Modeling Crushable Foam for the SAFER Racetrack Barrier

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Abstract

*One of the key components in the new SAFER barrier being installed at many IRL and NASCAR racetracks is the foam blocks placed between an outer steel tube structure and the existing concrete wall. Simple polystyrene insulation foams were proven to have good energy absorbing capabilities and were used as a primary means of energy absorption in the barrier. This foam is very low cost and easy to obtain. Foam research began with obtaining several samples of cubic foam blocks and then performing static and dynamic testing on them. Simulation of the dynamic test with LS-DYNA concentrated on the use of the *MAT_CRUSHABLE_FOAM material model. After successfully modeling of the bogie tests, the component model of the foam was placed in the full-scale model of the SAFER barrier. Later in the research program, the cubic shape foam blocks were replaced with a trapezoidal shape. These trapezoidal shapes were also tested and then, successfully simulated.*

Introduction

Research and development on energy absorbing barriers for high-speed racetracks has been ongoing at the Midwest Roadside Safety Facility (MwRSF) at the University of Nebraska-Lincoln (UNL) for the past several years [1]. During the course of this research, simple polystyrene insulation foams have proven to be good energy absorbing materials, and thus, are used as one of the primary means of energy absorption in the SAFER barrier. Polystyrene foams are low cost, readily available and easy to work with. This paper discusses the modeling effort, and associated verification, of this crushable foam using LS-DYNA [2]. The component foam model is then used in the system model of the SAFER barrier in order to simulate full scale crash testing.

Foam Material Modeling

After extensive static and dynamic testing on various foams, a common 15 psi polystyrene foam was selected for the high-speed race barrier research. In order to perform a detailed analysis on the barrier system, the first step was to develop accurate models of the components that are part of the system. This meant finding appropriate loading curves for the foam and developing validated models of the foam material.

Foam Cube Testing

Dynamic testing of the 15 psi polystyrene foam was conducted at MwRSF's outdoor crash test facility. The tests were performed by impacting 610-mm x 610-mm x 610-mm blocks of the foam with a 2,150 kg bogie vehicle at speeds of approximately 8.94 m/s. An accelerometer mounted at the center-of-gravity of the bogie vehicle recorded acceleration data that was later analyzed to provide the force vs. deflection data from the impacts.

A typical load curve from the dynamic bogie tests is shown in Figure 1. Analysis of the curve shows that the loading of the foam proceeds with an initial increase in load, then transitions to a region of relatively constant load, and finally ramps up quickly after approximately 80 percent crush as the foam is fully compressed. These curves along with high speed film data from the testing were used to develop a viable model of the foam material behavior.

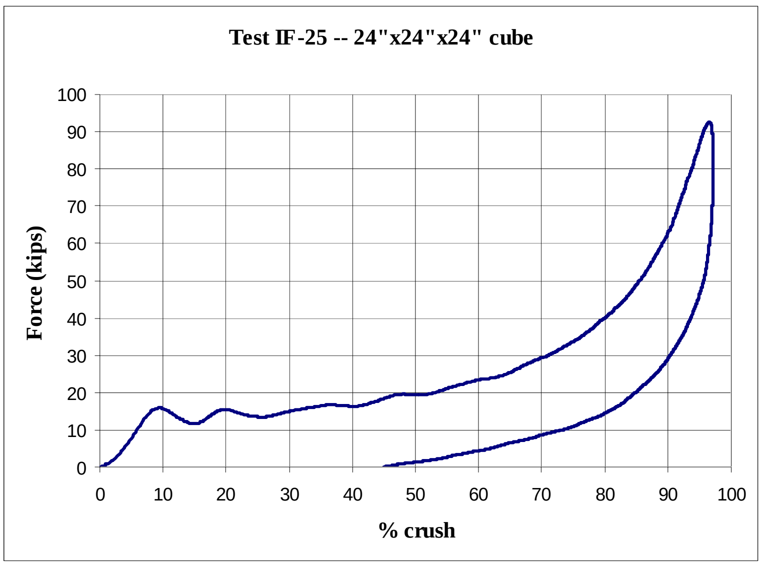

Figure 1. Typical 15 psi Polystyrene Foam Force vs. Percent Crush

Foam Cube Simulation

Modeling of the 15 psi polystyrene foam was performed using LS-DYNA; which has several foam material models. One of the easiest to use is the MAT_CRUSHABLE_FOAM model. This material model allows for description of the foam behavior through the input of a stress versus volumetric strain curve. Because this data was easily obtainable from the dynamic crash test data, it was decided to use this model to characterize the foam behavior.

The stress versus volumetric strain curve was generated for the foam by conversion of the stress versus percent crush data. It was assumed that the expansion of the foam under a compressive load was negligible. This was a reasonable assumption based on the behavior of the foam as observed in static and dynamic testing. Therefore, the only change in the volume of the foam was the change in the crush depth. This simplified the volumetric strain to be equal to the compressive strain, or the change in the depth of the block divided by the original depth of the block. The stress versus volumetric strain curve developed was discretized into 100 points and input into the model.

In order to validate the foam material model, a simple foam compression simulation model was developed to mimic the dynamic bogie testing that was conducted. A 610-mm x 610-mm x 610-mm block of foam was created from solid elements and crushed in the same manner as the dynamic bogie tests. Sequential comparisons of the foam crush between the dynamic testing and the simulation model is shown in Figure 2. A comparison of the force versus deflection curves from testing and simulation is shown in Figure 3. Comparison of the simulation model and the physical testing showed that the model was capable of accurately capturing the proper loading of the foam, as well as the correct physical deformation of the foam.

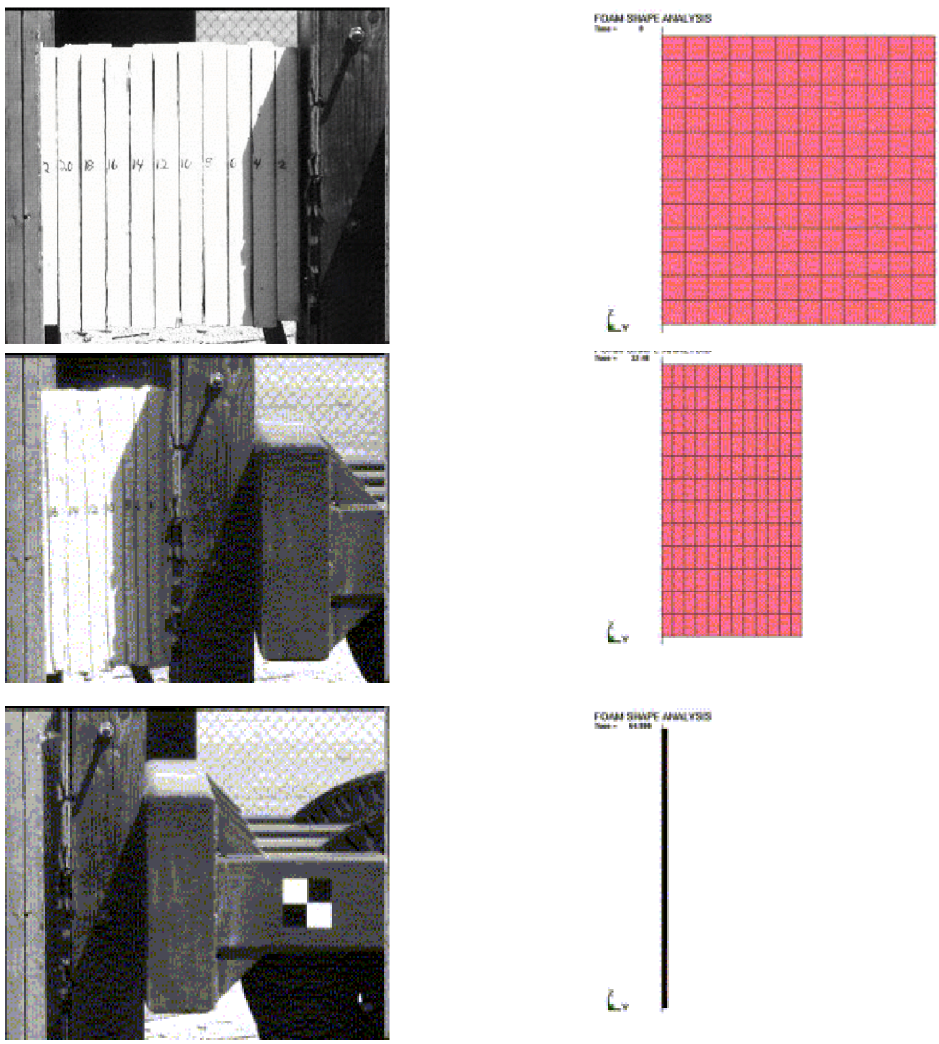

Figure 2. 15 psi Foam Modeling: Test vs. Simulation

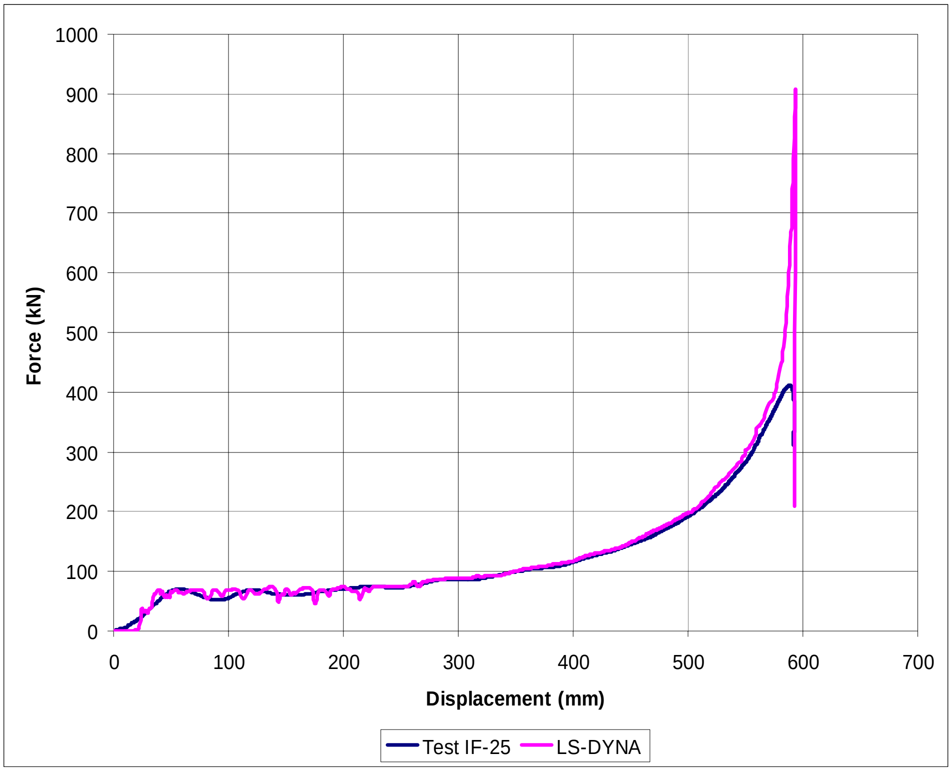

Figure 3. 15 psi Foam Modeling: Test vs. Simulation

It should be noted that, while the simulation model of the foam was very accurate for modeling the loading behavior of the foam, it was not capable of modeling the unloading properly. The foam model used required linear, elastic unloading of the foam. In addition, in order to preserve the stability of the model, the slope of the unloading curve of the foam had to be greater than the loading curve. As such, the foam model can not accurately model the rebound of the foam. However, as this research was focused mainly on the energy absorbed by the foam, the proper loading of the foam was deemed more crucial than the unloading behavior. Therefore, it was believed the limited rebound of the 15 psi polystyrene foam was not a critical behavior to model.

Additional Verification – Trapezoidal Testing and Simulation

During full-scale crash testing of the racetrack barrier, it became apparent that a more uniform increasing load rate for the foam would be desirable; as opposed to the relatively constant load rate between 50 mm and 300 mm, as shown in Figure 3. Uniformly increasing load rate can be achieved by tapering the foam blocks into a trapezoidal shape. Thus, multiple dynamic bogie tests were performed on various foam block shapes until a desired loading rate was achieved.

The new trapezoidal shaped foam block was then simulated using the same material model as discussed previously in this paper. Results are shown in Figures 4 and 5. Based on the good comparison of the simulation with the physical testing, it was believed that the foam behavior had been accurately characterized and modeled. Thus, the model of the 15 psi polystyrene foam material could be confidently used in the remainder of the research effort.

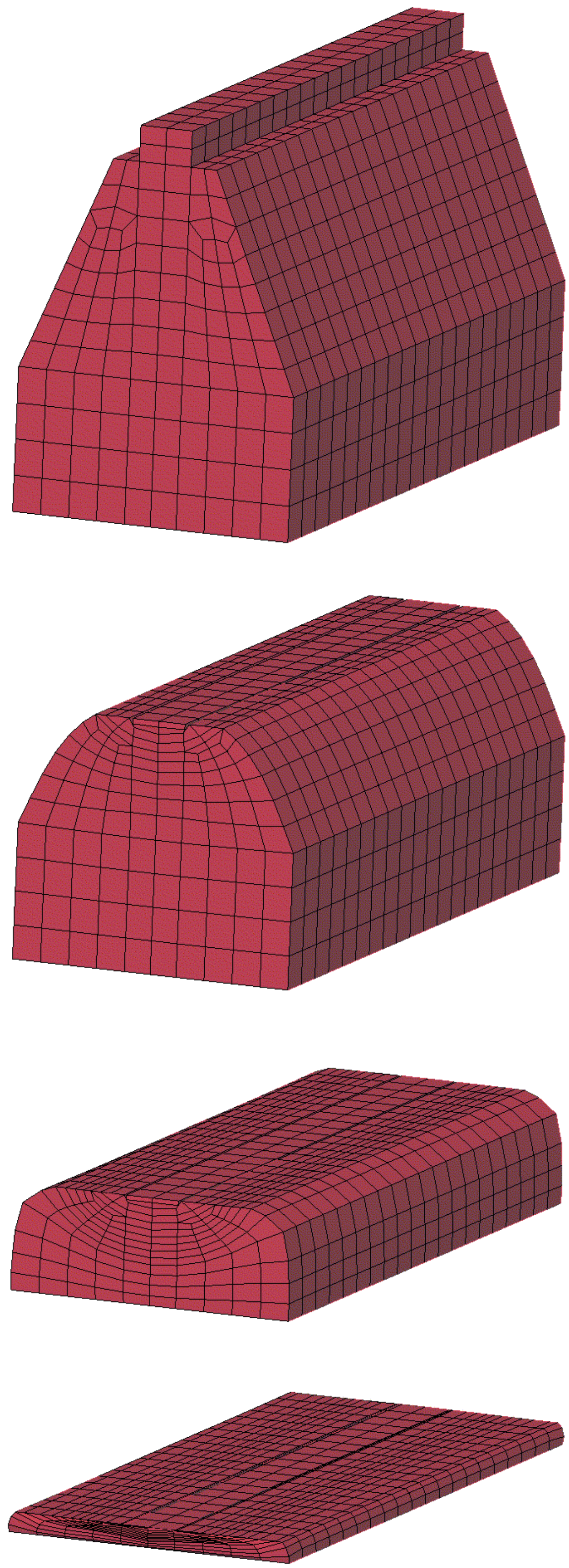

Figure 4. Trapezoidal Shape Foam Crushing

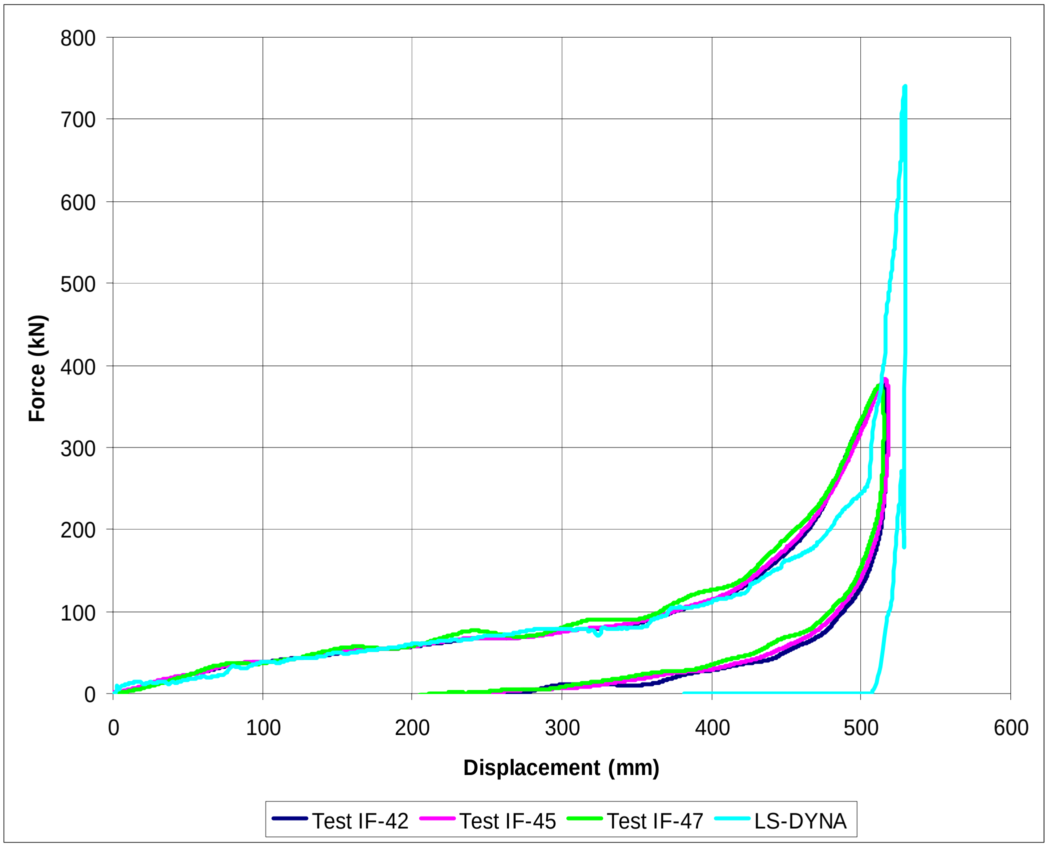

Figure 5. Trapezoidal Shape Foam Crushing: Test vs. Simulation

Negative Volume

Negative volume aborts during simulation was the most aggravating part of using the foam model. This occurred in both component simulation and full-scale simulation. Two parameters were identified that seemed to have the greatest impact on preventing negative volume; these were the choice of element formulation and the use of contact interior. As an example, Figure 6 compares the use of two different element formulations on the trapezoidal block crushing; the model on the left used element formulation 1 (constant stress), while the model on the right used element formulation 2 (fully integrated S/R). Both models absorbed nearly an identical amount of internal energy, while the constant stress element showed relatively little hourglass energy. However, the constant stress model aborted with a negative volume just a few cycles after the last image in the sequence shown in Figure 6. The fully integrated model was able to complete the simulation successfully.

At times, using the contact interior option helped prevent negative volumes; probably most notable on off-axis crushing. Eventually, it was determined that using fully integrated S/R solid element formulation for the foam was the best route to follow, with or without using contact interior. By using the contact interior option, the analyst can manipulate the peak loading values that occur when the foam bottoms out.

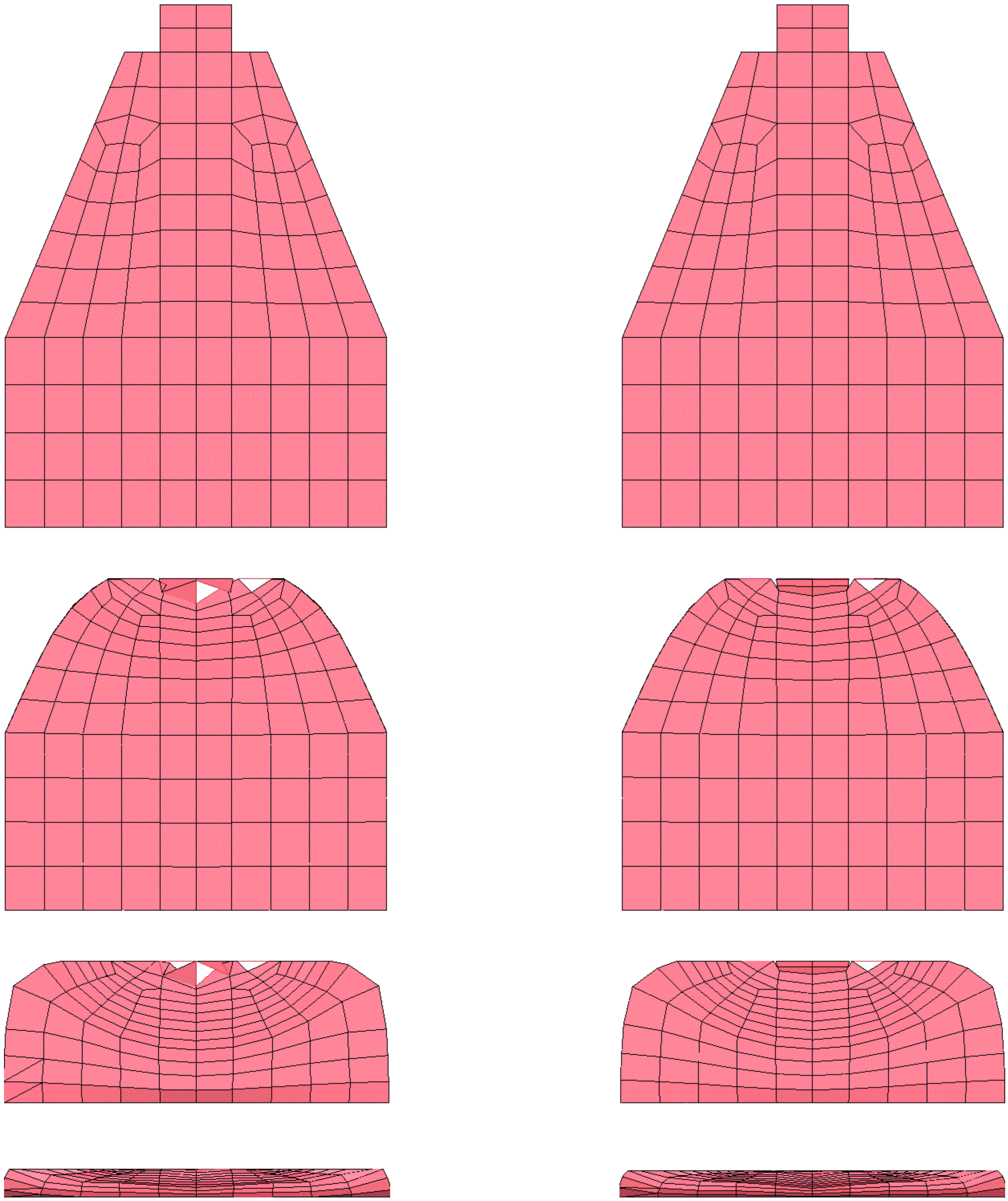

Figure 6. Solid Element Formulation: Constant Stress vs. Fully Integrated S/R

Application – Safer Barrier Simulation And Testing

An application of the 15 psi polystyrene foam discussed above is in the Steel And Foam Energy Reducing (SAFER) barrier for high-speed racetracks. Simulation and full-scale crash testing results of the SAFER barrier with the trapezoidal shaped foam blocks are shown in Figures 7 and 8, respectively.

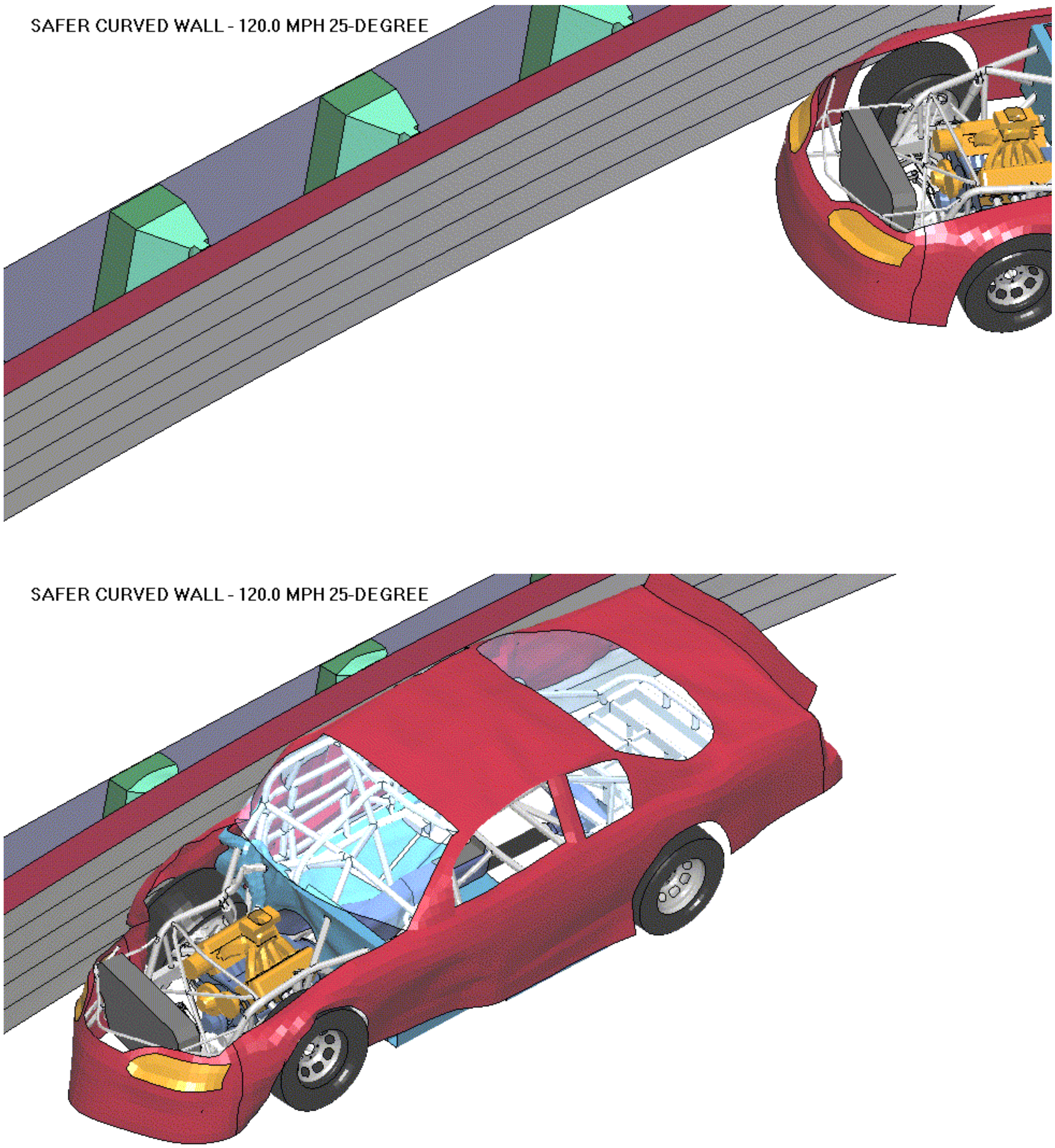

Figure 7. SAFER Barrier Simulation with Trapezoidal Foam Blocks

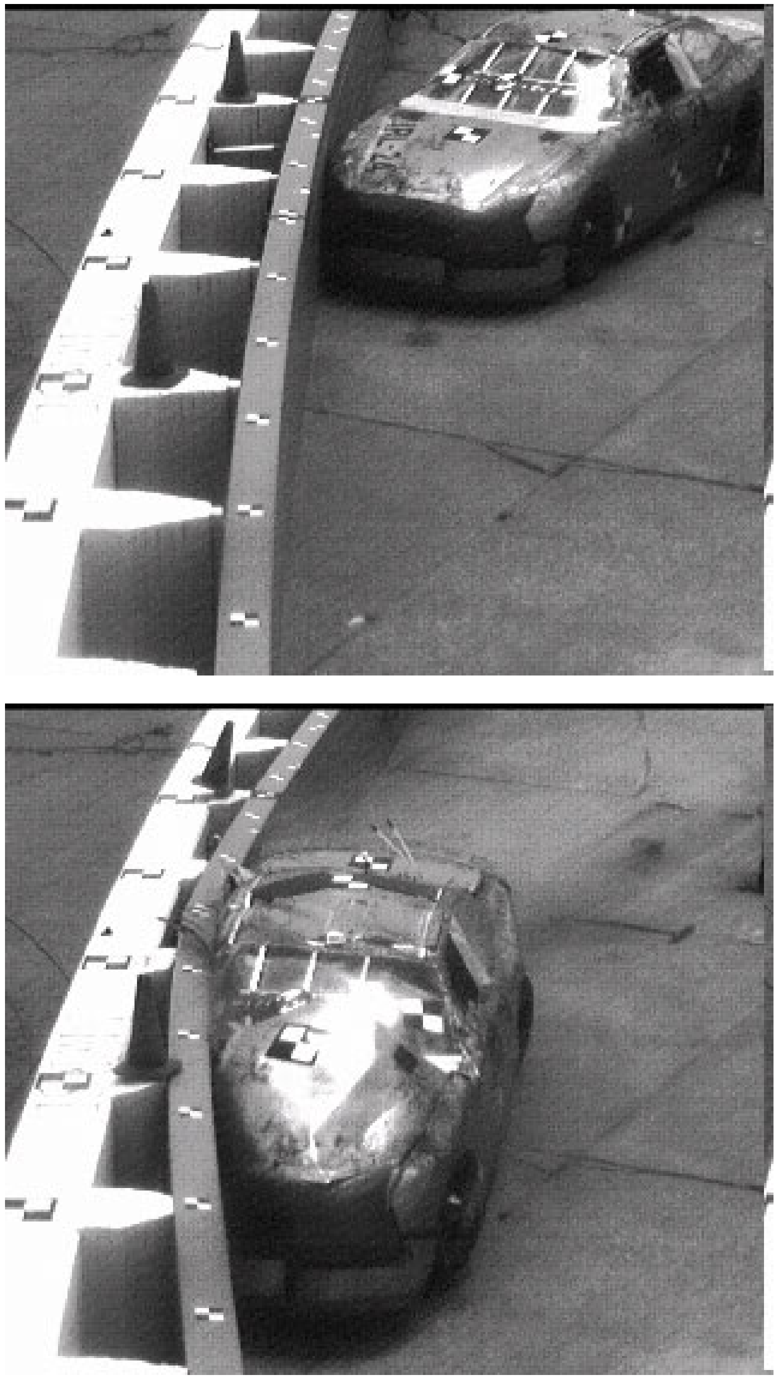

Figure 8. SAFER Barrier Crash Testing with Trapezoidal Foam Blocks

Conclusions

Low cost and readily available polystyrene foams can be effectively modeled using the crushable foam material model in LS-DYNA. Even though these are simple foams, they are excellent energy absorbers, which can be sized and shaped to absorb energy at a desired rate. One of the key components in the new SAFER barrier being installed at many IRL and NASCAR racetracks is the foam blocks placed between an outer steel tube structure and the existing concrete wall. Successfully modeling of the foam, as detailed in this paper, has played an important role in the development of the SAFER barrier.

Acknowledgments

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