Locomotive Crashworthiness Research

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Volume 3: Review and Discussion of Freight Locomotive Crashworthiness Concepts

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13. ABSTRACT (Maximum 200 words)

This is the third volume in a series of four that reports on a study in which computer models were developed and applied to evaluate whether various crashworthiness features, as defined in Public Law 102-365, can provide practical benefit to the occupants of freight locomotives. In particular, the benefit was assessed relative to the current industry standard, S-580. This report provides discussion on the concepts evaluated, which include: stronger collision posts, an interlocking anticlimber, three different crash refuges, a roll bar, deflection plates, shatterproof windows, and equipment to deter post-collision entry of flammable liquids. Of these features, the strong collision posts, crash refuges, and shatterproof windows appear to offer the most potential for providing practical benefit.

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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 third 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. This volume 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 January 3, 1994, to March 31, 1995. The work was conducted as part of the Center's support to the Office of Research and Development, Federal Railroad Administration. Volume 4 extends the modeling to additional effects, and the analysis to higher closing speeds.

During the course of the study, further work was assigned to provide for additional studies of selected freight locomotive crashworthiness improvement features in collisions at higher closing speeds and for evaluation of the crashworthiness of the cabs in control cars used in passenger service. The additional freight locomotive studies will appear as volume 4 of this series. The work on control car cabs will be published as a separate report.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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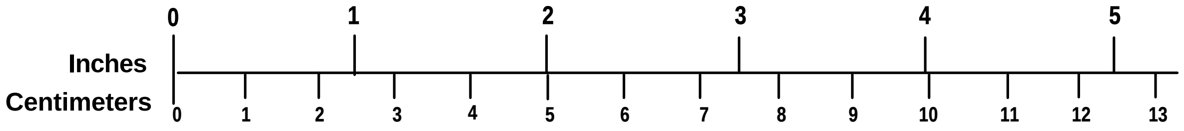
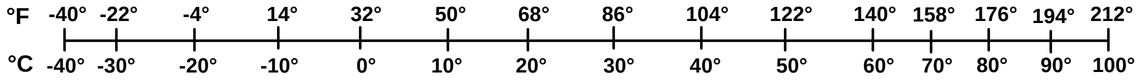


QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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1. INTRODUCTION

Arthur D. Little and its subcontractors, Arvin/Calspan and Parsons Brinckerhoff, conducted studies of locomotive crashworthiness in support of the Federal Railroad Administration's (FRA) response to Public Law 102-365. This law includes a statement that the Secretary of Transportation shall conduct research and analysis to consider the costs and benefits associated with equipping locomotives with the following crashworthiness features:

- Braced collision posts
- Crash refuges
- Rollover protection devices
- Uniform sill heights
- Deflection plates
- Anticlimbers
- Shatterproof windows
- Equipment to deter post-collision entry of flammable liquids

The Arthur D. Little team was awarded a contract to conduct engineering analyses to identify and evaluate various design concepts for the features described above. In particular, the team was asked to perform this evaluation with respect to the currently applied Association of American Railroads (AAR) industry standard, S-580, summarized in table 1-1. This standard applies to new road-type locomotives built after August 1, 1990, and has requirements for three of the features listed in the public law: anticlimbers, collision posts, and the short hood structure, which can be considered equipment to deter post-collision entry of flammable liquids.

Table 1-1. Summary of AAR's S-580 Standard on Locomotive Crashworthiness Requirements

Component	Requirement
Anticlimbers	Sustain an ultimate vertical load of 200,000 lbf at the short hood end
Collision posts	Two, each of which shall sustain an ultimate load of 200,000 lbf at 30 inches above the deck and 500,000 lbf at the deck
Short hood structure	The product of skin thickness and yield strength shall be at least 0.5 inches times 25,000 psi

The overall approach to the project included information gathering on locomotive design and crashworthiness, the development of computer models to evaluate crashworthiness, and the generation and evaluation of design concepts that could potentially improve locomotive cab survivability. No testing was included in the program. Rather, models were validated to the extent possible by comparing predicted results to actual accidents. Volume 1 [1] of the four-report series summarizes the results of the structural damage and collision dynamics model development and validation; volume 2 [2] describes the approach and results of the crashworthiness concept generation, as well as the occupant survivability model; volume 4 extends the modeling to additional effects and the analysis to higher closing speeds.

This report presents a discussion of the freight locomotive crashworthiness concepts generated in the project.

2. REVIEW OF CONCEPTS

2.1 OVERVIEW

The process for developing concepts that could potentially provide practical improvement to cab crashworthiness began by considering several concepts for each feature in Public Law 102-365. Through a process of general discussion and approximate analyses, this large list was narrowed down to one concept for each feature, which was then evaluated in great detail. The evaluation included computer modeling to determine the effect the concept had on certain occupant survivability measures for a head-on collision crash scenario. It also included estimates of cost, derived from actual vendor quotes, and weight increases, if any.

The computer model was applied to a 30 mph closing speed, head-on collision between two simulated locomotive consists; one consist had two and the other had five locomotives. This crash scenario was selected for a few reasons. Model and some actual accident results suggested that in such a collision a locomotive just satisfying S-580 would be overridden and the survivable cab volume would be lost. Therefore, such a scenario offered a means of demonstrating whether improvement in crashworthiness could be obtained. We also felt that improvements in crashworthiness for a head-on collision would translate to other collision modes, such as grade crossing accidents and rear-end collisions, in which a lead locomotive impacts the rear of another train. The baseline occupant position for this crash scenario was one in which the occupant lies face down at the rear of the cab with his or her body oriented transverse to the length of the vehicle.

Table 2-1 lists the concepts evaluated in our study, together with a summary of the evaluation data. The occupant survivability measures listed in this table are the Head Injury Criterion (HIC), the Resultant Chest Acceleration (CR), and the cab crush. The HIC is the maximum acceleration experienced by the center of gravity of the head, averaged over not more than a 36 msec interval. The maximum allowable value of this parameter in the U.S. government required 30 mph auto impact test is 1000 [2]. The **CR** is the maximum translational chest acceleration averaged over no more than a 3 msec interval and the maximum allowable value in the same auto impact test is 65. A particular value of HIC or CR actually corresponds to a probability of sustaining a severe injury as described in volume 2 [3]. For example, HIC = 1000 corresponds to a 43% probability of sustaining a linear skull fracture and/or a state of unconsciousness of less than one hour; CR = 65 corresponds to a 60% probability of sustaining various rib fractures. The amount of allowable cab crush we selected to correspond to loss of survivable volume is 6 ft. This is measured from the tip of the short hood and accounts for our expectation that various structural components and mechanical equipment will be pushed back into the cab with this crush.

The concepts that were eventually evaluated and the results of the evaluation are described in detail in volume 2 of this report series. Brief summaries of these concepts with emphasis on advantages and disadvantages are presented next.

Table 2-1. Summary of Crashworthiness Concept Evaluation Results

Concept	Description	Weight Increase*	Cost Increase*	Occupant Survivability Measures
Baseline (S-580)	Collision post strength: 200,000 lbf (each) at 30 inches Anticlimber vert. strength: 200,000 lbf Short hood: 0.5 inch x 25,000 psi yield	-	-	Peak loco accel.: 11 Crush: 8 ft HIC: 160 C_R : 20
1. Strong Collision Posts	Increase strength from 200,000 lbf/post at 30 inches to 750,000 lbf/post	0-400 lb	$1,000	Peak loco accel.: 11 g's Crush: 1 ft HIC: 330 C_R: 36
2. Rotating Refuge	Requires locking mechanism and some other protection measure in this list	300 lb	$10-15,000	Peak loco accel.: 11 g's Crush: (Depends on accompanying feature) HIC: 95 C_R: 28
3. Rotate & Drop Seat Crash Refuge	Requires locking and drop mechanism as well as some other protection measure	600 lb	$15-20,000	Peak loco accel.: 11 g's Crush: (Depends on accompanying feature) HIC: 62 C_R: 21
4. Trench Crash Refuge	Lever-action drop down floor panel in rear of cab exposes trench	400 lb	$2,000	Peak loco accel.: 11 g's Crush: (Depends on accompanying feature) HIC: 165 C_R: 15
5. Interlocking Anticlimber	Casting welded to front; replaces and also acts like anticlimber	2,000 lb	$5,000	Peak loco accel.: 15 g's Crush: 0 HIC: 925 C_R: 50

Table 2-1. Summary of Crashworthiness Concept Evaluation Results

Concept	**Description**	**Weight Increase***	**Cost Increase***	**Occupant Survivability Measures**
6. Deflection Plates	Angled plates on front of each locomotive derail one or both locomotives	2,000 lb	*$5,000*	Analysis suggests this feature is not effective
7. Roll Bar	Frame near front of cab	3,000 lb	$10,000	Not calculated
8. Shatterproof Windows	Semitempered glass/polycarbonate	Negligible	$1,000	Provides 4-5 times the impact resistance
9. Equipment to Deter Post-Collision Entry of Flammable Liquids	Shatterproof windows; opening (e.g., light) covers; doors that open out	Negligible	Negligible (currently in use)	Provides 4-5 times the impact resistance

HIC: Head Injury Criterion
C_R: Resultant Chest Acceleration

* Compare with typical weight and cost of freight locomotives:

Locomotive weight: 400,000 lb - 6 axle
260,000 lb - 4 axle
Cost: $1.5 - 2M (per new locomotive)

Notes: * 50% probability of serious injury values
* HIC: 1090
* C_R: 46
* Crush: 6 ft

2.2 BRACED COLLISION POSTS

The collision post geometry selected for analysis in this project is illustrated in figure 2-1. It is tapered in the vertical direction with a cross section that resembles a structural wide flange beam. It appears feasible to fix it in the same location as current posts; it would also be welded to the short hood structure. This geometry was found to provide a good balance between minimum weight and maximum load-deformation carrying capacity. The tapered geometry takes advantage of the need for greater bending resistance at the base than at the point of load application. A 50 ksi yield strength material was assumed here. We estimate that there is no increase in weight for this post over a post that satisfies S-580.

Details for the method of welding such a post to the underframe were not investigated. However, one possibility is to weld the proposed post web directly over the web of the primary underframe beams and to carry the post flanges through the deck for welding along the web of the underframe beam webs.

Evaluation of this concept indicated substantial improvement in protection against cab crush with a small increase in the HIC and CR values. Quotes obtained from vendors for the welded collision post structural shapes suggest a price of about $500/post. Our estimate of the differential cost over current designs, including welding to the underframe is about $1000 for both posts.

Collision posts stronger than those required by S-580 appear to offer substantial practical benefit to improving freight locomotive crashworthiness. Our results suggest that with no weight penalty and little additional cost, substantial improvement in protection against cab crush can be obtained. In addition, locomotives being built today generally have collision post strengths substantially greater than that required by S-580. For example, it is general knowledge that Canadian National requires each collision post to have a 500,000 lbf strength at 30 inches above the deck. Thus, not only do our results suggest the feasibility of equipping locomotives with collision posts stronger than that required by S-580, but it is now common practice.

We would like to point out that it is important for collision posts to sustain their load carrying capacity for a substantial amount of deformation, say three to four feet for loads applied above the deck. This ensures that a large amount of energy can be dissipated as well as transferring some of the required energy dissipation to other parts of the locomotive and consist. Current specifications for freight locomotives, both federal and AAR, do not contain such requirements.

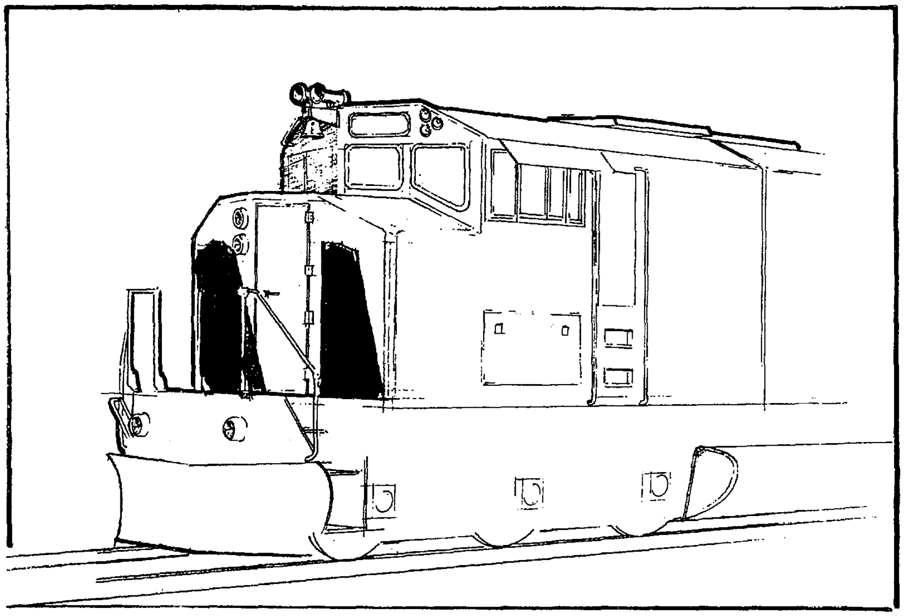

Figure 2-1 Illustration of the Stronger Collision Post Concept

2.3 ANTICLIMBER AND UNIFORM SILL HEIGHTS

An interlocking anticlimber concept was selected to address both the anticlimber and uniform sill height crashworthiness features of the public law. As described in volume 1 of this series, it is our belief, and there is accident evidence to support it, that current anticlimbers, including those satisfying S-580, are generally not effective in preventing override in head-on collisions between freight locomotives. Therefore, a more deliberate approach to prevent override was sought that would ensure the direct interaction of the underframes; we believe this was the intent of the uniform sill height feature listed in the Public Law.

The anticlimber analyzed here has the geometry depicted in figure 2-2. It is a cast piece welded to the underframe front plate that consists of integral protruding tangs such that two opposing interlocking anticlimbers would fit together and provide substantial resistance to relative vertical motion. The concept interlocking anticlimber is intended to project out beyond the front plate enough to provide protection against rising debris from grade crossing collisions and to have a small but positive engagement when two opposing locomotives are in a full buff position. This engagement in the buff position would cause no longitudinal load between anticlimbers. The anticlimber would also be designed to: (1) span less than the full width of the locomotive to ensure no load transfer during buff in curves; and (2) possess enough vertical play between the protruding tangs to accommodate wheel wear and other vertical height variations.

The evaluation results showed that there were substantial increases in the HIC and CR values, indicating that protection in the form of a crash refuge would probably be required with this feature. These results were obtained under the idealized assumption of zero offset between sill neutral axes, i.e., no underframe bending, no loss of interlocking, and no cab crush. The computer simulation results also showed that the peak longitudinal load in the underframe for the 30 mph closing speed collision was over 6,000,000 lbf. Thus, the anticlimber and supporting underframe structure would have to be designed to tolerate such high loads; it is not clear to us that current underframes could tolerate these loads locally. The increase in weight resulting from use of this interlocking anticlimber over current designs is estimated to be about 2000 lb. Quotes from vendors for a cast piece with the approximate geometry shown in figure 2-2 were roughly $5000, not including any modifications to the underframe.

Based on our analysis to date, we believe that the interlocking anticlimber does not provide practical benefit to improving freight locomotive crashworthiness. We do believe that an interlocking device does improve the chances of dissipating more energy into the underframe. However, in addition to the relatively high estimated weight increase, we are also concerned about the possibility of eccentric loading with respect to the underframe neutral axis that would result on impact because of the inevitable vertical mismatches between sills of locomotives. This could induce both local and overall bending of the underframe, possibly rendering the anticlimbing feature ineffective before a substantial amount of collision energy had been dissipated. Calculations to investigate this effect are reported in volume 4. A significant amount of engineering, analysis and, possibly, testing would be required to better establish the benefit and practicality of this feature.

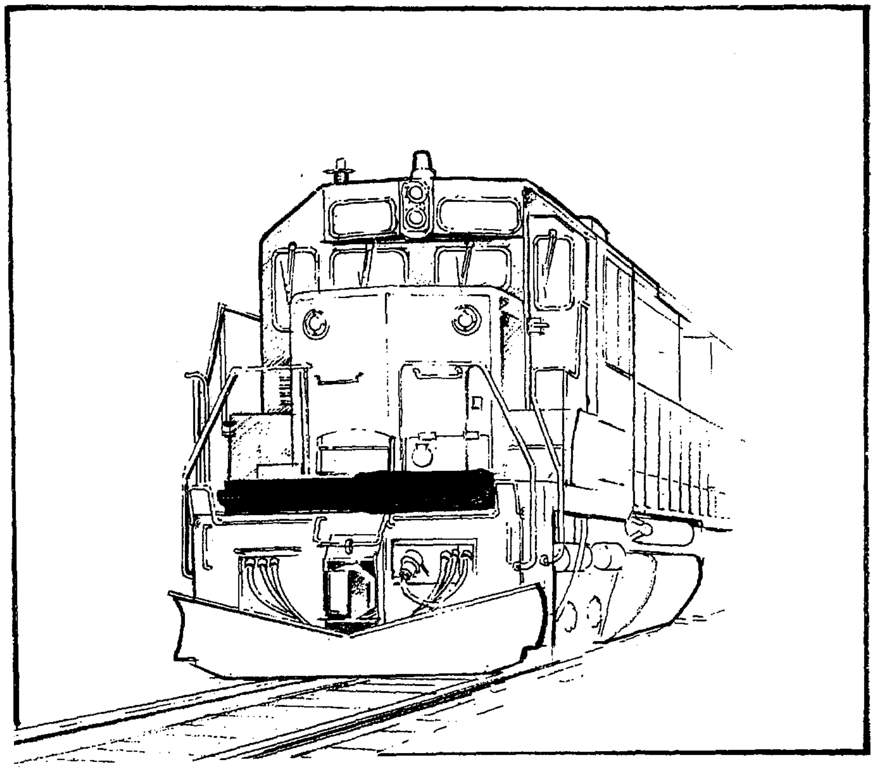

Figure 2-2. Illustration of the Interlocking Anticlimber Concept

The uniform sill height feature was included in the interlocking anticlimber concept, in part, because accident data as well as considerations on how colliding locomotives interact suggest that override can still occur even when sill heights are the same. This is primarily due, we believe, to the asymmetric deformation that is likely to occur when opposing anticlimbers contact. We believe that uniform sill height, as a concept on its own, does not provide benefit, although it may enhance the effectiveness of an interlocking anticlimber (see volume 4).

2.4 CRASH REFUGES

Three crash refuge concepts were considered for analysis in this study. The first two are related and utilize the crew member's seat as shown in figure 2-3. In both cases, protection against secondary impact is provided by rotating the seat so that the occupant can ride down the collision with his or her back to the oncoming vehicle or obstruction. Connecting the occupant to the vehicle in some manner as quickly as possible is one of the primary crashworthiness goals for passenger restraint systems in motor vehicles and aircraft. In one of the seat crash refuge concepts studied here, the seat simply rotates and locks to face aft; in the other, the seat rotates, locks, and drops in order to place the occupant closer to the floor, at which the chances of survivable volume are greater. We anticipate the need for somewhat more robust seats and a stronger seat support to absorb the shock of the collision. We believe that seat belts are not necessary to provide the basic protection against secondary impact with the rotating seat concept, even though there is likely to be some recoil action of the impact as the locomotive comes to rest. However, a seat belt would minimize the risk of injury from this event.

The third crash refuge resembles a trench. It is located at the rear of the cab and is formed when a lever is pulled and a floor panel drops down toward the front to expose a space between the cab floor level and the sill of the underframe (figure 2-4). Current locomotives include some crawl space in this area for access to various mechanical and electrical components. However, some modifications would likely be required to increase this space and to provide a resilient supported panel facing frontwards after activation.

All three of these crash refuge concepts protect the occupant against secondary impact but provide limited or no protection against crush. Thus, some other feature, such as stronger collision posts, would be required to protect the crew in the baseline crash scenario, for which a crush of 8 ft is predicted. Estimates of weight and cost increases associated with these three concepts are listed in table 2-2.

Some type of crash refuge appears to provide practical benefit for improving freight locomotive crashworthiness. A locomotive that just satisfies S-580 includes no deliberate crash refuge, so that the crew has little protection against secondary impact if they remain in the cab. All three of the refuge concepts studied here substantially reduce the HIC and CR occupant survivability measures over those that would result if an occupant is limited to the prone position in the rear of the cab in the baseline crash scenario. In addition, the costs for the three concepts investigated are not large, although there are some open questions about accommodating three crew members.

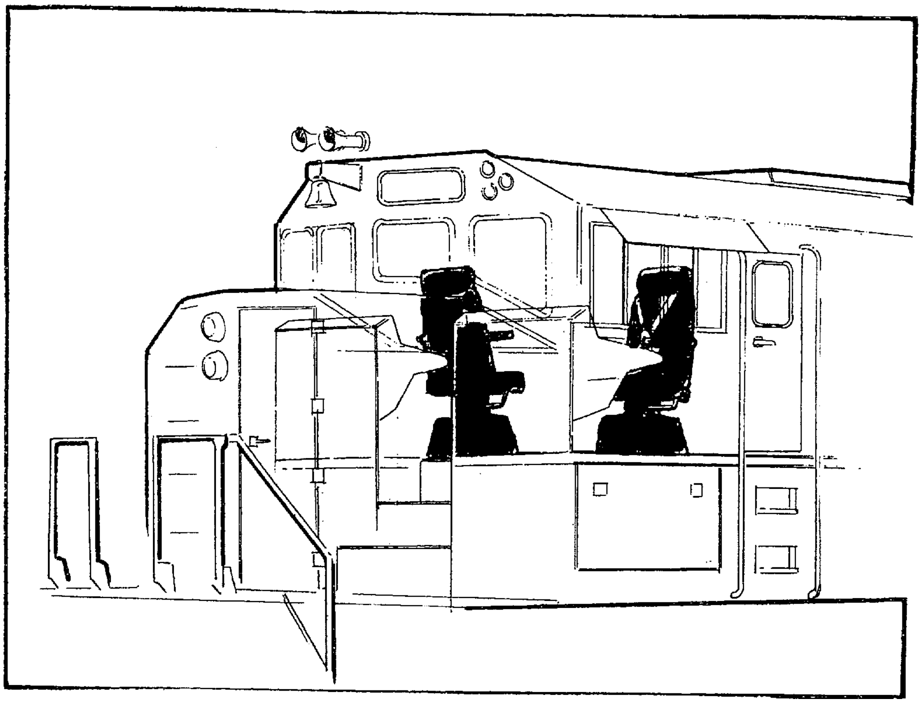

Figure 2-3. Illustration of the Rotating Seat Crash Refuge Concept

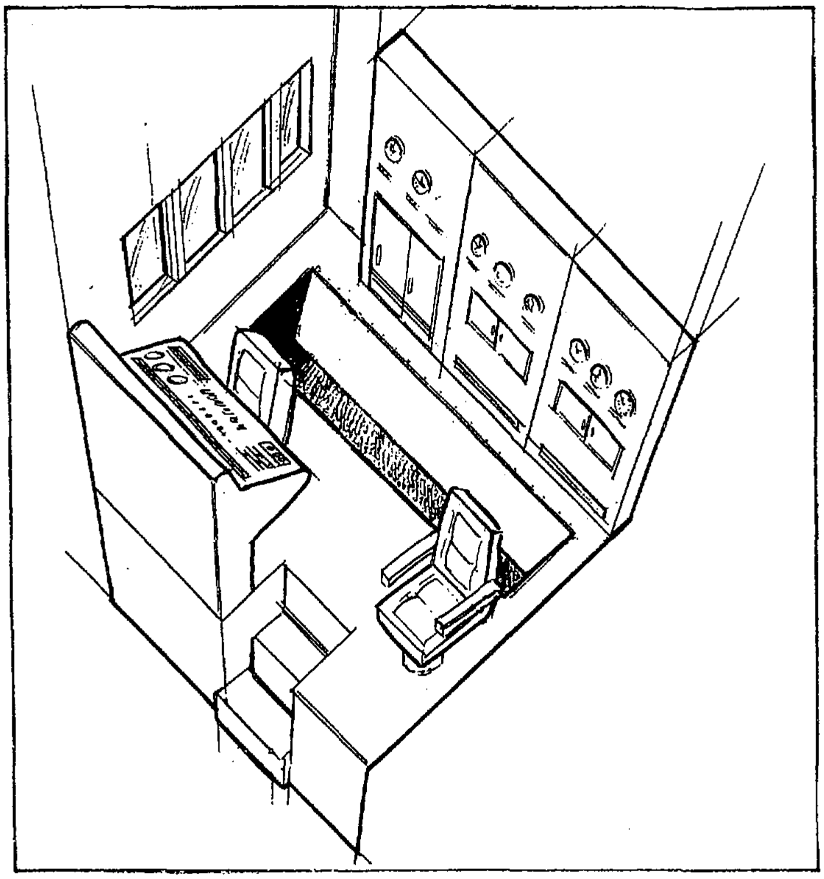

Figure 2-4. Illustration of the Trench Crash Refuge Concept

Table 2-2. Estimates of Weight and Cost Increase Over the Baseline Locomotive for the Three Crash Refuge Concepts Analyzed in This Study

Measure	Crash Refuge Concept		
	Rotate Seat Only	**Rotate & Drop Seat**	**Trench**
Weight	300	600	400
Cost increase	$15,000	$20,000	$2000

2.5 ROLL BAR

Figure 2-5 illustrates the roll bar concept generated and analyzed in this project. It is essentially a structural frame located near the front of the cab attached to the underframe at each side of its base. The structural member sizes that we estimate would be required to support rollover loads are large enough to require some redesign of the front cab; otherwise, there would be some obstruction of vision. We also investigated having another frame located at the rear of the cab but decided against this option in light of the added weight and the likelihood that the equipment in the long hood would provide some support during a rollover.

Design of this concept was based on its ability to withstand a 200,000 lbf side load applied at the roof line, which was derived from consideration of several types of loading that might result during a rollover event. We estimated that a side load at the roof line of less than 20,000 lbf was sufficient to cause substantial cab crush in current locomotive cabs. The estimated cost and weight associated with the front cab roll bar are $10,000 and 3,000 lb, respectively.

Our general assessment of the roll bar concept is that it does not provide practical benefit for crashworthiness of freight locomotives. This is primarily due to the relatively large increases in weight and cost associated with the concept we investigated. It is also due in part to the difficulty in assessing benefit to the crew provided by deliberate rollover protection. Although the analysis of accident statistics was not in the scope of our program, our extensive review of accidents reports, performed to obtain information on collision modes and locomotive crashworthiness, revealed only one case in which there was rollover. This was for a severe, 63 mph closing speed, head-on collision in which nine locomotives were involved. The type of rollover loading experienced by the cab in this accident could not be deduced.

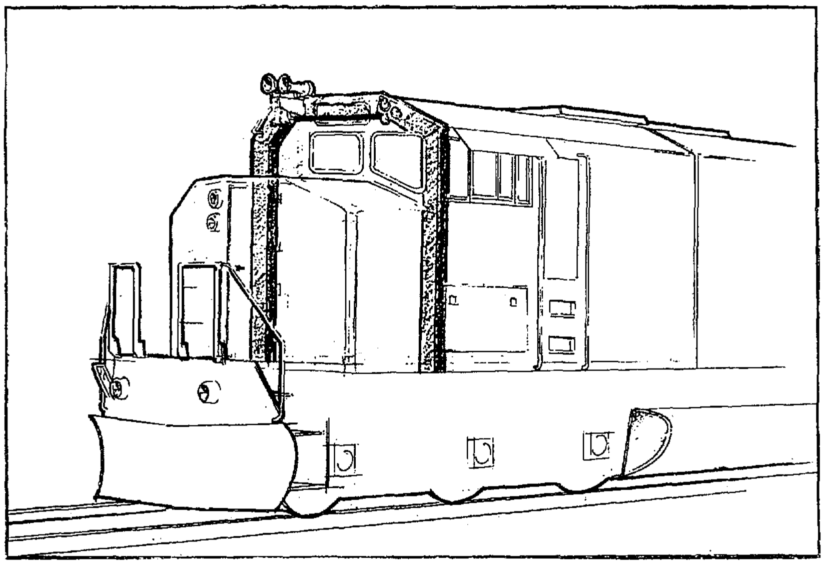

Figure 2-5. Illustration of the Roll Bar Concept

2.6 DEFLECTION PLATES

The deflection plate concept we analyzed was very similar to the interlocking anticlimber concept discussed above, except that the cast piece forms an angled tip in plan view. It is intended to act as an anticlimber and to include the interlocking tangs as shown in figure 2-6. The surfaces forming the point were selected to have a 12.5-degree angle with respect to the usual front plate, because this was felt to be the largest possible angle without substantially extending the length of the locomotive underframe.

The estimated cost and weight for this concept are $5,000 and 2,000 lb, respectively. Our evaluation of the performance of this concept in the baseline 30 mph collision showed that 12.5-degree deflection plates would not deflect the lead locomotives to the side. In fact, it was necessary to increase the angle to 45 degrees before a clear deflection would occur and even in this case no resistance to lateral movement from the rails was modeled and the peak longitudinal collision force was nearly 6,000,000 lbf. These results suggest that a substantial extension of the underframe would be required along with significant re-engineering of the underframe to sustain the high collision forces.

Thus, the deflection plate feature does not appear to provide practical benefit to improving crashworthiness when the relatively large estimated increases in cost and weight and the major underframe changes required for this concept are considered. There is also the issue, not addressed in this study, of the desirability of purposely deflecting the train off the track.

2.7 SHATTERPROOF WINDOWS

Our choice of the concept for shatterproof windows is a laminate system with tempered glass and polycarbonate (PC) interlayers and a spall shield that appears to offer substantial improvement in performance for a minor increase in cost. We have also assumed that some modification of the window frames would be required in order to take advantage of the increase in window strength associated with this concept. It is our understanding that currently used windows are based on a laminate system of glass and polyvinyl butyral (PVB).

Again, the lack of statistics or a clearly described accident involving the shattering of windows makes it difficult to evaluate the benefit of this feature to improving crashworthiness. Data provided by a glazing system manufacturer shows that the glass/PC system provides three to four times the protection against penetration as the glass/PVB system for a test involving a hemispherically tipped steel dart. We note that use of a more penetration resistant glazing improves protection against post-collision entry of flammable liquids, discussed below. Our estimate of the increase in cost for the shatterproof window concept is about $1000 for a locomotive, including glazing and stronger frames, with no significant increase in weight.

Based on these results, we believe that implementation of a more penetration resistant shatterproof window system does provide practical benefit to freight locomotive crashworthiness.

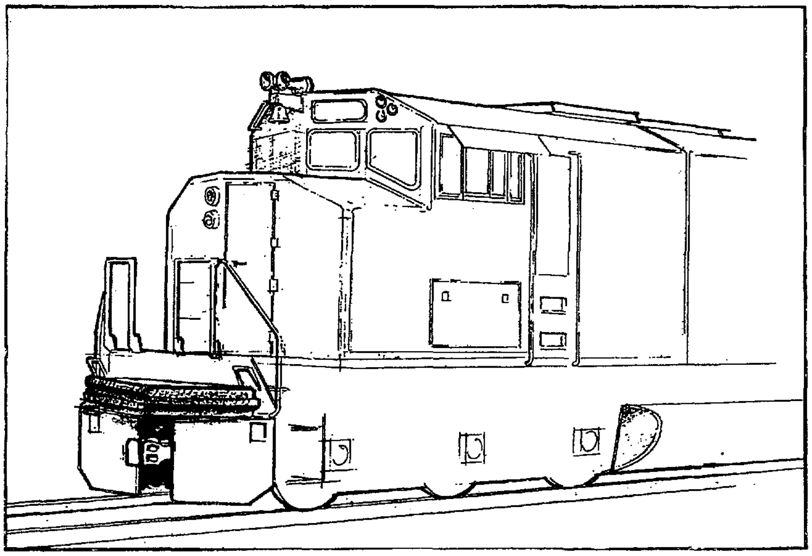

Figure 2-6. Illustration of the Deflection Plate Concept

2.8 EQUIPMENT TO DETER POST-COLLISION ENTRY OF FLAMMABLE LIQUIDS

The concepts investigated in this study to protect against post-collision entry of flammable liquids were essentially those currently being used by industry. At least one manufacturer, and perhaps others, includes covers over the openings for lights in the short hood explicitly to prevent penetration.

The short hood requirement in S-580 of a 0.5-inch wall thickness, 25 ksi yield strength product also provides protection against the entry of flammable liquids by providing resistance to openings that might be created by penetration of small objects. We estimate that the S-580 short hood effectively protects against penetration of a 1-inch diameter, 1-foot-long steel rod impacting the short hood head-on at a speed of 60 mph. Finally, the door in the front of the short hood opens outward, ensuring that it will not accidentally open inward.

A concept we considered for this category, apparently not currently used by industry, is glazing with greater penetration resistance as described in the previous section. Another concept considered was the use of some type of door gasket to prevent the ingress of fluids in an accident; we are not certain whether this concept is currently being used.

Thus, we believe that the use of the shatterproof window concept described above and of opening covers and outward opening doors provides practical benefit to improving crashworthiness for freight locomotives.

3. SUMMARY AND CONCLUSIONS

The purpose of the study undertaken on locomotive crashworthiness was to determine the costs and benefits of equipping freight locomotives with various crashworthiness features. The primary approach followed was to generate and investigate a set of design concepts in order to establish whether practical improvement is feasible. This was achieved in part by developing and applying computer models to simulate collisions between trains; no tests were conducted.

The results of the study, summarized in this report, suggest that a cost-effective improvement in locomotive crashworthiness is feasible, at least for a few of the features. In particular, a performance specification that requires ductile collision posts with greater strength appears to yield the clearest practical benefit. A crash refuge that is relatively simple to enter and provides a direct means of "riding down" a collision also has merit. Finally, an improvement in the penetration resistance of glazing and the continued use of some other features related to openings in the cab appear to have utility, although confirmation through a review of accident statistics is warranted to show benefit.

Furthermore, it is our opinion that while the crash refuge feature will have some benefit on its own, it would best serve the crew if used in conjunction with improved collision posts or some other feature that would provide additional protection - over that provided by S-580 - against cab crush. These combined features could protect against secondary impact and loss of survivable volume.

REFERENCES

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3. Code of Federal Regulations, Title 49, Part 571.