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Development of a Detailed Nonlinear Finite Element Analysis Model of Colliding Trains

SUMMARY

A simulation model of a train-to-train collision has been developed using explicit/dynamic finite element analysis (FEA), as shown in Figure 1. The ABAQUS/Explicit dynamic finite element code was used. In comparison to other vehicle collision studies, this study is the first in which the interactions of colliding passenger rail equipment have been modeled using detailed FEA. Such simulation models provide several benefits. It increases the capability for vehicle crush modeling to include vehicle-to-vehicle interactions. It also provides a platform for studying the effect of trailing vehicles on lead vehicle crush behaviour. Finally, it provides insight into the modes of deformation and crush forces that were observed in the test. This model has proven to be a useful tool for evaluating the structural effects of a collision and improving the design of cab car end structures so that they can better withstand the extreme forces associated with a collision.

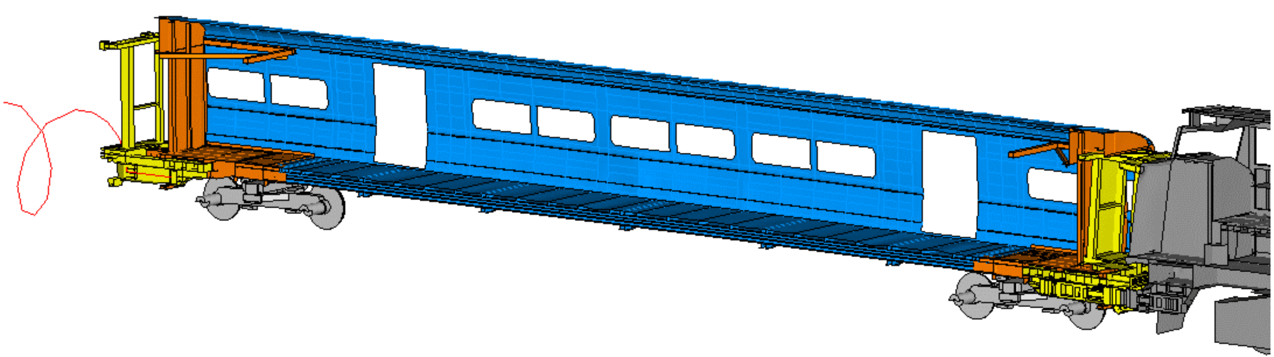

Figure 1. Detailed Nonlinear FEA Model for Analysis of Colliding Trains

The approach used by the Volpe Center included review of the high-speed film, development of Excel-based data and graphics files for direct comparisons to model results, and review of selected data sets to ensure that appropriate comparisons were selected. The finite element model of the two trains was then developed, starting with models that had been previously developed in prior programs for crush analysis of each of the two lead vehicles, the cab car and the standing locomotive. Volpe Center made a significant number of modifications to each of these models and developed new sub-models, defining truck-to-body connections for the cab car and defining the behaviour of the colliding couplers. Volpe Center used lumped mass elements to model trailing vehicles.

INTRODUCTION

Previous analyses of train collisions have typically broken the problem into two parts: the crush behavior of the cars and the overall dynamics of the train. The crush behavior of the cars is evaluated with nonlinear FEA to determine the force required to crush the car and the shape of the car as it crushes. The collision dynamics behavior is evaluated with lumped-parameter model to determine the distribution of crush among the cars and the trajectories of the cars during a collision, including the deceleration of the cars. Comparisons with the results of full-scale testing have shown this approach to be effective in predicting impact test results.

The approach used in the effort reported here was to integrate the crush analysis of the individual cars with the collision dynamics analysis of the entire train. By using FEA for both components of the analysis simultaneously, the interaction of the impacting equipment is more explicitly represented than it would be using separate models. The principal potential advantage of this approach lies in its ability to directly evaluate the influence of changes in the structural design of the vehicles, including geometry and materials, on the interaction of the colliding equipment. This approach therefore lends itself to refining a rail car's structural design more efficiently that it can be refined using typical analysis methods [1]. Figure 2 shows the various modeling approaches used to evaluate train collision dynamics.

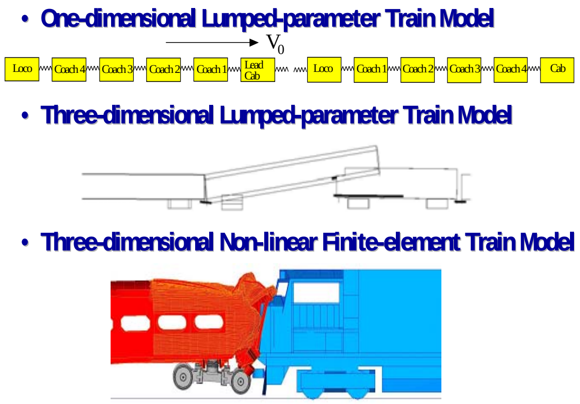

Figure 2. Train Collision Dynamics Modeling Approaches

One note of caution: although this approach allows for a more direct representation of the interaction of the impacting bodies, it does have potential pitfalls, including the modeling of material failure. The simple strain-to-failure approach embedded in current FEA codes greatly oversimplifies material failure in complex three dimensional stress states.

THE MODEL

The finite element model of the colliding trains is made up of four key elements:

1. The cab car body
2. Cab car trucks and truck-to-body connections
3. The locomotive
4. Trailing vehicles and vehicle-to-vehicle connections

Figure 3 shows the cab car portion of the model. This part of the model features a detailed discretization of the front 20 feet or so of the cab car, using a characteristic element length of approximately 1.5 inches. A model for the rear-most 60 feet or so of the vehicle was then added to it. To minimize the number of elements, this part of the vehicle was modeled in much less detail, with a characteristic element length of approximately 15 inches. A mesh transition zone about 4 feet in length was developed to link the refined and coarse parts of the mesh.

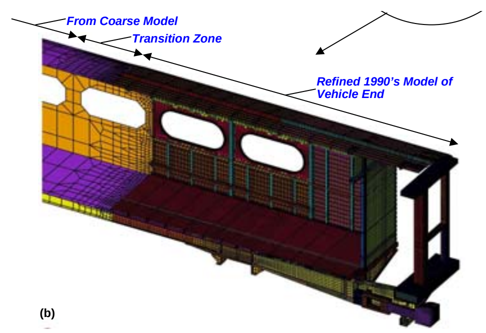

Figure 3. Cab Car Portion of Model

Figure 4 shows the locomotive portion of the model. The mesh for the locomotive includes detailed representations for the short hood, collision posts, anticlimber, draft pocket, and draft gear. Also shown are simplified representations for the underframe, engine, trucks, and fuel tank.

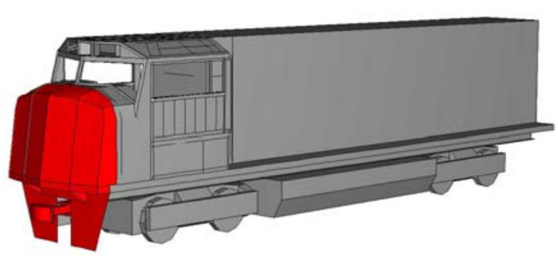

Figure 4. Locomotive Portion of Model

The cab car trucks were modeled as rigid bodies connected to the under frame of the cab car body through the use of ABAQUS connector elements. Figure 5 indicates the location of the connector elements. The stiff longitudinal connection of the truck to the body bolster was modeled as acting through the center pin using a SLIDE PLANE connector element. The much more compliant vertical and lateral connections to the body bolster acting through the diaphragms were modeled using RADIAL THRUST connector elements. The CONNECTOR STOP parameter is applied to the vertical component of motion for this element to prevent compression or extension of the secondary suspension beyond a defined maximum level of travel of ±1.0 inches. In addition, connectors simulating contact between the wheel and the rail were defined between a node located at the center of each of the four truck wheels and a rigid plane representing the rail using a CARTESIAN connector element. The mesh for each truck consists of approximately 13,000 rigid elements. Again, the presence of rigid elements does not significantly affect solution time.

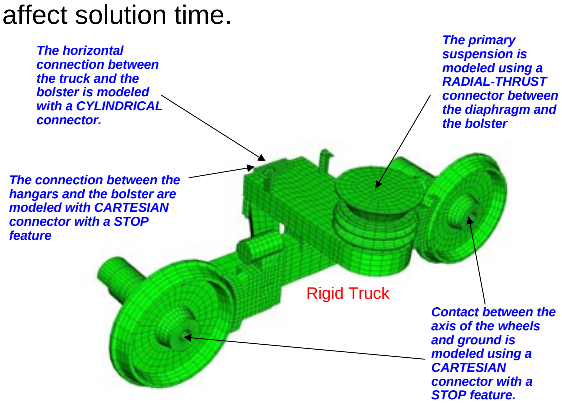

Figure 5. Cab Car Truck Portion of Model

As illustrated in Figure 6, trailing vehicles were modeled in a simplified manner using lumped masses, located at the vehicle c.g.'s and matched to the measured weight of the vehicle. Vehicle-to-vehicle connections were represented with nonlinear spring and linear dashpot elements acting in parallel. The force-deflection characteristics of the nonlinear spring elements represent, in series, the compliant behavior of the coupled draft gears and the much stiffer behavior of the vehicle under frames. Dashpot characteristics represent the damping of the vehicles and their connections, which occurs mostly through hysteresis of the draft gear pads. These elements were constrained to move only in the longitudinal direction.

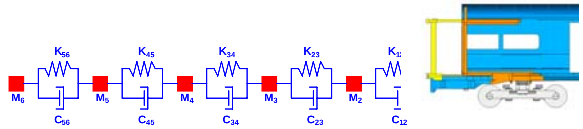

Figure 6. Trailing Equipment Portion of Model

ANALYSIS RESULTS

Figure 7 shows side-by-side comparisons of the model predictions and test results in terms of side views of the collision sequence at several roughly equal times during the first 0.25 seconds of the collision. The model captures the downward bending of the end frame of the cab car onto the front of the short hood and the eventual conforming and locking of the end frame onto the short hood. The model also captures the downward bending of the front of the draft sill and the impact of the cab car roof structure against the window frame of the locomotive cab, as indicated in Figure 7.

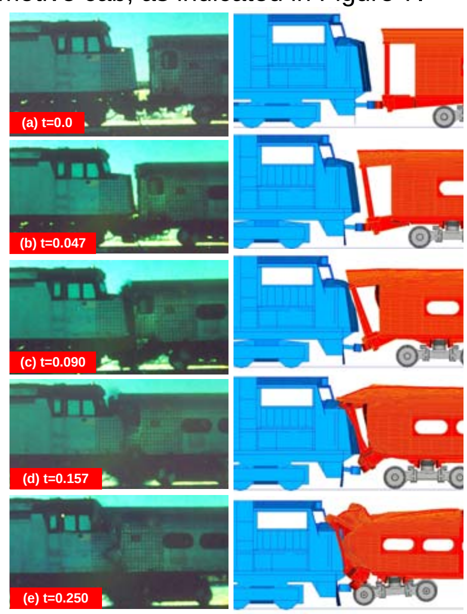

Figure 7. Comparison of Test and Analysis Results

In the train-to-train test of conventional equipment, the colliding cab car crushed by approximately 22 feet and overrode the locomotive [2]. Computer simulations of the train-to-train test of crash energy management (CEM) equipment indicate that the front of the cab car will crush by approximately 3 feet and that override will be prevented [3]. Structural crush will be pushed back to all of the trailer car crush zones, and all of the crew and passenger space will be preserved (Figure 8). The train-to-train test of CEM equipment, which is planned for March 2006, is expected to confirm these predictions.

Figure 8. Conventional Train-to-Train Test Result and CEM Train-to-Train Test Prediction

SUMMARY

A detailed FEA model of a train collision has been developed. This model can be used to directly evaluate the influence of changes in the structural design of the vehicles, including geometry and materials, on the interaction of the colliding equipment. The results of this model closely compare with test measurements. This model has been used to develop a cab car crush zone design to limit the potential for override.

A key feature of the modeling approach was the use of automatic contact, a relatively new feature of ABAQUS/Explicit. This feature's implementation made it much easier to model the complex contact interactions between the various components of the cab car. Its use did, however, require a significant number of modifications to the models, which had not originally been setup to run with the automatic contact feature. The model also includes limited use of one of the material failure features of ABAQUS/Explicit. Failure was restricted to the draft sill structures, using a strain-based material law with a failure strain of 30 percent.

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