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# SIMULATION AND BOGIE TESTING OF A NEW CABLE BARRIER TERMINAL

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## ABSTRACT

Roadside barriers of various designs are extensively used for the purpose of shielding obstacles along the road from impact with errant vehicles. One commonly applied roadside barrier system is a cable system, consisting of three steel cables supported by weak steel posts. Due to an increase in the use of cable systems, a tangent to the roadway, as opposed to flared away from the roadway, crashworthy end terminal has been designed by the Midwest Roadside Safety Facility. The design goal was to effectively disengage the pre-tensioned cables at the end anchor point when impacted on the end by a vehicle, allowing the vehicle to pass through the system virtually unobstructed. It is the objective of this study to help evaluate the new design through bogie testing and nonlinear finite element analysis using LS-DYNA. Based on bogie test results and detailed analysis of the simulation results, it was concluded that the new cable end terminal was ready for full-scale crash testing.

## INTRODUCTION

Roadside barriers of various designs are extensively used for the purpose of shielding obstacles along the road from impact with errant vehicles. One commonly applied roadside barrier system is the 3-strand cable system. This system consists of three steel cables supported by weak steel posts. The steel cables are pre-tensioned with a specified initial load, and are anchored at both ends of the system. When an errant vehicle obliquely impacts the 3-strand cable system, sufficient tension is developed within the cables to redirect the vehicle, effectively shielding the roadside hazard and increasing the safety of the vehicle operator. The weak steel posts supporting the cables offer very little resistance to the impacting vehicle. Due to the likelihood of a longitudinal impact with the end of the 3-strand cable system, a crashworthy end terminal has been designed by the Midwest Roadside Safety Facility (MwRSF). The design goal was to effectively disengage the pre-tensioned cables at the end anchor point upon impact with a vehicle, allowing the vehicle to pass through the system virtually unobstructed. To assist in the development of the 3-strand cable system end terminal, the CTB-4 bogie crash test was conducted. It is the objective of this study to simulate the cable terminal bogie test CTB-4 using LS-DYNA, a nonlinear finite element analysis code (1), and validate the simulation results with that of the physical test.

## 3-STRAND CABLE END TERMINAL DESIGN

To accomplish the task of disengaging the cable end fittings upon impact, the standard cable anchor bracket was modified to accommodate a cable release lever. The cable release lever is a mechanism that was designed to transmit the longitudinal force of the impacting vehicle to an upward force that lifts the cable end fittings from notches in the cable anchor bracket. Even though the system uses weak steel posts to support the cable, the end post is attached to a slip-base to further reduce its resistance to an impacting vehicle. Once the cable end fittings are dislodged from the cable anchor bracket, the tension in the cables is released, and the vehicle is allowed to pass through the system with minimal obstruction. Refer to Figure 1 for an illustration of the end terminal design.

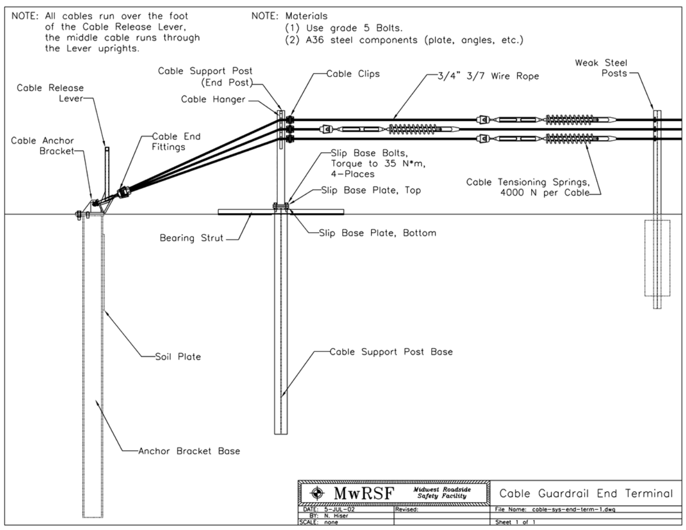



**Figure 1. 3-Strand Cable End Terminal Design**

## BOGIE CRASH TESTING (CTB-4)

In order to test the initial end terminal design concept, the CTB-4 bogie crash test was conducted. A 3-strand cable system was built with a prototype crashworthy end terminal as previously described, and was impacted longitudinally with a 909 kg bogie vehicle traveling at 20.1 m/s (45 mph). The bogie vehicle bumper, which contacts the cable release lever upon impact, is constructed of high-density polyethylene (HDPE) to cushion peak impact forces. The contact point between the bogie bumper and the cable release lever was at 400 mm above the ground. The CTB-4 crash test was conducted without any data acquisition equipment other than the use of high-speed film, and still photographs prior to and following the impact. Refer to Figure 2 for photos of the 3-strand cable system, prototype end terminal, and bogie vehicle used in bogie test CTB-4.

## SYSTEM MODELING IN HYPERMESH AND LS-DYNA

To further assist in the development of the cable system end terminal, impact simulation using LS-DYNA was performed. In order to simulate the CTB-4 crash test in LS-DYNA, the cable system end terminal had to first be modeled in HyperMesh and LS-DYNA, during which many approximations and simplifications were made. The following sections detail the modeling of the cable system.

**Figure 2. CTB-4, Prototype End Terminal and Bogie Vehicle**

**Cable Anchor Bracket and Release Lever**

The cable anchor bracket was modeled using deformable shell elements to represent the grade 250 steel plate from which the actual bracket was constructed. All of the nodes on the base-plate of the anchor bracket model were constrained in all 6 degrees-of-freedom to simulate a rigid anchor bracket base. If a more accurate method to constrain the anchor bracket is desired, it may be beneficial to constrain only those nodes near the bolts that attach it to the anchor bracket base. In LS-DYNA, fillet welds were added to the anchor bracket at the top two nodes of the vertical gussets where weld failure was observed in the tests.

The cable release lever was also modeled entirely with deformable shell elements to represent the grade 250 rolled steel tube and steel plate from which the actual lever was constructed. The lever was placed upright on the anchor bracket gussets without any constraints.

**Cable**

A cable model was utilized in this study. Both solid and discrete beam elements were used to model the cable. A circular cross-section was cut into eight pie-shaped elements, and was then extruded to create solid, 6-node elements. Discrete beam elements were placed at the center of the solid elements, and each beam element spanned the length of one solid element. The beam elements were used to provide the majority of the tensile load developed in the cable, and the solid elements were used to provide mass distribution, minor bending stiffness, and improved contact with other components.

Discrete spring elements, with a spring rate of 80 N/mm and an initial offset of 50.8 mm, were attached to the end of each cable downstream of the end post to simulate the spring compensators, which tension the cables. Spring compensators provide a specified preload of 4064 N per cable. The cables were extended 3 feet past the end post in order to obtain acceptable global system behavior while limiting computational time.

### Cable End Fittings

The cable end fittings were modeled with deformable solid elements and a pie-shaped cross-section consistent with the cable. Additional solid elements were added to represent the volume and mass of the threaded rod, nuts, washers, and shackle which make up the cable end fitting. Using LS-DYNA, a rigid body spherical joint with 20° rotation was placed between the cable and the cable end fitting to simulate the actual degrees of freedom allowed due to the presence of the shackle. In order to incorporate a spherical rigid body joint between the cable and cable end fittings, rigid elements were required at the ends of both cable and end fittings. Figure 3 illustrates the cable end fitting modeling approximation.

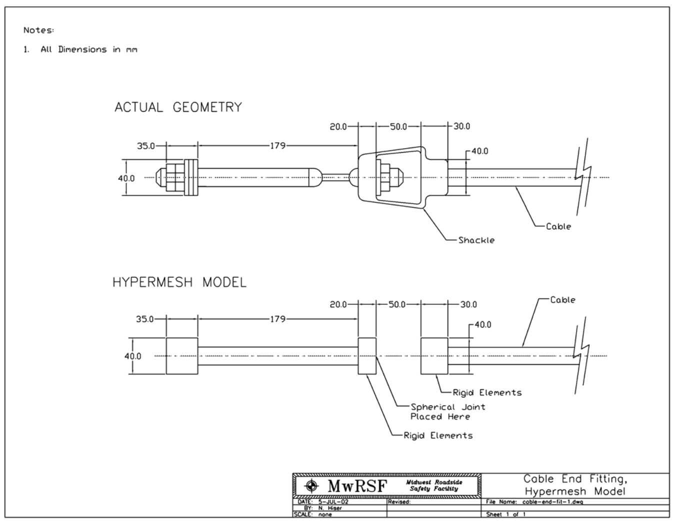



**Figure 3. Cable End Fitting Modeling Approximation**

### End Post

The end post, which sits on a slip base, was modeled using solid and shell elements. Both the top and bottom slip base plate, as well as the I-beam post, were modeled with deformable shell elements. Initially shell elements were used to model the cable hanger, but the final model used solid elements, which provided better contact behavior with the cable. The solid cable hanger elements were also made rigid because no deformations were observed after the bogie test. The bottom slip-base plate was constrained in all 6-dof to simulate a rigid cable support post base with bearing strut, as is shown in Figure 1.

### Slip Base

In the actual slip base joint, a normal force between top and bottom slip base plates is induced and controlled by a specified torque applied to four bolts that clamp the plates together. The frictional force between the two surfaces is a product of the frictional coefficient and the normal force induced by the bolt preload. Finally, activation of the slip base joint is dependent on an impacting force overcoming the frictional force present between the two slip base plates.

To model the slip base behavior in LS-DYNA, the bolt tension was simulated using four nonlinear discrete springs placed in the location of the bolts, in a similar manner as used by G.W. Paulsen (2). The springs were given a non-linear load curve with a load of 5.33 kN for a spring displacement between 0 and 10 mm, decreasing linearly to 0 kN between 10 and 20 mm displacement. The spring load was defined to coincide with the bolt preload due to torque, and was given a failure displacement of 20 mm, which is the slip distance of the actual slip base. Steel-on-steel friction was defined between the slip base plates. Upon simulation initialization, the springs create a normal clamping force equivalent to the bolt clamping force between the slip base plates, generating a frictional force that constrains the post until impacted by the bogie vehicle. During the course of the impact, the springs deflect past 20 mm there-by eliminating the spring load, activating the simulated slip base joint, releasing the post, and yielding acceptable global behavior between the post and the bogie.

**Bogie**

A bogie model from previous research projects at the MwRSF was used in this study, but required a bumper modification. The bumper used in CTB-4 was constructed of HDPE, and it was mounted at a height of 400 mm to match that of a small car bumper, such as a Geo Metro. The majority of the bumper was modeled with rigid, solid elements primarily for mass and geometric correlation. Deformable, solid elements with the *MAT_ELASTIC material definition were placed along the leading edge of the bumper. The presence of relatively soft, deformable elements on the leading edge of the bumper helped to reduce the peak contact forces that typically occur upon impact. A photograph of the bogie used in CTB-4 is shown in Figure 2.

## STEP-BY-STEP SIMULATION PROCESS

The 3-strand cable system was simulated incrementally, with various parts of the system simulated separately, and then later combined to recreate the complete system. An impact between the bogie, cable release lever, anchor bracket, and cable end fittings was simulated first. The purpose of this was to investigate the contact between the bumper and the cable release lever, as well as the effectiveness of the cable release lever in lifting the end fittings out of the anchor bracket. *CONTACT_AUTOMATIC_SINGLE_SURFACE was used as the global contact definition for all parts. There were some initial contact problems, as seen in Figure 4, which resulted in unusual deformations in the cable release lever and the cable end fittings. This was attributed to the large difference in stiffness between the HDPE bumper (E=0.930 GPa) and the steel end terminal components (E=200.0 GPa). Pinball segment-based contact was added to the contact definition along with the edge-to-edge penetration check. These changes increased the penalty stiffness of the impacting surfaces, and reduced the effects of the edge-to-edge contact that occurs between the lower part of the bumper and the gussets of the cable release lever. However, it is noted that contact problems were apparent during a later simulation, so the bumper stiffness was increased from E=0.930 GPa to E=1.860 Gpa, which helped minimize the contact instability.

The next step in the modeling process was to add the cables and the end post to the system model. The cable end fittings were connected to the end of the cables near the anchor bracket using spherical joints as previously described. Spot welds were used to fix the post to the slip base for the initial simulation. The simulation was run for 10 ms. This was sufficient time for the cable release lever to lift the end fittings out of the slots in the anchor bracket, and for the cable to respond to the release of tension. A cross section through the cables was used to verify that the cables were being tensioned properly to 4 kN by the discrete springs.

A contact problem was discovered between the cable and the post cable hanger. When tension was applied to the cables, the cable penetrated into the cable hanger, as illustrated in Figure 5. This penetration caused the cable to snag on the cable hanger, constraining it from sliding within the cable hanger groove. The cable hanger mesh was refined in the location where it made contact with the cable. The refined mesh fixed the visible penetration problem, but a longer simulation showed that the cables were still snagging on the cable hanger. Rigid, solid elements were then used to model the cable hanger. When the solid elements were created in HyperMesh, interference was apparent between the cables and the cable hanger. It is likely that this interference resulted in initial penetrations, which caused the snagging between the cable and the cable hanger. The cable routing was adjusted slightly to avoid interference with the solid elements of the cable hanger. These changes eliminated the cable snagging problem.

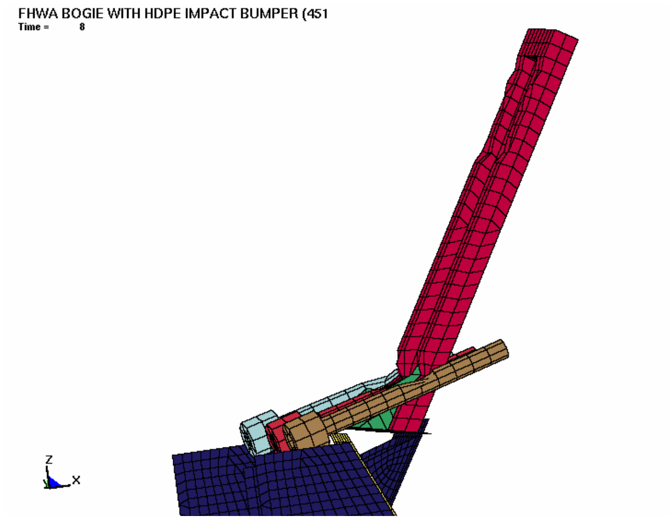



**Figure 4. Deformations Prior to Soft Contact Definitions**

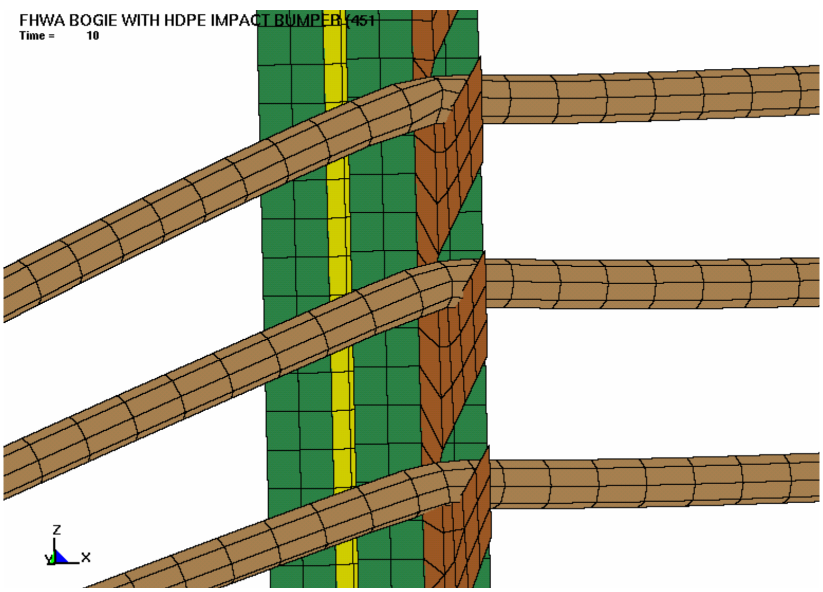



**Figure 5. Cable Penetrating and Snagging on Cable Hanger**

Next, spot welds constraining the slip base joint were eliminated and replaced with the slip-base model described previously. Upon subsequent simulations, it was determined that the slip-base model using discrete springs and friction produced desired system behavior.

A global friction was then added to the model in *CONTACT_AUTOMATIC_ SINGLE_SURFACE. The static friction coefficient was set to 0.74 and dynamic friction coefficient was set to 0.57 per published values of mild steel-on-steel friction (3). An exponential decay rate of 1.0 was used for the transition between static and dynamic friction. This friction coefficient was apparently too high for some of the contact locations, because overall system behavior was poor. The post was twisting severely due to cable tension, and the plastic deformation seen in the cable release lever and anchor bracket were too severe. However, adding friction improved rotation of the cable release lever, and improved slip base joint behavior.

Friction was then removed from the global contact definition and inserted into *PART_CONTACT cards in order to define friction within specific parts. It was determined that friction would be assigned to specific parts based on how they interact with the other parts in the simulation. The anchor bracket was given friction coefficients of fs = 0.74 and fd = 0.57, which adds friction between the anchor bracket, cable release lever, and the cable end fittings. The same friction coefficients were added to the post base plate in order to include frictional effects within the slip base joint. In all cases, an exponential decay rate of 1.0 was used for the transition between static and dynamic friction. Initially friction was defined on the cable hanger, but was later removed entirely because the frictional forces between the cable and the cable hanger were causing excessive initial twisting of the post. Without friction applied to the cable hanger, it was determined that the cable snagging on the sharp corner of the cable hanger resulted in acceptable deflections of the post.

After friction was added to the necessary parts of the model, it was determined that the interaction between the cable release lever and anchor bracket wasn't behaving as desired. The cable release lever was not rotating as observed in the film of CTB-4, and the fillet welds were failing prematurely using failure strain values published by Shigley and Mischke (4). An increase in the fillet weld strain failure criteria from 0.20 to 0.30 produced an increase in the rotation of the cable release lever, but excessive deformation occurred in the anchor bracket near the fillet welds. A third node was added to the fillet welds on each vertical gusset and the failure strain was reduced to simulate brittle weld failure. After several iterations, a failure strain of 0.06 was found to produce acceptable global system behavior. The welds failed in a brittle manner as desired, and the increased strength of the welded joint caused the cable release lever to rotate in a manner more consistent with CTB-4.

## SIMULATION VALIDATION

Ideally, accelerometer data would be used to compare energy loss in the actual bogie to the simulated bogie, however, since this data was not recorded, the next best validation technique is visual comparison. Time comparison between digital video of CTB-4 and the simulation is the main validation used for this model. Plastic deformation of the cable end fittings, end post, and anchor bracket was a second method used to validate the simulation of CTB-4.

Certain physical characteristics of the bogie test were chosen and used for validation of the simulation. Rotation of the cable release lever, the time of fillet weld failure, and the time of contact with the post can all be closely inspected using high-speed film. In a more subjective manner, the global impact behavior of the cable end fittings, cables, and post were used as secondary validation techniques. Figure 6 shows time comparisons of the actual and simulated end terminal test CTB-4.

When viewing the time comparisons, certain details were inspected for simulation validation. The lower part of the bumper contacts the cable release lever at 8 ms in both the simulation and the video. The fillet welds fail at 9 ms into the simulation, but they didn't fail in the video until 12 ms. However, the video was recorded at 500 frames per second, so it is possible that the weld failed within the range of 10 to 12 ms. At 18 ms, the cable release lever has almost lost contact with the anchor bracket, and it was almost parallel with the ground, which is evident in both the simulation and the video. The simulation accurately shows that the bogie made contact with the post at approximately 70 ms.

Permanent post, cable end fitting, and anchor bracket deformations were also compared for simulation validation, as shown in Figure 7. It is apparent from the visual comparison that the deformations observed in the damage photos coincides reasonably well with the simulation results.

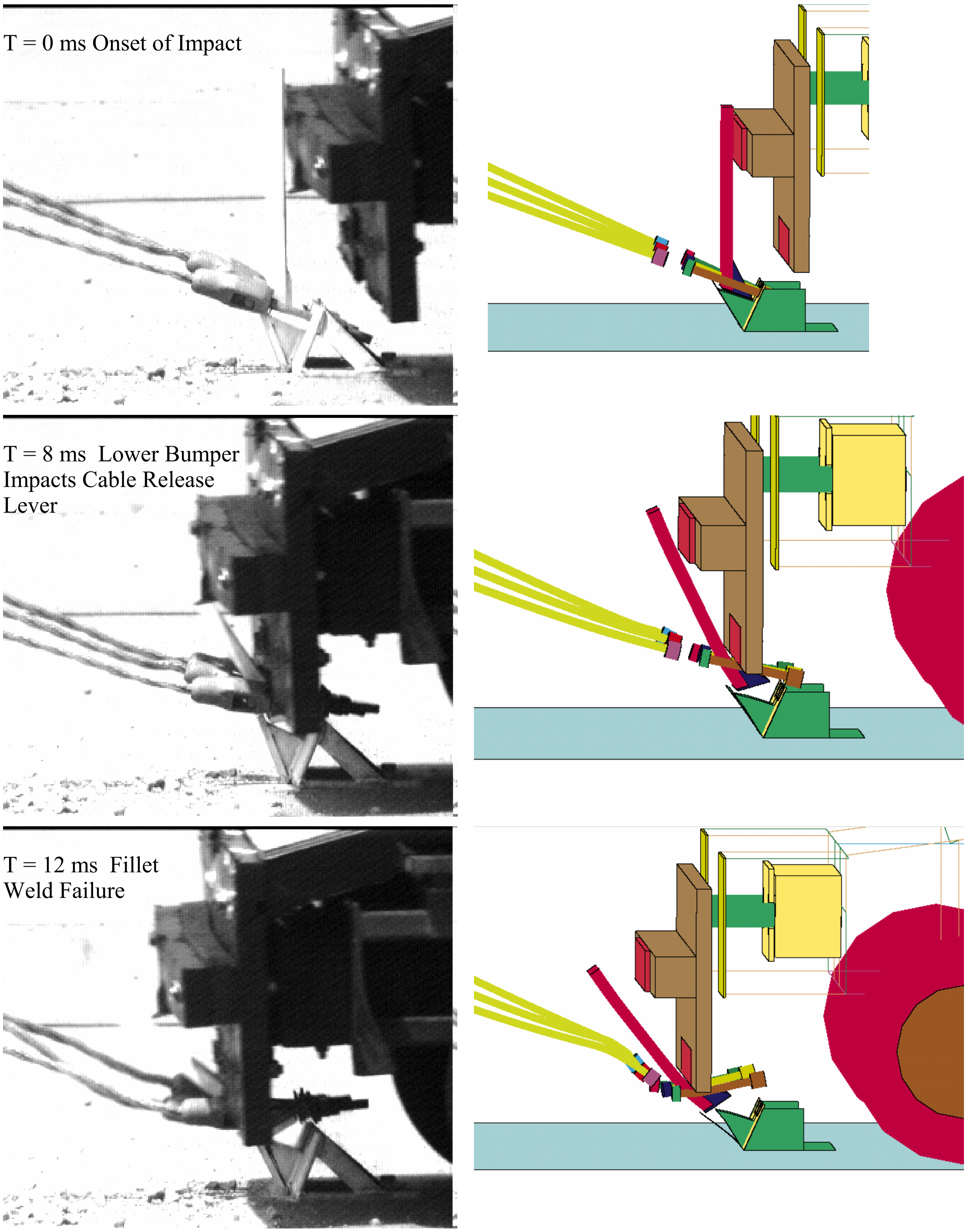
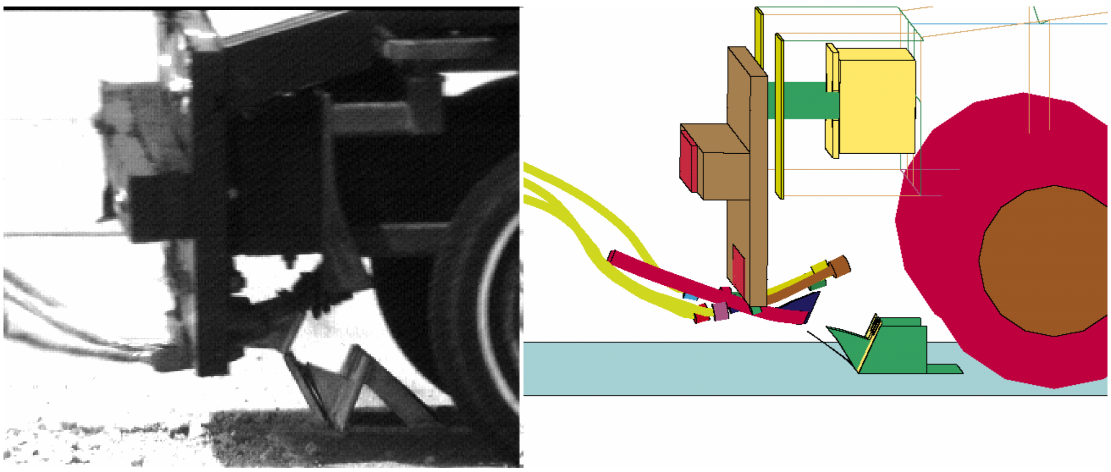
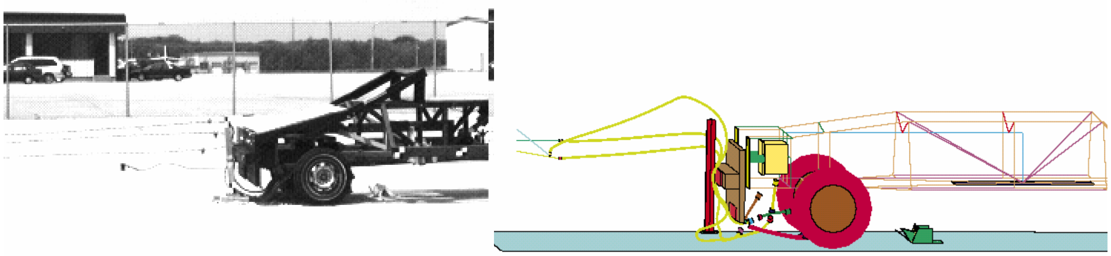



**Figure 6. Time Comparison, High-Speed Film vs. LS-DYNA Simulation**

T = 18 ms  Cable Release Lever Loses Contact with Anchor Bracket



T = 70 ms  Post impact



T = 80 ms  Post Releases from Slip Base

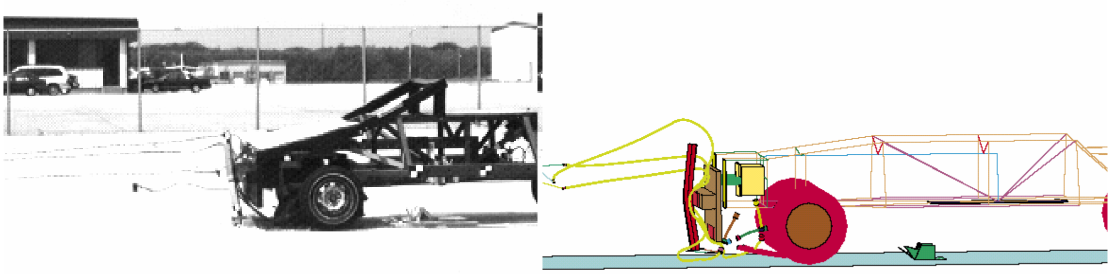


**Figure 6 (Continued).  Time Comparison, High-Speed Film vs. LS-DYNA Simulation**

**Figure 7. Deformation Comparison - Post, Cable End Fitting, and Anchor Bracket**

## FURTHER ANALYSIS

Since the simulation has been validated through visual means, it is useful to obtain other data from the simulation that was not, or could not be obtained from the bogie test. Contact forces and accelerometer data can be easily obtained using LS-POST. Figure 8 is a force-displacement plot of the contact forces on the bogie bumper, and Figure 9 is a time plot of the velocity of the bogie.

Major peaks in contact forces, as shown in Figure 8, coincide with noticeable drops in velocity. The reductions shown in the velocity curve coincide with the impacts with the end terminal components. The first drop in velocity represents initial impact with the cable release lever. Velocity reductions between 8 ms and 18 ms indicate the lower part of the bumper interacting with the cable release lever and failure of the anchor bracket fillet welds. The final velocity drop at 70 ms signifies bogie impact with the end post. Initially the bogie is at 20.1 m/s and the velocity drops to just below 19.0 m/s, indicating a relatively minor decrease in velocity.

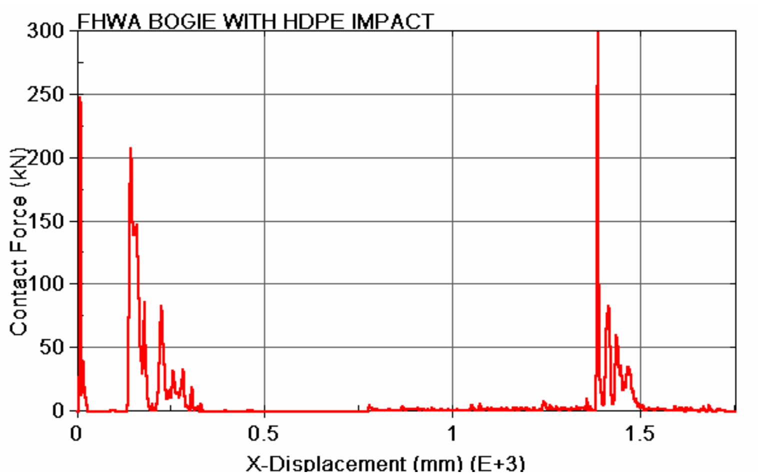



**Figure 8. Bogie Bumper Contact Forces, Force vs. Displacement**

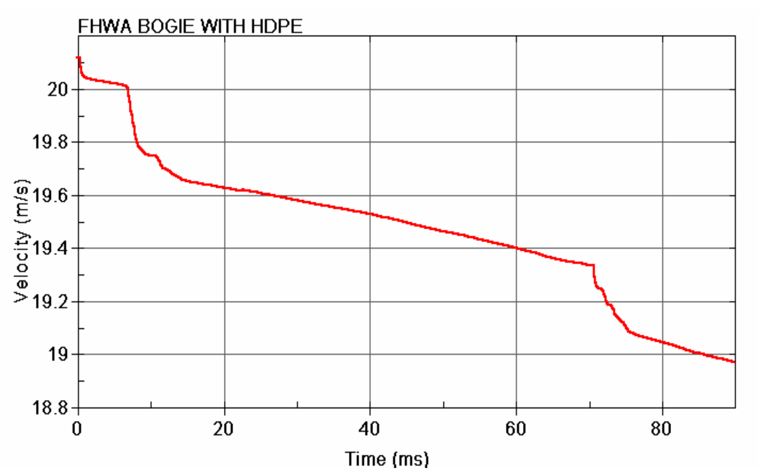



**Figure 9. Bogie Velocity vs Time**

## CONCLUSIONS AND RECOMMENDATIONS

LS-DYNA was used to simulate a new 3-strand cable terminal system. A 900-kg bogie vehicle with a bumper height of 400 mm impacted the system end-on at an initial velocity of 20.1 m/s (45 mph). Visual comparison of simulation results with high-speed video from the bogie test was used to validate the simulation. The cable end fittings were properly released from the anchor bracket with the cable release lever, thus eliminating the tension in the cables, and preventing the vehicle from ramping up the tensioned cables. The simulated slip base joint constrained the post during the simulation until activation by bogie impact, failing in manner consistent with observed behavior from the test film. Deformations in the simulated cable end fittings, end post, and anchor bracket were similar to the actual deformations seen in the damage photos. With this validation, it is reasonable to gather other results from the simulation that could not be produced in the actual crash test. The peak contact force was about 300 kN, and the velocity of the bogie after impact with the end post was 19.0 m/s.

Further work could be done in the modeling of the slip base on the end post. While the slip base model in this simulation works fairly well to replicate overall system behavior, a more realistic model could be developed. For example, using a detailed bolt model instead of discrete springs might prove to be a better method of modeling the slip base.

Based on bogie test results and detailed analysis of the simulation results, it was concluded that the new cable end terminal was ready for full-scale crash testing.

## ACKNOWLEDGMENTS

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