Modeling Rebound of Foam Backed Racetrack Barriers

John D. Reid and Robert W. Bielenberg
Midwest Roadside Safety Facility
Department of Mechanical Engineering
University of Nebraska-Lincoln
N104 WSEC (0656), Lincoln, NE 68588 USA
jreid@unl.edu

Abstract

Modeling energy absorbing foams that restore back to their original shape can be extremely challenging, especially when the foam is crushed over 90%. However, the foam used in the SAFER racetrack barrier does indeed nearly return to its' original shape after severe crushing. The desire to model this behavior led to the use of the Fu Chang foam model available in LS-DYNA®.

This paper format is a little different than most. It starts off with an executive summary and then provides some of the details that support the summary.

Executive Summary

Modeling energy absorbing foams that restore back to their original shape can be extremely challenging, especially when the foam is crushed over 90%.

During development of the Steel and Foam Energy Reduction (SAFER) Barrier for racetrack applications [1] it became apparent that the rebound was an important part of a high speed impact into the system. The rebound is governed by the loading and unloading of the foam that is used to back-up the steel tubes that are used as the front face of the barrier. However, during the initial design and analysis phase, which led to version 1 of the SAFER, only a relatively simple crushable foam model was used for the simulation effort [2]. Thus, the rebound was not captured for detailed analysis during the initial development.

Following the successful design, testing, and evaluation of the original system, further efforts were directed toward improving the barrier's design, adapting the system to smaller-radius, high-speed racetracks, and advancing the design of the energy absorber to allow a single barrier configuration for both open-wheel (900 kg) and stock car (1630 kg) race vehicles. The continued research and development effort resulted in the second generation of the system, known as SAFER Barrier Version 2 [3], as shown in Figure 1.

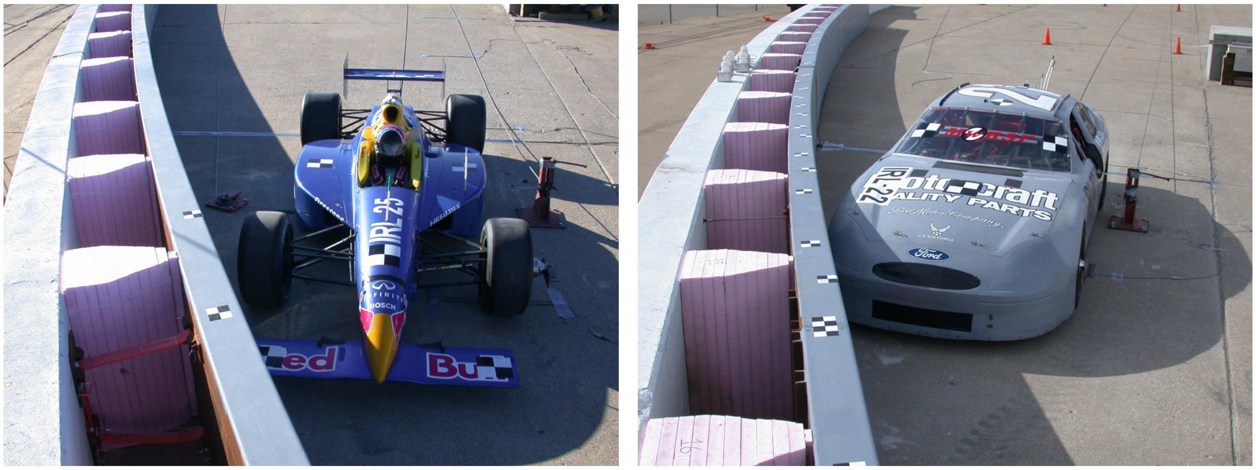

Figure 1. SAFER Barrier Ver. 2 – Open-wheel (IRL) and Stock Car Vehicles (NASCAR)

Desire to simulate rebound, while at the same time optimizing the foam block shape, led to using a Fu Chang foam material model; which in turn provided all sorts of learning opportunities, including areas associated with (1) element stability (e.g., element formulation, hourglassing, and negative volumes), (2) material parameter selection (e.g., viscous damping coefficient), and (3) smoothness of foam stress-volumetric strain curves.

A good understanding of the Fu Chang foam material model behavior was needed before using it in the component model of the optimized shapes, and ultimately, before the system model of the SAFER. Note that the goal was to understand the material behavior for applications and not necessarily to understand the underlying theory behind the material model. However, some fundamentals concerning foam materials were important for determining the proper usage of the material [4]. Some of the behavioural understanding was gained by performing various single element simulation studies and by simulating 610 mm cube compression bogie testing before using the material in component and system models. Ideally the process would be sequentially; from simplest to most complex models, but in practice it was more in parallel with feedback loops.

Foamular 150 is the type of foam being used in the system, which is essentially a low density elastic foam. In dynamic crushing of 610 mm cubes, the foam returned nearly to its original shape, even after 98% crush. In addition to dynamic testing, static testing was performed in order to help determine appropriate material properties to use for simulations. Non-linear finite element simulation of the dynamic testing was performed using LS-DYNA [5]. With a validated model for the foam material, various foam shapes were studied and eventually, the rebound observed during full-scale crash testing was successfully simulated.

Details Supporting the Executive Summary

Bogie Testing

Nearly 100 bogie tests were performed at various speeds to test different foams and foam shapes. A typical test set-up is shown in Figure 2. That particular test, IF-25, was used to help determine material properties for the foam models used in the simulation study.

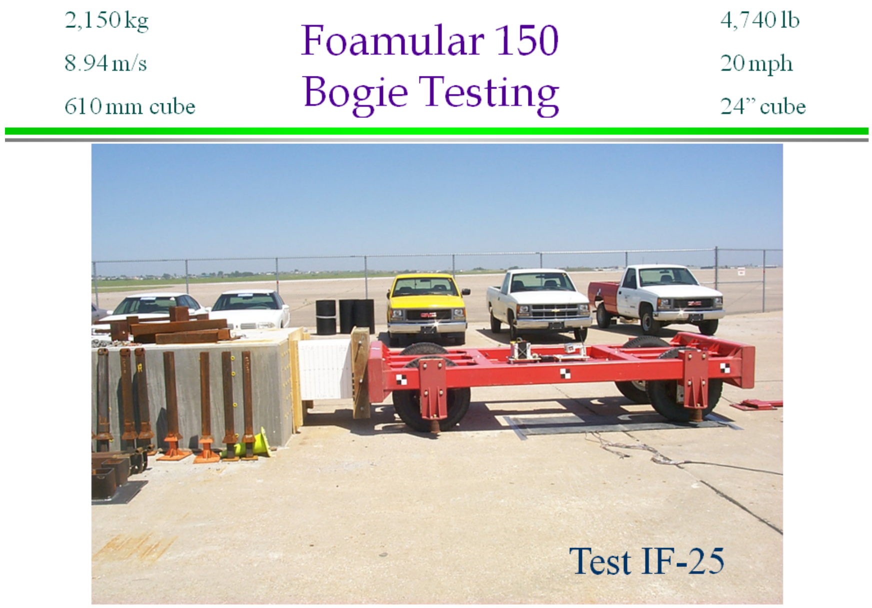

Figure 2. Typical Bogie Testing Set-up

Several test conditions were performed multiple times in order to investigate the repeatability of material behavior. For example, trapezoidal shaped blocks of Foamular 150 was tested 3 times at 20 mph, as shown in Figure 3. The force-deflection results show that this foam behaves consistently for this shape at this test speed. One of the tests shown in Figure 3, IF-45, was used to verify that the foam models used in the study were valid. That is, test IF-45 was compared to simulation results that were run after the foam models were developed using test IF-25.

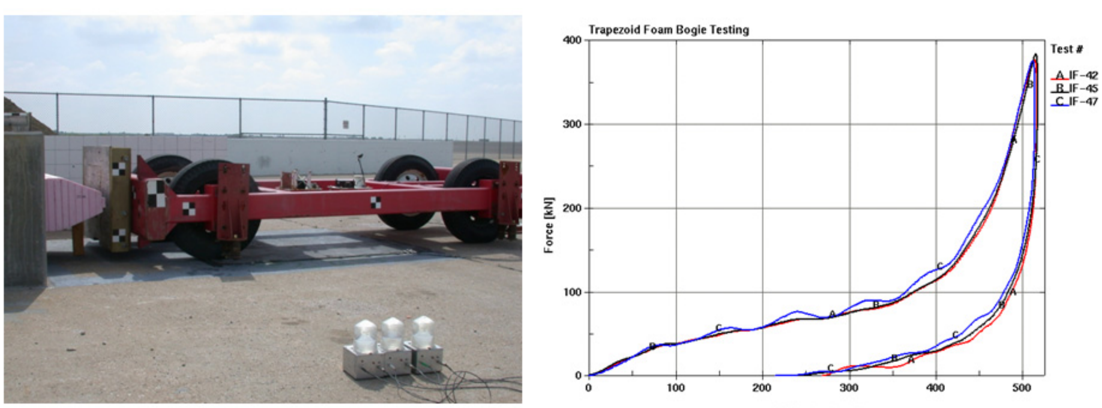

Figure 3. Trapezoidal Testing and Results

Material Modeling

Model for Determining Material Properties

Bogie test IF-25 was the primary physical test used for determining material properties for the two foam models used in the project. Simulation of the physical test involved a reduced model, as shown in Figure 4. The bogie was modeled with a rigid wall; which was given the prescribed motion as recorded in IF-25. The foam block was modeled with the same dimensions as the test. Stress versus volumetric strain data was calculated using the force-deflection data from test. The backup structure was modeled with a fixed, rigid wall.

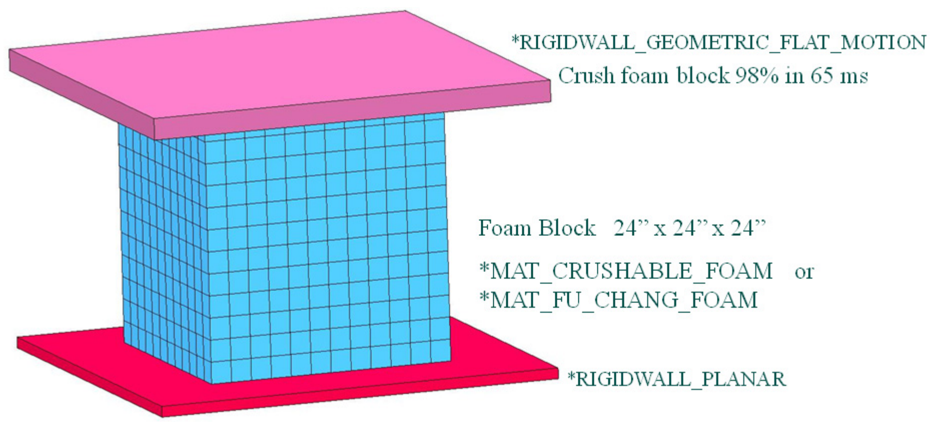

Figure 4. Simplified Model of Bogie Test

**MAT_CRUSHABLE_FOAM (*MAT_063)*

This material model is simple and effective for axial crush of foam. However, it does not capture rebound, as shown in Figure 5. Details using this material was report on previously by the authors [2].

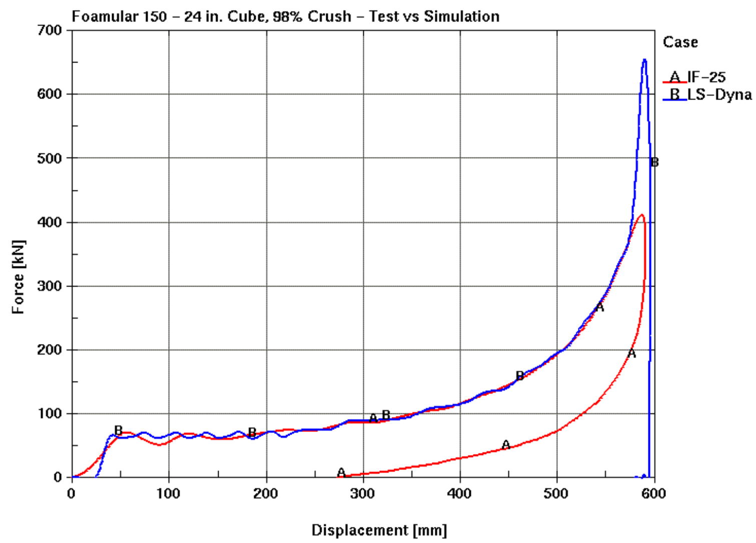

Figure 5. Crushable Foam does not Capture Rebound

**MAT_FU_CHANG_FOAM (*MAT_083)*

This material model is a bit more complicated than the crushable foam. However, it was able to capture rebound (unloading) of the foam used in the project. The model proved to be very sensitive to the pressure cutoff value (tc) and the damping constant (damp). Stress versus volumetric strain data requires a table of input, with a minimum of 3 curves: one for unloading, one for static crushing and one for dynamic crushing at some specified strain rate. Data from different strain rates may also be inputted, if available. The curves used in this study are shown in Figure 6.

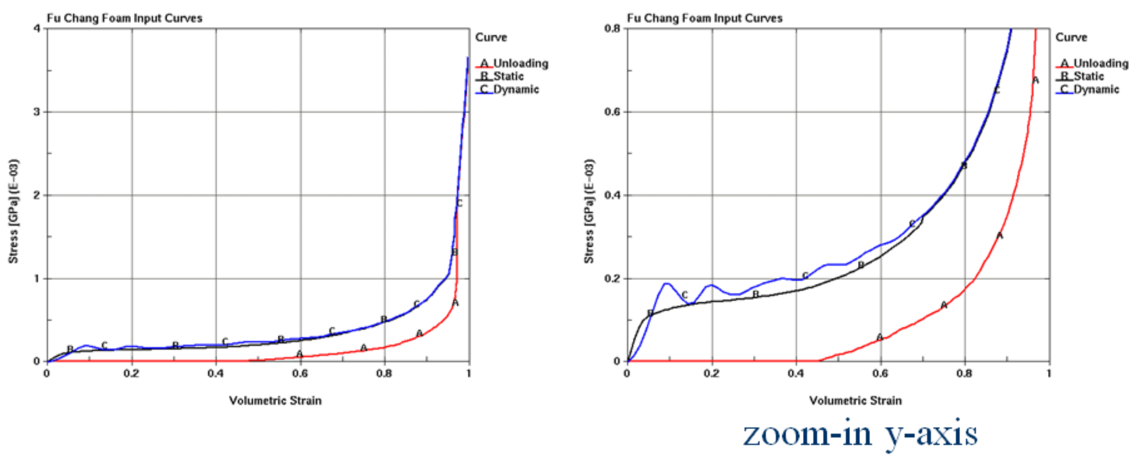

Figure 6. Fu Chang Foam Input Curves

Trapezoidal Testing versus Simulation

Once material properties were determined for the foam models, they were used in simulating bogie test IF-45; results are shown in Figures 7 and 8. Results after the end of the impact (i.e., after rebound) are shown in Figure 7; where it is seen that the Fu Chang foam recovers nearly to its original shape, just like the Foamular 150 foam does. Both models match the crushing portion of the test fairly well, as shown in Figure 8. But again, the rebound is only captured by the Fu Chang foam.

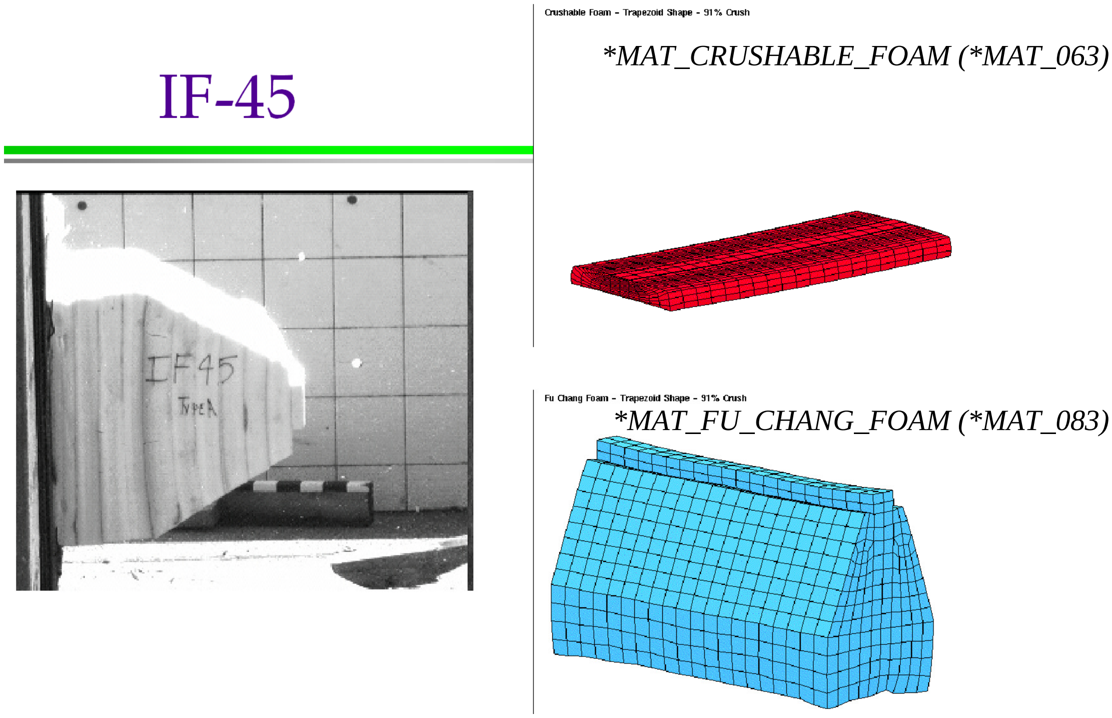

Figure 7. Trapezoidal Crush after Rebound

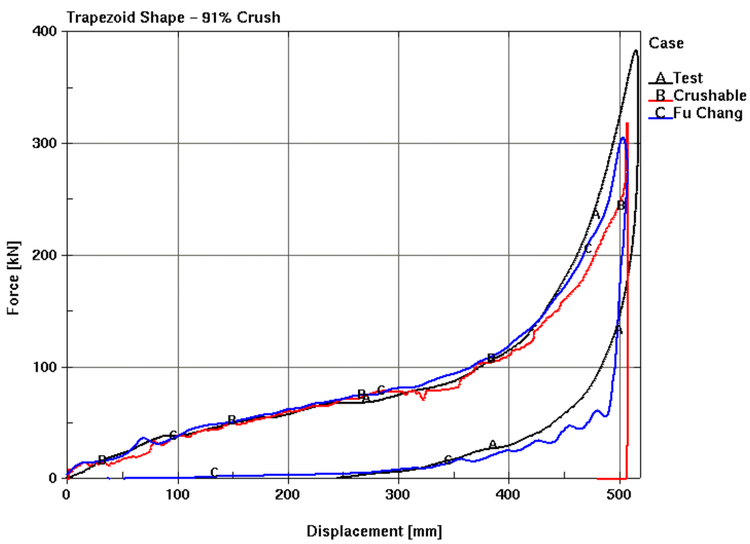

Figure 8. Test versus Simulation for Trapezoidal Test IF-45

***CONTACT_INTERIOR**

When crushing of foam is not predominantly axial, the simulation often becomes more unstable at high crush. Although the overall volume of an element may remain reasonable, one corner can be inverted (e.g., an edge going to zero length and beyond), causing a negative volume. Even though the stress-vol. strain for the foam stiffens at high compression, sometimes that is not enough to prevent the negative volume. Using *CONTACT_INTERIOR can sometimes alleviate the problem.

However, using *CONTACT_INTERIOR may affect the simulation. At 90% crush, the interior contact begins to dominate the F-d behavior of the foam – left side of Figure 9, which compares test IF-25 to simulation results without and with *CONTACT_INTERIOR.

The energy involved in the interior contact is recorded as global internal energy in the glstat file. This energy does not show up in the material (part) internal energy as reported in the matsum file. The interior contact energy is recoverable (behaves as linear elastic spring). The right side of Figure 9 demonstrates the above statements showing results from the model with *CONTACT_INTERIOR included.

Cross section forces do NOT pick up (record) the interior contact forces.

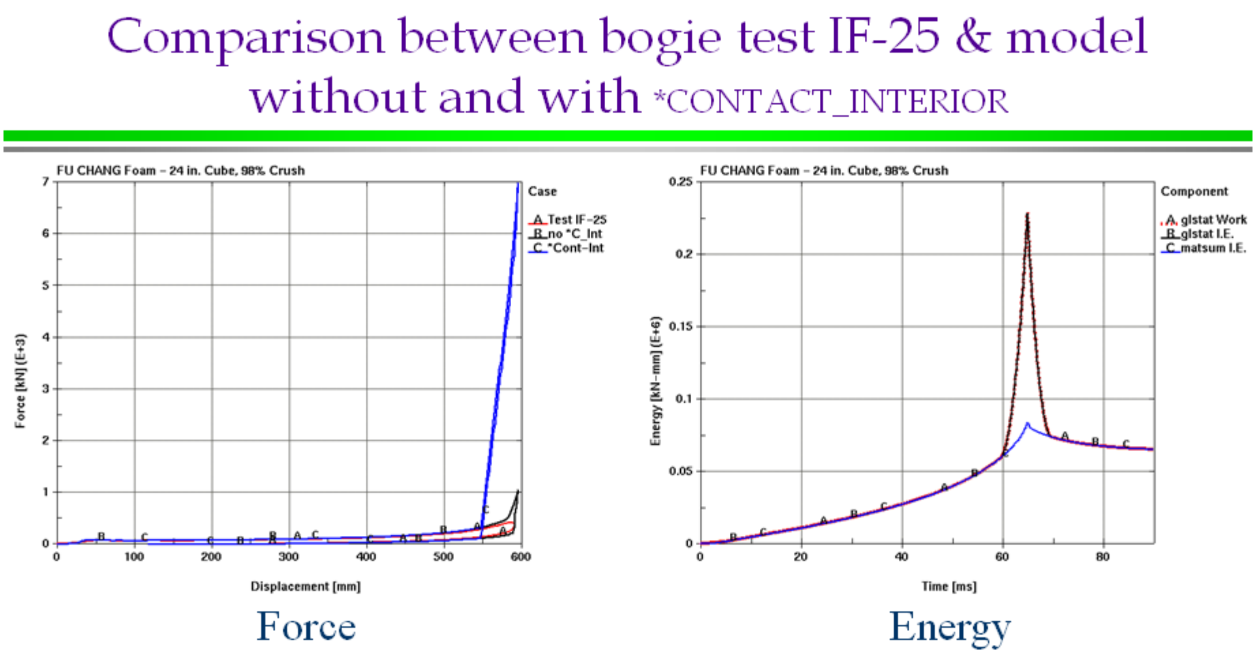

Figure 9. Contact Interior Example

Acknowledgments

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