



## Locomotive Crashworthiness Research

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Washington, DC 20590

### Volume 4: Additional Freight Locomotive Calculations

Research and  
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Cambridge, MA 02142-1093

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13. ABSTRACT (Maximum 200 words)  Previously developed computer models (see volume 1) are used to carry out additional calculations for evaluation of road freight locomotive crashworthiness. The effect of fewer locomotives (as would be expected after transition from DC motor to higher-traction AC motor locomotives) is investigated and found to benefit cab crashworthiness to the same degree as would incorporation of high strength collision posts in head-on collisions at 30 mph closing speed. The effects of cab structure improvements are also investigated for higher closing speeds. The combination of high strength collision posts with an interlocking anticlimber appears to preserve survivable cab volume at closing speeds up to 45 mph, as compared with 30 mph for a structure meeting the minimum current industry specifications, in a head-on collision when override occurs. For closing speeds of 60 mph and greater, some type of crash refuge would be required to protect the crew from severe injury or death due to secondary impact with cab interior fixtures.				
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## PREFACE

In September 1992, the Congress passed Public Law 102-365, the Railroad Safety Enforcement and Review Act, which required, in part, that the Secretary of Transportation conduct research and analysis to consider the costs and benefits of several types of crashworthiness improvement features.

This report is the fourth of four volumes on the crashworthiness of the cab area in existing road freight locomotives. Volume 1 covers model development and validation. Volume 2 covers the representation of proposed crashworthiness features, evaluation of their effectiveness in limiting cab intrusion, and evaluation of their influence on occupant survivability. Volume 3 discusses the pros and cons, and summarizes the estimated costs versus benefits, for each of the represented crashworthiness improvement features. The work was carried out by Arthur D. Little, Inc., under contract to the Volpe National Transportation Systems Center, from March 1, 1995, to May 15, 1995. The work was conducted as part of the Center's support to the Office of Research and Development, Federal Railroad Administration. This volume extends the modeling to additional effects, and the analysis to higher closing speeds.

During the course of study, further work was assigned to provide for evaluation of the crashworthiness of the cabs in control cars used in passenger service. The work on control car cabs will be published as a separate report.

# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC

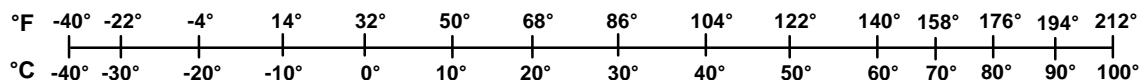
## METRIC TO ENGLISH

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<p><b>AREA (APPROXIMATE)</b></p> <p>1 square inch (sq in, in<sup>2</sup>) = 6.5 square centimeters (cm<sup>2</sup>)</p> <p>1 square foot (sq ft, ft<sup>2</sup>) = 0.09 square meter (m<sup>2</sup>)</p> <p>1 square yard (sq yd, yd<sup>2</sup>) = 0.8 square meter (m<sup>2</sup>)</p> <p>1 square mile (sq mi, mi<sup>2</sup>) = 2.6 square kilometers (km<sup>2</sup>)</p> <p>1 acre = 0.4 hectare (he) = 4,000 square meters (m<sup>2</sup>)</p>	<p><b>AREA (APPROXIMATE)</b></p> <p>1 square centimeter (cm<sup>2</sup>) = 0.16 square inch (sq in, in<sup>2</sup>)</p> <p>1 square meter (m<sup>2</sup>) = 1.2 square yards (sq yd, yd<sup>2</sup>)</p> <p>1 square kilometer (km<sup>2</sup>) = 0.4 square mile (sq mi, mi<sup>2</sup>)</p> <p>10,000 square meters (m<sup>2</sup>) = 1 hectare (ha) = 2.5 acres</p>
<p><b>MASS - WEIGHT (APPROXIMATE)</b></p> <p>1 ounce (oz) = 28 grams (gm)</p> <p>1 pound (lb) = 0.45 kilogram (kg)</p> <p>1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)</p>	<p><b>MASS - WEIGHT (APPROXIMATE)</b></p> <p>1 gram (gm) = 0.036 ounce (oz)</p> <p>1 kilogram (kg) = 2.2 pounds (lb)</p> <p>1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons</p>
<p><b>VOLUME (APPROXIMATE)</b></p> <p>1 teaspoon (tsp) = 5 milliliters (ml)</p> <p>1 tablespoon (tbsp) = 15 milliliters (ml)</p> <p>1 fluid ounce (fl oz) = 30 milliliters (ml)</p> <p>1 cup (c) = 0.24 liter (l)</p> <p>1 pint (pt) = 0.47 liter (l)</p> <p>1 quart (qt) = 0.96 liter (l)</p> <p>1 gallon (gal) = 3.8 liters (l)</p> <p>1 cubic foot (cu ft, ft<sup>3</sup>) = 0.03 cubic meter (m<sup>3</sup>)</p> <p>1 cubic yard (cu yd, yd<sup>3</sup>) = 0.76 cubic meter (m<sup>3</sup>)</p>	<p><b>VOLUME (APPROXIMATE)</b></p> <p>1 milliliter (ml) = 0.03 fluid ounce (fl oz)</p> <p>1 liter (l) = 2.1 pints (pt)</p> <p>1 liter (l) = 1.06 quarts (qt)</p> <p>1 liter (l) = 0.26 gallon (gal)</p> <p>1 cubic meter (m<sup>3</sup>) = 36 cubic feet (cu ft, ft<sup>3</sup>)</p> <p>1 cubic meter (m<sup>3</sup>) = 1.3 cubic yards (cu yd, yd<sup>3</sup>)</p>
<p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(x-32)(5/9)] \text{ } ^\circ\text{F} = y \text{ } ^\circ\text{C}</math></p>	<p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(9/5)y + 32] \text{ } ^\circ\text{C} = x \text{ } ^\circ\text{F}</math></p>

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## 1. INTRODUCTION

A program has been conducted to investigate freight locomotive crashworthiness. The effort included the development and validation of computer programs to simulate train-to-train collisions and the secondary impact of an occupant with the interior of the cab [1], [2]. The objective of the research was to determine the extent to which practical benefit could be provided for the crew by implementing various crashworthiness features over those currently specified in the industry standard, S-580 (see appendix). These features included stronger collision posts, uniform sill heights, anticlimbers, and crash refuges. Several concepts were identified for each feature and, for the most promising of these, preliminary designs were derived, including estimates of cost and weight. Calculations were conducted with the computer models to evaluate the degree of occupant survivability each provided [2], [3]. A single crash scenario was used as the simulated test to compare the effectiveness of a locomotive that included the various concepts to the baseline locomotive, which just satisfied S-580 (i.e., with no margin of extra strength). The scenario involved a 30 mph closing speed collision between a two-locomotive consist and a five-locomotive consist.

The results of this work suggested that a stronger collision post concept that includes a requirement of substantial ductility was one of the most practical ways of substantially improving locomotive crashworthiness. An interlocking anticlimber concept, intended to prevent override, also appeared to be effective in improving crashworthiness. However, questions were raised about the effects of underframe bending during a head-on impact that could render such a concept practically ineffective. Finally, there was some interest in determining the predictions of the model at closing speeds higher than 30 mph, and in assessing the effects of having fewer locomotives in the consist - a trend expected with the current introduction of alternating current (AC) locomotives.

The results of the effort reported here suggest that the interlocking anticlimber feature provides greater protection to the crew even when underframe bending is included in the model. However, the additional benefit provided over that given by the stronger collision post concept depends on the vertical offset between the neutral axes of the colliding underframes. In addition, there is still some question about how difficult and expensive it will be to engineer and build the interlocking anticlimber. Results also show that the tendency for underframe interaction is increased as closing speed increases, even without a deliberate interlocking mechanism, because of the increasing role that locomotive body rotational inertia plays. Finally, decreasing the number of locomotives in a consist can have as dramatic an effect on improving crashworthiness as implementing new concepts.



## 2. THE EFFECT OF FEWER LOCOMOTIVES

The introduction of AC motor technology expected over the next few years will reduce the number of locomotives required to pull the same load. It is logical to inquire whether a fleet with fewer lead locomotives on average will reduce the consequences of train-to-train collisions. The previous work [1] showed that only the heavier, structurally stronger locomotives and not the trailing vehicles need be modeled to evaluate the degree of crush and the crash pulse that will occur in the lead locomotive in a head-on collision between two trains. Furthermore, crush was shown to increase significantly as more locomotives of the same mass and strength are added to the consist. This result alone suggests that fewer locomotives will mitigate the consequences of a collision.

However, to illustrate this in the context of previous calculations, a simulation was run for which direct comparison could be made to the baseline crash scenario used in the previous analyses. The baseline crash scenario involved a two-locomotive consist traveling at a speed of 21 mph colliding with a five-locomotive consist traveling in the opposite direction at a speed of 9 mph. The predicted cab crush in this case, for a locomotive just satisfying S-580, was 8 ft, which corresponds to loss of survivable cab space. The reduced locomotive consist was derived from the baseline configuration by removing the second locomotive in the two-locomotive consist and the fourth and fifth locomotives in the five-locomotive consist. All other masses, dimensions, and spring and crush properties were kept the same. The amount of predicted cab crush for this latter case is just 1.2 ft as listed in table 2-1. Also listed in table 2-1 is the amount of predicted cab crush for the case corresponding to the baseline crash configuration - seven locomotives total - in which the lead locomotives are simulated to have collision posts whose strength is four times that currently required by S-580. The cab crush for this case is also low at 1.3 ft.

Thus, the model predicts, in essence, that, using the baseline crash scenario derived in the previous calculations for which there were a total of seven locomotives, removing three locomotives has the same effect on cab crush as implementing the strong collision post concept.

**Table 2-1. Collision Post Crush for Various Locomotive Consist Configurations and Collision Post Strengths**

Consist Configuration	Closing Speed (mph)	Collision Post Crush (ft)
2 locos/5 locos	30	8.0
1 loco/3 locos	30	1.3
2 locos/5 locos and strong collision posts	30	1.2

### 3. THE EFFECT OF HIGHER CLOSING SPEEDS

Nearly all of the collision dynamics and occupant survivability calculations conducted previously were for a closing speed of 30 mph using the baseline crash scenario and configuration; one analysis was conducted for a closing speed of 43 mph. Evidence for improved crashworthiness was based on the 30 mph collision, for example, the reduced crush provided by stronger collision posts (table 2-1). Of interest are the predictions of the models for higher closing speeds, both in terms of the predicted improvement with alternative crashworthiness concepts and in terms of overall collision response.

#### 3.1 COLLISION DYNAMICS CALCULATIONS

These higher closing speed collision calculations were conducted for a configuration different from the baseline case. Namely, the configuration used corresponds to the higher, 43 mph closing speed collision involving a single locomotive traveling at 24 mph and a three-locomotive consist traveling in the opposite direction at 19 mph; this configuration is designated as scenario C in [1]. Furthermore, the lead locomotive onto which override is initiated in this case - which was in the 19 mph consist - was simulated to have collision posts whose peak strength was 800,000 lbf each at 30 inches above the deck; this is four times that required by S-580.

The resulting plot of short hood structure/collision post crush vs. closing speed exhibits a peak in crush, as shown in figure 3-1; the ratio of the two consist speeds was maintained constant in this case. The cause of the peak crush, which is less than the 6 ft of crush that corresponds approximately to elimination of survivable space, is the effect of locomotive body rotational inertia. (See volume 1 for definition of collision post crush.) This inertia, which becomes dominant as closing speed increases, prevents significant pitching motion - and, hence, override - from occurring before there is substantial crush of the underframe, whose energy absorbing capability is simulated to be far greater than that of the short hood/collision post structure. The underframe crush vs. closing speed, also shown in the figure, reflects this.

The important implication of this predicted behavior is that greater deformation of the underframes is likely at higher closing speeds, even in the absence of an interlocking anticlimber, provided the colliding underframes are at approximately the same height. However, as discussed in section 4, it is unlikely that the predictions of the model, as used for the development of figure 3-1, are accurate at the higher closing speeds because of underframe bending effects.

Higher closing speed calculations were also conducted for the original baseline configuration - that is, the two-locomotive consist colliding with the five-locomotive consist - in which the collision posts in the lead locomotives were simulated to also have a strength of 800,000 lbf each at 30 inches above the deck. The results, shown in figure 3-2, reflect the previously calculated 1.2 ft of short hood structure/collision post crush at a closing speed of 30 mph. Computations at higher closing speeds show that the survivable cab volume is consumed at a closing speed of about 40 mph for this configuration. This represents an increase in closing

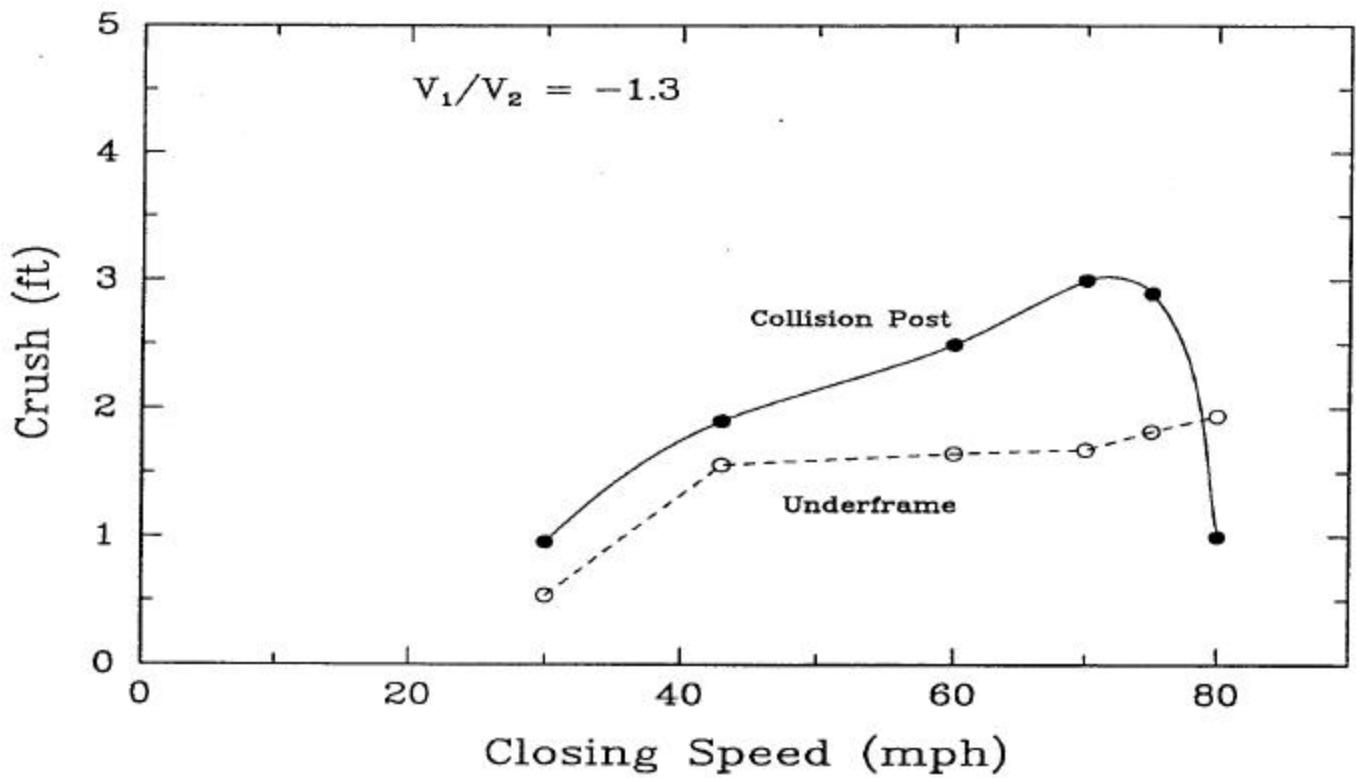
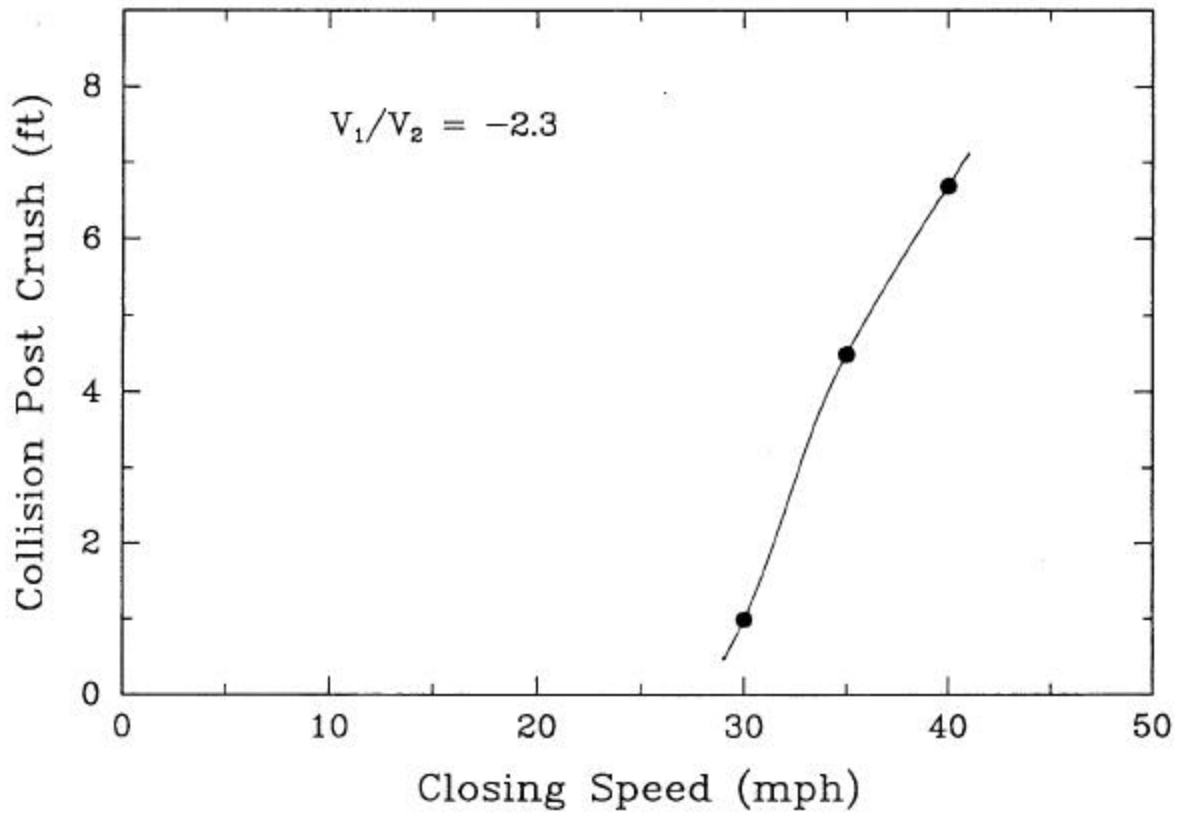


Figure 3-1. Collision Post Crush vs. Closing Speed for a 3/1 Locomotive Configuration;  
Collision Post Strength = 800,000 lbf at 30 Inches (each)



**Figure 3-2. Collision Post Crush vs. Closing Speed for the Strong Collision Post Concept;  
5/2 Locomotive Configuration**

speed at which survivable volume of about 10 mph over that predicted to be provided by a locomotive whose collision posts just satisfy S-580 remains.

### 3.2 OCCUPANT SURVIVABILITY CALCULATIONS

Several occupant survivability calculations were conducted for the simulations whose crush results are depicted in figure 3-1. These were carried out using the Articulated Total Body (ATB) model, described in [2], which models the occupant as a series of connected masses and calculates the forces and accelerations to which this occupant is subjected during a collision.

As before, simulations were run for the occupant lying face down, prone, in the rear of the cab, in four different positions. The occupant survivability measures, also described in [2], were averaged for these four runs and are reported in table 3-1 for three closing speeds. Also reported in table 3-1 are the results for an occupant sitting in one of the seats with his or her back toward the front of the locomotive; this represents one of the crash refuge concepts studied [2], [3].

The results show that the survivability measures are quite unfavorable for the prone positions when the collision occurs at a closing speed of 60 mph. A Head Injury Criterion (HIC) = 1000 and a Resultant Chest Acceleration ( $C_R$ ) = 60 are the federal limits for the 30 mph impact test required for automobiles sold in the U.S. They correspond approximately to 45% and 55% probabilities of experiencing a particular type of severe injury as described in [2]. Note that the model was unable to adequately simulate the severe deformation associated with occupant collisions at the closing speed of 80 mph for the prone positions.

On the other hand, the occupant survivability measures are relatively low for an occupant seated facing the rear for both the 60 and 80 mph closing speed collisions; an HIC = 586 and a  $C_R$  = 72 correspond to probabilities of 25% and 60%, respectively, of experiencing the particular type of severe injuries. A better design of the seat would likely reduce the  $C_R$  even further. We note that the calculation for the seated occupant in the 80 mph closing speed collision resulted in a recoil action; however, the survivability measures for this impact are estimated to be less than those reported, which correspond to the primary impact.

We note in closing this section that as peak locomotive collision accelerations increase, there is a point at which connections between superstructure equipment and the underframe will fail, allowing the equipment to move toward the cab, possibly crushing it from behind.

**Table 3-1. Occupant Survivability Measures for High Speed Collisions**

<b>Closing Speed (mph; <math>V_2/V_1 = 2.3</math>)</b>	<b>Occupant Configuration</b>	<b>Peak Locomotive Acceleration (g's)</b>	<b>HIC (g's)</b>	<b>C<sub>R</sub> (g's)</b>	<b>Comments</b>
43	Prone (4 positions)	10	766	46	–
60	Prone (4 positions)	21	2834	90	Occupant became airborne and cleared front console in one case
80	Prone	32	–	–	Model does not converge
60	Rotated Seat	21	110	27	–
80	Rotated Seat	32	586	72	Occupant thrown toward rear during latter part of crash pulse

#### 4. THE EFFECT OF UNDERFRAME BENDING

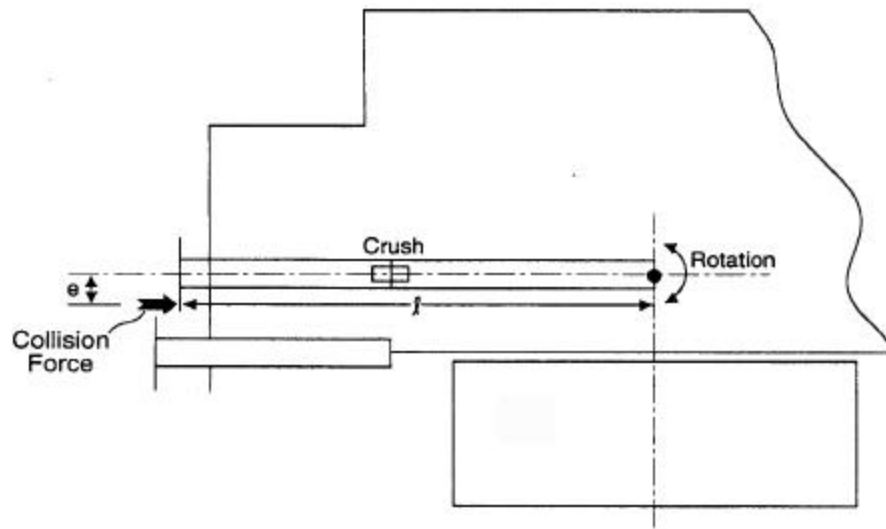
One of the primary concerns in evaluating the interlocking anticlimber concept was the possibility of underframe bending, which was not included in the previous model calculations. In fact, the previous model was based on the assumption that the neutral axes of the two underframes were at the same height and that only axial crush of the underframes could occur. We recognized that it is extremely unlikely for two underframes to load each other perfectly symmetrically through their neutral axes during a collision. Underframes are situated at different heights for different models and manufacturers; and asymmetries arise from stack-up tolerances, wheel wear, and dynamic vertical motions just prior to the collision. As a result, there will be some bending component of the load into the underframes. In addition to including this effect in the model, there was also interest in investigating the model predictions for the interlocking anticlimber at higher closing speeds than the 30 mph value used previously.

The collision dynamics model was first modified to allow underframe bending about a point on the underframe located a distance  $l$  from the tip of the anticlimber, as illustrated in figure 4-1 a. The anticlimber/underframe element up to this point is forced to remain straight, although axial (linear) crush can occur in this bending element. The bending moment/rotation angle relationship used for the bending element is shown in figure 4-1b. This curve is an idealization meant to represent the attainment of a plastic collapse moment, whose magnitude was derived from calculations for actual freight locomotive underframes [1].

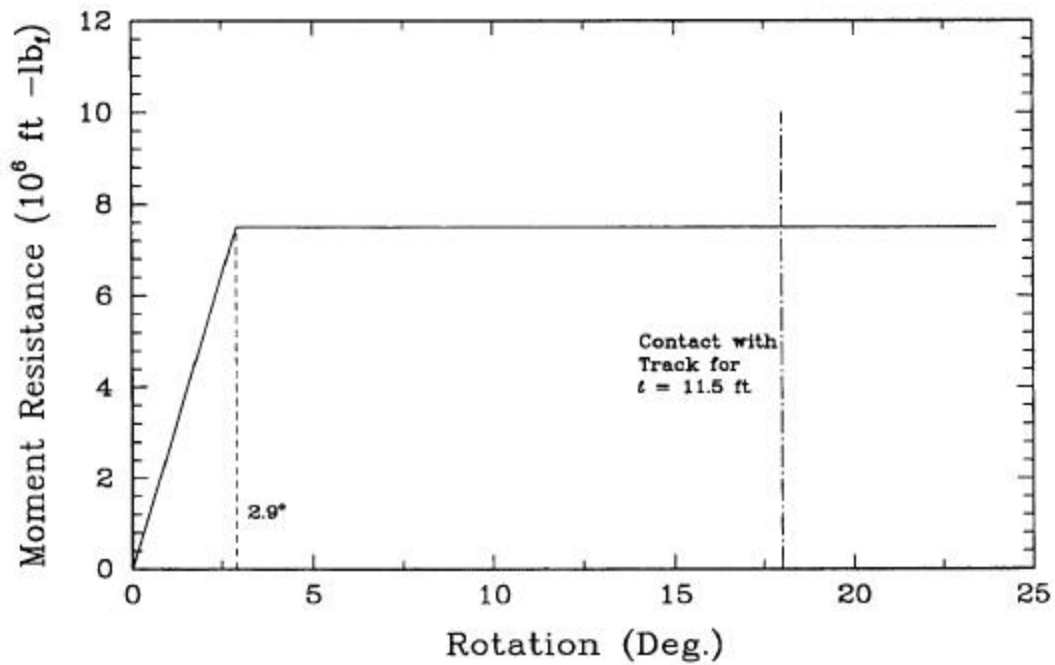
The moment-rotation curve depicted in figure 4-1 b applies for either upward or downward rotation. The vertical dashed line drawn in the figure represents the approximate limit of downward rotation at which the underframe or its attached components would contact the track for  $l = 11.5$  ft (for rotation at the bolster).

In the calculations reported below, only the underframe of one of the lead locomotives was permitted to bend; we assumed that there would be enough difference between impacting underframes to preferentially induce bending in one of the underframes over the other. The non-bending underframe was simulated to maintain contact with the bending underframe for the entire simulation. In reality, such contact cannot occur indefinitely without one of the underframes overriding the other. However, we have not attempted to estimate the rotation at which override will occur, and indeed, this does not seem to be necessary as described below. Finally, an initial, vertical offset,  $e$ , between the neutral axes of the underframes was simulated as shown in figure 4-1 a; the offset was selected to induce downward rotation of the bending underframe.

The results of underframe rotation as a function of closing speed are shown in figure 4-2. These calculations were carried out with the baseline locomotive consist configurations (two-on-five), a velocity ratio of -2.3, and values of  $l = 11.5$  ft (the approximate location of the bolster) and  $e = 4$  inches (a modest offset). Substantial rotation is predicted at a closing speed just over 40 mph. The consequences of this rotation are not captured by the model in the form applied for the generation of figure 4-2; override would likely occur after some rotation and there would be some residual energy absorption capacity of the short hood/collision post structure. The exact



(a)



(b)

Figure 4-1. Illustration of the Underframe Bending Model: (a) Geometric Model; (b) Moment-Rotation Relationship



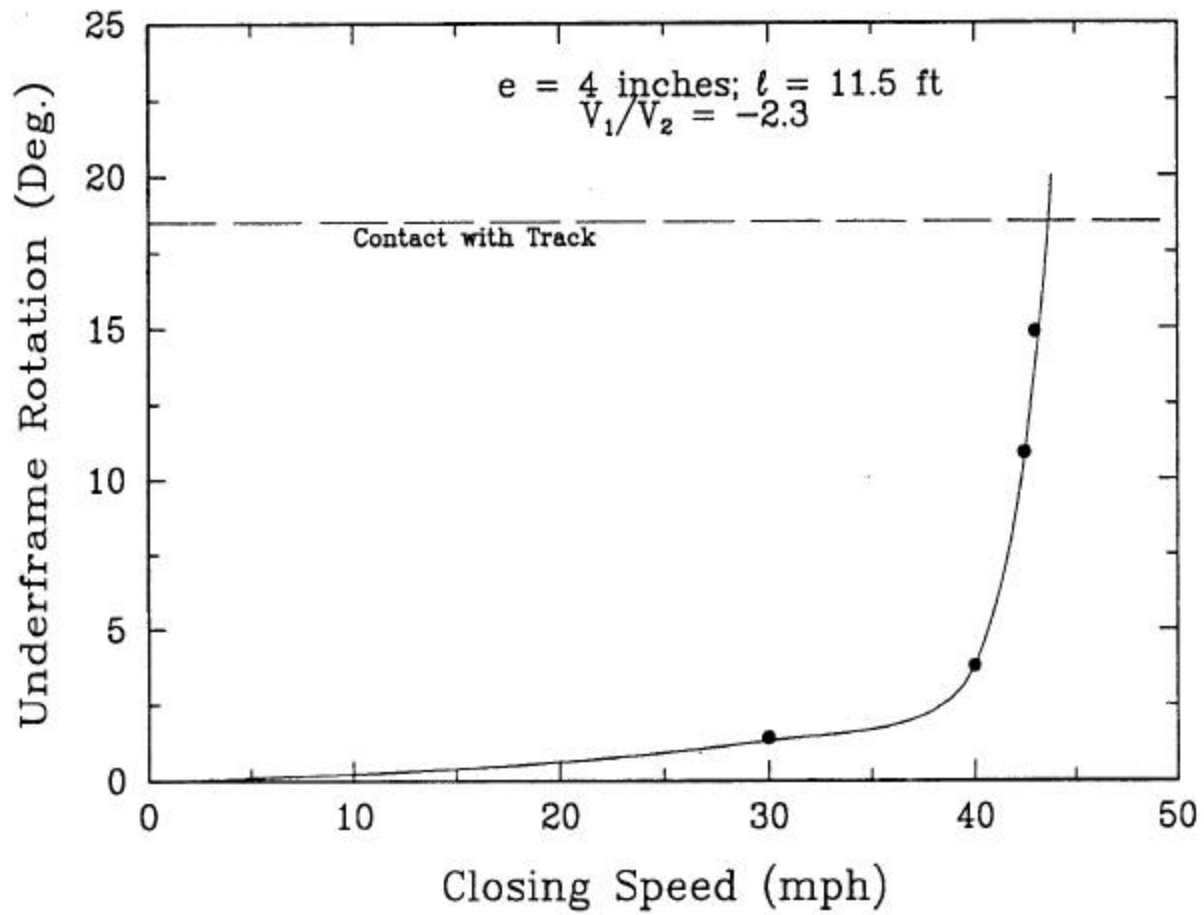


Figure 4-2. Predicted Underframe Rotation vs. Closing Speed for a Vertically Offset Interlocking Anticlimber

amount of rotation at which override would occur is probably not significant considering the steepness of the curve in figure 4-2.

It is possible to estimate the additional closing speed at which cab survivable volume would be lost by equating the energy absorbed by the collision posts to the collision energy increase associated with raising the closing speed above 40 mph. The assumption in such a calculation is that all of the added collision energy goes into crush of the collision posts; in reality some energy would be dissipated in other vehicle-to-vehicle connections.

We consider two types of collision posts - one whose strength just satisfies S-580 with a strength of 200,000 lbf, and one whose strength is 800,000 lbf - both at 30 inches above the deck. We also assume that this strength is constant for the 6 ft of crush required to eliminate survivable volume. Under these conditions, the energy that can be absorbed by crush of the two collision posts is:

- Strength = 200,000 lbf;  $E_{abs} = 2.4 \times 10^6$  ft-lbf
- Strength = 800,000 lbf;  $E_{abs} = 9.6 \times 10^6$  ft-lbf.

Collision energy is calculated from the equation,

$$E_{coll} = 0.5[m_1 m_2 / (m_1 + m_2)](V_2 - V_1)^2,$$

where  $m_1$ ,  $m_2$  and  $V_1$ ,  $V_2$  are the masses and velocities of the two consists. This equation is used to determine the closing speed at which the added collision energy equals the energy absorbed by the collision post:

$$E_{coll}(V_2 - V_1) - E_{coll}(40 \text{ mph}) = E_{abs}.$$

With this equation we find that the closing speed needed to crush the collision posts 6 ft is:

- Strength = 200,000 lbf, AV = 41.5 mph
- Strength = 800,000 lbf, AV = 45.9 mph.

This calculation, which is approximate, suggests that there would be little increase in closing speed capacity for collision posts that just satisfy S-580, but there would be a 10% increase if the collision posts had a strength four times greater than that required by S-580 (with the associated ductility requirement).

The results of the underframe rotation, and hence the closing speed at which loss of survivable volume will occur, are influenced by the selection of the parameters  $e$  and  $e$  in the bending model. Figure 4-3 shows some results for the following combinations: (1)  $e = 4$  inches,  $e = 2.7$  ft, which corresponds to rotation about a point located at the very front of the short hood; (2)  $e = 8$  inches (a large vertical offset) and  $l = 11.5$  ft. A decrease in  $e$ , keeping  $e$  the same, has the effect

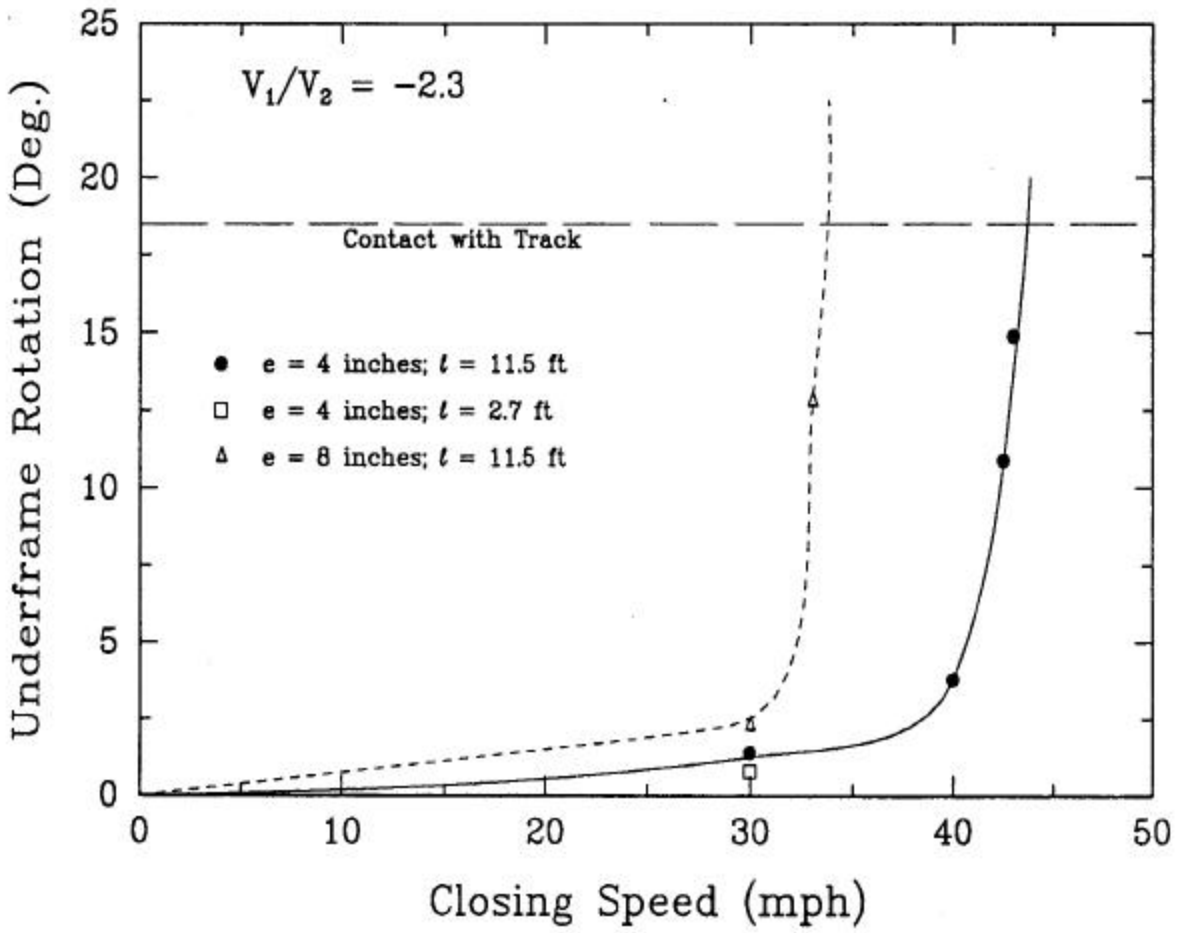


Figure 4-3. Predicted Underframe Rotation vs. Closing Speed for Different Values of  $e$  and

of increasing the "critical" closing speed. On the other hand, the two-fold increase in  $e$ , keeping  $e$  the same, reduces the "critical" speed at which survivable space is lost by about 7 mph compared to the combination of  $e = 4$  inches,  $l = 11.5$  ft. In other words, the benefit provided by the interlocking anticlimber is reduced as the vertical offset between underframe neutral axes is increased.

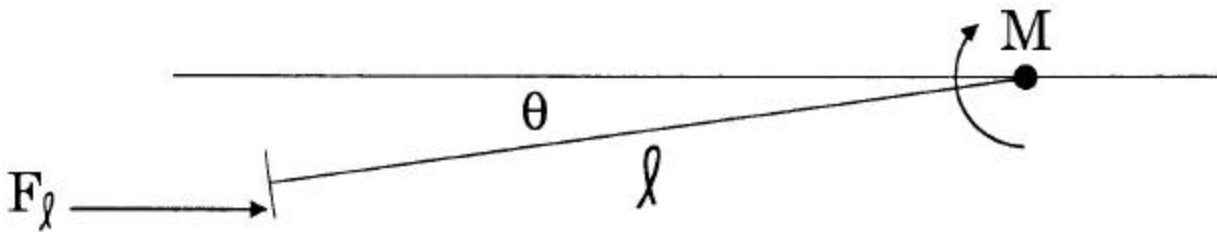
Finally, the underframe bending model can be used to provide a basis for the vertical restraint requirement; by vertical, we mean perpendicular to the longitudinal axis of the underframe. Using the illustration shown in figure 4-4, the vertical, or perpendicular, force on the tip of the underframe element, needed to ensure that the collapse moment is achieved, is given by,

$$F_v = F_l \sin \theta = M_p/l \text{ (for small rotations).}$$

Thus, for  $M_p = 7.5 \times 10^6$  ft-lbf,  $l = 11.5$  ft,

$$F_v = 650,000 \text{ lbf.}$$

This value is considerably larger than the current 200,000 lbf vertical strength requirement included in S-580. We believe that the practical requirement for vertical strength of an interlocking anticlimber would exceed 200,000 lbf, but a precise value cannot be stated because frictional resistance may contribute a significant amount of the needed vertical restraint.



**Figure 4-4. Illustration of the Load Diagram Used to Estimate Interlocking Anticlimber Vertical Strength Required**

## 5. DISCUSSION

One of the primary objectives of the additional calculations reported in this volume was an assessment of the closing speed at which loss of survivable volume is predicted for a particular train configuration in a head-on collision. Figure 5-1 provides a summary of the key results and shows the predicted short hood structure/collision post crush as a function of closing speed for three structural configurations:

1. A locomotive that just satisfies S-580 (that is, collision posts whose strength at 30 inches above the deck is 200,000 lbf each and has no deliberate interlocking anticlimber).
2. A locomotive whose collision posts have an ultimate strength of 800,000 lbf sustained over 6 ft of crush, but which contains no deliberate interlocking anticlimber.
3. A locomotive with the 800,000 lbf collision posts and a deliberate interlocking anticlimber challenged at a vertical offset of 4 inches and with a bending moment arm of 11.5 ft.

There are, of course, a number of important assumptions associated with the calculations on which the results in figure 5-1 are based. These include the particular configuration, five locomotives colliding with two locomotives with a speed ratio of -2.3, and a constant load-crush curve for the short hood structure/collision posts.

Nevertheless, the model suggests that providing a locomotive with the stronger collision posts raises the closing speed at which loss of survivable volume occurs by about 10 mph over that provided by a locomotive that just satisfies S-580. Furthermore, an additional, comparable increase in this closing speed is achieved by forcing the underframes to interact through an interlocking anticlimber device. Together, the concepts of strong collision posts and interlocking anticlimber are predicted to raise the closing speed at which loss of survivable volume occurs by about 15 mph, from about 30 mph, for the locomotive simulated to just satisfy S-580, to 45 mph, for the simulated concept locomotive.

This last prediction depends strongly on the vertical offset between the colliding underframe neutral axes, which determines the extent of bending that will occur. The results of the underframe bending model calculations suggest that the interlocking anticlimber provides more benefit the closer the underframe neutral axes are. However, it must be recognized that a requirement for uniform sill heights will not guarantee zero offset between the underframe neutral axes.

A question that remains is how difficult it is to design the underframe to ensure that it can carry the peak collision loads predicted by the model for the interlocking anticlimber. While some estimate of this was made in the previous study [2], the crush behavior is difficult to predict for such localized loads on this structure, which is relatively complex compared to collision posts, for example.

As survivable volume is maintained for higher closing speeds by implementation of the crashworthiness concepts, there is an increase in the potential severity of secondary impact between the occupants and the interior of the cab. In fact, the model predictions suggest that for

an occupant who rides down the collision in a prone, face-down position in the back of the cab, there is a relatively high probability of sustaining a severe injury at the maximum closing speed - about 45 mph - at which the strong collision post and interlocking anticlimber concepts provide protection for the configuration studied. Therefore, it appears that some type of crash refuge would be required to minimize this injury potential at the higher closing speeds.

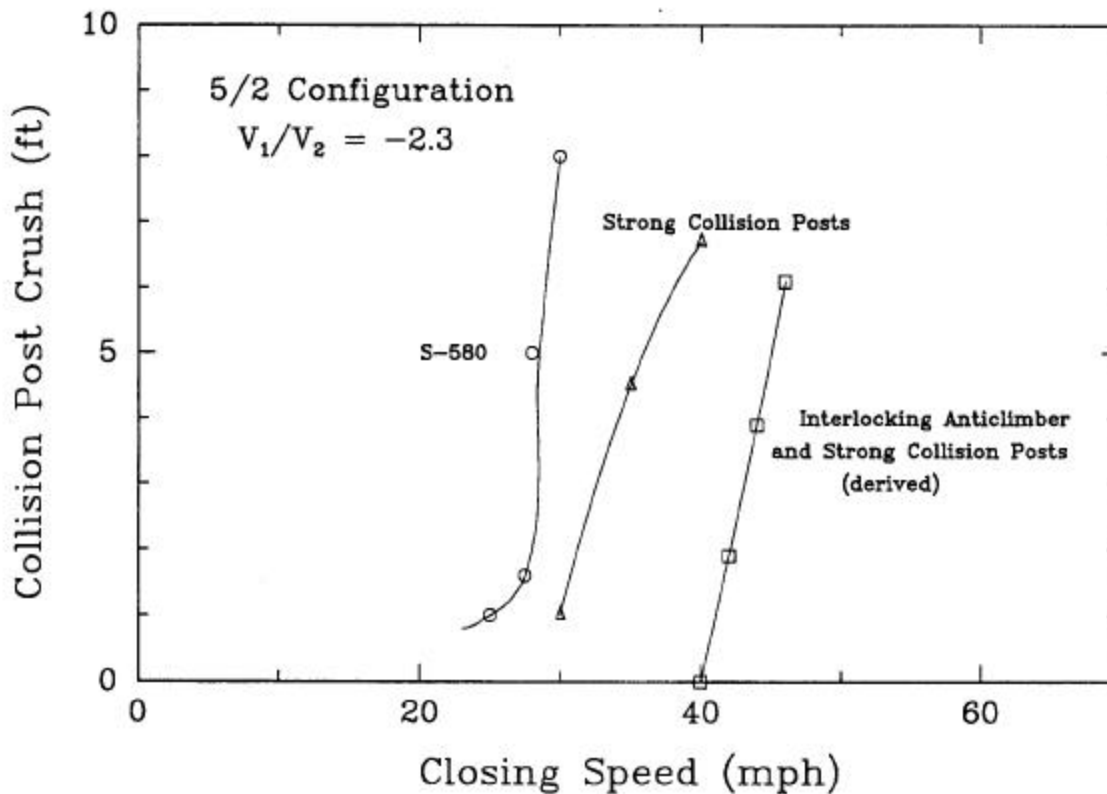


Figure 5-1. Summary of Collision Post Crush vs. Closing Speed Results

## 6. CONCLUSIONS

A number of conclusions can be drawn from these additional calculations on freight locomotive crashworthiness:

- Decreasing the number of lead locomotives, as is anticipated to occur with the introduction of AC motor technology, dramatically mitigates the consequences of head-on collisions.
- The closing speed at which survivable cab volume is eliminated is increased by approximately 10 mph, with respect to a locomotive that just satisfies S-580, by use of collision posts whose strength is four times that currently required by S-580 and whose minimum strength is maintained for substantial crush. The "critical" closing speed is increased from about 30 to about 40 mph for the train configuration analyzed.
- The closing speed at which survivable cab volume is eliminated is increased by approximately 15 mph, with respect to a locomotive that just satisfies S-580, by use of both the stronger collision posts and an interlocking anticlimber. The "critical" closing speed is increased from about 30 to about 45 mph for the train configuration analyzed.
- The benefit of the interlocking anticlimber is improved when the neutral axis heights of the colliding underframes are approximately the same.
- As closing speed is increased, underframes whose height is approximately the same will interact more directly, even in the absence of an interlocking anticlimber.
- Underframe bending is likely to limit the closing speed at which interacting underframes can dissipate energy.
- Secondary impact occupant survivability measures are very severe for closing speeds of 60 mph and greater unless the occupant is provided with some type of refuge.
- Accelerations of the locomotive body at closing speed collisions of 60 mph or greater may lead to failure of connections between superstructure equipment and the underframe leading to cab crush from the rear.

## APPENDIX: AAR LOCOMOTIVE DESIGN REQUIREMENTS

The Association of American Railroads (AAR) has put into effect a standard (S-580) for increasing the crashworthiness of locomotives by imposing requirements on anticlimber, collision post, and short hood structure design. The standard applies to all new road type locomotives built after August 1, 1990.

The specific requirements are listed as follows:

- ***Anticlimbers:*** An anticlimber arrangement will be standard on the short hood end of the locomotive and shall be designed to withstand a minimum of 200,000 lbs without exceeding the ultimate strength of the material, when applied vertically and uniformly between the center sill webs under the anticlimbers of the locomotive. The anticlimber arrangement shall be attached to the underframe end plate in line with the center sill web.
- ***Collision Posts:*** A minimum of two collision posts, located on the underframe longitudinals (center sills), shall be designed to withstand a longitudinal force of 200,000 lbs each at 30 inches above the deck and 500,000 lbs each at the underframe deck without exceeding the ultimate strength of the material.
- ***Short Hood Structure:*** The skin of the short hood end-facing area shall be equivalent to 1/2 in. steel plate at 25,000 psi yield strength (where thickness varies inversely with the square root of yield strength).

This end nose plate assembly shall be securely fastened to the collision posts.

Any personnel doors in the short hood end-facing area shall be suitably reinforced to the equivalent strength of the short hood skin. Any windows must meet FRA standards.



## REFERENCES

1. Mayville, R. A., R. G. Stringfellow, R. J. Rancatore, and T. P. Hosmer. 1995. *Locomotive Crashworthiness Research, Volume 1: Model Development and Validation*. Report to U.S. Department of Transportation, Volpe National Transportation Systems Center. Arthur D. Little, Inc., Cambridge, MA. DOT/FRA/ORD-95/08. 1. DOT-VNTSC-FRA-95-4. 1.
2. Mayville, R. A., R. G. Stringfellow, R. J. Rancatore, and T. P. Hosmer. 1995. *Locomotive Crashworthiness Research, Volume 2: Design Concept Generation and Evaluation*. Report to U.S. Department of Transportation, Volpe National Transportation Systems Center. Arthur D. Little, Inc., Cambridge, MA. DOT/FRA/ORD-95/08.2. DOT-VNTSC-FRA-95-4.2.
3. Mayville, R. A., R. G. Stringfellow, R. J. Rancatore, and T. P. Hosmer. 1995. *Locomotive Crashworthiness Research, Volume 3: Review and Discussion of Freight Locomotive Crashworthiness Concepts*. Report to U.S. Department of Transportation, Volpe National Transportation Systems Center. Arthur D. Little, Inc., Cambridge, MA. DOT/FRA/ORD-95/08.3. DOT-VNTSC-FRA-95-4.3.