NTRCI

NATIONAL TRANSPORTATION RESEARCH CENTER, INCORPORATED

HEAVY VEHICLE RESEARCH CENTER

HEAVY VEHICLE INFRASTRUCTURE ASSET INTERACTION AND COLLISION

PREPARED FOR: U.S. Department Of Transportation
Federal Highway Administration
Turner-Fairbank Highway Research Center
Cooperative Agreement #DTFH61-03-X-00030

SEPTEMBER 2005

HEAVY VEHICLE-INFRASTRUCTURE ASSET INTERACTION AND COLLISION

Executive Summary

Research Objectives

The main objectives of this research task were to conduct an in-depth evaluation of the single-unit truck (SUT) finite element model with respect to its ability to accurately simulate its interaction with roadside safety hardware and to identify areas of possible improvements. The model's primary purpose is to be used as a "bullet" object for computational evaluation of roadside safety hardware.

A cooperative effort between the National Transportation Research Center, Inc. (NTRCI), Oak Ridge National Laboratory (ORNL), Battelle, and NCAC was initiated to update and enhance the kinematic and structural accuracy of NCAC's Ford F800 single-unit truck FE model. This report outlines the methodology used in evaluating, validating against experimental data and updating the FE model. A new Hypertext Markup Language (HTML)-based documentation has been developed to facilitate the model adoption and understanding of prospective users. The overall methodology used by the participants - from evaluation to validation to documentation - is outlined in this report and can be applied to other basic vehicle FE models currently available in public domain. The goal of the project was also to establish a methodology for validation and verification of the finite element models used in roadside hardware analysis so that it could be applied to other vehicle finite element models currently under development.

Test Correlations

Model analyses and comparison between simulations and test results led to recommendations for the SUT model modifications that were implemented by the original developers of the model, National Crash Analysis Center (NCAC) and participants in this project, Battelle, Oak Ridge National Laboratory and the University of Tennessee.

Interactive Web-Based User Manual

The interactive web-based user's manual is available online at http://www-cms.ornl.gov/downloads/pub/FHWA/F800WebPage/description/.

This website documents the model and allows the user to visualize the main components of the model, including mechanical and material properties, detailed information regarding connections between components, and detailed contact information used in defining interaction between the various parts. The goal of the interactive 3D environment is to make the model more accessible to end users and facilitate transfer of the developed models and technologies to end users. A "paper" document User's Manual (derived from the Web-based User's manual) is also being provided as a "hard-copy" reference for convenience, and as a deliverable under our original contract.

HEAVY VEHICLE-INFRASTRUCTURE ASSET INTERACTION AND COLLISION

C.R. Miele, C.A. Plaxico, J.C. Kennedy, Battelle
S. Simunovic, Oak Ridge National Laboratory
N. Zisi, University of Tennessee Knoxville

ABSTRACT

This document reports the results of an evaluation of the Ford F800 single-unit truck (SUT) Heavy Vehicle Finite Element (FE) Model, and the subsequent improvements and enhancements made to that FE Model. The SUT model was developed by the Federal Highway Administration (FHWA) at the National Crash Analysis Center (NCAC) as a bullet vehicle for modeling heavy vehicle interactions with roadside hardware.

This research was performed as a collaborative effort by Battelle BMI, the Oak Ridge National Laboratory (ORNL) and the University of Tennessee under auspices of the project on Heavy Vehicles at the National Transportation Research Center, Inc. (NTRC Inc.). The purpose of this task was to model and assess different scenarios of truck vehicle run-off-road collisions with roadway infrastructure elements, vehicle structural modes of failure, and subsequent vehicle stability.

The model modifications, improvements and enhancements that resulted from this study were ultimately implemented by NCAC into the Ford F800 SUT finite element model. A list of the actual model modifications, which improved the model's accuracy for roadside hardware impact analyses, is included. These modifications did not decrease the model's computational efficiency for crash simulations.

Impact of the SUT model with a Single-Slope Bridge Rail and a New Jersey style barrier, were simulated. The initial overall evaluations of the original SUT model that led to the recommendations for model modifications were performed using these two barriers, but the final evaluation of the enhanced model concentrated only on impact with the Single-Slope Bridge Rail. The evaluation process, the enhancements made to the model and the final evaluation of the enhanced model are discussed in this report.

INTRODUCTION

It has become a standard practice in roadside hardware research to evaluate new and existing designs with computational simulations using large and complex models based on the Finite Element Method (FEM). Building a FE model of an entire vehicle of any kind is a considerable undertaking. Significant technical expertise and FEM tradecraft are needed to develop a computationally feasible and practical model that replicates the main kinematics of the vehicle and the deformation response due to the impact loads.

The most challenging aspect of model development is the constant tradeoff between the real world complexity of the vehicle and engineering simplification of its model that should not compromise the final goal of a sufficiently accurate model suited for its purpose. This tradeoff process evolves with advances in computing and, therefore, the already developed models may need to be updated not only to remedy some of their drawbacks, but also to bring them up to the ever-improving levels of computational capabilities.

A FE model of a representative single-unit truck (SUT) was developed by the NCAC for the FHWA.[1] The model has been released to public use and has been used for numerous computational studies of roadside hardware. The model's primary purpose is to be used as a "bullet" object for computational evaluation of roadside safety hardware, and as such it does not warrant the complexity ordinarily employed in vehicle crash analysis models. In fact, too much complexity in a bullet model may be detrimental to its primary purpose because of an increased computational burden and structural failures in the bullet that may overshadow the target's response. Therefore, possible modifications of the vehicle model must always be evaluated within the context of the roadside model development.

PROJECT OBJECTIVES

The objectives of this research were to conduct an evaluation of the SUT model with respect to its ability to accurately simulate its interaction with roadside safety hardware, to identify areas of possible improvements based on comparison of simulations and full-scale crash tests, modify and update the model to improve its accuracy and take advantage of current advances in FEM and to develop a User Manual to facilitate the use of the model.

To be able to use the model efficiently and appropriately, a prospective user has to understand its structure and the modeling decisions made during its development. The traditional user's manual format is not very effective for describing a three-dimensional model, the interconnections between different parts and their participation in different sub-modeling entities. Therefore, a long lead-time is necessary for a new user to be able to use the model with sufficient confidence to know that the perceived impact configuration is indeed the modeled one. An interactive, web-based User's Manual of this vehicle FE model was developed to simplify this learning process and make the model more transparent to new users.

This vehicle model is fairly well suited to its purpose as a bullet vehicle. For example, on a 2-cpu 1.8 MHz. Dell workstation with the Linux operating system, the truck-model-only run time using LS-DYNA 970 was 2 hours 40 minutes clock time to run 226 milliseconds of simulation time.[2] The nominal time-step was about 4 μSec. This appeared to be a good trade-off between mesh refinement and speed.

Comments on the Choice of F800, 18000 lb. SUT to Represent the Generic Single-Unit Truck
All roadside safety hardware used on the National Highway System (NHS) must meet the testing requirements of NCHRP Report 350. Test levels 4, 5 and 6 in Report 350 are intended to evaluate strength of safety barriers for containing and redirecting heavy vehicles such as single-unit trucks and Tractor-Trailer vehicles. Report 350 does not require a specific make or model for the test vehicle, but rather provides recommended properties for test vehicles for representing various classes of vehicles. The recommended properties for the 8000S class vehicle (i.e., SUT) are listed in Table 1.

Table 1: Recommended properties of 8000S test vehicles

Property	**8000S (Single-Unit Truck)**
Mass	
Curb	5,450 +/- 450 kg
Ballast	As needed
Test Inertial	8,000 +/- 200 kg
Dimensions	
Wheel Base	535 cm (max)
Overall Length	870 cm (max)
Cargo Bed Height	130 +/- 3 cm
Center of Mass Location	
Ballast	170 +/- 5 cm
Test Inertial	125 +/- 5 cm

There are many makes and models of SUT vehicles that meet the requirements of the 8000S vehicle class, including Ford, GMC, Chevrolet, Freightliner, and International. Due to practical considerations in roadside hardware analysis, it is not practical or feasible to develop FE models of all such vehicles. For the purpose of using finite element analysis to simulate Test Level 4 impacts, the FHWA provided funding for the NCAC to develop a FE model of the Ford F800 series truck to represent the 8000S vehicle class.

A cursory inspection of several makes and models of SUT's at a local truck dealer revealed generally more similarities than differences. The chassis were all parallel-rail frame types with front and rear leaf spring suspension. They all had V-8 diesel or gasoline engines, and all had dual-wheel rear axles. The cargo bodies are mounted on a series of lateral C- or I-Beams which are welded to C-Channels that run parallel and directly atop the chassis main frames. There is typically a wooden member used as a buffer between the Parallel C-Channels and the main chassis frame rails. Large U-bolts fasten the Cargo-body C-Channels to the chassis main frame rails. (Refer to Figure 24)

The NCAC F800 SUT model reflects this basic construction. All these differences and similarities notwithstanding, there is anecdotal evidence that suggests that GMC's do, in fact, perform differently from Fords in crash tests in significant ways. To our knowledge, there has never been an organized effort to quantify or document those differences due to different makes and models. Therefore, kinematic behavior of the F800 model may not always coincide with experimental data but it is assumed that the differences in the structural behavior between models of the same class are negligible with respect to the roadside hardware response and performance. Through the process of making various modifications to the model with the intent of better emulating full-scale tests in which various makes and models of test vehicles were used, the F800 model will gravitate away from an exact reflection of the Ford's behavior and towards a better general representation of this class of vehicle.

ANALYSIS PROCESS

The procedure established to validate, verify and implement enhancements to this SUT model provides the methodology for validation, verification and enhancement of other heavy-vehicle models currently under development at NCAC. This first task was to establish a baseline level of model fidelity with a goal that the updated SUT model would serve as a better starting point for users from which they could more easily make custom modifications to the vehicle model for their specific needs.

The model's primary purpose is to be used as a "bullet" vehicle for computational evaluation of roadside safety hardware. The model must, therefore, provide realistic characterization of the overall dynamics of the vehicle and provide accurate loading to the roadside safety feature. In general, there are two basic aspects that are important in a "bullet" model: accurate mass distribution and realistic global stiffness properties. Another important aspect that must be considered for models used to evaluate roadside safety hardware is proper modeling of the wheels and suspension components, which can have significant effects on both vehicle and barrier response when the wheels interact with the barrier.

The analysis of the SUT model was conducted and based on evolving model versions as they were being developed by the NCAC and consisted of the following tasks:

- Preliminary evaluation of the SUT models using FEM simulations
- Comparison of the simulations with the crash experiments
- Identification of the model areas critical for its performance in roadside hardware analysis
- Analysis and review:
  - of the SUT service manuals with respect to FEM modeling approaches
  - of the SUT model material characterization
  - of the connectivity and joint models
  - of the suspension and its possible failure modes
- Provide suggested modifications to the model to enhance its accuracy in crash analysis
- Implementation of model modifications
- Analysis of the enhanced version of the SUT

The model and the project developments are documented in the HTML based environment that allows for dynamic visualization and interaction with the model. Users can analyze all the main components of the model and their interactions. The goal of the interactive 3D environment is to make the model more transparent to the end users and to facilitate transfer of the developed models and technologies to the end users.

MODEL EVALUATION

Finite element simulations were conducted using LS-DYNA to evaluate the status of the as-downloaded version of the original (version 01-d, created April 2003) F800 SUT model that was available on the NCAC Finite Element Model Archive. A detailed discussion of the Finite Element analyses made on the original SUT model to assess the required enhancements is documented in a report to FHWA.[3] Assessments were made of various aspects of that model based on:

1. Review of service manuals for the Ford F800 regarding geometric detail of structural components and material characterization, and
2. Fundamental modeling aspects regarding element type, mesh refinement, connection methodology, contact definitions, etc.

Areas that could be relatively easily improved or enhanced were identified and a list suggested modifications were provided to the NCAC. Table 2 is a summary of those assessments and the current status of the enhancements to the finite element model of the Ford F800 single-unit truck. Most of the recommended enhancements have been implemented in the finite element model with the exception of the tire-blowout failure mechanism. NCAC made most of the geometric and meshing modifications, while ORNL and Battelle made modifications related to material characterization and failure mechanisms.

Table 2: List of Enhancements Suggested for the V01d F800 Vehicle Model

Area of Model	Component	Area of Concern	Suggested Enhancement	Comments
Front	Axle Beam	Axle Beam Connection too Strong	Provide for Separation/Failure	**Strain based failure was added to U-bolts**
Front and Rear	Axles/Spindles	Wheels cannot rotate	Add Rotational Capability	**Joints were added to simulate connection of wheels to axles**
All	All	Need accurate material characterization of truck components	Add Material Models for HSLA, DQSK, Spring Steel, etc. with Strain-rate Effects Where Appropriate	**Key components in the truck are modeled with appropriate material characterization**
All		No Convenient Way to Recover Accelerations at CG	Add Accelerometer Elements	**Accelerometer added at the cabin and bed**
Rear	Rear wheels	Rear wheel hubs were not modeled	Remesh the rear axle and hubs with correct geometry	**Added Rear axle with the correct geometry**
Front	Brakes	Rotor Snags on Caliper	Fix Contact	**Contact modified**
All	Tires	No Failure Provided	Add Failure Mode/Blowout if Practical	**Tire blowout not incorporated**
All	Bolted Connections	No Failure Provided	Add Realistic Bolt/Connection Strengths	**Most of the critical connections were modeled using weld options in ls-dyna. Accuracy in failure strength not verified.**
All	All	One (Self) Contact Set For All Contact	Individual Contact Sets in Key Locations as Required	**Additional contacts were incorporated**
All	Various	Triangle Elements	Replace with Quad Elements/Improved Mesh	**Elements re-meshed as required**
All	Various	Inconsistent Element Normals	Set Element Connectivity to Normalize	**Normals verified and corrections made where necessary**
All	All	No Shell Element Thickness Considered for Contact	Add Shell Element Thickness to Contact Where Practical	**Contacts were defined to consider element thicknesses**
All	All	One Contact Friction Everywhere	Individual Contact Friction in Locations	**Contact friction was defined appropriately**
Front and Rear	Leaf Springs	Leafs Not Acting/Contacting Independently	- Add Individual Contact Between Leafs - Include failure mechanism for axle to leaf spring connection - Account for Preload of sprung mass	**- Contact definition added - U bolts with failure added - Constant-load spring was added to simulate preload**

From the review of the 1996 Ford F800 Chassis/Body and Drivetrain/Powertrain service manuals, several critical aspects of the model were identified for enhancement[4,5]:

- Frame material – The material for the F800 frame is high-strength low alloy steel of either 350 MPa or 690 MPa yield stress.[6] The detailed properties of this material are available from the experiments conducted in a material research project between ORNL and the Auto/Steel Partnership.[7] The developed material model also accounts for the strain-rate sensitivity that is particularly pronounced in steels.
- Reinforcements of the truck frame, as shown in the service manual, were not present in the original SUT FE model. This would affect bending and torsion stiffness of the entire truck.
- Spring mounts in the service manuals appear to be more stiff than they were modeled in the original SUT model. It is possible for the spring mounts to break during impact which will affect the response of the vehicle.
- In the service manual, the front axle is connected to the leaf spring suspension by U-bolts only, which provide another failure mechanism that would affect the kinematic response of the vehicle. This was missing in the original version of the SUT model.
- In the service manual, the steering gear is mounted on the left frame and adds additional stiffness compared to the right-side frame mount. The steering is then transferred to the steering arm on the left wheel and over the tie-rod to the right wheel. This appears to stiffen the right-side of the frame-wheel system more than the left-frame.
- Engine and transmission connections and their mounting on the SUT frame depend on the engine and transmission options and may make a big difference on the deformation in the engine compartment.

Figure 1 shows an overall view of the enhanced SUT finite element model. The following figures show various “before and after” comparison of the finite element model of the F800 SUT. The purpose of this is to show the overall level of increase in mesh refinement and details that were captured. Figures 2 and 3 show a comparison of the front suspension models between the original and enhanced model; Figures 4 and 5 show a comparison of the rear suspension models between the original and enhanced model; and Figures 6 and 7 show a comparison of the rear axle models between the original and enhanced model. These figures illustrate the improved geometric detail of the enhanced version. There is a significant improvement evident in the model of the wheel spindle that now allows for rotation of the wheels. Another important modification is the connection of the leaf-spring to the axle which is now explicitly-modeled with U-bolts.

Finite Element Mesh

The original version of the SUT model had 24,919 Nodes, 21,726 Elements, and 192 Parts. The enhanced version ended up with 36,032 Nodes, 32,669 Elements and 159 Parts. This is a 44% and a 50% increase (respectively) in Nodes and Elements. This increase is offset by the current state of computing capability compared to that of 4 years ago. Typical element size for non-structural components in the model, such as sheet metal on the hood and doors, range from 75 – 150 mm and typical element size for structural components, such as main frame rails, range from 60 – 70 mm.

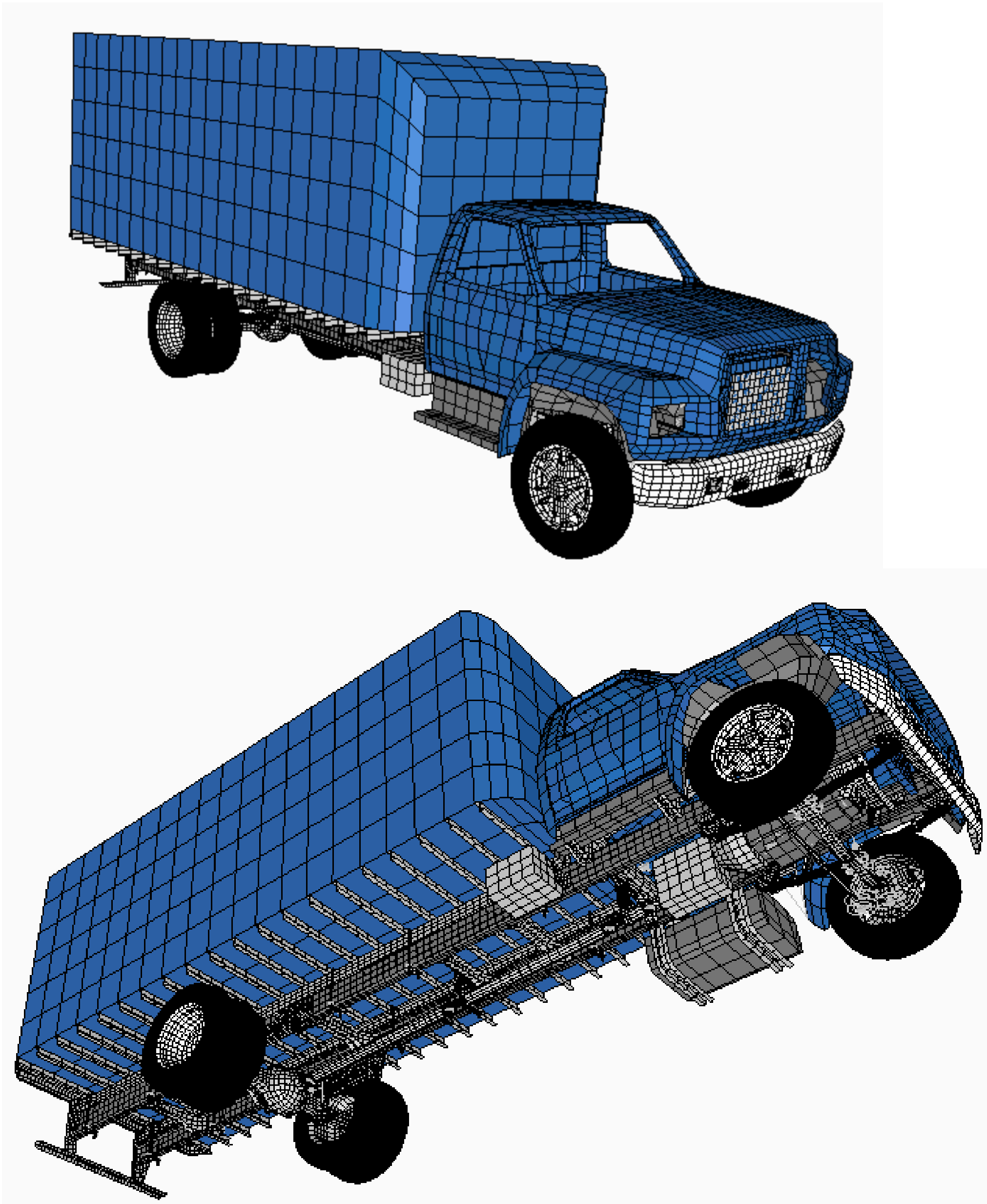


Figure 1: Enhanced Ford F800 Finite Element Model

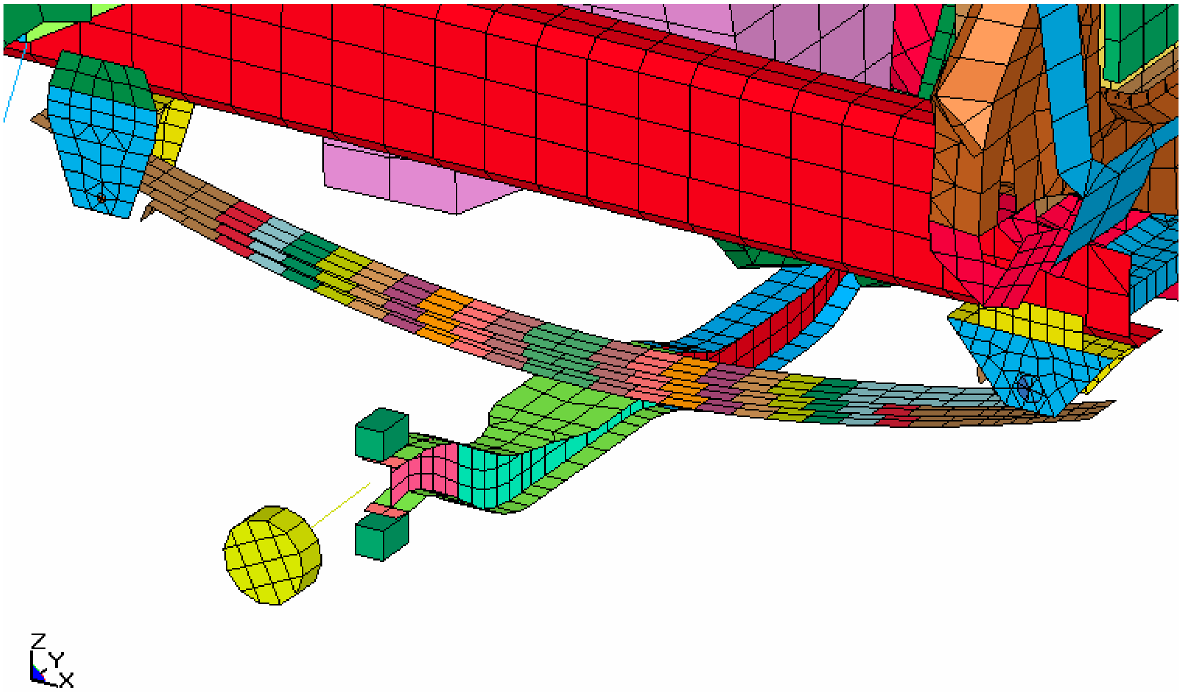


Figure 2: F800 version 01-d (original) model front suspension

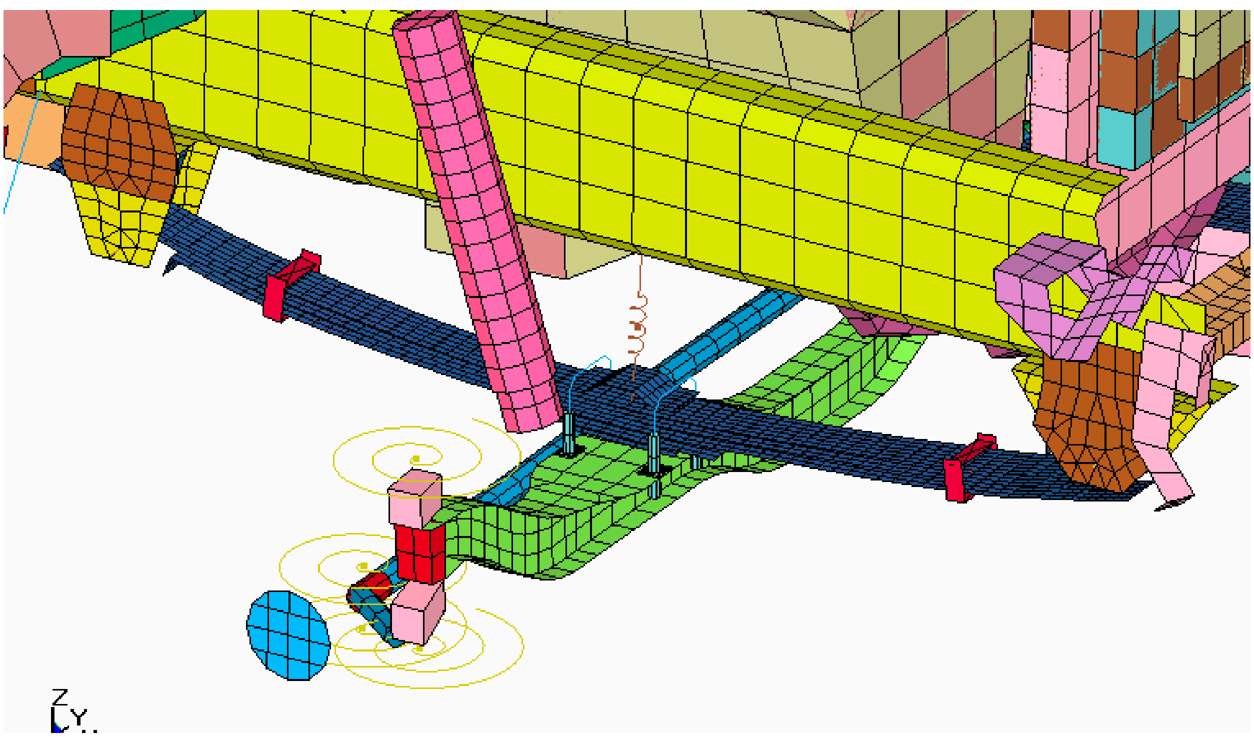


Figure 3: Enhanced F800 model front suspension

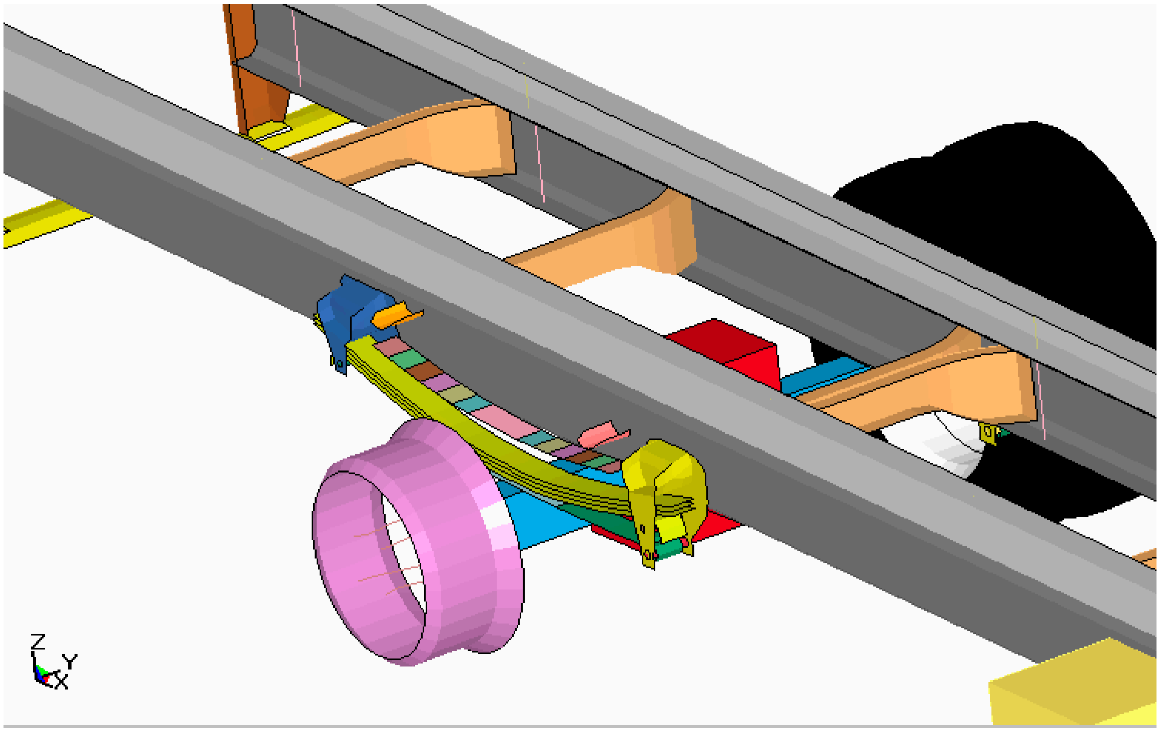


Figure 4: F800 version 01-d (original) model rear suspension

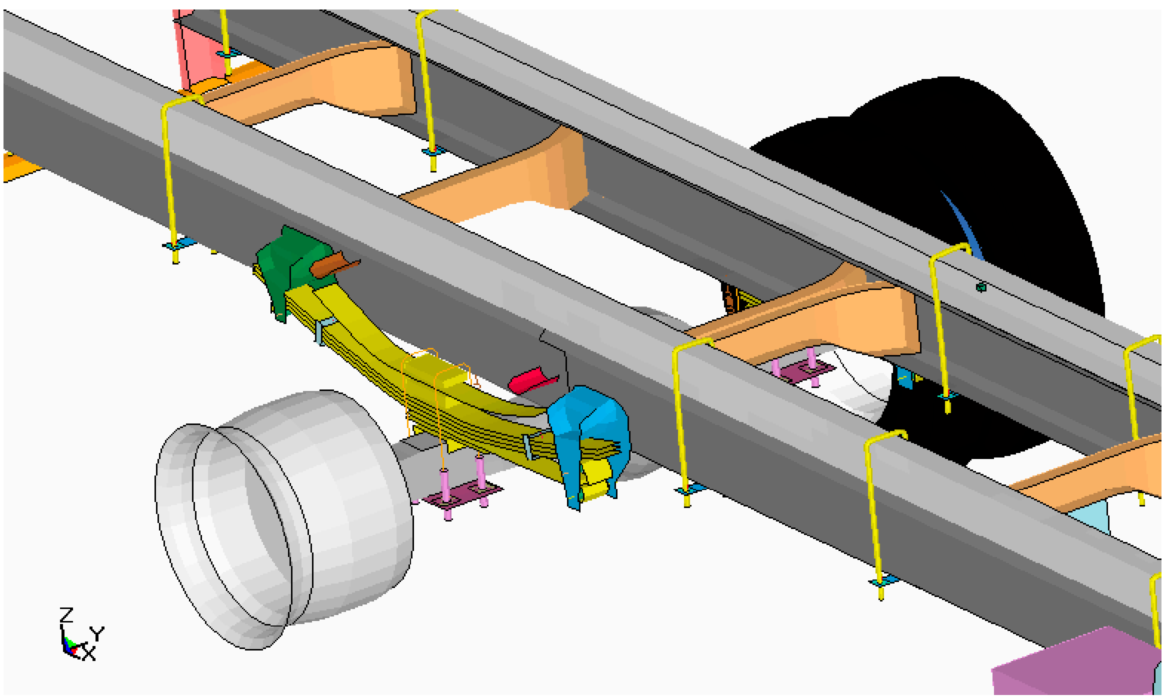


Figure 5: Enhanced F800 model rear suspension

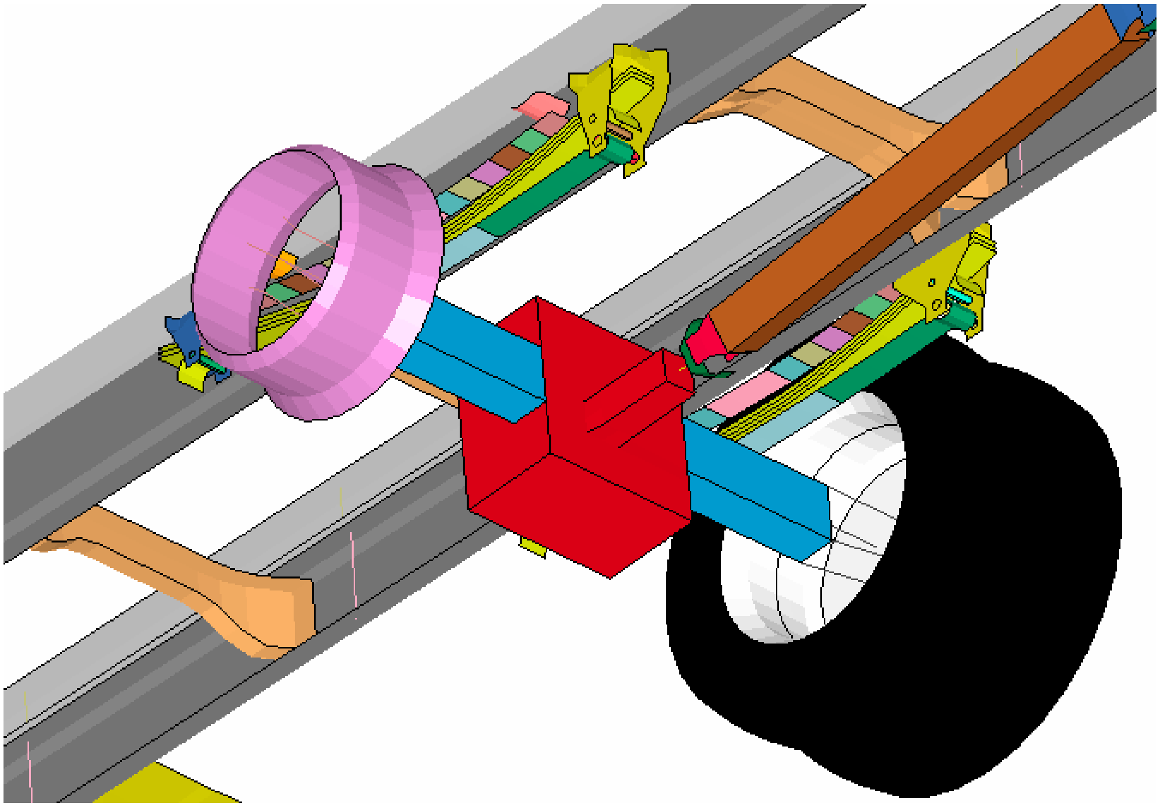


Figure 6: F800 version 01-d (original) model rear axle

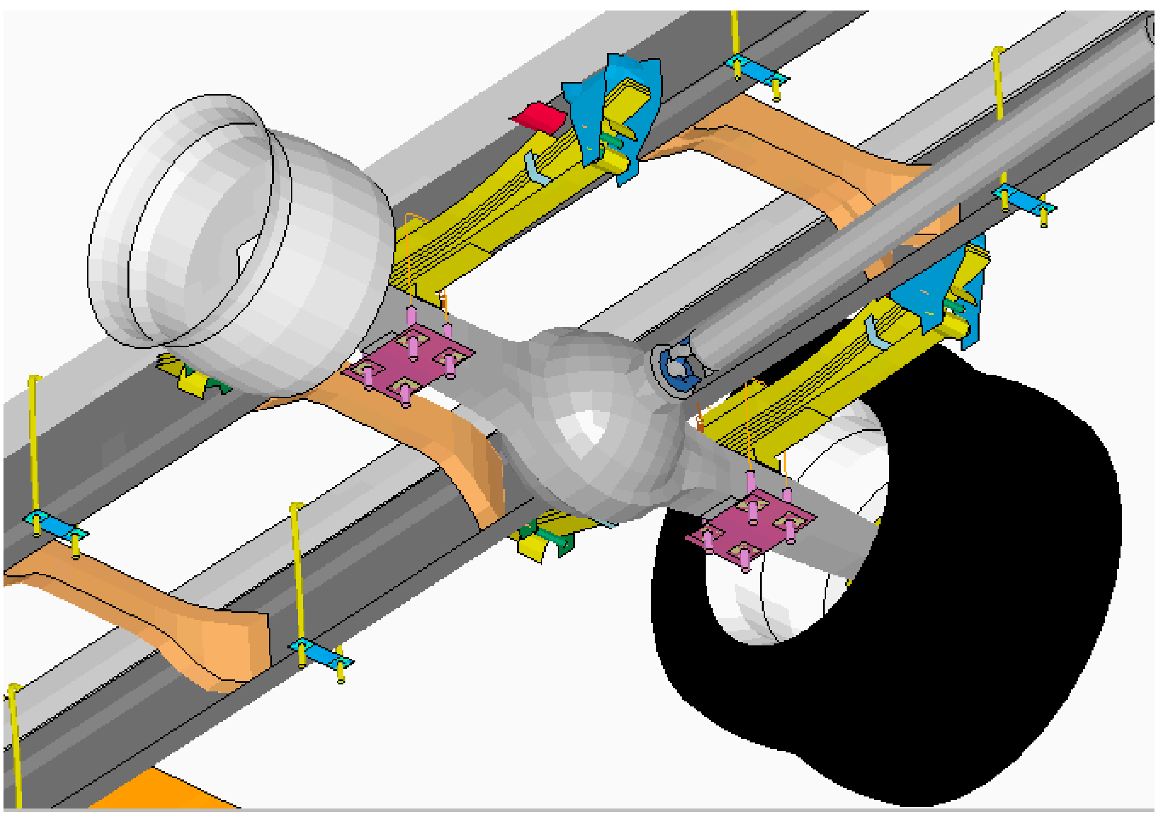


Figure 7: Enhanced F800 model rear axle

The original SUT model used the least computationally expensive element formulations and default options on hourglass stabilization. Stiffness-based hourglass control is better suited for parts that experience large deformations, and does not significantly increase computational time. For all types of elements in the original vehicle model, the number of integration points is set at the default value. In light of the model's purpose, such decision is prudent because the number of integration points tend to linearly increase the simulation time. However, for the important structural parts such as the main frame and the parts that are expected to bear the brunt of the impact force, five integration points through thickness is the currently accepted minimum because default two points may make the shell too soft and deform too abruptly. The enhanced vehicle model incorporated this improvement.

Suspension System

An important aspect of a bullet vehicle model is its ability to simulate the overall kinematics of the vehicle in an impact event, which implies the existence of accurate models for mass distribution, global bending stiffness, torsion stiffness, and response of wheels and suspension components. For example, when a vehicle impacts a concrete safety shape barrier (e.g., F-shape and New Jersey shape barrier) at oblique angles, the spinning wheels of the vehicle tend to climb the barrier, which can significantly affect the dynamic behavior of the vehicle and, consequently, affect the loading on the barrier. If such capability is missing in the model, the simulation results can not be expected to provide reliable information regarding performance of the roadside safety barrier.

The geometry of the suspension in the SUT model was based on its equilibrium position under the weight of the sprung mass of the truck, however, the model did not account for any preload in the suspension components. Consequently, the sprung mass of the truck displaced significantly downward when gravity was applied to the model. The most appropriate way to model the preload in the suspension system would be to model the geometry of the leaf-spring suspension in its unloaded configuration, apply appropriate sprung-mass loading to the connection points, compute the stresses in the suspension components, and then apply those stresses back into the original model as initial stress conditions. The effort required in such a task was beyond the scope of this project. The preload in the suspension system was accounted for in the model by adding a nonlinear-elastic spring element with one node connected to the leaf spring and the other node connected to the truck frame, as shown in Figure 8. The force-displacement relationship of this spring was defined to provide essentially a *constant force* equal to the sprung mass of the truck for the expected range of motion of the suspension.

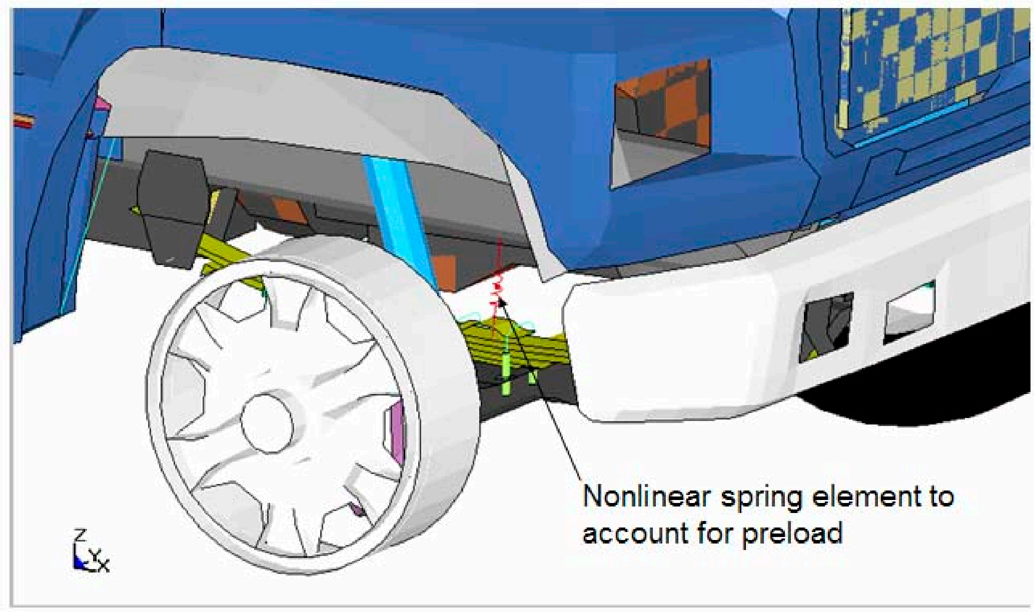


Figure 8: Nonlinear spring added to account for preload due to sprung mass of truck.

Axles and Rotating Tires

One of the primary uses of the SUT model will be to simulate NCHRP Report 350 Test level 4 impacts into longitudinal barriers. These impact scenarios involve an SUT impacting at 80 km/hr at an impact angle of 15 degrees. In such an impact scenario, the front tires and the front axle are the first to experience the brunt of the impact force, thus these components must be modeled in sufficient geometric and material detail. In the original model the wheel assembly was connected to the axle using four beam element (refer to Figure 6) which, consequently, restrained the rotation of the wheels. The SUT model was initially developed to simulate head-on impacts into rigid barriers. For 90-degree, frontal impacts wheel rotation has little effect on the overall response of the vehicle, however, in oblique impacts wheel rotation is critical to achieve realistic dynamic response of the vehicle interacting with a barrier.

When a vehicle impacts against an object such as a roadside safety barrier, one or more of its tires may deflate or “blowout” as the tire(s) interact with the object. Tire deflation affects the dynamics of a vehicle during impact because it alters the magnitude of forces and the mechanism of how those forces are transferred between various vehicle components. For example, during full-scale, low-angle impacts with longitudinal concrete barriers the front, impact side tire of a SUT often gets pushed back into the wheel well of the vehicle. If the tire remains inflated during this event, the wheel will stack against adjacent parts and impose significant forces on its surroundings. The magnitude of these forces may be sufficient to cause failure of critical components (e.g., suspension), which will affect subsequent kinematic behavior of the vehicle.

The tires of the SUT model are modeled using a simple airbag option in LS-DYNA and can not simulate deflation or “blowout” of the tire. The simulation of accurate and correct timing of tire blow-out requires a significant increase in model complexity and computing resources that would take the SUT away from its purpose as a bullet vehicle. Therefore, the tire model in the enhanced vehicle model continues to use the simple airbag option that was used in the original SUT model to simulate tire behavior.

Contact

One simple "self contact" model with zero friction was specified for all component interactions throughout the original F800 SUT model. This one large contact set worked fine mechanically, but using one contact set for every contact interaction in the model does not provide for different specific friction coefficients between different materials – dry metal-to-metal, lubricated metal-to-metal, painted metal-to-metal, metal-to-rubber, etc. The thickness of contact surfaces were all set to 1 mm in the original model instead of using actual thicknesses; presumably because the actual thickness values would create numerous initial contact surface penetrations. The enhanced SUT model includes more specific contacts based on part thicknesses and more realistic friction values.

Material Models

Regardless of the amount of geometric detail and mesh refinement of a FE model, realistic results can not be obtained without proper characterization of material properties of the various model components. One of the important areas of the SUT model update is the implementation of more detailed material model assignment and material properties. An exploded view of the SUT parts is shown in Figure 9.

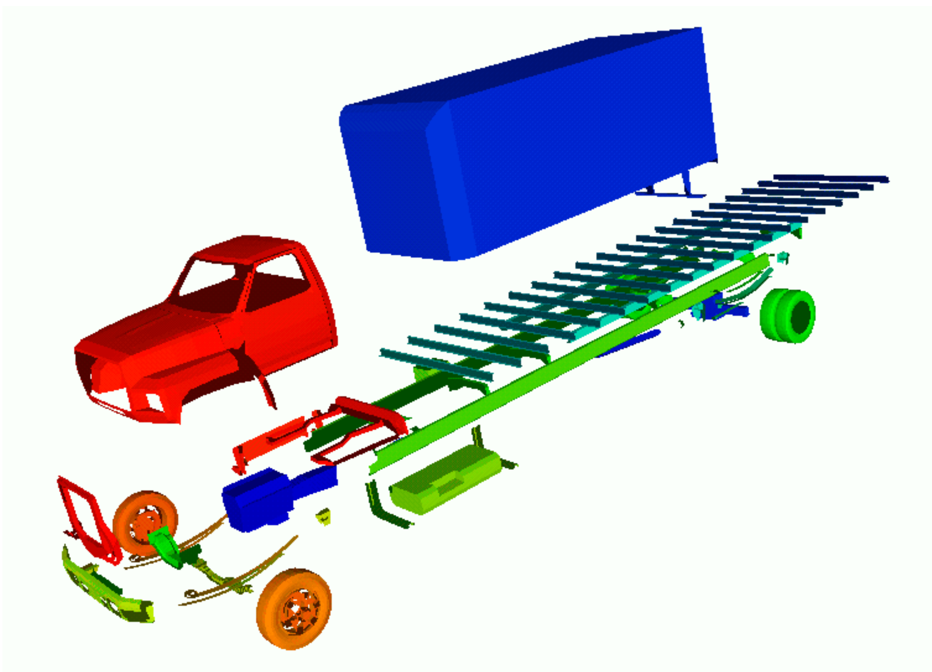


Figure 9: Exploded view of SUT model parts (original model)

The original model used only three material types to characterize the many different material parts in the model. The stress-strain curves for these three material types are shown in Figure 10.

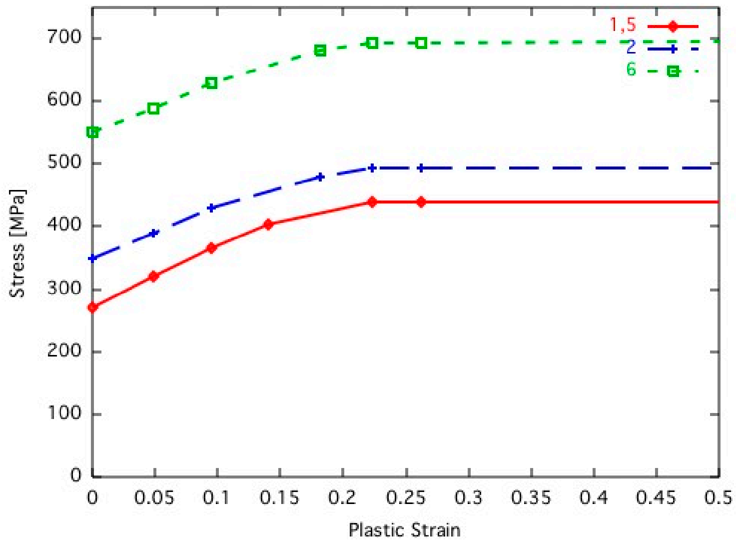


Figure 10: F800 version 01-d (original) model material properties

The parts that were characterized in the original model with low strength (270 MPa) steel (material characterized by curves 1 and 5 in Figure 10) are shown in Figure 11. The 270 MPa steel was intended to represent parts made of mild steel, such as Drawing Quality Special-Killed (DQSK) steels.

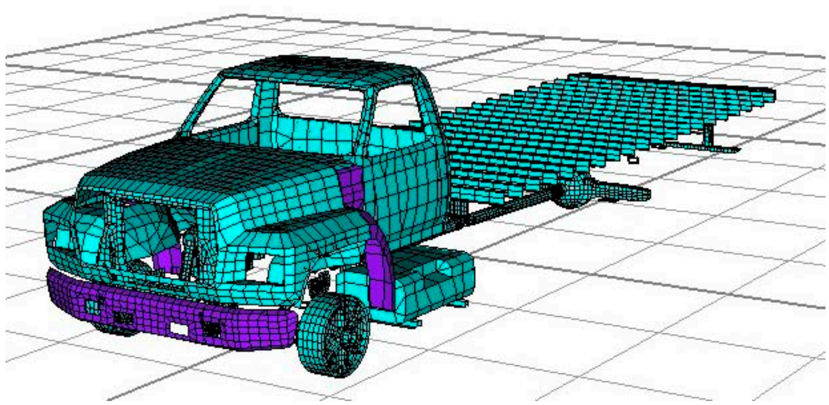


Figure 11: Parts characterized by 270 MPa steel in the F800 version 01-d (original model)

The parts that were characterized in the original model with 350 MPa yield strength steel (material characterized by curve 2 in Figure 10) are shown in Figure 12. The 350 MPa steel was intended to model high strength steels in the structure.

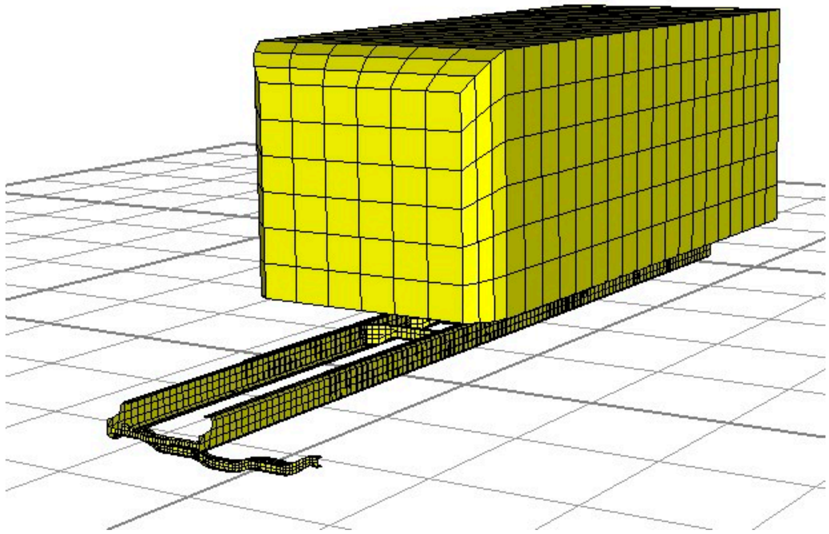


Figure 12: Parts characterized by 350 MPa steel in the F800 version 01-d (original model)

The parts that were modeled with material 6 in the original model are shown in Figure 13. Material 6 was intended to model high strength alloyed steel in the leaf springs.

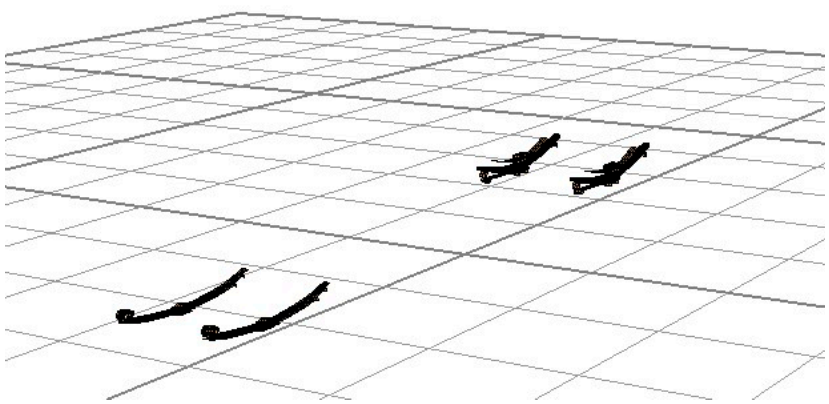


Figure 13: F800 version 01-d (original model) Material 6

The above figures offer several possibilities for improvement by material model modifications. The most commonly used approach to modeling strain-rate sensitivity of steels in automotive crash simulations is to use isotropic plasticity models with a rate sensitivity component that has moderate requirements on the experimental program. The types of material models that are frequently used are the Johnson-Cook model, the Zerilli-Armstrong model and the piecewise linear strain-rate sensitive material model. [2,7] The models are appealing because they have been implemented in commercial codes used for crash simulations and have a relatively small number of material parameters that must be determined by experiments.

In the enhanced model, material assignments are in better agreement with the material designations denoted in the service manual. The material model characterization in the enhanced model reflects experimental data exactly, however, testing artifacts or errors contained in the experimental data will be carried over to the simulations. The piecewise linear plasticity model is used to characterize the various materials. Using this material model, effective stress-strain curves from experiments are directly included in the computational material models and require the least amount of effort for material model development. In simulations, for a given strain-rate, the resulting stress in the plastic region is linearly interpolated between the stress-strain values that were experimentally determined in strain-rate tests. The highest strain-rate in the experimental data acts as a saturation plateau for strain-rate effects.

Figures 14 - 19 show the characterization of the various types of materials used in the enhanced model as well as denoting the various parts associated with those material definitions. The stress-strain plots showing multiple curves are used to characterize the material response for different strain-rates ranging from qausi-static to 4000 1/s. For exact tabulated material definition refer to the online User's Manual.

A more accurate material model for DQSK that includes strain-rate sensitivity was used in the enhanced SUT model. The bumper material in SUT vehicles is usually made of hot rolled steel, such as HR30SQ that has typical yield stress of 274 MPa and strength of 393MPa. The bumper material in the enhanced SUT model was characterized accordingly.

The SUT is built as a body on a main longitudinal rail structure that acts as its backbone. It is therefore important to accurately model the geometry and the material of the rails. According to the F800 Service Manual, the main rails in the F800 are made of High Strength Low Alloy (HSLA) steel. Depending on the model, the frame can be made of 50,000 psi or 110,000 psi steel. The former corresponds to HSLA350 while the later is made of HSLA700 steel. The HSLA350 was most likely the material modeled in the F800 truck. The strain-rate dependent model for the HSLA 350 steel used in the main rails of the SUT were developed by the Auto/Steel Partnership and are shown in Figure 20.[7] The dashed curves show the results from the quasi-static uniaxial tensile experiments.

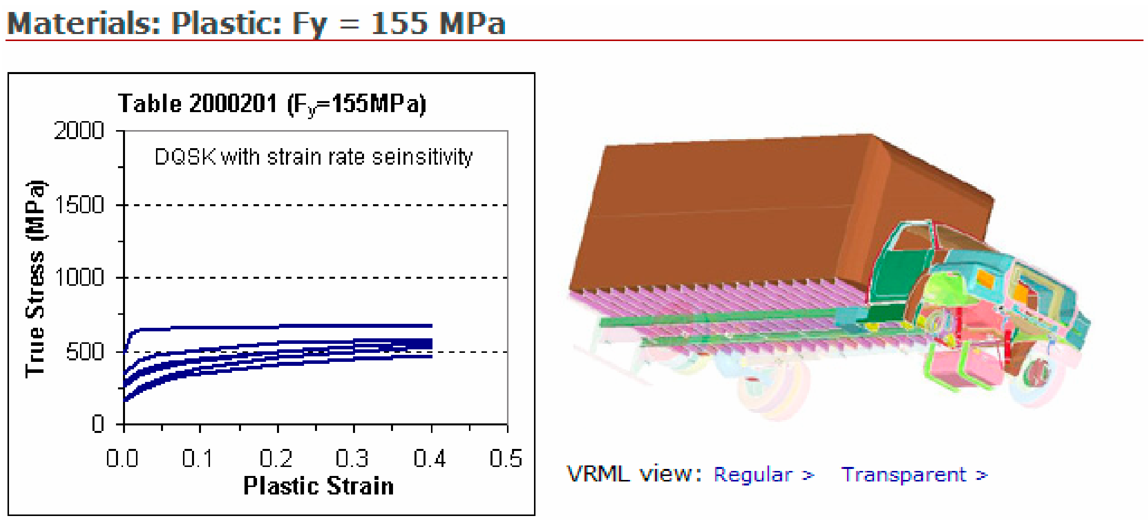


Figure 14: Material characterization for DQSK steel and SUT parts associated with this material characterization.

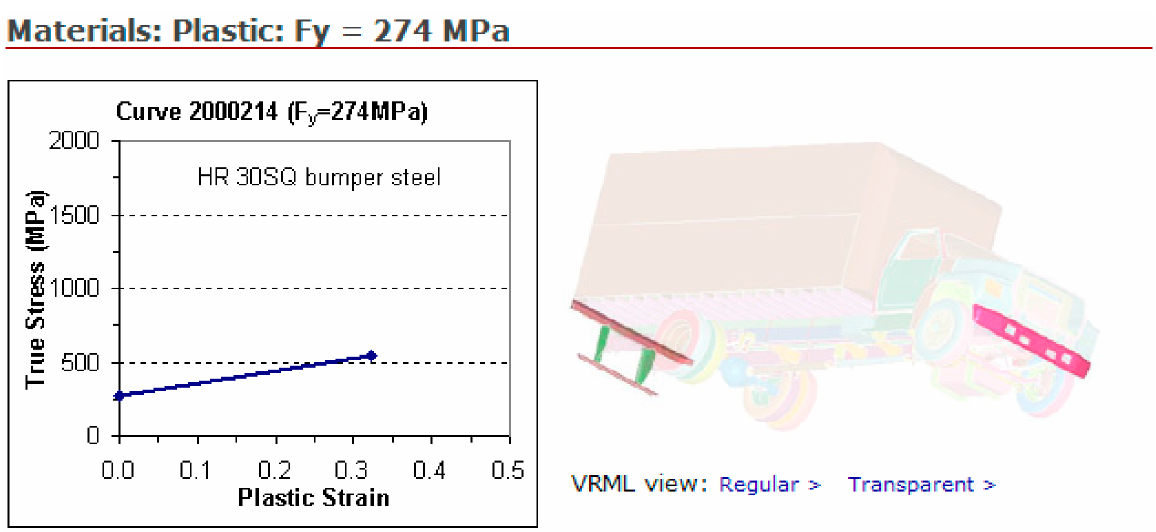


Figure 15: Material characterization for HR30SQ steel and SUT parts associated with this material characterization.

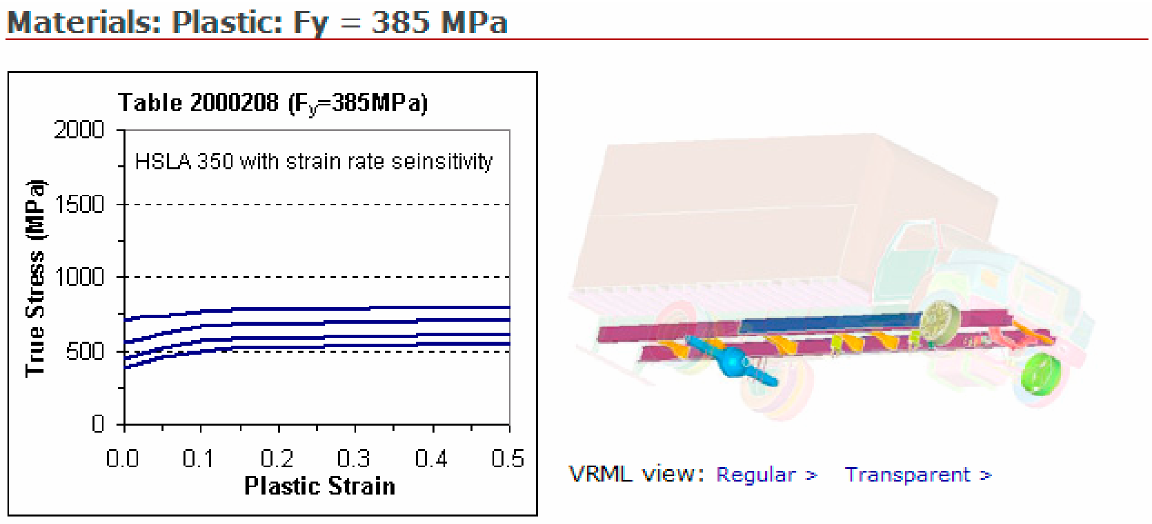


Figure 16: Material characterization for HSLA350 steel and SUT parts associated with this material characterization.

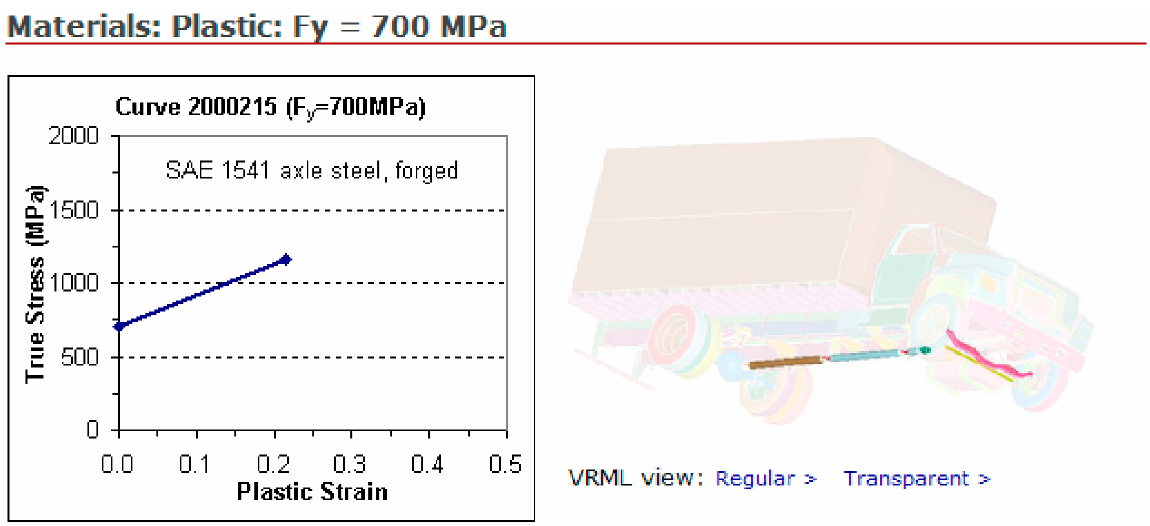


Figure 17: Material characterization for SAE 1541 forged axel steel and SUT parts associated with this material characterization

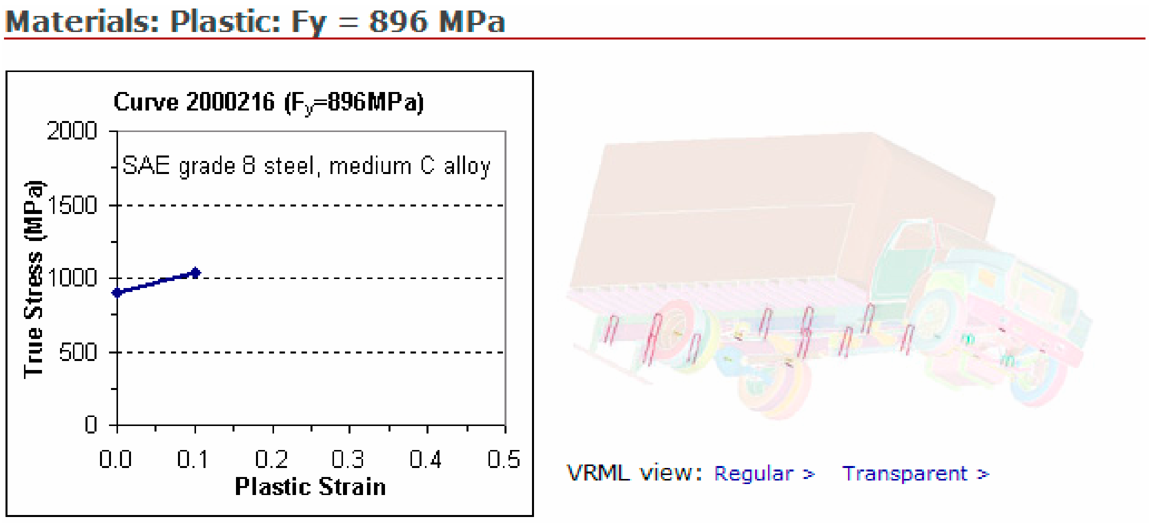


Figure 18: Material characterization for SAE grade 8 steel and SUT parts associated with this material characterization

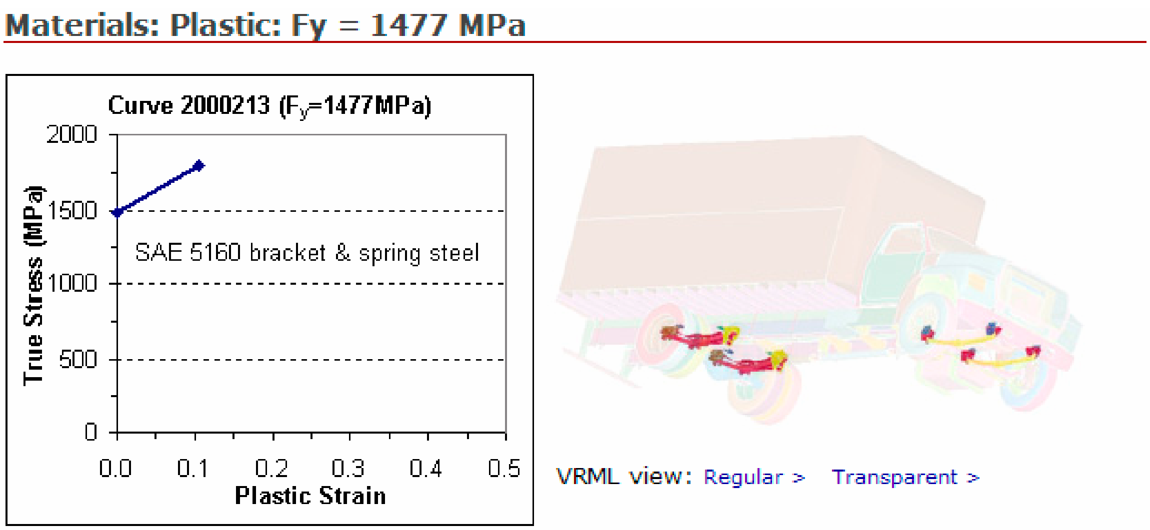


Figure 19: Material characterization for SAE 5160 steel and SUT parts associated with this material characterization

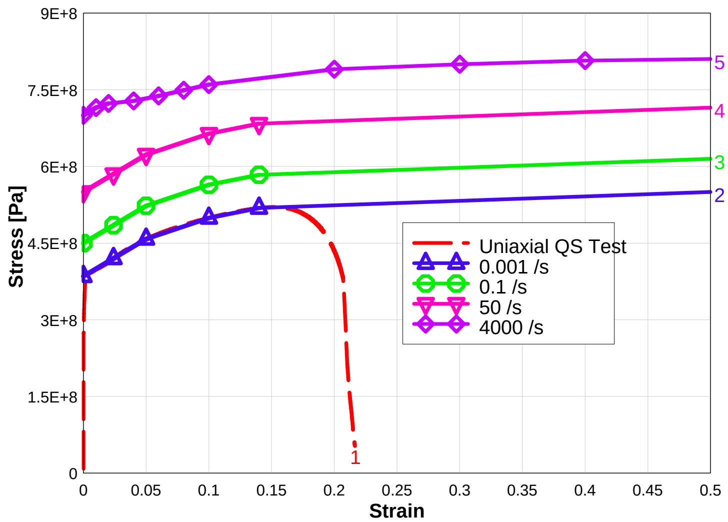


Figure 20: Material parameters for HSLA350 developed by the Auto/Steel Partnership[6]

The leaf springs (Figure 13) are usually made of heat treated high carbon steels such as SAE 5160 or 1085. The yield strength can vary depending on the thermal treatment, which also changes the ductility of the material. The material also tends to exhibit pronounced strain-rate sensitivity. Other material models implemented were the SAE 5160 bracket and spring steel, SAE 1541 forged axle steel, and medium Carbon alloyed SAE Grade 8 steel for nuts and bolts. Parts made of each of these materials can be interactively viewed using the online User's Manual as described previously and detailed later in this report.

Suspension Failure

All test scenarios conducted by the FHWA involved a single-unit truck impacting a barrier system at a nominal speed of 80 km/hr and impact angle of 15 degrees to investigate deflection characteristics of the barrier for NCHRP Report 350 Test Level 4. In all the crash tests, the most apparent damage to the vehicle was failure of the front suspension, which occurred very soon after initial impact. The failures occurred in connections between suspension parts that then caused the connected parts to separate. Figure 21 shows the failure locations of the various connection points of the front suspension denoted by labels A1 to C2.

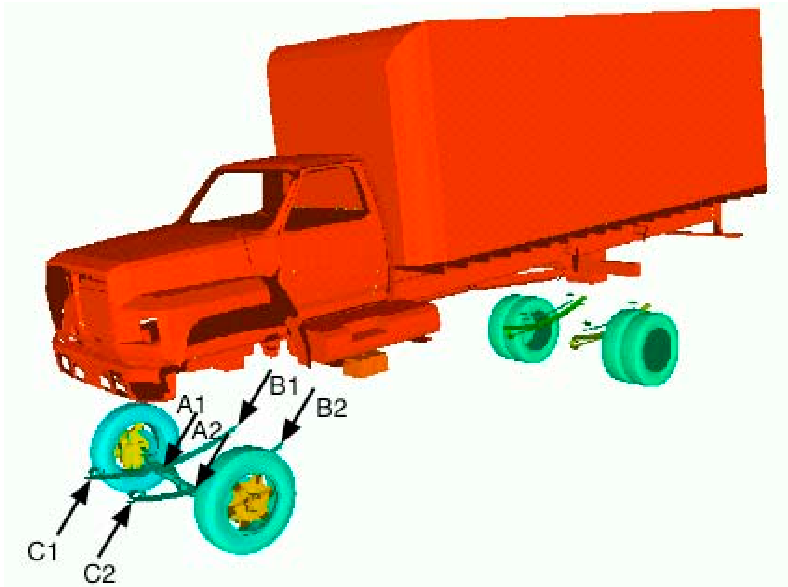


Figure 21: Failure points of front suspension

To a large extent, the shape of the barrier face influences the severity of the suspension damage and mechanism of its failure. In a low-angle impact with a New Jersey style barrier, its angled base promotes the wheel impact and corresponding suspension damage. The exact sequence of failure events for the suspensions cannot be readily determined from the high-speed crash test films due to low image resolution and camera positioning. However, in all the available SUT crash tests, the locations of failure involve a combination of points shown in Figure 21. In tests where connection points A1 and A2 fail, the front I-beam axle detaches from the leaf spring and separates from the vehicle with the front wheels attached to it. In all the tests that were reviewed, the truck impacted the barrier on the passenger side of the vehicle and, therefore, points A1, B1 and C1 bore the brunt of the impact force on the front suspension. Another point of detachment that can be conclusively discerned from the high-speed film is B1. The failure at point C1 can be postulated from the kinematics of the points A1 and B1. The failure at points B2 and C2 has not been directly observed from the crash films, but it is likely based on the behavior of the right suspension. The failure sequences depend on the tests and the vehicles involved. The two main failure sequences appear to be:

1. Failure at (a) A1+A2, which then renders failure at other suspension points unimportant for the remainder of the crash event

2. Failure (a) at B1, possibly at (b) C1, followed by failure (c) at A1. It is very likely that partial failure at the left front suspension also occurs, most likely at point A2.

As was mentioned previously, correct modeling of the suspension system, including failure, is important because of the influence it has on the overall truck body dynamics.

An important part of the suspension that was implemented in the enhanced model was the shock absorber. The detail view from the Service Manual of the front suspension and its connections are shown in Figure 22. The shock absorber affects the dynamics of the suspension on impact and may significantly influence the kinematics of the vehicle in low-angle impacts.

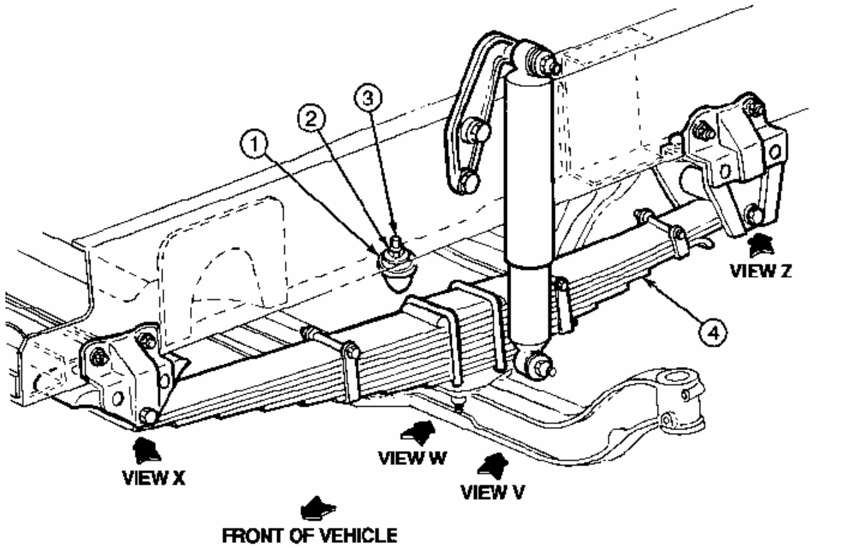


Figure 22: Front suspension detail

Failure mechanisms for the front suspension were implemented for the enhanced model as well. The failure mechanism that corresponds to points A1 and A2 in Figure 21 is shearing of U bolts (view W in Figure 22). The bolts are SAE Grade 8 material with ¾" diameter. The corresponding failure forces in tension and shear are 220kN and 110 kN, respectively, which were found in the literature (SAE J429 or equivalent ASTM A490M [8]).[8,9] A simple model for U-bolt failure based on failure strain was added to the SUT model. The rear suspension detail is shown in Figure 23. No modifications were made to the model to accommodate for the rear axle failures, although such an addition would be useful. Modification of the rear suspension would require adding failure modes to the connections and the model for the shock absorber.

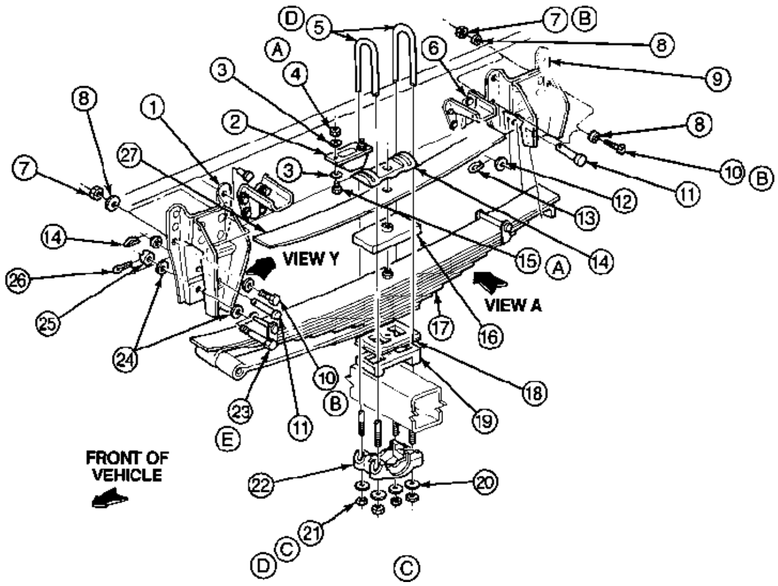


Figure 23: Rear suspension detail

EVALUATION OF THE ENHANCED SUT MODEL

For evaluation of the model, the study focused on impacts with rigid barriers so that the mechanics of the impact could be isolated to the response of the vehicle.   A full-scale crash test was used for evaluating the fidelity of the enhanced SUT model. The test was conducted at the Texas Transportation Institute (TTI) and involved a single-slope concrete bridge rail (TTI Test No. 7147-17). [10]

An important feature of a SUT which has a significant effect on the dynamic behavior of the vehicle is the connection of bed-frame to the truck's main-frame. The standard connection method is a weldment at the rear of the bed-frame to truck rail and a series of U-bolts along the length of the bed, as shown in Figure 24 (see also Figure 4).

Figure 24 : Bed-frame is connected to main frame-rails of truck with weldments and U-bolts.

In some cases, an additional connection is used at the front of the bed to restrain lateral displacement of the bed relative to the truck's frame-rails, as shown in Figure 25. The addition of this lateral constraint aids in keeping the truck-bed from sliding off the main frame-rails during impacts and can have a significant effect on the dynamics of the vehicle, as shown in Figure 26. The truck body and the truck-bed move relatively independent of each other when the truck-bed is not sufficiently restrained laterally. The method of connecting the bed to the truck is not peculiar to vehicle type. For example, the test vehicles shown in Figure 26 are both GMC but have different bed-connection strategies.

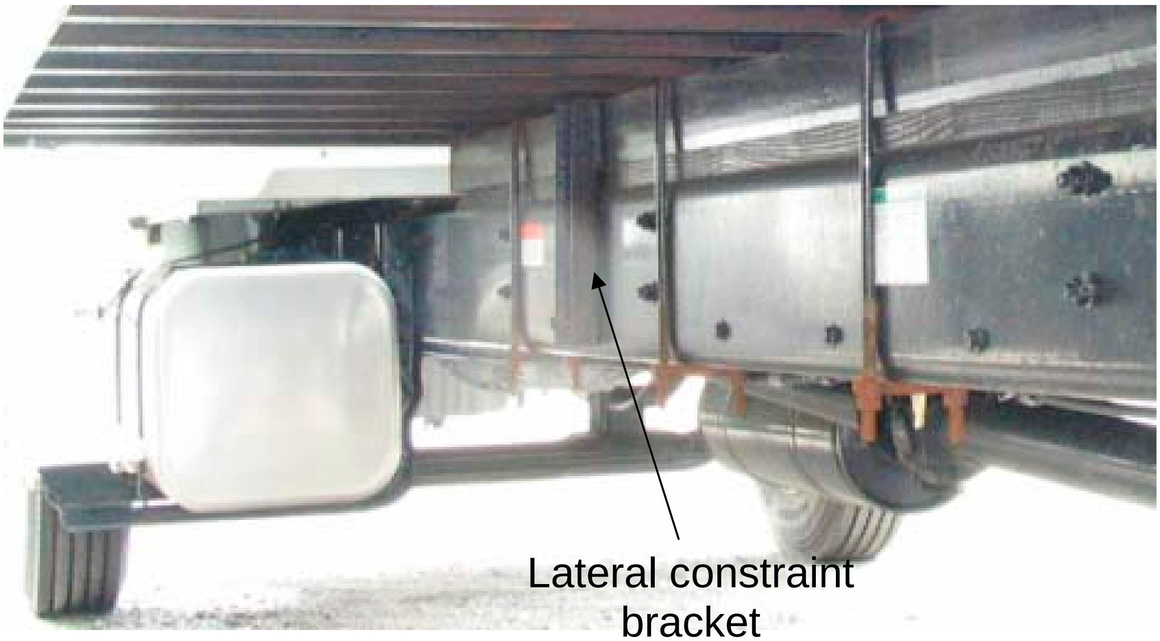


Figure 25: C-channel welded to bed-frame and bolted to main frame-rail for lateral support.

Figure 26: a) Truck-bed "rigidly" restrained (TTI Test 7147-17) and b) Truck-bed translates laterally with respect to truck body due to insufficient lateral constraint (TTI Test 7147-16). [10,11]

Full details of the crash tests are available from the TTI reports.[10,11] A detailed discussion of the Finite Element analyses and evaluations of the original SUT is documented in a report to FHWA.[3] After implementing all the recommended improvements in the model, simulation of the TTI test was re-run to evaluate the efficacy of the enhancements. The following section summarizes the results of those simulations.

Comparison of F.E. Analysis with Full-Scale Crash Test (TTI Test 7147-17)

Crash analysis simulations were run using the NCAC F800 single-unit truck Enhanced Model to compare with the TTI Crash Test No. 7147-17 – single-unit truck impacting Single Slope Concrete Bridge Rail.[10] The full-scale test was conducted at TTI in 1995.

The crash test vehicle was an 8172 kg (18,000 lb) GMC 7000 single-unit truck (11470 lb curb weight plus 6530 lb ballast load). The vehicle was impacted into a single-slope bridge rail at 82.5 km/hr (51.3 mph), at an impact angle of 17.9°. The vehicle model used in the simulation had a weight of 8142 kg (17950) lb including ballast load. The simulation entailed the vehicle impacting a single-slope bridge rail (modeled with rigid elements) at 51.3 mph, at an impact angle of 18°.

The SUT model was modified for this simulation by including an additional connection (via the nodal constraint option in LS-DYNA) at the front of the truck-bed to connect the truck-bed to the truck-frame, as shown in Figure 27. It could not be confirmed from the crash test report that the vehicle actually had such a constraint, however, based on the relative motion of the truck bed with respect to the truck body in the high-speed video (refer to Figures 25 and 26) it was inferred that the constraint was present.

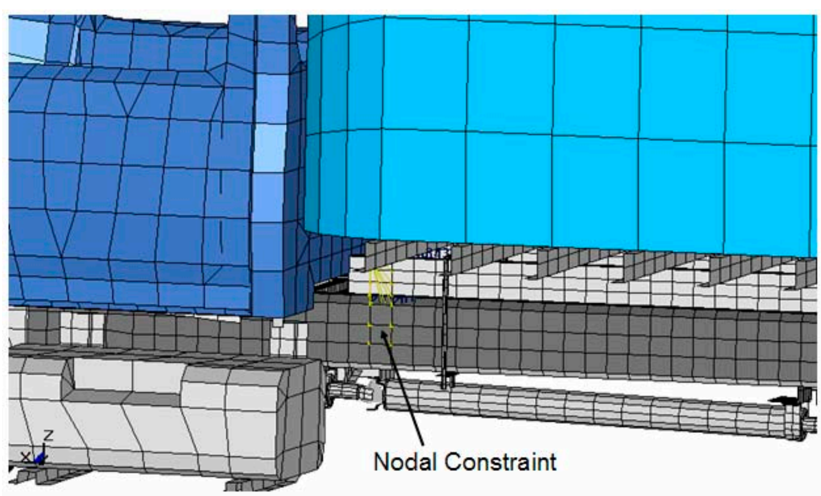


Figure 27: Nodal-rigid-body option in LS-DYNA was used to simulate an additional connection of bed-frame to truck-frame near the front of truck-bed

Qualitative and quantitative comparisons were made between the FE simulation and the full-scale crash test. A qualitative assessment was made by comparing sequential snapshots of the impact event from the results of the crash test and the simulations. A quantitative assessment was made by comparing occupant risk measures (i.e., occupant impact velocities, maximum ridedown accelerations, maximum 50-ms average accelerations and CEN values) as well as vehicle roll, pitch, yaw and acceleration data collected at the center of gravity of the vehicle. A summary of this data is provided in Table 3.

Test Description from TTI Test Report for Test 47147-17[10]

"The vehicle impacted the bridge rail 13.1 m (43.0 ft) from the upstream end at a speed of 82.5 km/h (51.3 mi/h) and an angle of 17.9 degrees. At approximately 0.032 s after impact, the right front tire began to climb the face of the bridge rail and, shortly thereafter, the front axle became partially separated from the vehicle. At 0.125 s after impact, the vehicle began to redirect significantly and, at 0.135 s, the right front edge of the bumper reached the top of the bridge rail. The box van began to roll to the right at 0.301 s, and the lower right corner and edge of the box van set down on top of the rail at 0.420 s and rode along in this fashion until the vehicle rode off the end of the bridge rail test installation. At 1.285 s, the cab and box van reached a maximum roll angle of 53 degrees. After the vehicle rode off the end of the bridge rail test installation, the front axle separated from the vehicle as the front end contacted the pavement and the rear tires of the vehicle dug into the dirt. The vehicle began to roll to the left and eventually rolled onto its left side."

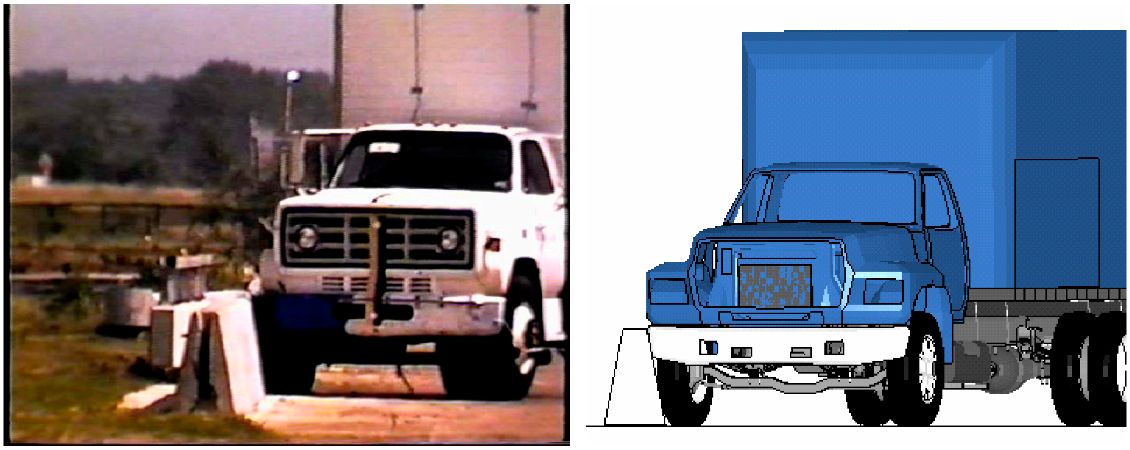
TABLE 3: Comparison of Performance Measures from F.E.A. predictions and full-scale test (measurements taken over the first 1.000 seconds of impact)

	Test	**F.E. Simulation**
Vehicle Information		
Make and Model	1985 GMC 7000	1996 Ford F800
Overall length	8.179 m	8.562 m
Total Mass	8172 kg	8142 kg
Mass Distribution		
Front wheels	3201 kg	3392 kg
Rear wheels	4971 kg	4750 kg
C.G. Height	1.245 m	1.280 m
Impact Conditions		
Speed (km/h)	82.5	82.5
Angle (deg)	17.9	18.0
Occupant Risk Values		
Impact Velocity (m/s)		
x-direction	2.9	3.2
y-direction	2.8	2.9
Max Ridedown Acceleration (g's)		
x-direction	-2.7	-3.0
y-direction	-10.2	-8.5
Max 50-ms Average Acceleration		
x-direction	-2.0	-2.2
y-direction	-5.6	-5.1
European Com. for Standardization (CEN) Values		
THIV (km/hr)	11.8	14.2
PHD (g's)	10.5	8.6
ASI	0.63	0.61
Post Impact Vehicle Behavior (deg)		
Max. roll angle	41.0	37.2
Max. pitch angle	4.3	2.9
Max. yaw angle	-18.9	-17.7

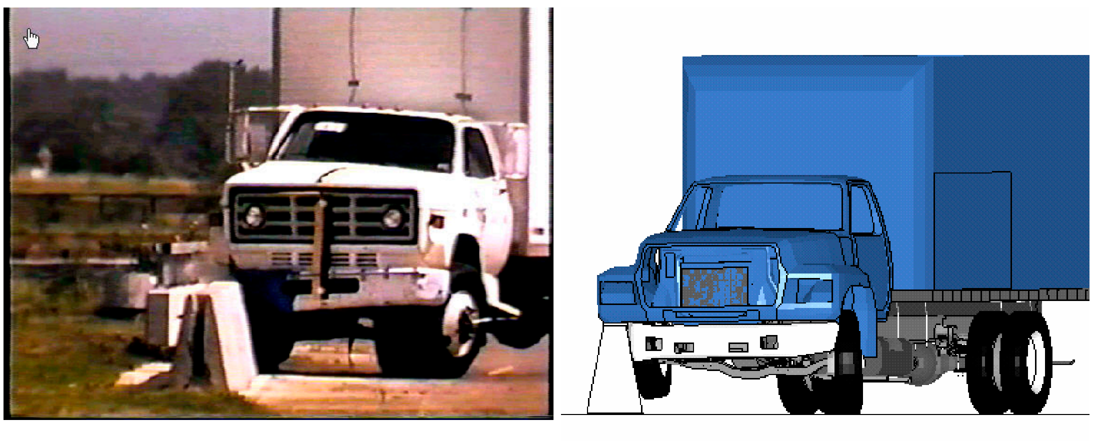
Figure 28 shows sequential snapshots from a downstream, head-on view of the impact event at specific times comparing the results of the simulation to the full-scale test. Figures 29, 30 and 31 show the roll, pitch and yaw rotations at the truck CG for the crash test and simulation. Figure 32 shows a comparison of the longitudinal acceleration-time histories from the crash test and simulation.

The FE model adequately simulated the overall dynamics of the test vehicle in test TTI 7147-17. Upon impact, the front, passenger-side wheel started to ride up the barrier and the axle was pushed back along the leaf spring. The rear of the vehicle contacted the barrier at approximately 0.3 seconds and the truck bed started to roll toward the barrier. The bed of the truck set down on top of the barrier at 0.5 seconds and continued to ride along in this fashion until approximately 1.0 second. The maximum roll of the FE model was 37.1 degrees toward the barrier, which was less than the roll angle experienced in the full-scale crash test and consequently influenced the timing of subsequent impact events. The roll angle began to decrease at approximately 0.9 seconds and started roll away from the barrier. The vehicle was continuously in contact with the barrier until it reached the end of the barrier installation at 1.5 seconds. After the vehicle separated from the barrier the front axle U-bolts failed as the front wheels contacted the ground and the vehicle continued to roll to the left (away from the barrier) and eventually rolled onto its left side.

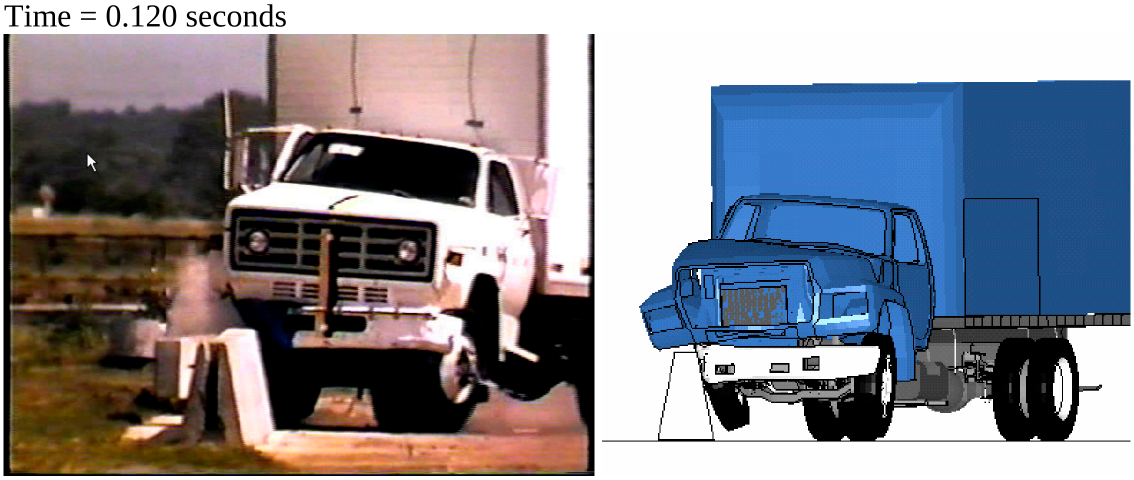
Time = 0.000 seconds



Time = 0.060 seconds



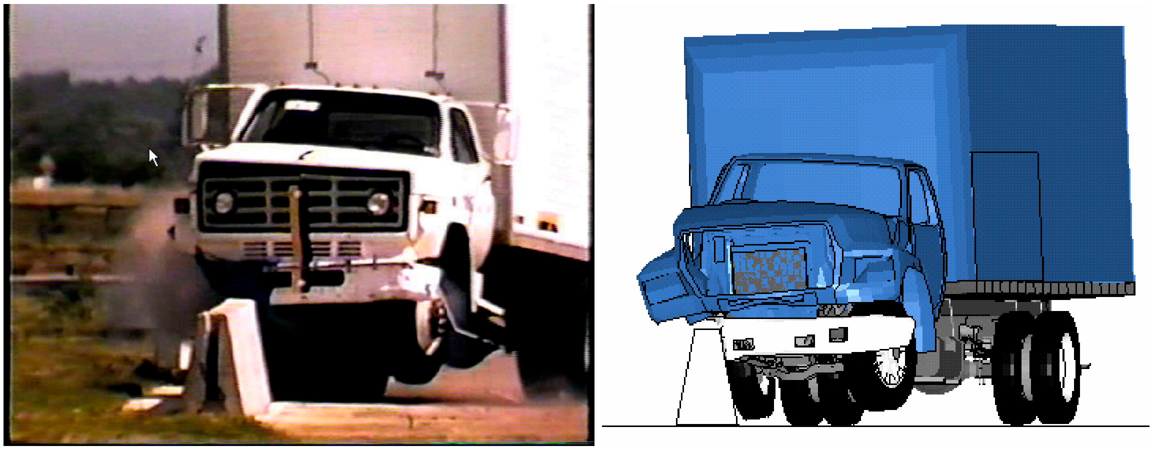
Time = 0.120 seconds



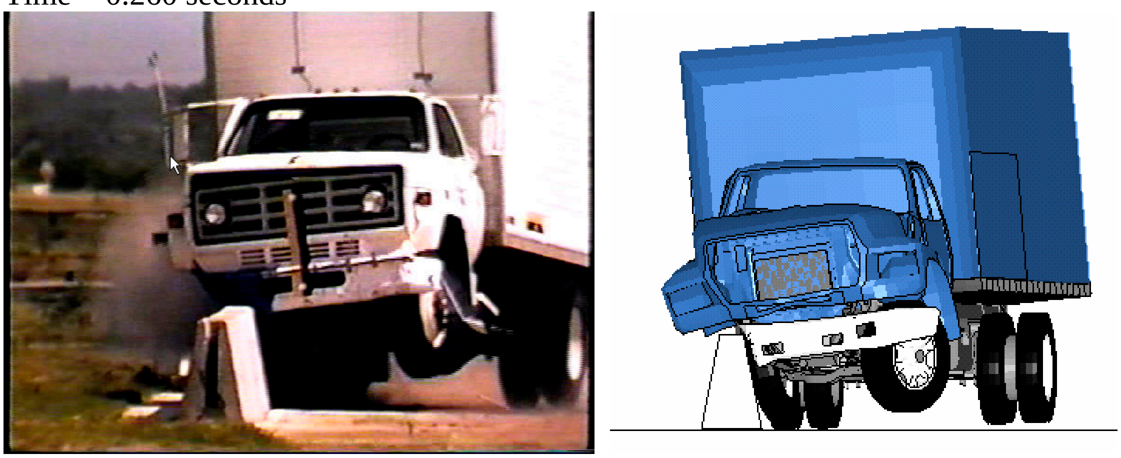
a) Test b) FE Simulation

Figure 28: Sequential snapshots of SUT impact into the concrete single-slope barrier for test (left) and FE simulation (right)

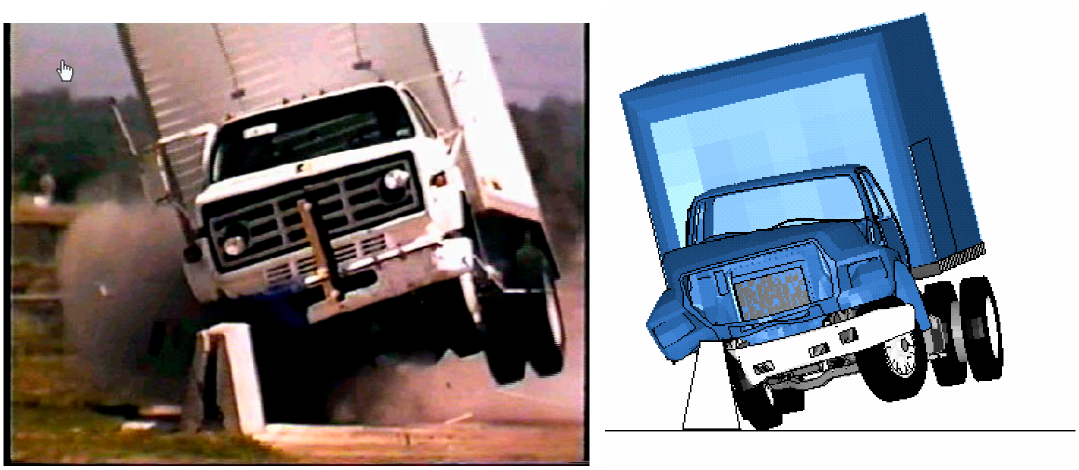
Time = 0.201 seconds



Time = 0.260 seconds



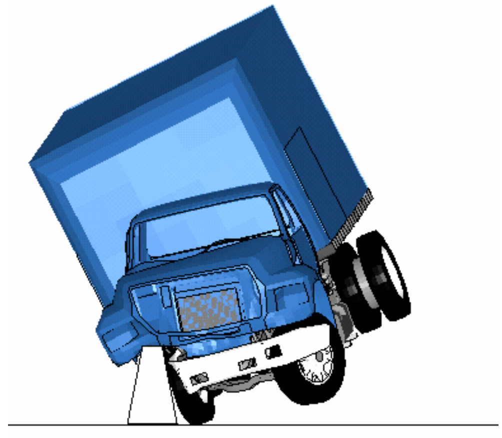
Time = 0.370 seconds



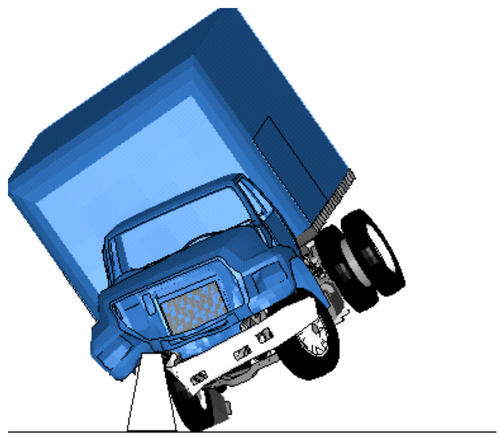
a) Test b) FE Simulation

Figure 28: CONTINUED Sequential snapshots of SUT impact into the concrete single-slope barrier for test (left) and FE simulation (right)

Time = 0.510 seconds



Time = 0.700 seconds



Time = 1.000 seconds

a) Test b) FE Simulation

Figure 28: CONTINUED Sequential snapshots of SUT impact into the concrete single-slope barrier for test (left) and FE simulation (right)

Pitch-Yaw Time History

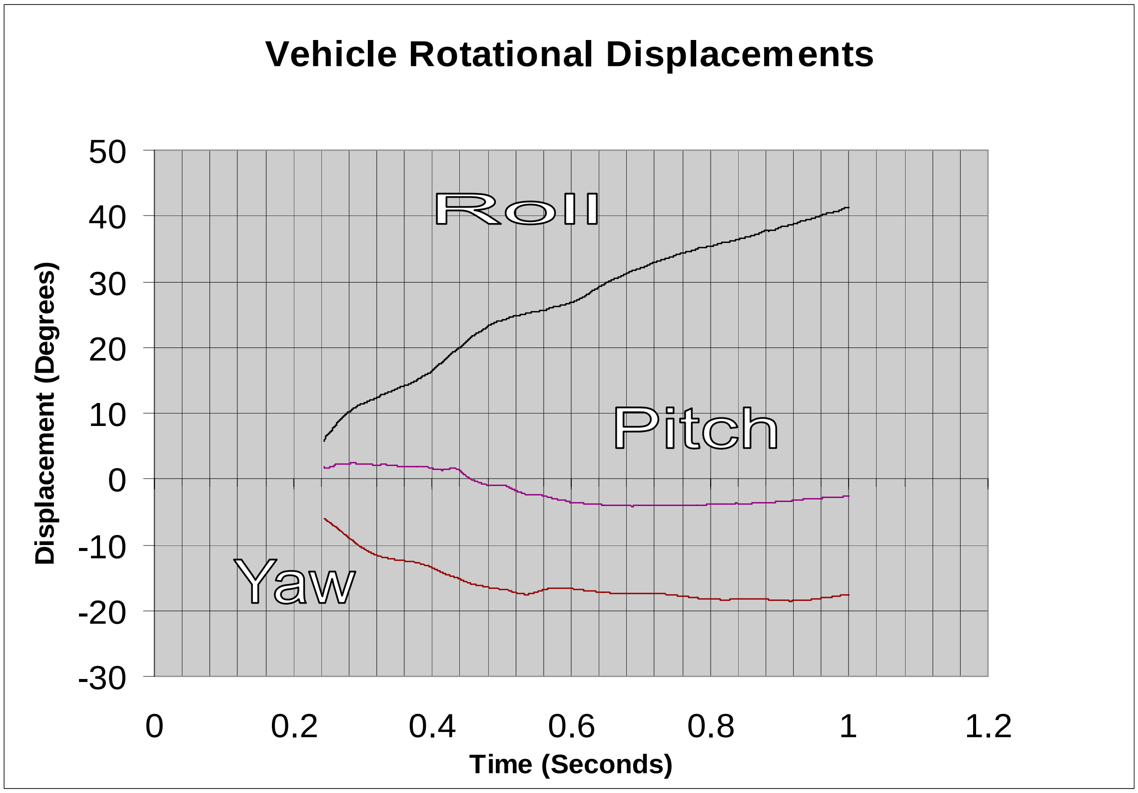


Figure 29: TTI Crash Test 7147-17 Roll-Pitch-Yaw Time History

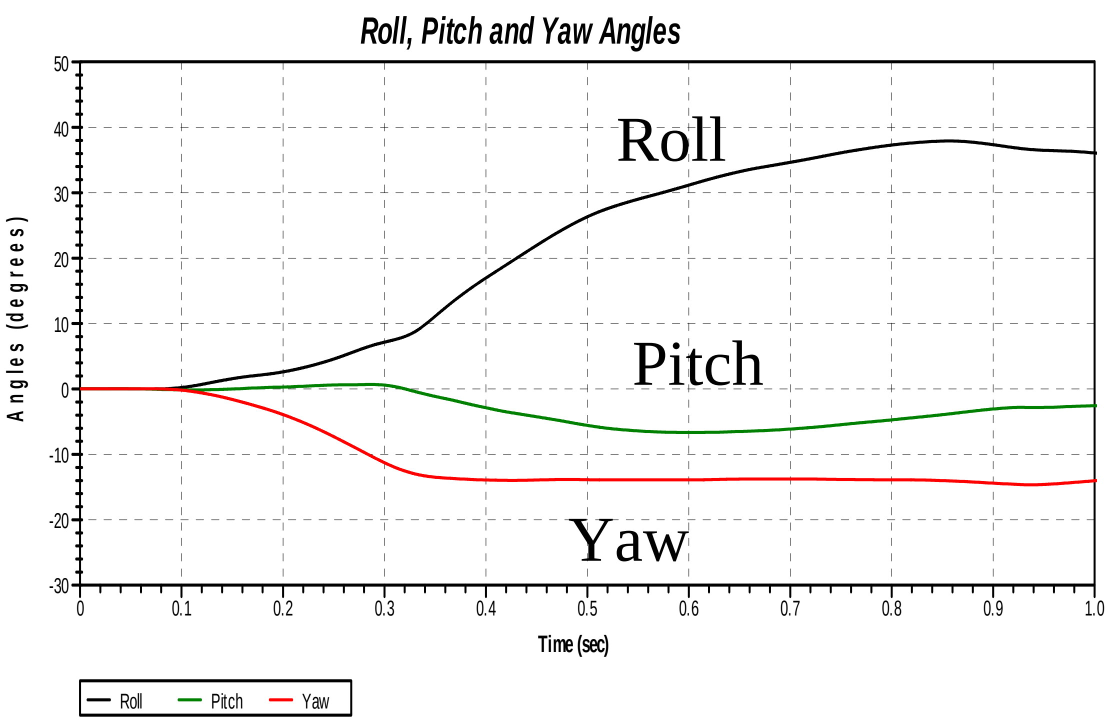


Figure 30: Roll-Pitch-Yaw Results from Enhanced SUT Model Simulation

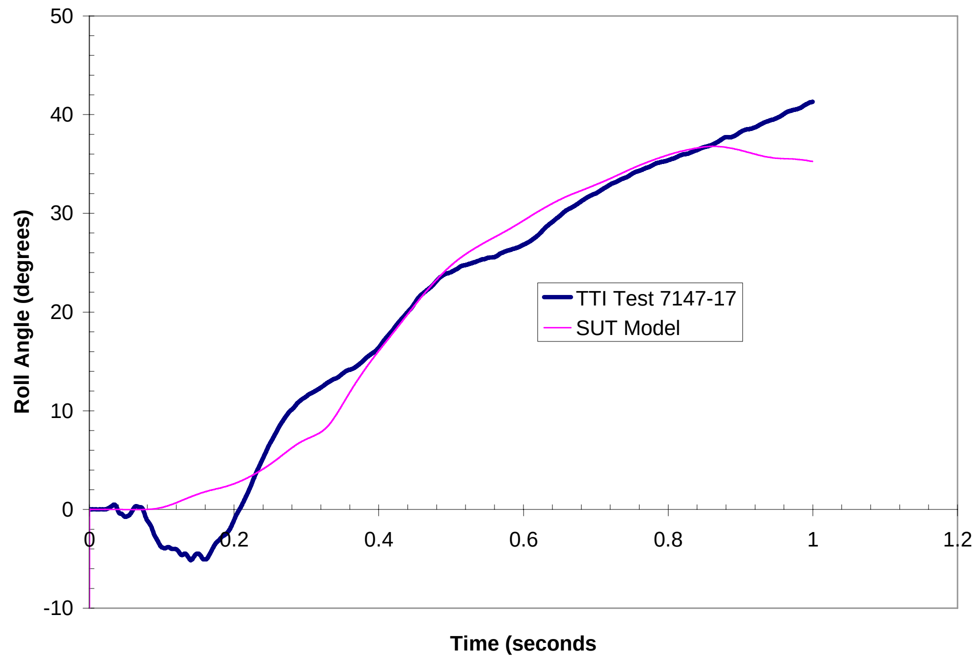


Figure 31: Comparison of Vehicle Roll-Time Histories from Test 7147-17 and F.E. Simulation Using Enhanced SUT Model

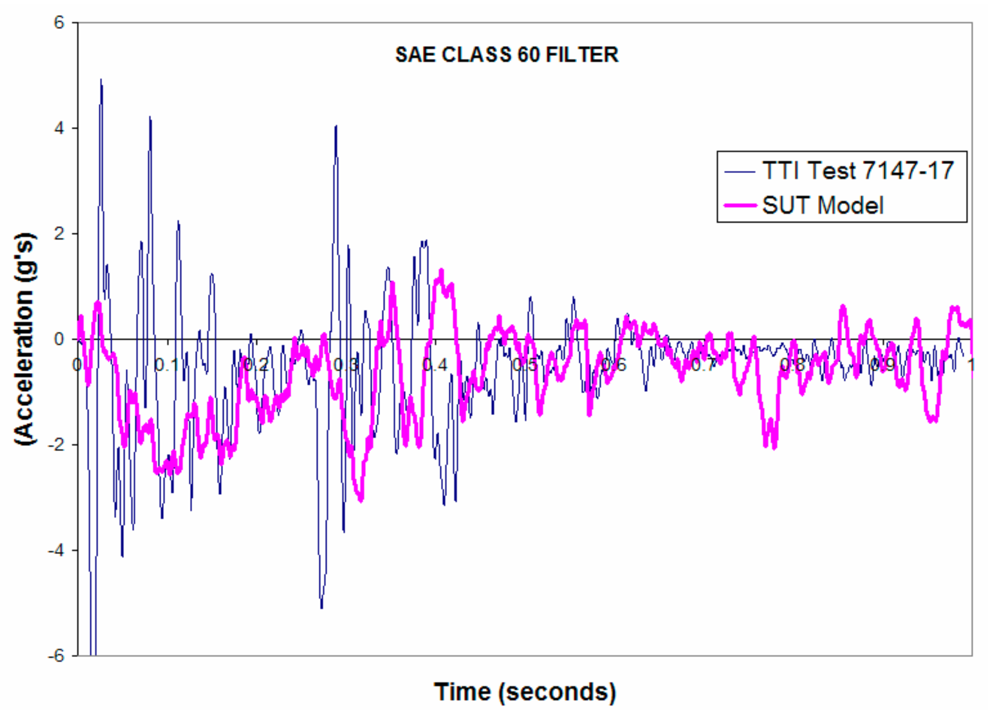


Figure 32: Comparison of Vehicle Longitudinal Acceleration-Time Histories from Test 7147-17 and F.E. Simulation Using Enhanced SUT Model

SUT MODEL DOCUMENTATION

Vehicle and roadside hardware FEM models developed by DOT and NCAC are available in public domain so that they can be modified and combined with other models. The availability of verified FEM models greatly facilitates research in the transportation field. Perhaps the biggest difficulties in adoption of the FEM models are their complexity and the respective startup time before they can be confidently used in new impact scenarios. Since the computer simulations are very tolerant to modeling errors, even the verified FEM models can be inappropriately used if they are not fully understood.

Ever increasing computing capability leads to correspondingly larger and more detailed FEM models so that the written documentation cannot efficiently convey the model's structure and development considerations and keep up with inevitable model updates. One of the objectives of this research was to introduce new internet-based technologies to the model documentation and presentation. The FEM vehicle modeling is inherently complex and three-dimensional so the ability to effectively view the model's information is very important.

To view the vehicle model, a combination of Virtual Reality Modeling Language (VRML) and Hypertext Markup Language (HTML) was used to build the Visualization Module of the documentation package. Additionally, the Visualization Module allows for easy access of other tools within the documentation package.[12] Although new languages for three-dimensional computer environments have been proposed, VRML with all its limitations is still the prevailing standard. A VRML file format is a plain text format that describes the shapes and their properties within a 3D world. This file only specifies objects and shapes within a virtual environment; it does not handle the navigation and the interaction. Moving through the world, rotating objects, and similar functions are handled through a VRML player, an application that displays the VRML file.

Other important considerations are the size of model documentation and the ability to efficiently transmit that information in today's network environment. The dynamics of computing development will inevitably lead to faster networks and better ways of model presentation, but it is reasonable to expect that they will be based on three-dimensional modes of data display. The VRML mode of interaction with the automotive crashworthiness models was also explored in Reference [13] and briefly reviewed below.[13]

Vehicle geometry is converted into a VRML file by a Perl script that sorts the parts, assigns them positions and rotations, colors them, and assigns them appropriate behaviors. Due to this automated process it is possible to quickly export new versions of the vehicle model to VRML format and post them for viewing and analyzing on the World Wide Web. A virtual control panel constantly follows the user inside the VRML world (Figure 33). The panel allows the user to select individual vehicle parts, examine their mesh makeup, move, rotate, and eventually call up an information page about the part and further cross-referencing as its participation in different contact sets, element types, etc.

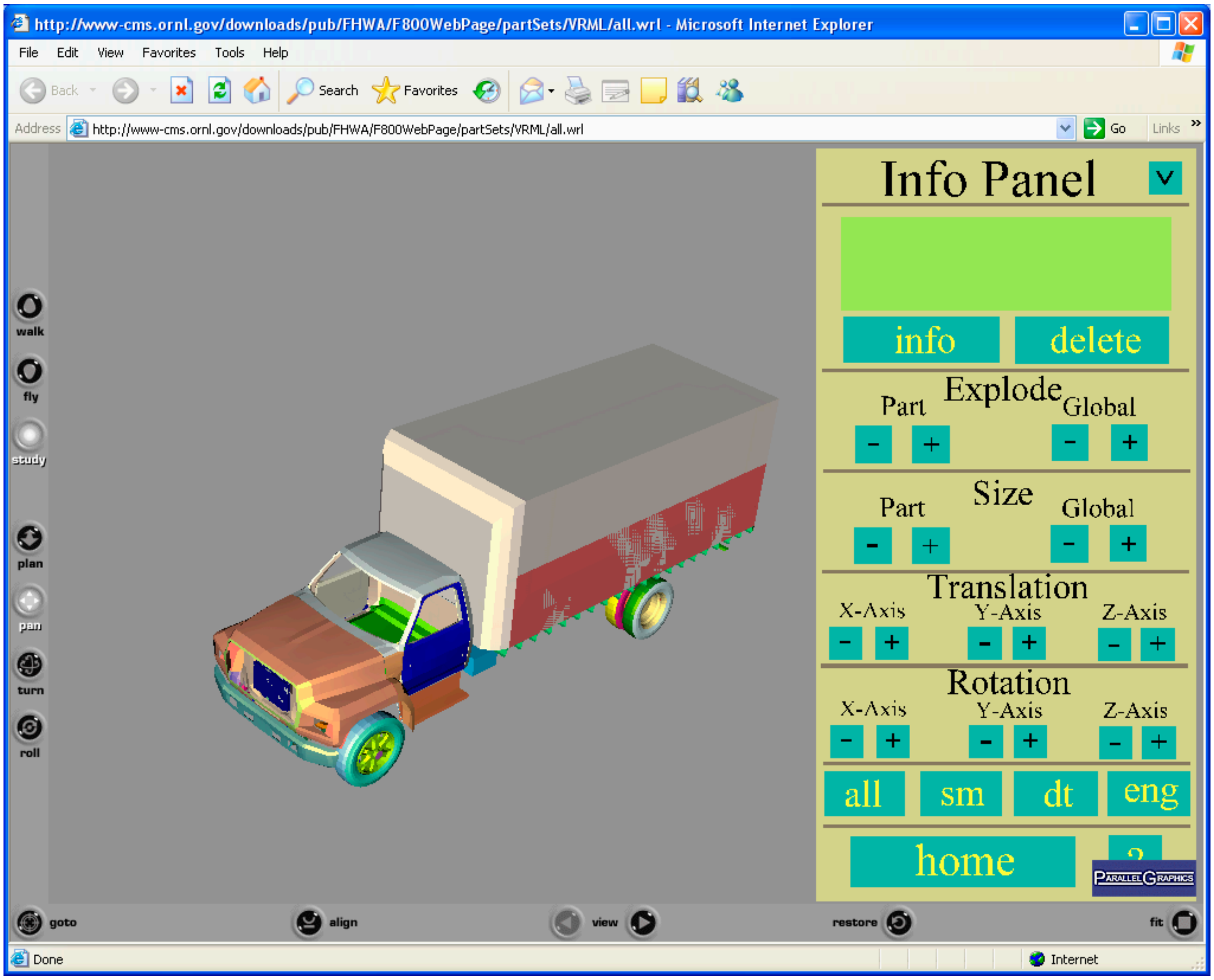


Figure 33: VRML Interface to the Documentation

The "explode" feature separates the individual parts, allowing the user to get a good idea about the interconnectivity of the vehicle (Figure 34).

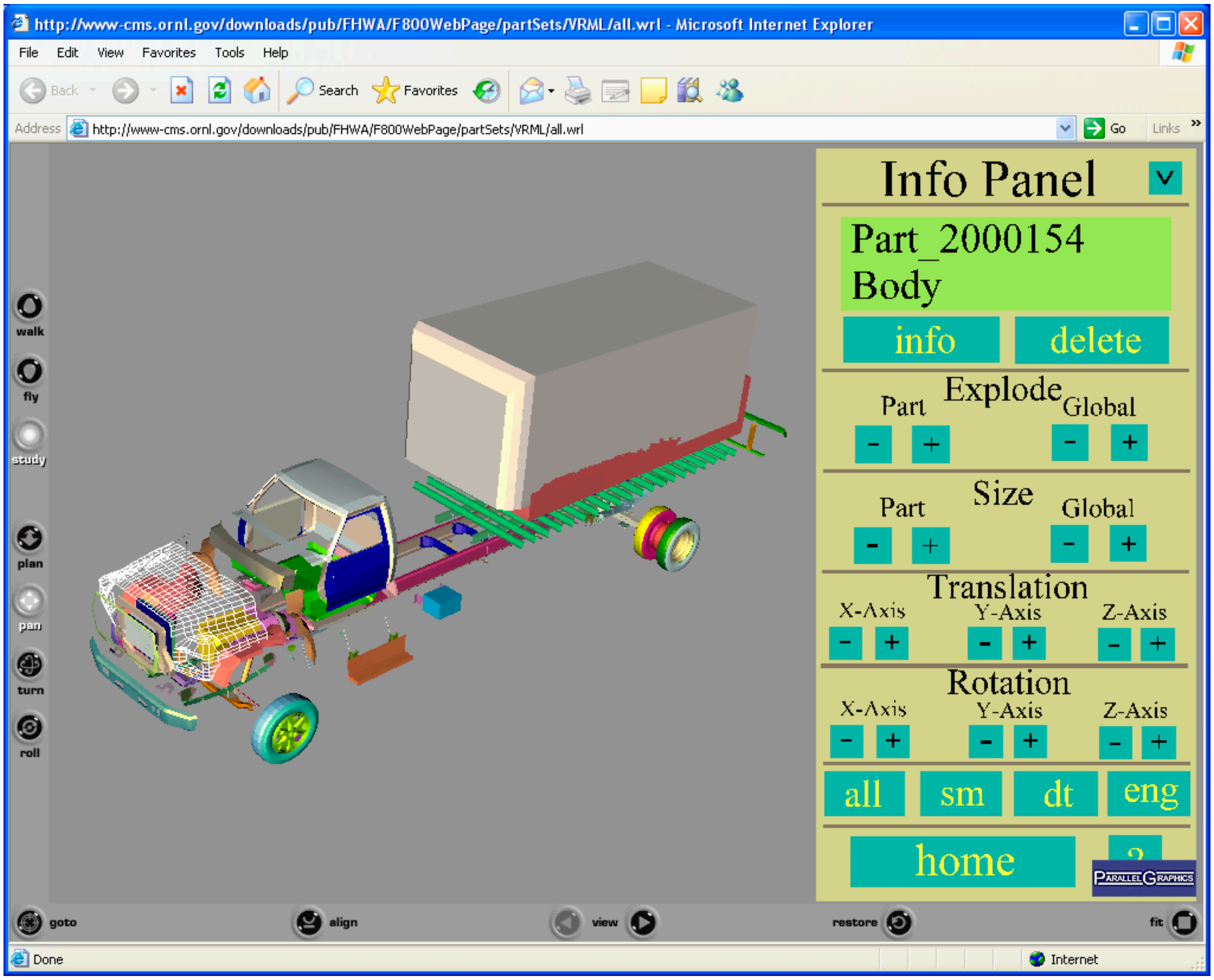


Figure 34: Exploded View with Selected Part

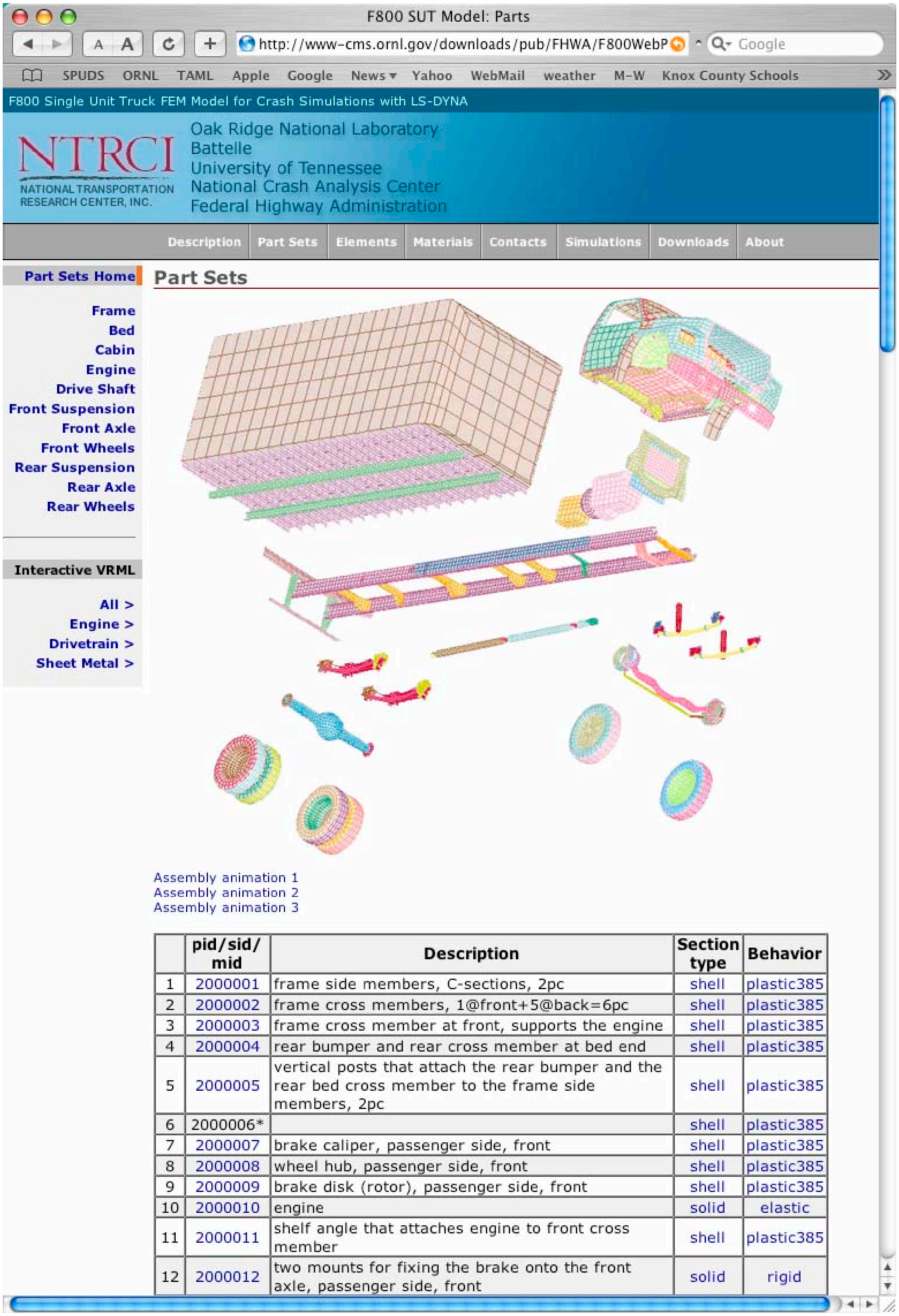
The name of the part and the subsystem it belongs to are also displayed in the control panel. By using this control panel, the user can easily navigate through the vehicle and gather information about it. The delete function allows the user to remove any parts that are obstructing the area of interest. This is a common occurrence - especially if the user wants to examine a cramped area such as the engine compartment. Additionally, the user is able to examine a part's mesh composition by selecting it. These features are easy to add, delete, or alter, due to the object-oriented design of the VRML interface.

We have organized the model documentation in 5 categories

1. Part sets (subsystems)
2. Parts
3. FEM element types
4. Material models
5. Contacts

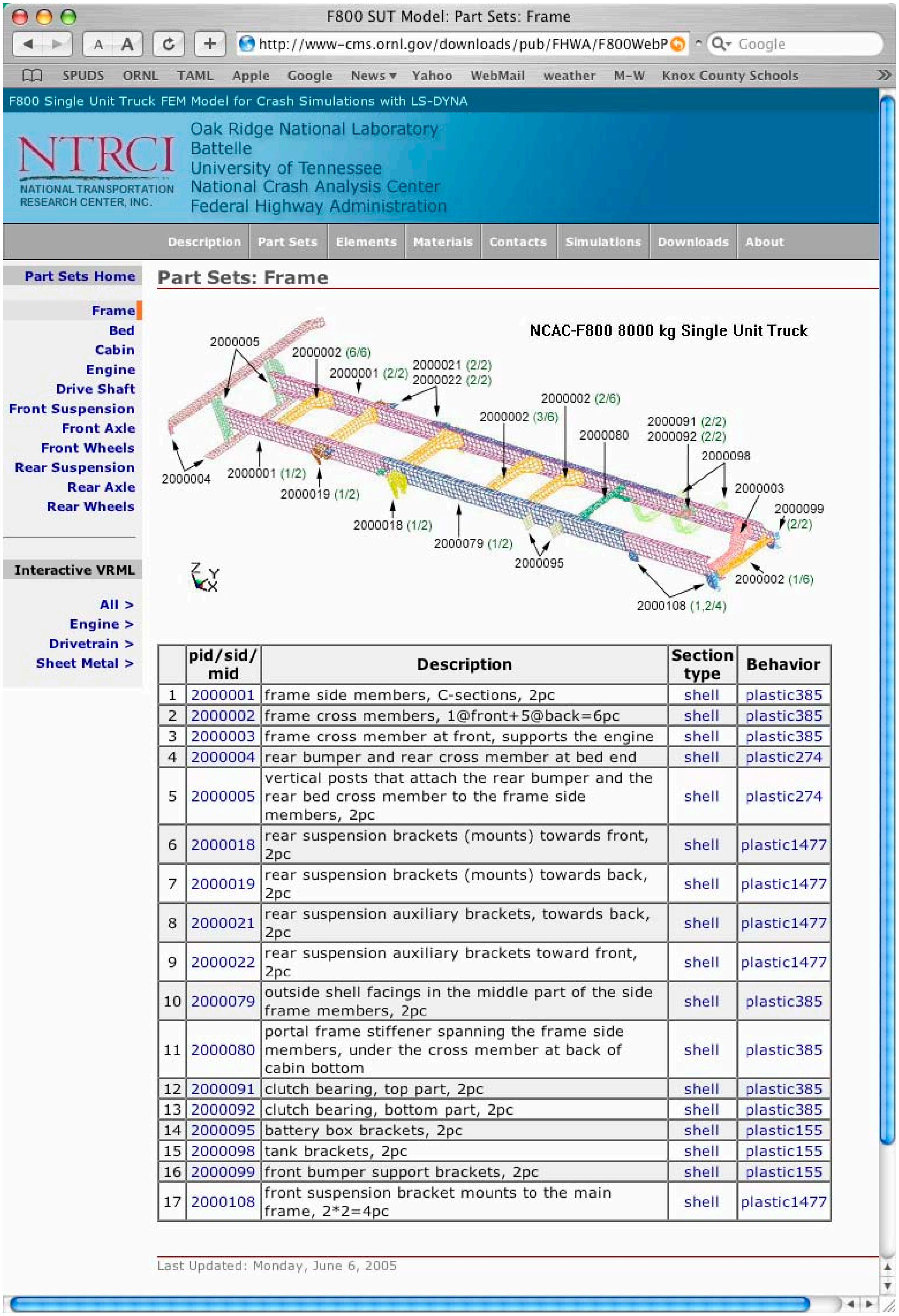
The part sets categories are selected based on their organization in SUT Service Manuals. The parts sets can be viewed in both HTML and VRML modes. The HTML documentation is programmed as the staring point due to the low data transfer requirement. As the user searches for more details, the VRML interactive environment is offered to clarify the details of spatial information. The starting HTML page for the part sub-systems is shown in Figure 35.

The user can select specific sub-system either from the graphical representation or directly from the table using the text description of the part. Selection of a sub-system leads to a more detailed graphical rendering of the parts (Figure 36) which can be further refined by selecting a specific part.



	pid/sid/mid	Description	Section type	Behavior
1	2000001	frame side members, C-sections, 2pc	shell	plastic385
2	2000002	frame cross members, 1@front+5@back=6pc	shell	plastic385
3	2000003	frame cross member at front, supports the engine	shell	plastic385
4	2000004	rear bumper and rear cross member at bed end	shell	plastic385
5	2000005	vertical posts that attach the rear bumper and the rear bed cross member to the frame side members, 2pc	shell	plastic385
6	2000006*		shell	plastic385
7	2000007	brake caliper, passenger side, front	shell	plastic385
8	2000008	wheel hub, passenger side, front	shell	plastic385
9	2000009	brake disk (rotor), passenger side, front	shell	plastic385
10	2000010	engine	solid	elastic
11	2000011	shelf angle that attaches engine to front cross member	shell	plastic385
12	2000012	two mounts for fixing the brake onto the front axle, passenger side, front	solid	rigid

Figure 35: Main part sets


F800 SUT Model: Part Sets: Frame

http://www-cms.ornl.gov/downloads/pub/FHWA/F800WebP

SPUDS ORNL TAML Apple Google News Yahoo WebMail weather M-W Knox County Schools

F800 Single Unit Truck FEM Model for Crash Simulations with LS-DYNA

NTRCI NATIONAL TRANSPORTATION RESEARCH CENTER, INC.

Oak Ridge National Laboratory
Battelle
University of Tennessee
National Crash Analysis Center
Federal Highway Administration

Description | Part Sets | Elements | Materials | Contacts | Simulations | Downloads | About

Part Sets Home

Frame
Bed
Cabin
Engine
Drive Shaft
Front Suspension
Front Axle
Front Wheels
Rear Suspension
Rear Axle
Rear Wheels

Interactive VRML

All >
Engine >
Drivetrain >
Sheet Metal >

Part Sets: Frame

	pid/sid/ mid	Description	Section type	Behavior
1	2000001	frame side members, C-sections, 2pc	shell	plastic385
2	2000002	frame cross members, 1@front+5@back=6pc	shell	plastic385
3	2000003	frame cross member at front, supports the engine	shell	plastic385
4	2000004	rear bumper and rear cross member at bed end	shell	plastic274
5	2000005	vertical posts that attach the rear bumper and the rear bed cross member to the frame side members, 2pc	shell	plastic274
6	2000018	rear suspension brackets (mounts) towards front, 2pc	shell	plastic1477
7	2000019	rear suspension brackets (mounts) towards back, 2pc	shell	plastic1477
8	2000021	rear suspension auxiliary brackets, towards back, 2pc	shell	plastic1477
9	2000022	rear suspension auxiliary brackets toward front, 2pc	shell	plastic1477
10	2000079	outside shell facings in the middle part of the side frame members, 2pc	shell	plastic385
11	2000080	portal frame stiffener spanning the frame side members, under the cross member at back of cabin bottom	shell	plastic385
12	2000091	clutch bearing, top part, 2pc	shell	plastic385
13	2000092	clutch bearing, bottom part, 2pc	shell	plastic385
14	2000095	battery box brackets, 2pc	shell	plastic155
15	2000098	tank brackets, 2pc	shell	plastic155
16	2000099	front bumper support brackets, 2pc	shell	plastic155
17	2000108	front suspension bracket mounts to the main frame, 2*2=4pc	shell	plastic1477

Last Updated: Monday, June 6, 2005

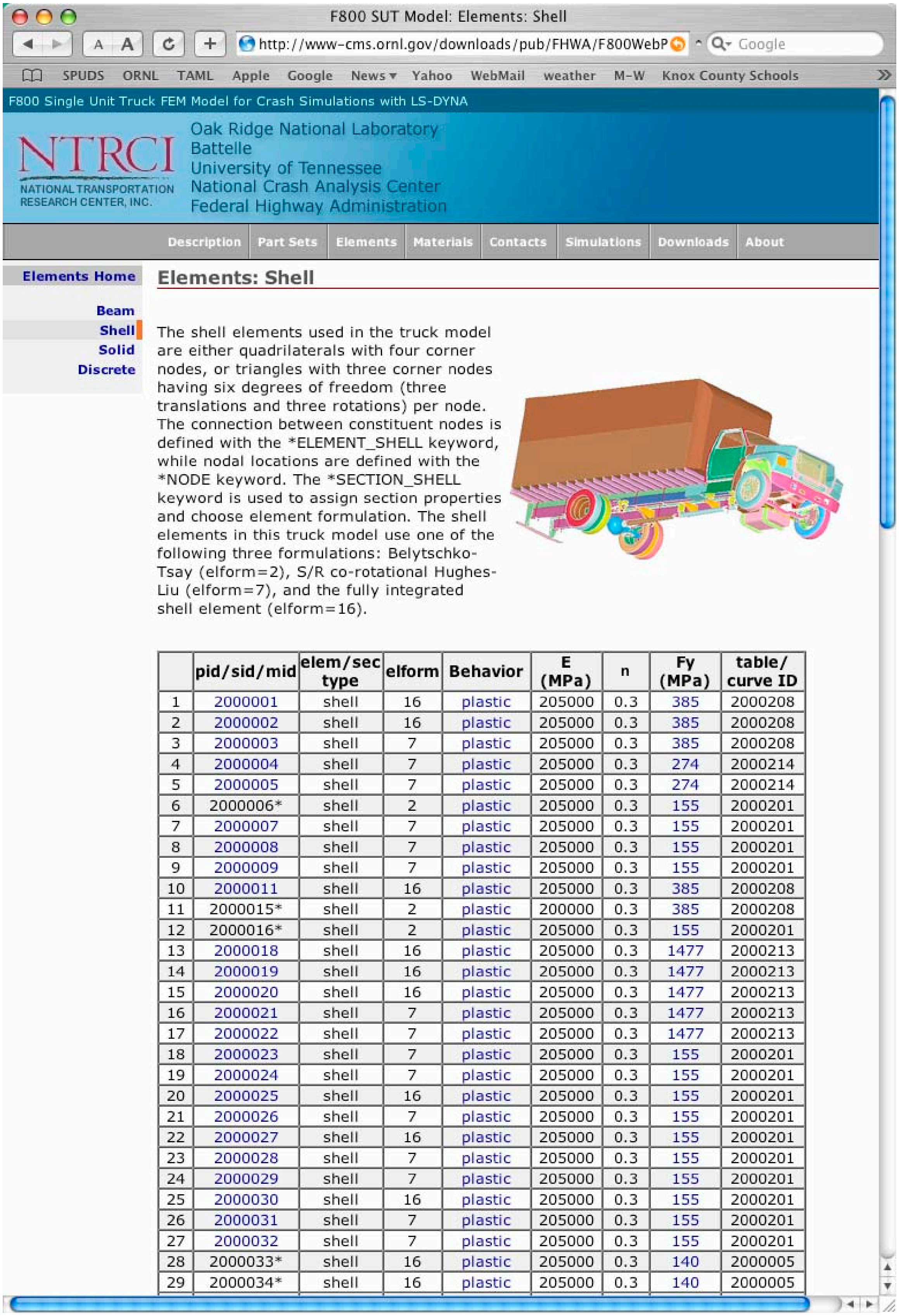
Figure 36: Frame sub-sytem

The documentation can be also viewed for the FEM element type perspective. The starting page for the shell element formulation is shown in Figure 37. A user can further follow the links to specific parts modeled using the shell element formulations. Hyperlinks are provided to describe the type and material models used for the parts. The documentation is also organized by material formulations used in the model. Figure 38 shows the starting material model interface for the documentation.

From there, users can select specific material formulations to obtain a list of all the parts modeled with that material definition as well as to visualize details regarding properties defined for that specific material type. For example, Figure 39 shows a list of all the model parts that use HSLA350 steel and detailed information of material properties and stress-strain behavior that are used to characterize the material.

Information about contact definitions is provided using the HTML contact interface. The information can also be found by looking at the part data which list all the contact surfaces it participates in. Figure 40 shows HTML contact interface for a particular type of contact surface definition.

Further information about the contact surface can be found by following the provided links, as shown in Figure 41. The contact surface data can be viewed in different VRML configurations, or further investigated by analyzing individual parts participating in the contact surface.



F800 SUT Model: Elements: Shell

F800 Single Unit Truck FEM Model for Crash Simulations with LS-DYNA

NTRCI NATIONAL TRANSPORTATION RESEARCH CENTER, INC.

Oak Ridge National Laboratory
Battelle
University of Tennessee
National Crash Analysis Center
Federal Highway Administration

Description | Part Sets | Elements | Materials | Contacts | Simulations | Downloads | About

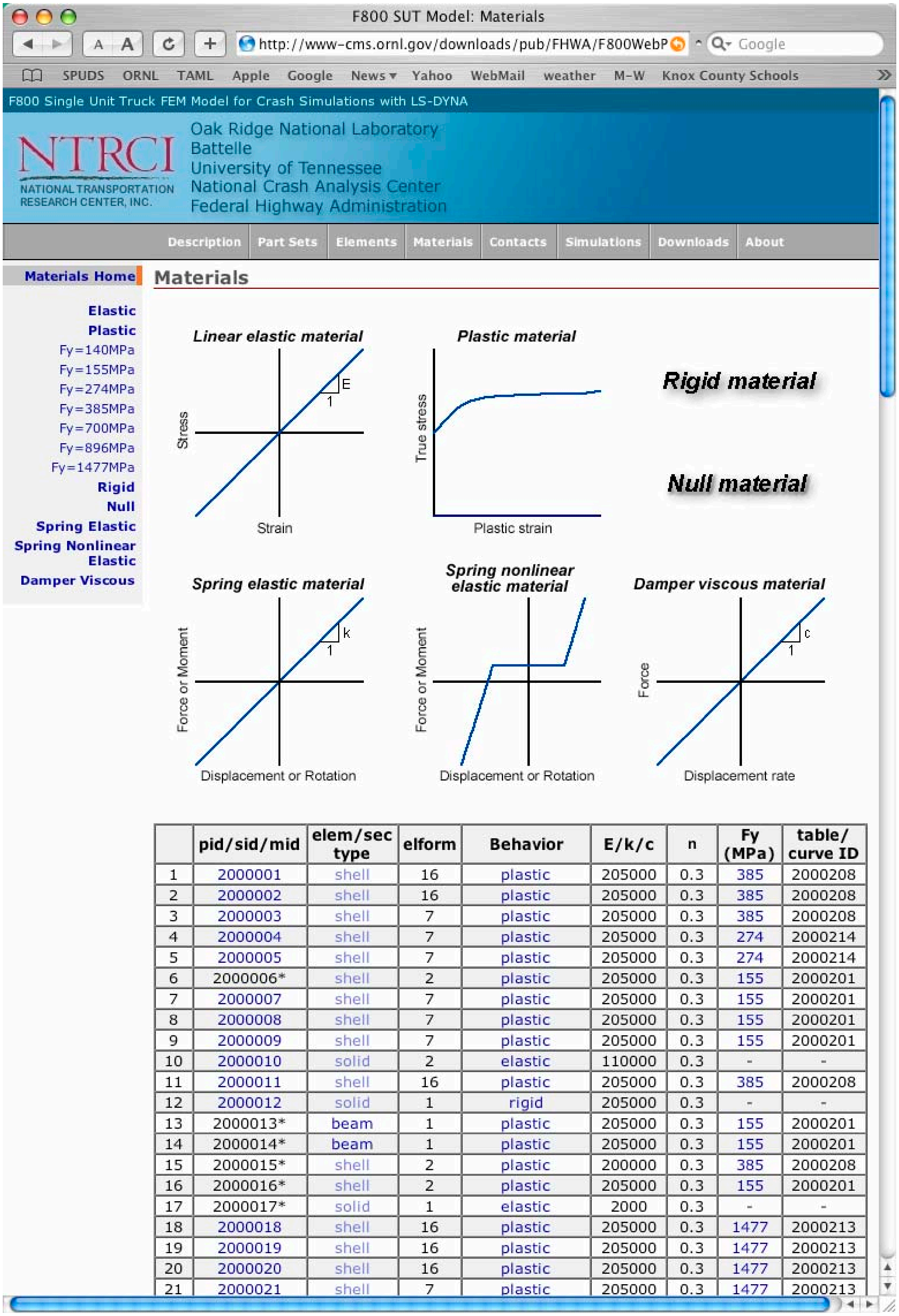
Elements Home
Beam
Shell
Solid
Discrete

Elements: Shell

The shell elements used in the truck model are either quadrilaterals with four corner nodes, or triangles with three corner nodes having six degrees of freedom (three translations and three rotations) per node. The connection between constituent nodes is defined with the *ELEMENT_SHELL keyword, while nodal locations are defined with the *NODE keyword. The *SECTION_SHELL keyword is used to assign section properties and choose element formulation. The shell elements in this truck model use one of the following three formulations: Belytschko-Tsay (elform=2), S/R co-rotational Hughes-Liu (elform=7), and the fully integrated shell element (elform=16).

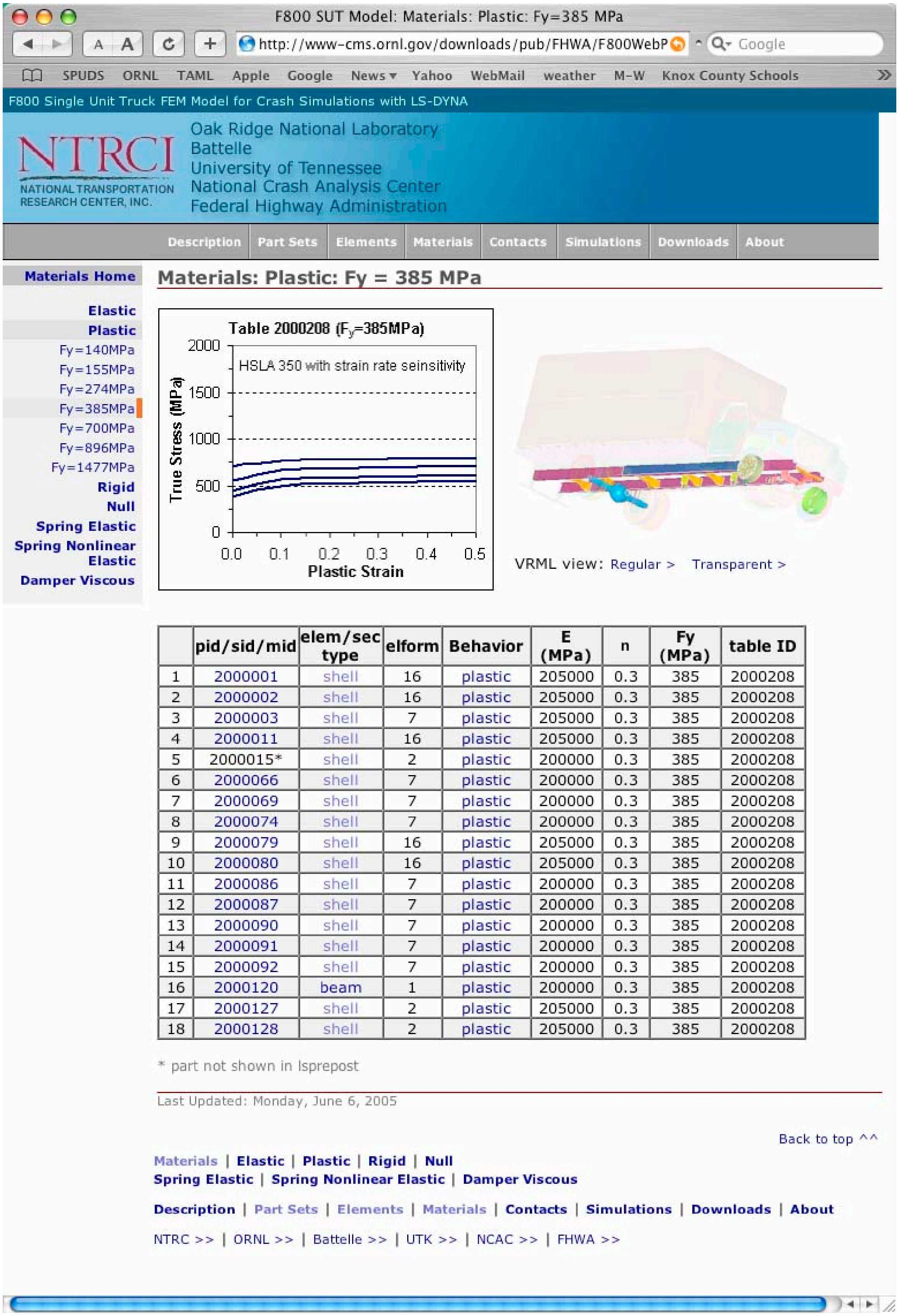
	pid/sid/mid	elem/sec type	elform	Behavior	E (MPa)	n	Fy (MPa)	table/ curve ID
1	2000001	shell	16	plastic	205000	0.3	385	2000208
2	2000002	shell	16	plastic	205000	0.3	385	2000208
3	2000003	shell	7	plastic	205000	0.3	385	2000208
4	2000004	shell	7	plastic	205000	0.3	274	2000214
5	2000005	shell	7	plastic	205000	0.3	274	2000214
6	2000006*	shell	2	plastic	205000	0.3	155	2000201
7	2000007	shell	7	plastic	205000	0.3	155	2000201
8	2000008	shell	7	plastic	205000	0.3	155	2000201
9	2000009	shell	7	plastic	205000	0.3	155	2000201
10	2000011	shell	16	plastic	205000	0.3	385	2000208
11	2000015*	shell	2	plastic	200000	0.3	385	2000208
12	2000016*	shell	2	plastic	205000	0.3	155	2000201
13	2000018	shell	16	plastic	205000	0.3	1477	2000213
14	2000019	shell	16	plastic	205000	0.3	1477	2000213
15	2000020	shell	16	plastic	205000	0.3	1477	2000213
16	2000021	shell	7	plastic	205000	0.3	1477	2000213
17	2000022	shell	7	plastic	205000	0.3	1477	2000213
18	2000023	shell	7	plastic	205000	0.3	155	2000201
19	2000024	shell	7	plastic	205000	0.3	155	2000201
20	2000025	shell	16	plastic	205000	0.3	155	2000201
21	2000026	shell	7	plastic	205000	0.3	155	2000201
22	2000027	shell	16	plastic	205000	0.3	155	2000201
23	2000028	shell	7	plastic	205000	0.3	155	2000201
24	2000029	shell	7	plastic	205000	0.3	155	2000201
25	2000030	shell	16	plastic	205000	0.3	155	2000201
26	2000031	shell	7	plastic	205000	0.3	155	2000201
27	2000032	shell	7	plastic	205000	0.3	155	2000201
28	2000033*	shell	16	plastic	205000	0.3	140	2000005
29	2000034*	shell	16	plastic	205000	0.3	140	2000005

Figure 37: Shell element interface



	pid/sid/mid	elem/sec type	elform	Behavior	E/k/c	n	Fy (MPa)	table/ curve ID
1	2000001	shell	16	plastic	205000	0.3	385	2000208
2	2000002	shell	16	plastic	205000	0.3	385	2000208
3	2000003	shell	7	plastic	205000	0.3	385	2000208
4	2000004	shell	7	plastic	205000	0.3	274	2000214
5	2000005	shell	7	plastic	205000	0.3	274	2000214
6	2000006*	shell	2	plastic	205000	0.3	155	2000201
7	2000007	shell	7	plastic	205000	0.3	155	2000201
8	2000008	shell	7	plastic	205000	0.3	155	2000201
9	2000009	shell	7	plastic	205000	0.3	155	2000201
10	2000010	solid	2	elastic	110000	0.3	-	-
11	2000011	shell	16	plastic	205000	0.3	385	2000208
12	2000012	solid	1	rigid	205000	0.3	-	-
13	2000013*	beam	1	plastic	205000	0.3	155	2000201
14	2000014*	beam	1	plastic	205000	0.3	155	2000201
15	2000015*	shell	2	plastic	200000	0.3	385	2000208
16	2000016*	shell	2	plastic	205000	0.3	155	2000201
17	2000017*	solid	1	elastic	2000	0.3	-	-
18	2000018	shell	16	plastic	205000	0.3	1477	2000213
19	2000019	shell	16	plastic	205000	0.3	1477	2000213
20	2000020	shell	16	plastic	205000	0.3	1477	2000213
21	2000021	shell	7	plastic	205000	0.3	1477	2000213

Figure 38: Material model interface



F800 SUT Model: Materials: Plastic: Fy=385 MPa

http://www-cms.ornl.gov/downloads/pub/FHWA/F800WebP

SPUDS ORNL TAML Apple Google News Yahoo WebMail weather M-W Knox County Schools

F800 Single Unit Truck FEM Model for Crash Simulations with LS-DYNA

NTRCI NATIONAL TRANSPORTATION RESEARCH CENTER, INC.

Oak Ridge National Laboratory
Battelle
University of Tennessee
National Crash Analysis Center
Federal Highway Administration

Description | Part Sets | Elements | Materials | Contacts | Simulations | Downloads | About

Materials Home
Elastic
Plastic
Fy=140MPa
Fy=155MPa
Fy=274MPa
Fy=385MPa
Fy=700MPa
Fy=896MPa
Fy=1477MPa
Rigid
Null
Spring Elastic
Spring Nonlinear Elastic
Damper Viscous

Materials: Plastic: Fy = 385 MPa

VRML view: Regular > Transparent >

	pid/sid/mid	elem/sec type	elform	Behavior	E (MPa)	n	Fy (MPa)	table ID
1	2000001	shell	16	plastic	205000	0.3	385	2000208
2	2000002	shell	16	plastic	205000	0.3	385	2000208
3	2000003	shell	7	plastic	205000	0.3	385	2000208
4	2000011	shell	16	plastic	205000	0.3	385	2000208
5	2000015*	shell	2	plastic	200000	0.3	385	2000208
6	2000066	shell	7	plastic	200000	0.3	385	2000208
7	2000069	shell	7	plastic	200000	0.3	385	2000208
8	2000074	shell	7	plastic	200000	0.3	385	2000208
9	2000079	shell	16	plastic	205000	0.3	385	2000208
10	2000080	shell	16	plastic	205000	0.3	385	2000208
11	2000086	shell	7	plastic	200000	0.3	385	2000208
12	2000087	shell	7	plastic	200000	0.3	385	2000208
13	2000090	shell	7	plastic	200000	0.3	385	2000208
14	2000091	shell	7	plastic	200000	0.3	385	2000208
15	2000092	shell	7	plastic	200000	0.3	385	2000208
16	2000120	beam	1	plastic	200000	0.3	385	2000208
17	2000127	shell	2	plastic	205000	0.3	385	2000208
18	2000128	shell	2	plastic	205000	0.3	385	2000208

* part not shown in lsprepost

Last Updated: Monday, June 6, 2005

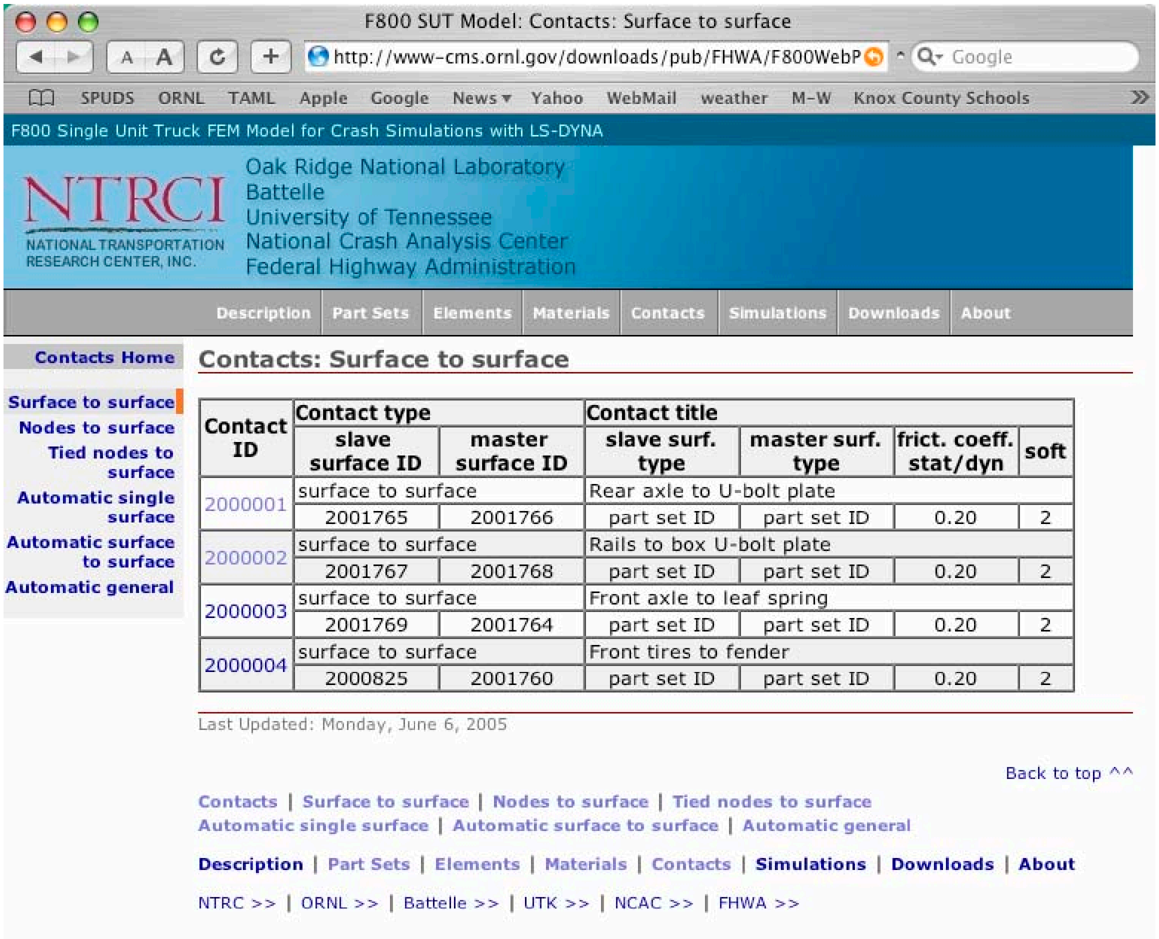
Back to top ^^

Materials | Elastic | Plastic | Rigid | Null
Spring Elastic | Spring Nonlinear Elastic | Damper Viscous

Description | Part Sets | Elements | Materials | Contacts | Simulations | Downloads | About

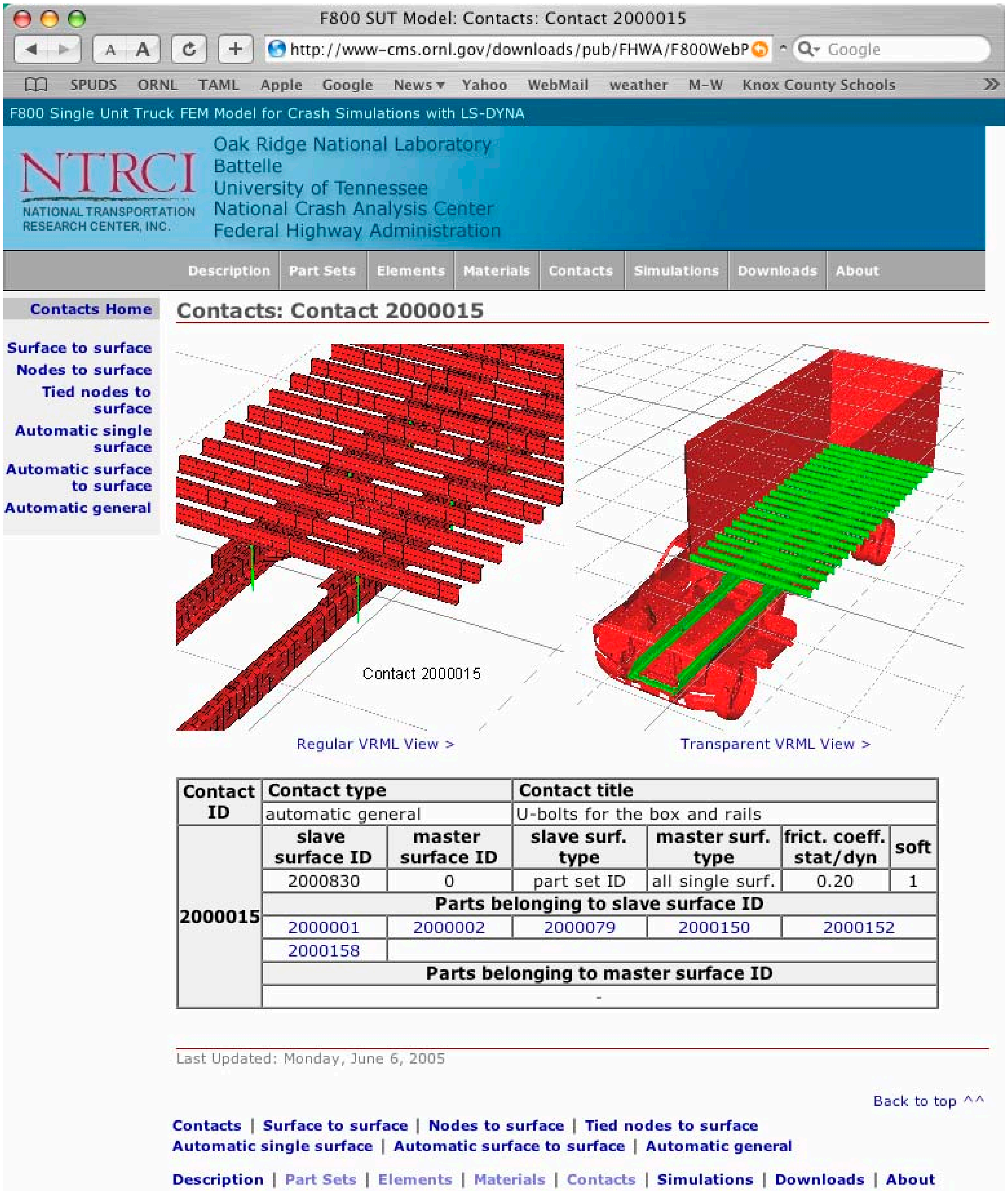
NTRC >> | ORNL >> | Battelle >> | UTK >> | NCAC >> | FHWA >>

Figure 39: HSLA350 material



Contact ID	Contact type		Contact title			
	slave surface ID	master surface ID	slave surf. type	master surf. type	frict. coeff. stat/dyn	soft
2000001	surface to surface		Rear axle to U-bolt plate			
	2001765	2001766	part set ID	part set ID	0.20	2
2000002	surface to surface		Rails to box U-bolt plate			
	2001767	2001768	part set ID	part set ID	0.20	2
2000003	surface to surface		Front axle to leaf spring			
	2001769	2001764	part set ID	part set ID	0.20	2
2000004	surface to surface		Front tires to fender			
	2000825	2001760	part set ID	part set ID	0.20	2

Figure 40: Interface for Surface-to-surface contact formulation



F800 SUT Model: Contacts: Contact 2000015

http://www-cms.ornl.gov/downloads/pub/FHWA/F800WebP

SPUDS ORNL TAML Apple Google News Yahoo WebMail weather M-W Knox County Schools

F800 Single Unit Truck FEM Model for Crash Simulations with LS-DYNA

NTRCI NATIONAL TRANSPORTATION RESEARCH CENTER, INC.

Oak Ridge National Laboratory
Battelle
University of Tennessee
National Crash Analysis Center
Federal Highway Administration

Description | Part Sets | Elements | Materials | Contacts | Simulations | Downloads | About

Contacts Home

Surface to surface
Nodes to surface
Tied nodes to surface
Automatic single surface
Automatic surface to surface
Automatic general

Contacts: Contact 2000015

Regular VRML View >

Transparent VRML View >

Contact ID	Contact type		Contact title			
	automatic general		U-bolts for the box and rails			
2000015	slave surface ID	master surface ID	slave surf. type	master surf. type	frict. coeff. stat/dyn	soft
	2000830	0	part set ID	all single surf.	0.20	1
	Parts belonging to slave surface ID					
	2000001	2000002	2000079	2000150	2000152	
	2000158					
	Parts belonging to master surface ID					
	-					

Last Updated: Monday, June 6, 2005

Back to top ^^

Contacts | Surface to surface | Nodes to surface | Tied nodes to surface
Automatic single surface | Automatic surface to surface | Automatic general

Description | Part Sets | Elements | Materials | Contacts | Simulations | Downloads | About

Figure 41: Contact surface 2000015

CONCLUSIONS

The enhanced NCAC Finite Element Model of the Ford F800 single-unit truck is an good starting point for the 18,000 lb single-unit truck model for researchers and designers of roadside safety devices. With the modifications and enhancements outlined in Table 2, the F800 model was upgraded to a significantly higher degree of fidelity for all users. These upgrades and enhancements are assumed to be relevant to the requirements of most analytical models, however, model users are ultimately responsible for the accuracy of their results.

The model has not been validated for impact cases other than those identified in this report. If impact conditions vary significantly from these cases, the analyst should critically and carefully assess model results to verify its validity. The role of this model as a bullet vehicle for analysis of safety hardware was adhered to when making the modifications to enhance its fidelity so that the efficiency of the model was maintained.

The modeling of three-dimensional vehicles is inherently complex so the ability to effectively view the model's information is very important. An interactive, web-based User's Manual of the SUT FE model was developed to facilitate use of the model. To view the vehicle model, a combination of Virtual Reality Modeling Language (VRML) and Hypertext Markup Language (HTML) was used to build the Visualization Module of the documentation package. Additionally, the Visualization Module allows for easy access of other tools within the documentation package. The interactive web-based user's manual is available online at: http://www-cms.ornl.gov/downloads/pub/FHWA/F800WebPage/description/.

This website documents the model and allows the user to visualize the main components of the model, including mechanical and material properties, detailed information regarding connections between components, and detailed contact information used in defining interaction between the various parts. The goal of the interactive 3D environment is to make the model more accessible to the end users and to facilitate transfer of the developed models and technologies to the end users.

ACKNOWLEDGMENTS

Use of the supercomputers at the ORNL Center for Computational Sciences (CCS) is gratefully acknowledged.

Our thanks to Roger Bligh of the Texas Transportation Institute for his generous contribution of the experimental test data that was essential to this study

REFERENCES

1. http://www.ncac.gwu.edu/archives/model.index.html, National Crashworthiness Analysis Center model archive, 2003.
2. Hallquist, J.O., LS-DYNA Keyword User's Manual, Version 970, Livermore, California, 2003.
3. Heavy Vehicle Safety Research, Quarterly Report July-September 2003, Battelle, Columbus, OH, 2003.
4. 1996 F & B 700, 800, 900, Body Chassis, Service Manual, Ford Motor Co., 1995
5. 1996 F & B 700, 800, 900, Powertrain/Drivetrain, Service Manual, Ford Motor Co., 1995
6. Constitution and Properties of Steel, vol. ed. Pickering, F.B., Materials Science and Technology, Vol. 7, VCH, New York, 1992.
7. Simunovic, S, Shaw, J. Aramayo, G., "Material Modeling Effects on Impact Deformation of Ultralight Steel Auto Body," SAE Paper 2000-01-2715, 2000.
8. SAE J429 Mechanical and Material Requirements for Externally Threaded Fasteners, Society of Automotive Engineers, 1998.
9. ASTM A490M Standard Specification for High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints [Metric], ASTM International, 2003.
10. Mak, King K., Menges, Wanda L., Testing of State Roadside Safety Systems Volume VIII: Appendix G – Crash Testing and Evaluation of the Single Slope Bridge Rail, Report No. FHWA-RD-98-043, Texas Transportation Institute, College Station, Texas, February 1998.
11. Buth, E., Hirsch, T.J. and Menges, W.L., "Testing of New Bridge Rail and Transition Designs," Report No. FHWA-RD-93-063, Texas Transportation Institute, College Station, Texas, February 1997.
12. VRML97 Functional specification and VRML97 External Authoring Interface (EAI) International Standard ISO/IEC 14772-1:1997 and ISO/IEC 14772-2:2002 ISO/IEC 14772-1:1997 and ISO/IEC 14772-2:2002
13. Bobrek, A., Simunovic, S., Aramayo, G., Collaborative Toolkit for Crashworthiness Research HICSS-34, Minitrack on Developing and Deploying Collaborative Problem Solving Environments 2001.