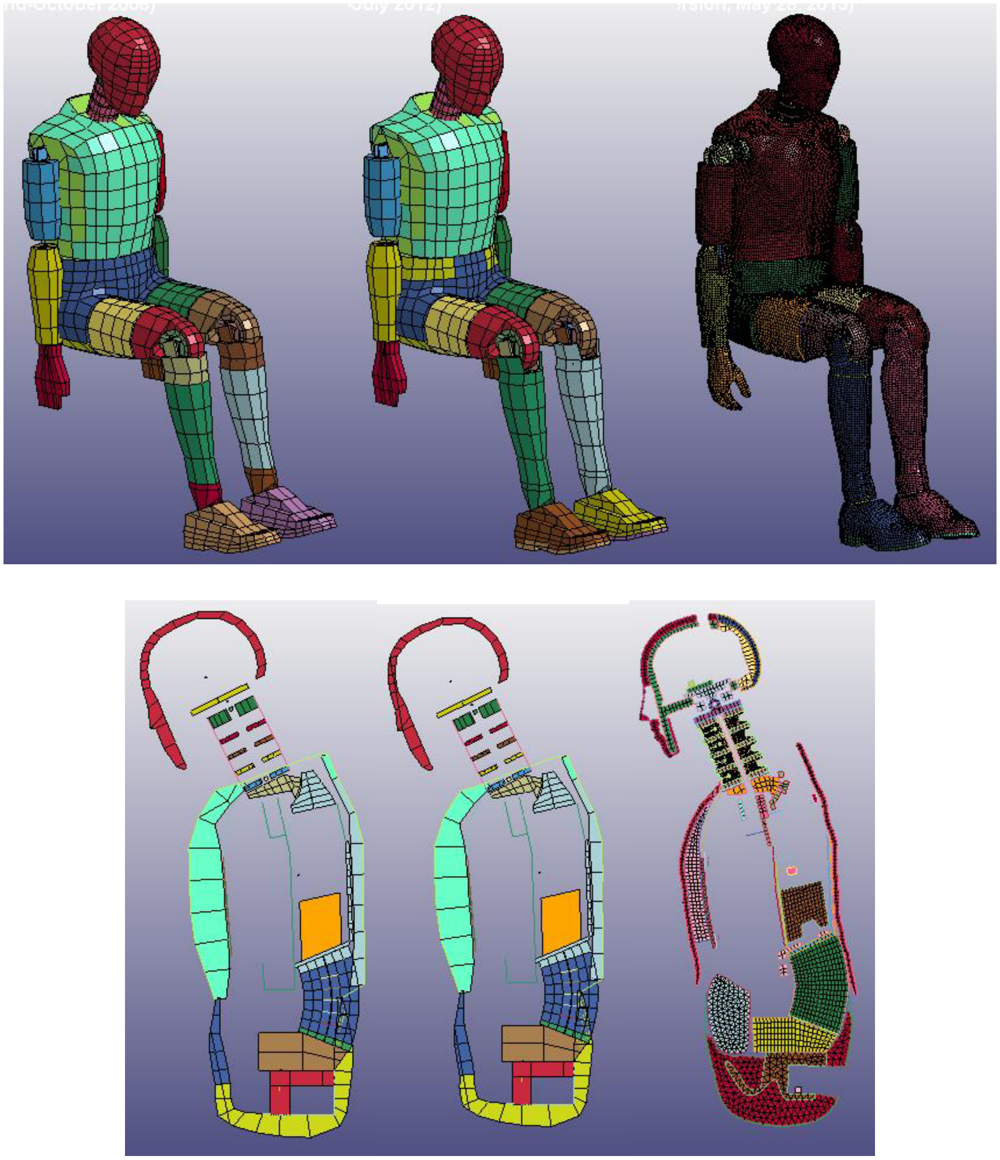

Figure 1: RIGID (left) FAST (middle) and DETAILED (right) dummy models

Table 1: Number of nodes and elements for each dummy model

Dummy Model	Number of Nodes	Number of Rigid Elements	Number of Deformable Elements
RIGID	7,444	2,453	1,842
FAST	7,402	1,566	2,712
DETAILED	292,231	14,415	437,932

Test Setup

All tests were conducted using a vertical drop tower at ShockRide (Figure 2). The ATD sat on a rigid seat with a platform connected to the drop tower rails. Targets were placed at various components of the ATD for both relative motion measurement between ATD components and dummy positioning in finite element model development. The ATD and seat were lifted 20 inches above the ground and were subsequently accelerated by a bungee acceleration system. Short duration half sine shock pulse was generated by impacting the platform against high strength plastic elements. The peak acceleration level of the half sine shock pulse was determined by the drop height and the bungee acceleration level. The duration of the pulse was determined by the height of the high strength plastic elements. During the test, the ATD was instrumented with accelerometers and load cells. The platform was instrumented with two accelerometers. Each test was filmed with three high speed cameras at 1,700 frames per second.

Figure 2: Drop tower with Hybrid III 50th percentile ATD

Test Results

Three repeated tests were conducted to ensure consistency and repeatability of the test data. Input pulses measured on the platform are shown in Figure 3. The pulses were filtered with SAE J211 CFC 180. The average peak acceleration, duration, and velocity change was 137.1 g, 6.93 ms, and 5.182 m/s, respectively.

All ATD response data was filtered in accordance with SAE J211 CFC 600 and 1000. Lumbar and neck loads are shown in Figures 4-5. Vertical pelvis acceleration time history curves are shown in Figure 6.

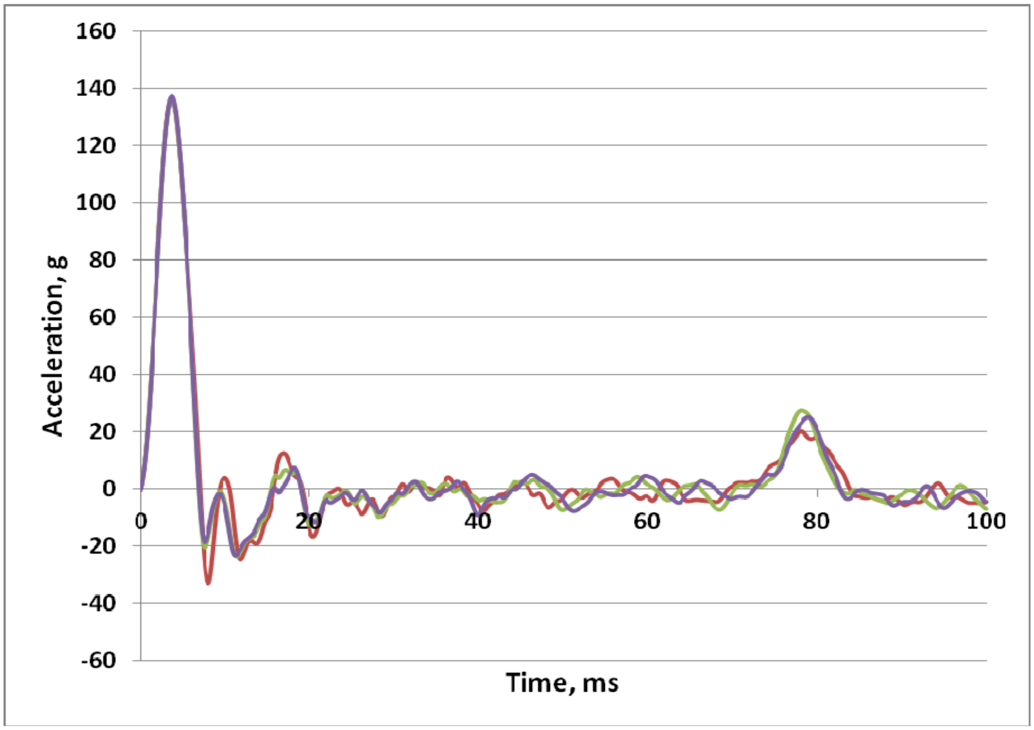

Figure 3: Seat platform acceleration

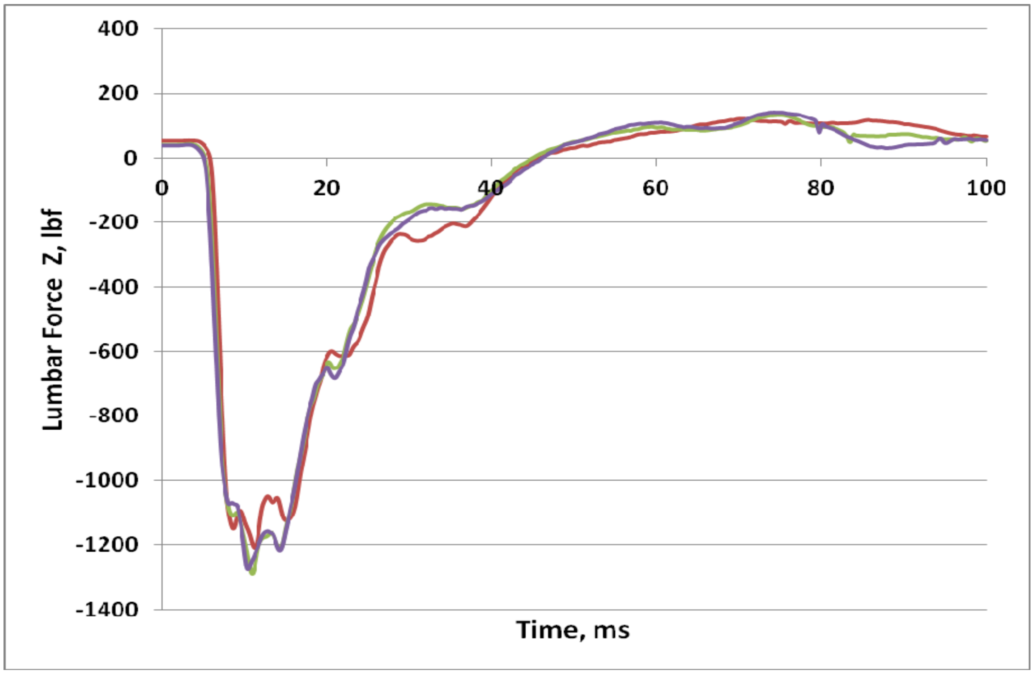

Figure 4: Lumbar F_z test results

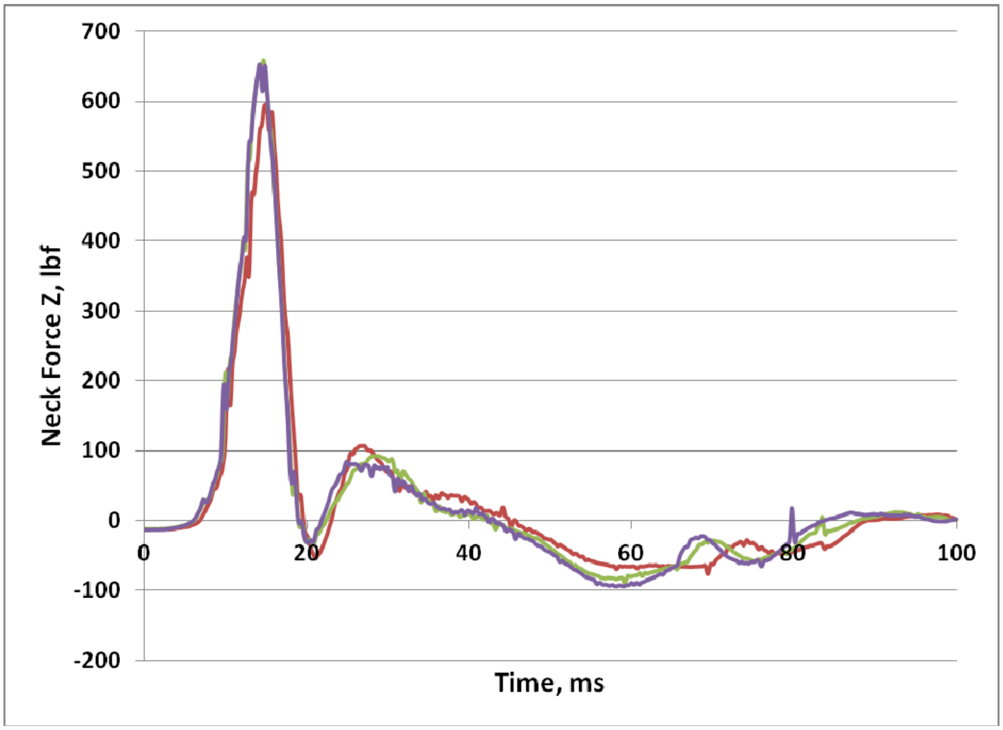

Figure 5: Neck F_z test results

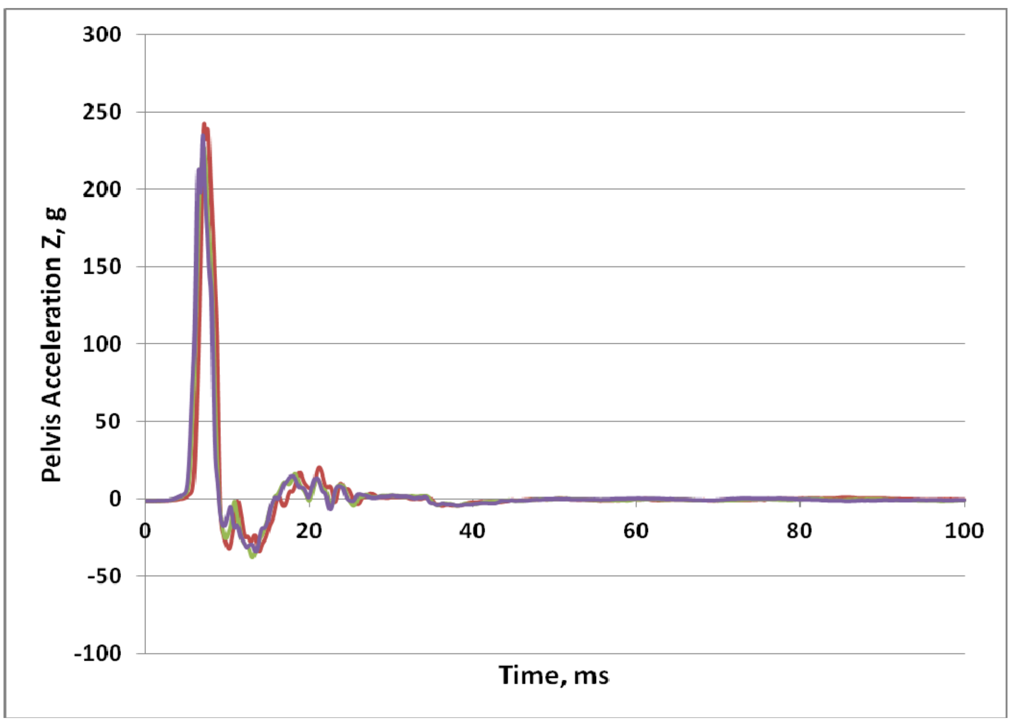

Figure 6: Pelvis a_z test results

Finite Element Analyses of Drop Tests

Seat model setup - Finite element seat model (Figure 7) was generated based on a Computer-Aided Design (CAD) seat model. The entire seat was assigned with a rigid material.

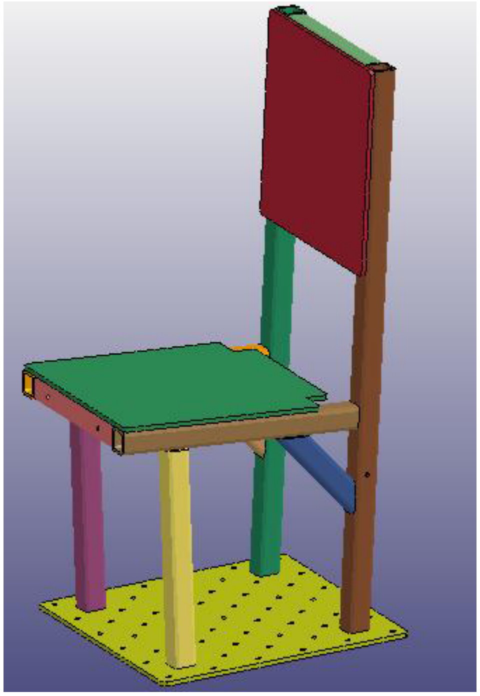

Figure 7: Rigid seat finite element model

Dummy model setup - To position dummy correctly, the dummy H-point was positioned so the pelvis of dummy just contacted the seat pan. DETAILED dummy model placed on the rigid seat is presented in Figure 8.

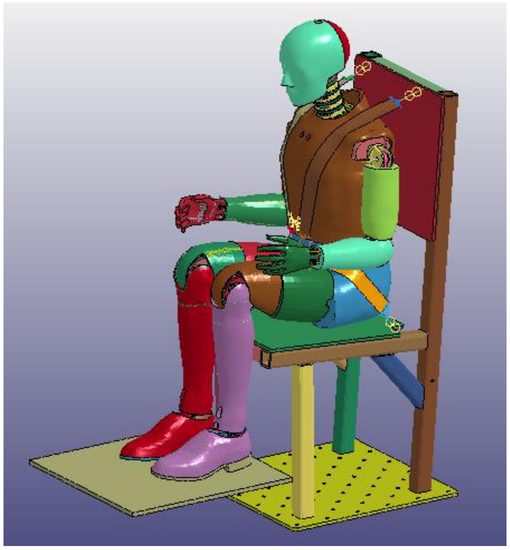

Figure 8: Position of dummy on rigid seat

Correlation to Test Data

Comparisons between simulation results and test data were made. Since the pelvis experiences the up-thrust mine blast pulse from the seat first, the vertical pelvis acceleration is the first indicator of how the dummy model is responding. The simulation was ran to 20 ms to cover the primary portion of the event. The vertical pelvis acceleration response is shown in Figure 9. The peak pelvis a_z is significantly over-predicted and under-predicted by the RIGID and FAST dummy model, respectively. Thus, both the RIGID and FAST dummy models are out of comparison. Figures 10-11 show the DETAILED dummy model lumbar spine and neck force responses. The model predictions show extremely poor correlation with the lumbar force test data. The discrepancy is attributed to the lumbar spine in the DETAILED dummy model is overly stiff. Hence, greater force was transmitted through the lumbar to the upper body.

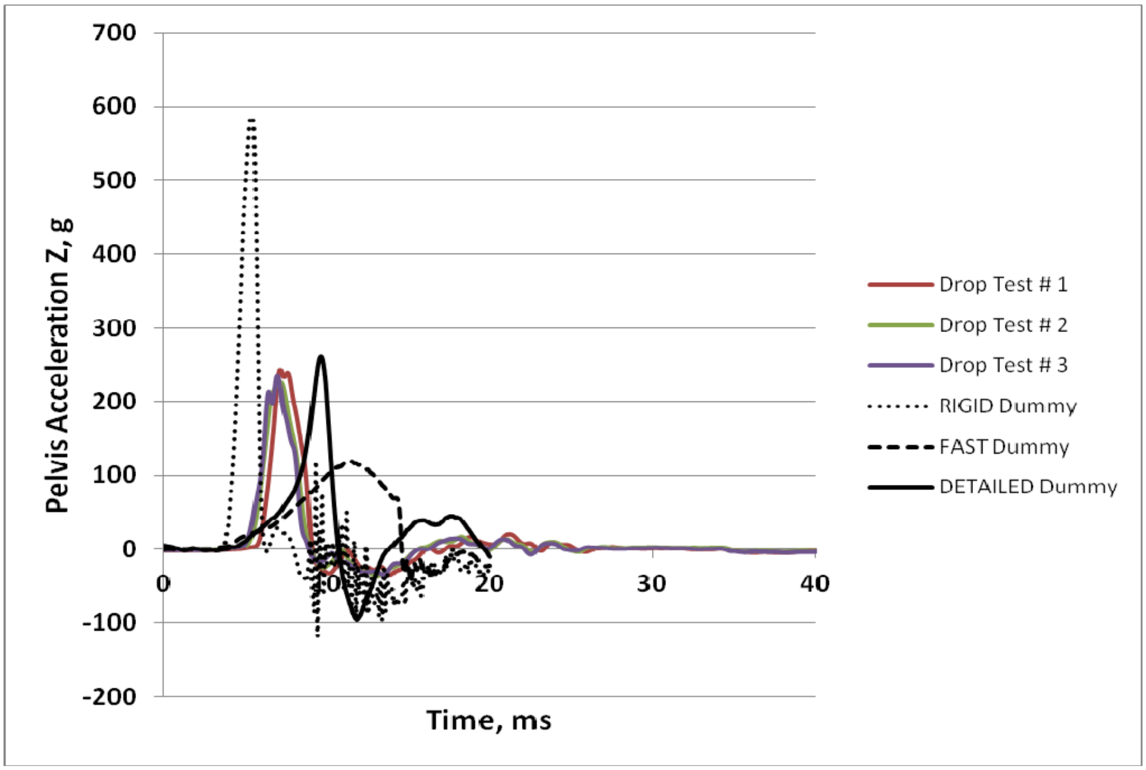

Figure 9: Pelvis a_z test and analysis results

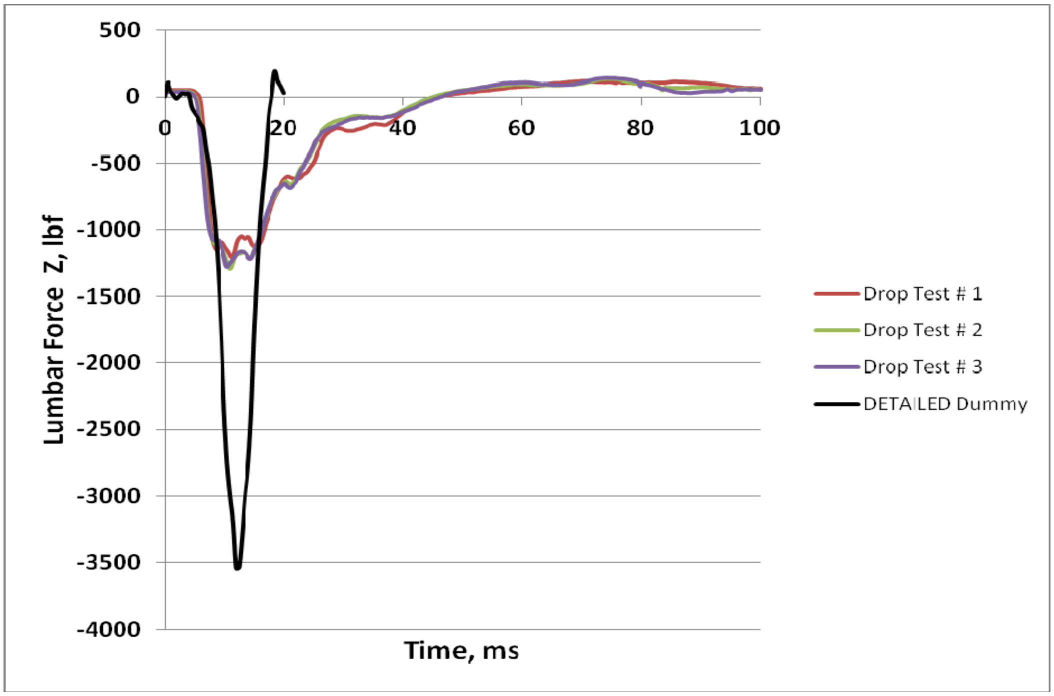

Figure 10: Lumbar F_z test and analysis results

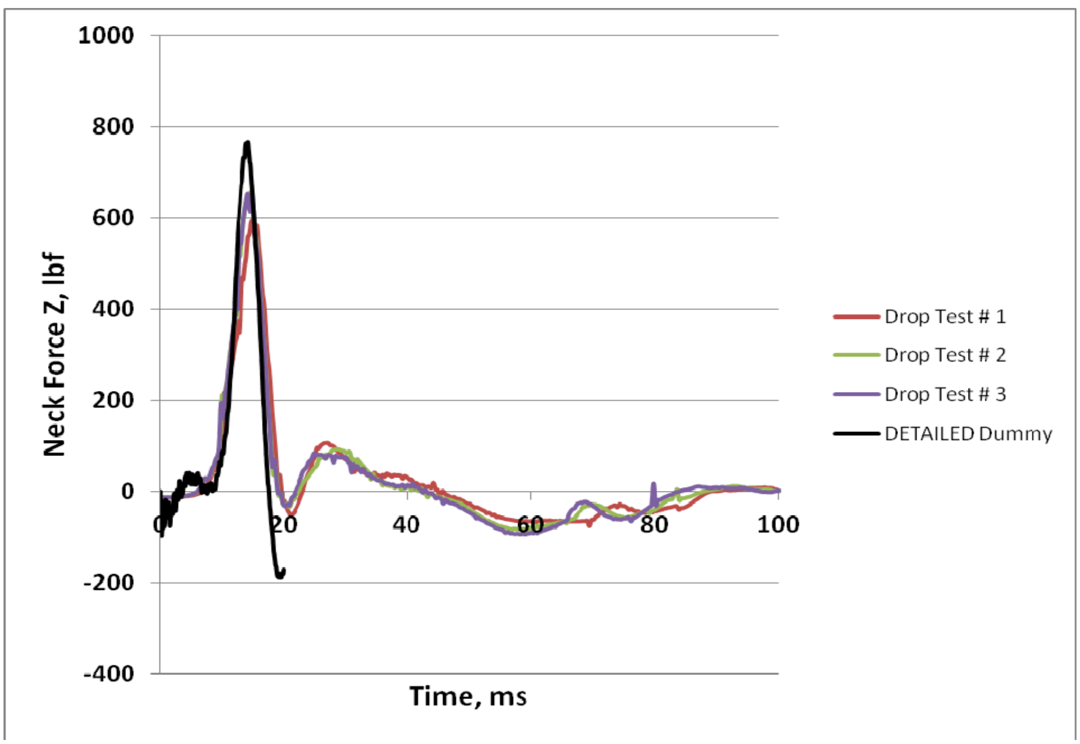

Figure 11: Neck F_z test and analysis results

The lumbar spine in the DETAILED dummy model is modeled as a viscoelastic material (material no. 6 in LS-DYNA® code). As a first step, to improve correlation with test data, the material properties were tuned (Table 2 and Figure 12) to give more acceptable bending of the lumbar. The model was rerun and the vertical pelvis acceleration, lumbar spine and neck force response between the test and simulation are shown in Figures 13-15. The peak lumbar load is reduced but still not enough, to match the test data. On the contrary, the peak neck force now is much lower than the test data.

Dynamic Response Index (DRI) model was developed for compression injuries to the spine in evaluating seat ejection scenarios [2]. The DRI model is also used for injury assessment to mine threats. The human spine is modeled as a lumped single-degree-of-freedom spring-shock absorber system. The forcing function to the single-degree-of-freedom system is the accelerative shock load delivered to the pelvis by the mine blast. The DRI is related to the maximum spinal compression and the limiting DRI value according to NATO STANAG 4569 is 17.7 with a 10% chance of serious injury. Table 3 shows the calculated DRI values from the tests and final DETAILED dummy model run. The DRI is over-predicted by 14%. The DRI correlation between the test and analysis results strongly depends on good correlation results for the pelvis a_z time history curves (Figure 13). Important factors in the time history data include duration, peak acceleration, onset rate, frequency content, and mean.

Table 2: Viscoelastic material properties

Variable	Original	New
Bulk modulus, k (Gpa)	0.0155	0.1128
Short-time shear modulus, G_0 (Gpa)	0.0187	0.0046
Long-time shear modulus, G_∞ (Gpa)	0.002	0.001
Decay constant, β (ms^{-1})	0.0603	0.11

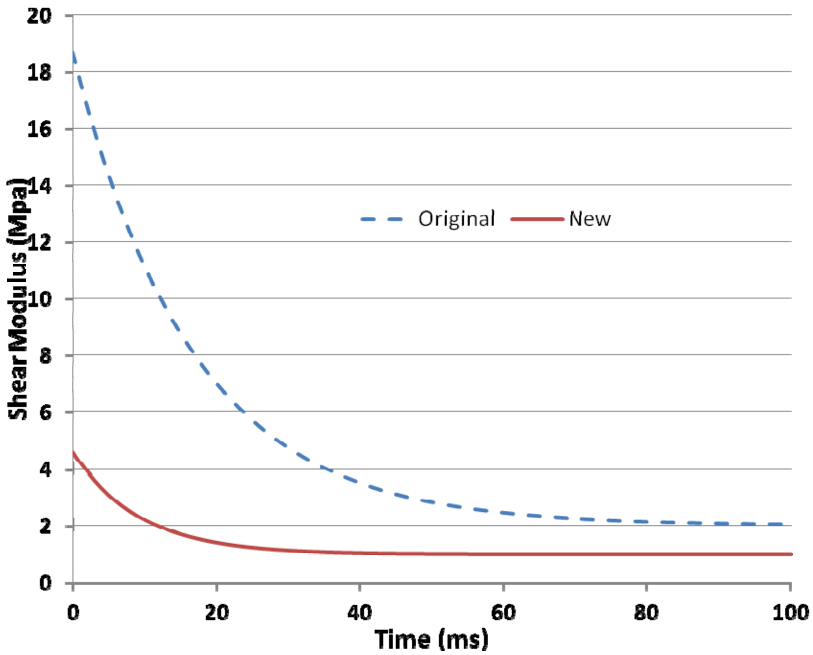

Figure 12: Shear relaxation behavior for lumbar spine material

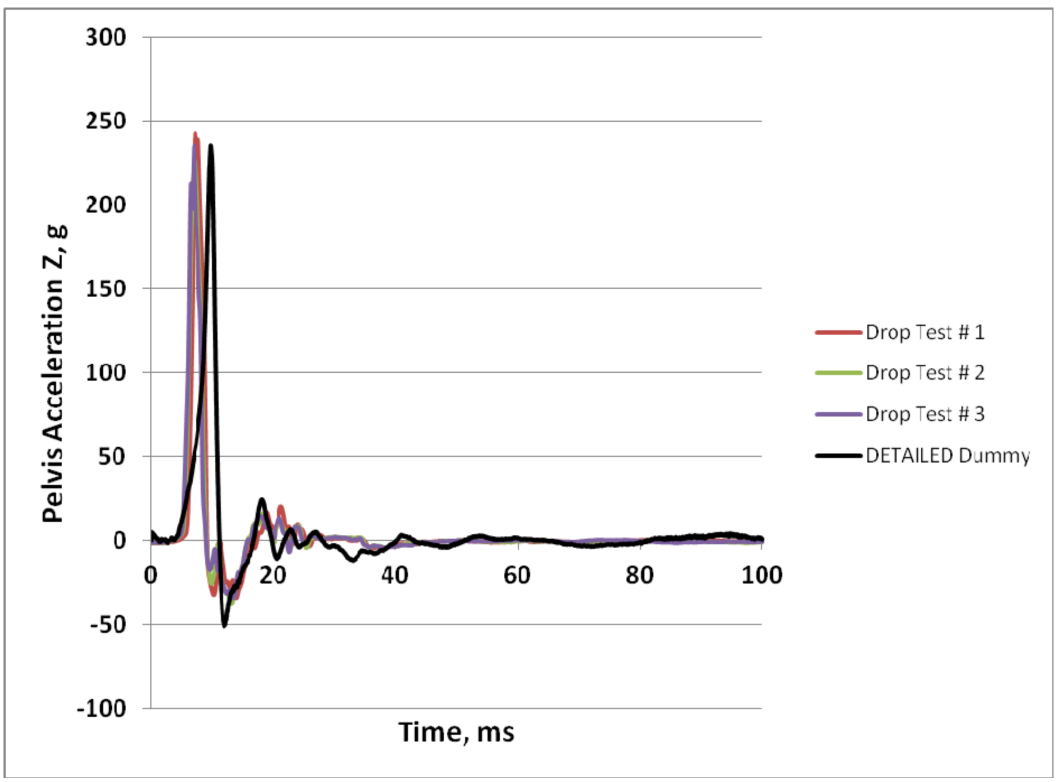

Figure 13: Pelvis a_z test and analysis results

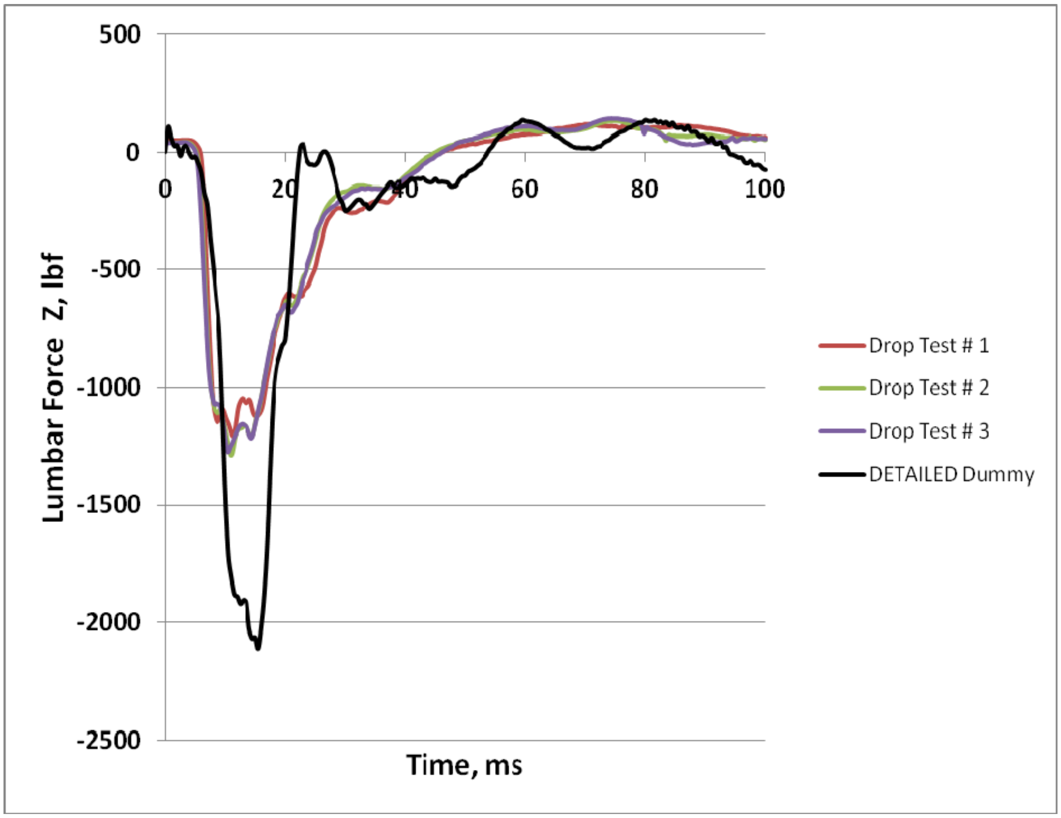

Figure 14: Lumbar F_z test and analysis results

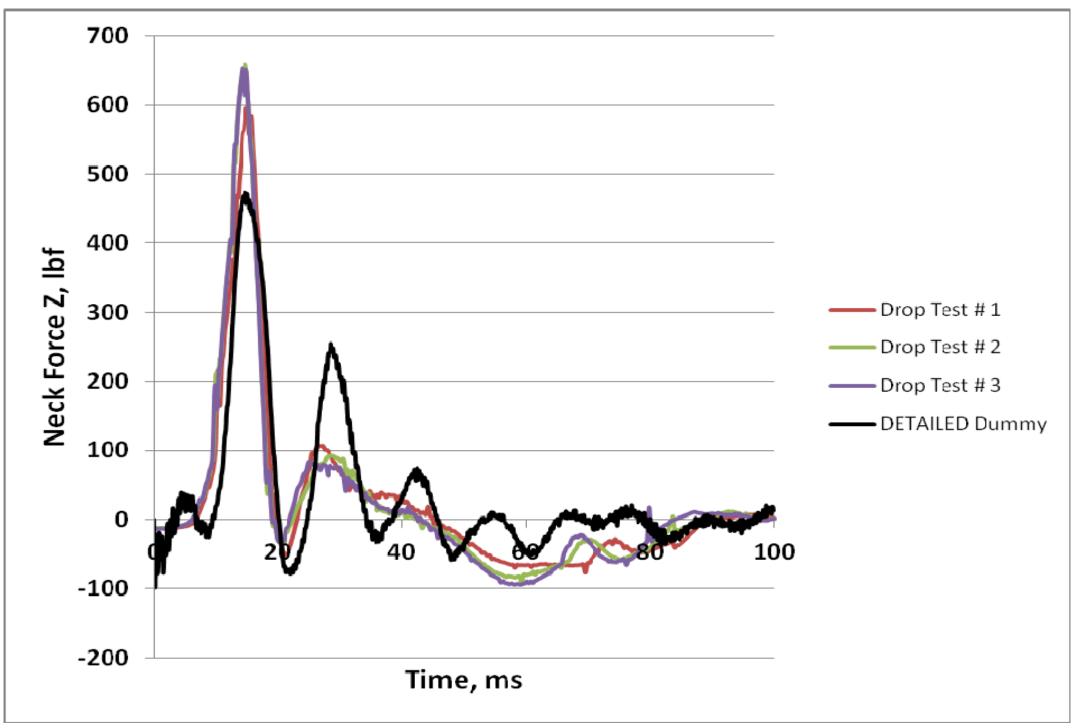

Figure 15: Neck F_z test and analysis results

Table 3: DRI from tests and simulation

Drop test #1	Drop test #2	Drop test #3	Average for drop tests	Simulation
15.09	14.92	15.05	15.02	17.12

Recommendations and Conclusions

Without any surprise, the DETAILED dummy model which has more significant deformable elements is identified to be better than the RIGID and FAST dummy models for studying the vertical impact loads on human body. The test data including videos and photos from the drop tests will be sent to LSTC to be used for future and further dummy model development. A new DETAILED 50th percentile dummy might be developed solely for vertical impact application. It's recommended to continue develop the 50th percentile DETAILED dummy model as well as new 5th and 95th percentile DETAILED dummy models to model the spinal response to mine blast.

Acknowledgements

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References

[1] Pradeep Mohan, Chung-Kyu Park, Dhafer Marzougui, Cing-Dao Kan, Sarba Guha, Christoph Maurath, and Dilip Bhalsod, "LSTC/NCAC Dummy Model Development," 11th International LS-DYNA Users Conference, June 6-8, 2010, Dearborn , Michigan, USA.

[2] Stech, E.L., and Payne, P.R., DYNAMIC MODELS OF THE HUMAN BODY, Frost Engineering Development Corp.; AMRL Technical Report 66-157, Aerospace Medical Research Lab, Wright-Patteraon Air Force Base, Ohio, November 1969, AD 701383.