ANALYSIS OF LOCOMOTIVE CABS

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SEPTEMBER 1982

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20590

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REPORT DOCUMENTATION PAGE

1. Report No. DOT/FRA/ORD-81/84	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Analysis of Locomotive Cabs		5. Report Date: September 1982
		6. Performing Organization Code
7. Author (s)		8. Performing Organization Report No.
9. Performing Organization Name and Address: National Space Technology Laboratories, NSTL Station, Bay St. Louis MS. 39529		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development, Washington, D.C. 20590		13. Type of Report and Period Covered: Final report, October 1979 to September 1982
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report covers research that was performed to investigate the present crashworthiness state of in-service locomotives and design applications for new locomotives to protect occupants from serious or fatal injury during collision conditions. The tasks that were performed are: (1) identify past and present accident histories of railroads covering all types of accidents, especially rear-end and head-on collisions resulting in car override; (2) analyze concepts that are currently available for mitigating the car override problem and identify improved concepts; (3) analyze the impact of these concepts on railroad operations considering both implementation and cost; (4) develop performance guidelines for the most beneficial concepts to be implemented on existing and new locomotives; and (5) evaluate the abilities of representative locomotive cabs to support a static load. Five EMD locomotive cabs in general use were analyzed to determine the uniform roof loads at first yield and the allowable roof loads with reasonable safety factors. Three of the cabs were also analyzed for their post-yield behavior up to the point of collapse. Specific, advisable, general design recommendations are included and areas for further research are also identified.

17. Key Words: Accident Statistics; Crashworthy; Trade-off Study; Performance Guidelines; Structures Evaluations	18. Distribution Statement: Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	173	

Form DOT F 1700.7 (8-72)

ACKNOWLEDGEMENTS

Many individuals and organizations have cooperated in the effort to initiate and to perform the first phase of the Railroad Crashworthiness Project. National Space Technology Laboratories' Engineering Laboratory (NSTL/EL), working under a Technical Work Request from Mr. Doug Koger, Chief of U.S. Army ARRADCOM Resident Operations Office, was tasked with the development, coordination, and preparation of this document. Special recognition goes to the System Technology Laboratory (STL) of Arlington, Virginia, for their efforts in the collection and analysis of the data for the first four tasks. They investigated the past and existing problems associated with car override and conducted an engineering economy study for the override concepts that aided in drawing up recommended performance guidelines for those concepts.

The assistance of Dr. Berkley Traughber of Traughber and Associates, Inc., is gratefully acknowledged. His expertise in evaluating the locomotive cab structures through hand calculations and the use of the STRUDL II computer code contributed significantly to the success of the project.

Recognition also goes to the NSTL Data Systems Laboratory for their assistance in computer programming, data entry, and data processing in support of the structural analysis of the locomotive cab.

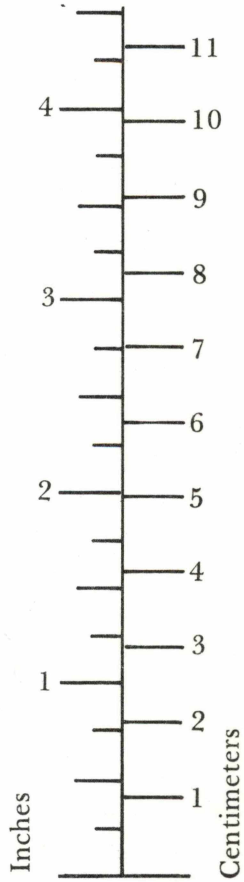
Special thanks also goes to the management of the Southern, Am-Trak, and Louisville & Nashville Railroads of the New Orleans area who graciously allowed NSTL/EL personnel to physically measure the various locomotive cabs and to make the necessary notes, photographs, and sketches needed in the structural analysis of this study.

The technical guidance of Mr. David Dancer, the cognizant Federal Railroad Administration (FRA) Rail Vehicle Safety Research Division Contract Officer Technical Representative (COTR), was invaluable. His helpful suggestions, thorough reviews, and guidance throughout the course of this project are gratefully acknowledged.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
		VOLUME		
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	milliliters	mL
fl oz	fluid ounces	30	milliliters	mL
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	5/9 (after subtracting 32)	degrees Celsius	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1000 kg)	1.1	short tons	
		VOLUME		
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5 (then add 32)	degrees Fahrenheit	°F

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

1 EXECUTIVE SUMMARY

This report covers the performance of the following five tasks: (1) identification of accident statistics regarding car override during locomotive rear-end collisions; (2) analysis of the concepts that are currently available for mitigating the car override problem and identification of improved concepts; (3) analysis of the impact of these concepts on railroad operations, considering implementation and cost; (4) development of performance guidelines for the most beneficial concepts; and (5) analysis of locomotive cab structures to provide a baseline for development of improved cab structures. These improved cab structures are designed to provide adequate space for the survival of the locomotive crew within each cab in the event of a rear-end collision resulting in rear-car override of the locomotive.

Analysis of train accident data for the years 1960 through 1979 (ICC Accident Bulletins 1960-1965, FRA Accident Bulletins 1966-1979) revealed that a total of 2,381 rear-end and head-on collision accidents occurred. Of this total, 1,581 (66 percent) were rear-end collisions and 800 (34 percent) were head-on collisions, resulting in combined damages of over $133,823,000. Rear-end collisions accounted for $63,635,000 (48 percent) and head-on collisions for $70,188,000 (52 percent) of the combined damages.

For the years 1974 through 1978, the number of injuries that resulted from combined rear-end and head-on collision accidents was 428. Fatalities for both collision types totaled 21. Rear-end collisions were responsible for 48 percent of the fatalities and 63 percent of the injuries. Head-on collisions resulted in 52 percent of the fatalities and 37 percent of the injuries. An analysis of the causes of train collisions demonstrated that most accidents were caused by operations rather than by track or vehicle conditions.

A study of the impact of speed upon accident severity for a large accident sample indicated that all fatalities occurred in accidents at 35 mph (56 km/hr) or less. Likewise, 96 percent of all injuries in this accident sample occurred in the same speed range. In terms of damage cost, 96 percent of all damage occurred at speeds of 50 mph (80 km/hr) or less. Therefore, the most-prevalent accident speeds are less than 50 mph with most of the fatalities and injuries occurring at less than 35 mph.

Compilation and analysis of locomotive population statistics revealed that general-purpose/diesel-electric and road-freight locomotives comprised the largest group of in-service locomotives (81 percent). The largest manufacturer of all types of locomotives was the Electro-Motive Division (EMD) of General Motors.

Investigation of a sample of 162 accidents that involved rear-end and head-on collisions revealed that the SD40, SD45, GP7, and GP9 models had the highest injury and fatality rates. The SD40 and SD45 locomotives seemed to sustain the greatest amounts of physical damage of all the models.

The investigation into past and present override mitigation concepts that have been the subject of research and development defined three concept areas: (1) operational considerations, (2) nonlocomotive concepts, and (3) locomotive structural modifications. The following operational and nonlocomotive concepts were identified for further analysis in terms of cost-benefit and viability:

- Locomotive anticlimbers
- Safety glass
- Protective padding in interior
- Occupant restraint
- Improved communications
- Shelf couplers
- Truck retention

Three modification designs were developed and evaluated for technical feasibility and crashworthiness capability. Of the three, the braced collision/roll posts appeared to provide the greatest level of crew protection in the event of rear-car override in a locomotive rear-end collision. The braced collision/roll posts design was also applicable to proposed new locomotive designs.

The impact analysis of the proposed override mitigation concepts, in terms of their effect on railroad operations, showed that implementation of the structural modifications would only marginally affect locomotive weight, balance, visibility, and cab habitability. The braced collision/roll posts design, which provided the greatest crew protection, was costed in consultation with railroad personnel and found to be implementable for approximately $16,000 per locomotive, including downtime. For the nonlocomotive concepts, such as improved freight car couplers and truck retention, there were some minor implementation problems due to increased maintenance complexity and interchange considerations. In terms of the operational equipment, concepts such as shelf couplers, occupant restraints, and protective padding in the interior of the cab may be implementable without major impact on railroad operations. Of the operational procedures concepts, the one identified as attractive dealt with effective communications by provision of an improved radio link between the locomotive engineer and railroad operations personnel. Other override mitigation concepts, such as longhood-forward operations and consist make-up practice, were found to have major implementation and financial penalties that made them unattractive for further analysis.

Ranking of the proposed override mitigation concepts showed that concepts such as improved interior design, truck retention, and shelf couplers were high on the list. On the other hand, when ranking was carried out on the basis of benefit to crew safety and equipment survivability, the structural modifications, such as the braced collision/roll posts and BN collision nose ranked high.

Based on considerations of both crew safety and cost effectiveness, a modification package was selected for implementation as the optimum set of concepts for providing the maximum crew safety at the least cost. The modifications package consists of a sturdy cab structure such as the braced collision/roll posts, shelf couplers, and anticlimbers; and secondary impact protection such as improved interior design, safety glass, and emergency exits together with improved communications. In addition, the use of truck retention devices appeared effective.

Performance guidelines for the modification package are presented. These guidelines can be used by railroads to develop their own override mitigation designs along the lines of the specific concepts developed in the study. Performance guidelines incorporate three aspects - the performance expected, the design practices to be used, and the validation tests required. It is noted that implementation of the override mitigation package presented is well within the capabilities of the railroads' own diesel and car repair shops. Additionally, the various modifications are broken into major and minor categories to help railroads in the implementation of a modification program. The performance guidelines are shown to apply to the most-prevalent accident situations. Methods of modifying the locomotive structural modification designs to types of locomotives other than EMD are also presented.

In view of the feasibility of the concepts package for improving locomotive cab crashworthiness and mitigating car override during rear-end collisions, a more detailed analysis of the various concepts should be carried out and specific designs developed. These designs should be implemented on a specific locomotive and testing performed to verify their crashworthiness performance. It appears that the braced collision/roll posts design can provide a high degree of crew protection in the event of a collision.

The purpose of the railroad crashworthiness structural analysis task was to evaluate the abilities of representative locomotive cabs to support a static load (characterized as the weight of a freight car atop the locomotive cab). The specific analysis involved the determination of the allowable magnitude of a uniformly distributed vertical load applied to the cab roof. Five EMD locomotive cabs, which are in general use, were analyzed to determine the uniform roof loads at first yield and the allowable roof loads with reasonable safety factors. Three of the cabs were also analyzed for their post-yield behavior up to the point of collapse. The five locomotives that represented a cross-section of the operational fleet were the GP38-2, GP40-2, F40-PH, SD40-2, and SDP40.

To perform the structural analyses, detailed structural drawings were required that indicated the structural member geometry, dimensions, materials of construction, type and extent of welding, cross-section orientation, type and degree of support, and joint fixity. Because structural drawings were not always available, it was necessary to physically measure the various locomotive cabs. Once the information was gathered through field trips, engineering representations were drawn for use in the analyses of the locomotive cab structures. The locomotive cabs were analyzed by hand calculations and with the aid of the STRUDL II computer code.

The analyses utilized elastic, elastic-plastic, buckling, and plastic collapse theories.

The results of the structural analyses were based on modeling idealizations obtained from the inspection/measurements and on the results of sensitivity studies performed to assess the applicability of what was considered the best modeling idealization. The cabs could be described as "shop constructed." The actual cab construction varied somewhat from shop to shop and from time to time.

The inspections and measurements clearly indicated the variabilities with such types of shop construction. Enough variation was found among locomotives of the same model number to warrant creating a "typical" locomotive cab of a particular model number for analysis purposes.

All cab models had limiting load levels that were controlled by the yielding of the roof members. The uniformly distributed load and total loads at first yield are listed for the five locomotives in Table 1-1.

TABLE 1-1. THE UNIFORMLY DISTRIBUTED LOAD FOR VARIOUS DIESEL LOCOMOTIVES

Loco. Model	Intensity at First Yield (psi)	Roof Area (sq in)	Approx. Tot. Load at First Yield (lb)
GP38-2	3.3	9,134	30,000
GP40-2	1.1	9,243	10,000
SD40-2	4.2	8,562	36,000
SDP40	2.5	10,230	26,000
F40-PH	2.8	9,200	26,000

First yield occurred in the longitudinal roof members of all cabs except the SDP40, which had a transverse roof member yield first. The SDP40 and F40-PH had hatches in the roof and experienced yield at lower load levels than the GP38-2 and SD40-2, which did not have openings. The lower load capacity of the GP40-2, with respect to the other cabs, was directly attributed to the 1.5-inch-deep roof channels as compared to the 2.5-inch-deep channels in the other cabs.

The post-yield behavior of three locomotives (GP38-2, GP40-2, and SD40-2) was analyzed to determine their collapse load. Failure sequence and modes due to uniform vertical loading were established. The total load on the roof was equal to the uniform load intensity multiplied by the horizontal projected roof areas.

It should be noted that the load considered was in all cases a uniformly distributed pressure. The same total load applied at one, or several points, would cause higher bending moments and greater likelihood of localized web crippling. Therefore, a locomotive cab capable of supporting a uniformly distributed load approximately equal to that of a car (approximately 30,000-35,000 lb) would not be expected to perform as satisfactorily under a dead weight not uniformly distributed because of the concentration of loading. Also, the analyses did not take into account the higher loads associated with the impact of a caboose falling upon the roof. The analyses, however, did illustrate the general inability of any of the cabs to support a car with an adequate margin of safety.

Analyses of the post-yield behavior of the locomotive cabs indicated that a 1.5 factor of safety against first yield was satisfactory for the GP38-2 and GP40-2, but that a 1.8 factor of safety should be applied to obtain the allowable working load for the SD40-2. The greater number of member joints associated with the roof hatches of the F40-PH and SDP40 models introduced an added uncertainty that substantiated the use of the 1.8 factor of safety. The allowable working loads for the cab models using a 1.5 factor of safety for the GP38-2 and GP40-2 and 1.8 factor of safety against first yield for the remaining three cabs are shown in Table 1-2.

TABLE 1-2. THE ALLOWABLE WORKING LOADS USING SAFETY FACTOR OF 1.5 AND 1.8 FOR VARIOUS DIESEL LOCOMOTIVES

Locomotive	Safety Factor	Allowable Intensity (psi)	Roof Area (sq in)	Allowable Total Load (lb)
GP38-2	1.5	2.2	9,134	20,000
GP40-2	1.5	0.7	9,243	6,800
SD40-2	1.8	2.3	8,562	20,000
SDP40	1.8	1.4	10,230	14,000
F40-PH	1.8	1.6	9,200	14,000

The structural analyses performed on available locomotives verified that the existing fleet had very limited vertical load carrying capability. Strengthening of the cab structures to withstand a vertical load must also be viewed with respect to the longitudinal and lateral loads, which will most likely be imposed upon an impacted cab. The longitudinal forces were so obviously large that design of a braced collision/roll posts frame system to withstand substantial horizontal loading should, consequently, satisfy vertical support requirements also.

General design recommendations, with reasons for their advisability, are presented in the report. Optimization of the strengthening of the cab structures must await the choice of the locomotive to be tested. However, the following concepts should be incorporated into the design process:

- Emphasis on energy dissipation

- Low carbon steel with high toughness index

- Multi-tiered structural configuration

- Integral collision posts and roll bar structure

- Use of closed structural sections.

Areas for further structural analysis were identified. The areas of greatest uncertainty lie in the cab modeling and not in the methods of analysis. The areas of further analysis deal principally with determining the actual load-deformation of selected cab structures, materials optimization, and impact loading. The general areas for further analysis are summarized below:

- Dismantling of locomotive cabs for inspection/measurement of welds and joints

- Structural analyses with application of point loads at one, two, four, or more points to simulate the actual support of a caboose

- Field-test determination of specific flexibility terms by application of jack loads to locomotive cabs

- Additional structural analyses of other locomotives in common use such as the GP9 and SD45

- Materials research such as variation of the toughness index of commonly available steels as a function of normalization temperature and times

- Impact test determination of actual horizontal and vertical loads during rear-end collisions.

2 DATA BASE REVIEW

2.1 DATA SOURCES AND ANALYSIS METHODOLOGY

2.1.1 Acquisition of Data

A data file was compiled of railroad accidents that occurred during the years 1960 through 1979. [1-3] Five primary data sources were utilized:

- ICC Accident Bulletins (Annual Summary: 1960-1965)
- NTSB Railroad Accident Reports (Railroad Accident Reports and Summary Bulletins)
- FRA T-Forms - Train Accidents (1974-1978)
- FRA Railroad Accident Reports
  - Accident Summary Reports (1966 - June 30, 1979)
  - Accident Reports.

Other organizations were contacted to determine the extent of information availability, and these, together with the primary data sources, are summarized in Table 2-1.

TABLE 2-1 DATA SOURCES

1. Interstate Commerce Commission (ICC)
   - Bureau of Railroad Safety and Service
   - Bureau of Economics and Statistics
2. Department of Defense (DoD)
   - Military Traffic Management Command
3. Association of American Railroads (AAR)
   - Mechanical Engineering Division
   - Cab Safety Committee
4. Brotherhood of Locomotive Engineers (BLE)
5. Federal Railroad Administration (FRA)
   - Office of Safety
   - Office of Policy and Plans
6. National Transportation Safety Board (NTSB)
7. Railroad Research Information Service (RRIS)
8. Transportation Systems Center (TSC)
9. Federal Highway Administration (FHWA)
10. Boeing Vertol Company
11. Central Technology, Inc.
12. Mass Transit

The Interstate Commerce Commission (ICC) published formal reports regarding train accident data for the years 1960 through 1965. All of the Accident/Incident Bulletins, NRs 129-134, were included in this data file.

Public Law 93-633 empowers the National Transportation Safety Board (NTSB) to investigate all railroad accidents in which there is a fatality, substantial property damage, or involves a passenger train. Additionally, investigations must also be conducted by the NTSB in which an accident occurs in connection with the transportation of people or property that, in the judgement of the Board, is catastrophic, involves problems of recurring character, or would otherwise carry out the policy of the NTSB. [4] This data file included the accidents investigated by the NTSB between 1966-1979. A list of the accidents investigated by the NTSB is given in Appendix A.

The Federal Railroad Administration (FRA) has numerous methods of presenting accident data.

- Accident Summary Bulletins: This document contains the yearly summary statistics on train accidents compiled by the FRA, Office of Safety, "Accident Bulletin," NRs 135-147, and a "Preliminary 1979 Report" in compilation of the data base for use in this report. The "Preliminary 1979 Report" includes train accidents through June 30, 1979.

- T-Forms: Railroad operating companies are required under the Federal Railroad Safety Act of 1970, Accident Reports Act, and 49 CFR (Code of Federal Regulations) 225 to submit, on a monthly basis to the FRA, Office of Rail Safety, a detailed report of any railroad accident/incident that resulted in personal injury or fatality to individuals or property damage (railroad and nonrailroad property) in excess of an established minimum financial threshold. Criteria for reporting accidents as defined by the FRA [5] are outlined as follows:

1. Accident/Incident. An accident/incident is:

a. Any impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle, or pedestrian at a rail-highway grade crossing.

b. Any collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) which results in more than $2,900 (based on 1979 dollars) in damages to railroad on-track equipment, signals, track, track structures, and roadbed. Prior to 1975, however, the damage threshold for reporting accidents was at $750.

c. Any event arising from the operation of a railroad which results in:

- Death of one or more persons;
- Injury to one or more persons other than railroad employees that requires medical treatment;
- Injuries to one or more

employees that requires medical treatment or result in restriction of work or motion for one or more days, one or more lost workdays, transfer to another job, termination of employment, or loss of consciousness; or

- Any occupantional illness of a railroad employee, as diagnosed by a physician.

2. Accident Type.

a. Derailment: A derailment is when a train, locomotive, or car leaves the rails for a cause other than a collision, explosion, or fire to equipment superstructure or cargo.

b. Head-On Collision: A collision in which the trains, locomotives, or cars involved are bound in opposite directions on the same track. (The timetable or schedule direction, when applicable, should govern the classification of collisions if at the time of the accident/incident either of the trains, locomotives, or cars is at rest or if its incidental movement differs from the timetable or schedule direction. If the standing equipment has no timetable or schedule direction, the accident/incident should be classified as a "rear-end collision.")

c. Rear-End Collision: A collision in which the trains, locomotives, or cars involved are bound in the same direction on the same track.

d. Side Collision: A collision at a turnout where a train, locomotive, or other car strikes the side of another train, locomotive, or car.

d. Raking Collision: A collision caused by parts or lading of a train, locomotive, or car on the rails of one track coming in contact with parts or lading of a train, locomotive, or car on the rails of an adjacent track, or with a structure.

e. Broken Train Collision: A collision in which a moving train breaks into parts with a violent impact of two or more of the uncoupled parts of the same train, or one or more of the parts collide with another train, locomotive, or car.

f. Railraod Crossing Collision: A collision of a train, locomotive, or car with another train, locomotive or car at a railroad grade crossing.

3. Monetary Threshold. The dollar amount stated in the FRA's Rules Governing Reports of Railroad Accident/Incidents [Part 225.5(b) of Title 49 of the Code of Federal Regulations] governs the reportability of a railroad accident/incident.

4. Medical Treatment. Treatment administered by a physician or by a registered professional person under the standing orders of a physician. Medical treatment does not include first aid treatment, precautionary measures such as tetanus shots, and subsequent observation of minor scratches, cuts, bruises, etc. that do not require medical care even though these services were provided by a physician or registered personnel.

5. Death, Injury, and Occupational Illness. Any death, injury, or occupational illness arising from the operation of a railroad must be reported to the FRA on Form FRA F 6180-55. Such accidents/incidents to be reported are:

a. The death of any person from an injury within 365 days of the accident/incident;

b. The death of a railroad employee from occupational illness within 365 days after the occupational illness was diagnosed by a physician;

c. Injury to any person other than a railroad employee that requires medical treatment;

d. Injury to a railroad employee that requires medical treatment or results in restriction of work or motion for one or more workdays, termination of employment, transfer to another job, or loss of consciousness; and

e. Occupational illness of a railroad employee, as diagnosed by a physician.

6. Definition. For purposes of these requirements, a "railroad" is any system of surface transportation over rails that is used by freight and passenger trains, including commuter trains. Railcar systems used exclusively by rapid transit are not included.

The monetary reportability requirement has increased as a function of inflationary costs. Figure 2-1 illustrates the monetary threshold value during the 1960 through 1979 reporting period. Discussions with appropriate railroad officials, both Federal and private, indicated that an increase in the monetary threshold requirement from 1960 through 1979 had no significant impact upon decreasing the number of reportable accidents.

In reporting an accident, the railroad company submits the FRA T-Form (Federal

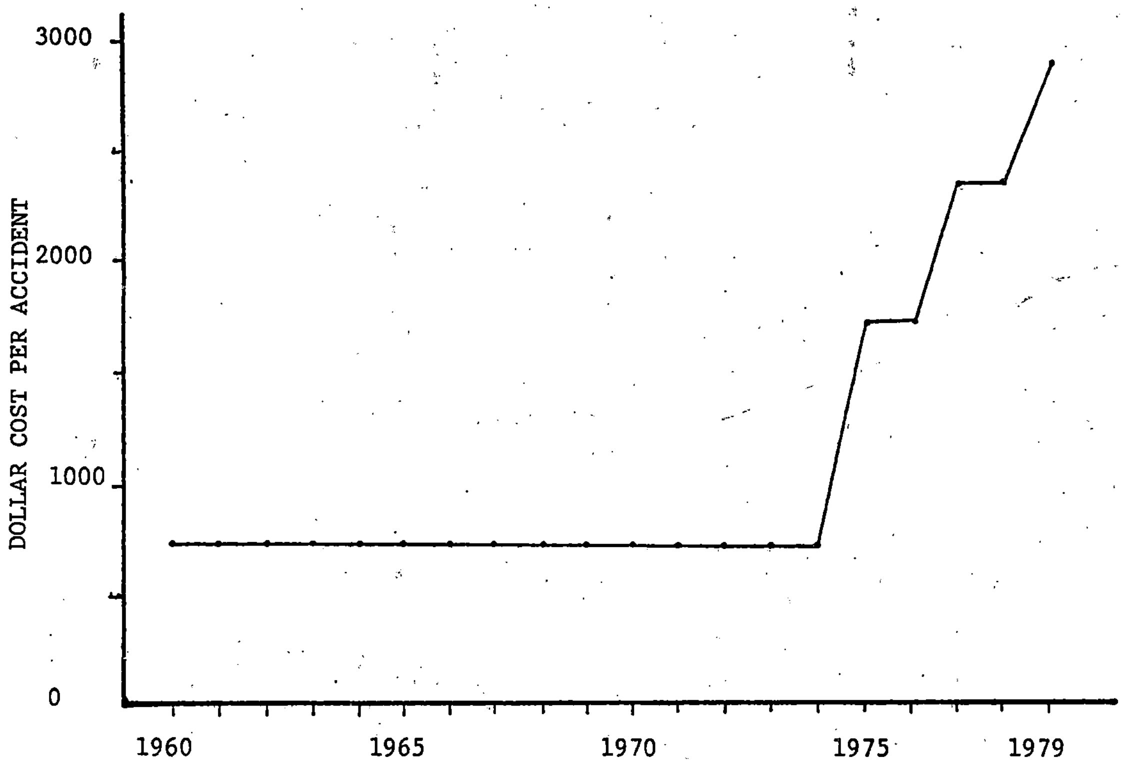


FIGURE 2-1. MONETARY REPORTABILITY THRESHOLD ESTABLISHED BY FRA

Forms FRA F 6180-54 and FRA F 6180-55). Examples of T-Form reports are displayed in Appendix B. This report contains a written description of the accident, and includes relevant information such as accident cause, damage to railroad and nonrailroad property (excluding the cost of clearing the wreck and damage to lading), and resulting fatalities or injuries. [6] Once received by the FRA, the information is encoded and stored on magnetic tape. At the end of the calendar year, the magnetic tape is processed and the coded data are indexed, categorized, and quantified resulting in tabular summaries of the year's composite accident history. This composite accident history is later published by the FRA as an "Accident/Incident Bulletin."

The rail companies are responsible for reporting accidents involving their equipment to the FRA. The FRA is responsible only for compiling and analyzing these data as well as regulating the industry. These rail companies employ investigators who are responsible for determining accident causation. Due to individual perception, perceived accident causation may be subjective, and therefore, could result in misrepresentation of the accident data base for the years under investigation.

T-Forms for the years 1975 through 1978 were acquired and analyzed. Results of this analysis will be discussed further in Section 2.2.

In addition, other secondary data sources were used in compilation of accident information for the years 1960 through 1979. These secondary data sources are identified in Table 2-1, excluding those sources that were previously identified as primary sources (i.e., FRA, NTSB, and ICC).

2.1.2 Analytical Methodology

A methodology to illustrate an accurate accident/incident data base since 1960 was developed. It appeared that there were two distinct periods in which reporting requirements/techniques varied. The periods of data collection included the years 1960 through 1974 and 1975 through June 30, 1979.

2.2 ANALYSIS OF DATA BASE

An analysis of train collisions was conducted to investigate the severity and relative frequency of rear-end and head-on locomotive/train collision accidents between 1960 and 1979. In so doing, an intensive examination was made of the following information:

- Rear-end collision accidents as a function of the number of collision accidents, 1960-1979

- Cost per accident in dollars as a function of the number of collision accidents, 1960-1979

- Comparison between the damage per collision accident in real dollars and 1959 constant dollars, 1960-1979

- Accident causes for rear-end and head-on collision accidents, 1974-1978

- Accident causation as a result of human error and equipment failure for collision accidents, 1960-1979

- Fatalities and injuries to all individuals including trainmen, passengers, etc. by accident cause for collision accidents, 1960-1979

- Fatalities, injuries, and damage resulting from rear-end and head-on locomotive collisions, 1975-1978.

2.2.1 Total Train Accidents

Figures 2-2 and 2-3 show a statistical breakdown of 147,351 train accidents occurring during 1960 through 1979. Review of this information showed that 106,840 (73 percent) of these were derailments; 27,056 (18 percent) were collisions; and 13,455 (9 percent) were other train accidents. Note that "Other Train Accidents" are defined as those accidents involving trains in revenue operations that result in an accident other than a collision or derailment. Train-service accidents were not included in this analysis because these accidents either resulted in damage below the minimum reportable threshold requirements, were nonrevenue operations, or resulted in minor damage because of low-speed operation.

Subdividing collision accidents by type showed a total of 27,056 collision accidents during the years 1960 through 1979:

- 16,760 (61.9 percent) were switching collisions

- 5,572 (20.6 percent) were side or raking collisions (after 1975, side or raking collisions were reported separately, but for consistency of data in this analysis, they were combined).

- 1,581 (5.8 percent) were rear-end collisions

- 1,103 (4.1 percent) were collisions not classified elsewhere

- 800 (2.9 percent) were head-on collisions

- 731 (2.7 percent) were broken train collisions

- 383 (1.5 percent) were collisions from trains with cars not in trains

- 126 (0.5 percent) were collisions at railroad crossings (see figure 2-3).

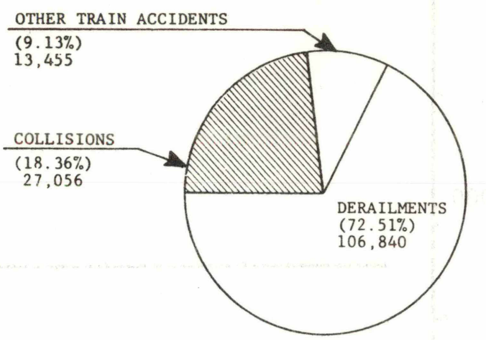


FIGURE 2-2. COLLISIONS, DERAILMENTS AND OTHER TRAIN ACCIDENTS AS IDENTIFIED IN ICC AND FRA ACCIDENT BULLETINS 1960 - 6/30/79

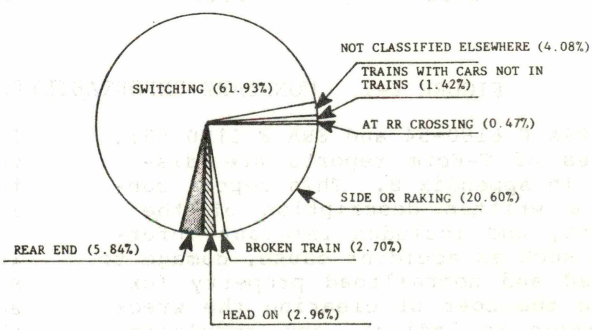


FIGURE 2-3. COLLISIONS/ACCIDENTS AS IDENTIFIED THROUGH ICC AND FRA SUMMARY ACCIDENT BULLETINS 1960 - 6/30/79

2.2.2 Accident Statistics on a Yearly Basis

Tables 2-2 through 2-5 show the yearly and total number of accidents for the period 1960 through 1979.

In the context of crashworthiness, the total number of rear-end, head-on, broken train, and side or raking collision accidents gradually increased from 1960 to 1974. However, in 1975, there was a dramatic increase reported in these types of collision accidents. This anomaly can be attributed to the fact that the standards for reporting the collisions changed. At the time (1974), accidents involving trains with

TABLE 2-2. NUMBER OF TRAIN ACCIDENTS BY ALL CAUSES
(1960 - 1966)

	1960	1961	1962	1963	1964	1965	1966
Total collisions	989	982	999	1,092	1,229	1,380	1,552
. Rear-end	29	37	39	33	44	31	32
. Head-on	16	14	15	17	31	34	20
. Broken train	25	24	28	28	28	27	38
. Side or raking	104	123	81	98	76	86	113
. At RR crossings	8	5	5	10	5	13	6
. Trains with cars not in trains	29	34	13	19	30	26	25
. Switching	704	682	740	841	956	1,081	1,240
. Not classified elsewhere	74	63	78	46	59	82	78
Derailments	2,918	2,671	2,830	3,170	3,399	3,869	4,447
Other train accidents	109	496	549	560	689	718	794
Total train accidents	4,016	4,149	4,378	4,822	5,317	5,967	6,793

TABLE 2-3. NUMBER OF TRAIN ACCIDENTS BY ALL CAUSES (1967 - 1973)

	1967	1968	1969	1970	1971	1972	1973
Total collisions	1,522	1,727	1,810	1,756	1,529	1,348	1,657
. Rear-end	24	36	57	48	34	42	59
. Head-on	30	31	29	30	30	26	24
. Broken train	38	36	41	40	30	40	62
. Side or raking	107	88	131	94	39	42	36
. At RR crossings	12	15	8	13	10	5	--
. Trains with cars not in trains	33	9	42	23	24	31	24
. Switching	1,204	1,427	1,409	1,426	1,279	1,090	1,383
. Not classified elsewhere	74	85	93	82	83	72	69
Derailments	4,960	5,487	5,960	5,602	5,131	5,509	7,307
Other train accidents	812	814	773	737	644	675	411
Total train accidents	7,294	8,028	8,543	8,095	7,304	7,532	9,375

TABLE 2-4. NUMBER OF TRAIN ACCIDENTS BY ALL CAUSES
(1974 - 1979)

	1974	1975	1976	1977	1978	1979*
Total collisions	1,551	1,002	1,370	1,363	1,476	722
. Rear-end	40	169	242	228	235	122
. Head-on	26	69	94	110	117	37
. Broken train	45	59	54	37	34	17
. Side or raking	56	701	978	987	1,087	545
. At RR crossings	--	4	2	1	3	1
. Trains with cars not in trains	21	--	--	--	--	--
. Switching	1,298	--	--	--	--	--
. Not classified elsewhere	65	--	--	--	--	--
Derailments	8,513	6,328	7,934	8,073	8,763	3,969
Other train accidents	630	711	944	927	1,038	424
Total train accidents	10,694	8,041	10,248	10,363	11,277	5,115

*Through June 30, 1979

TABLE 2-5. TOTAL NUMBER OF TRAIN ACCIDENTS BY ALL CAUSES (1960 - 1979)*

	Total Number of Accidents	Percent of Train Accidents	Percent of Collision Accidents
Total collisions	27,056	18.36	100.00
. Rear-end	1,581	1.07	5.84
. Head-on	800	0.54	2.96
. Broken train	731	0.50	2.70
. Side or raking	5,572	3.78	20.60
. At RR crossings	126	0.09	0.47
. Trains with cars not in trains	383	0.26	1.42
. Switching	16,760	11.37	61.93
. Not classified elsewhere	1,103	0.75	4.08
Derailments	106,840	72.51	--
Other train accidents	13,455	9.13	--
Total train accidents	147,351	100.00	--

*Through June 30, 1979

cars not in trains, switching, and collisions not classified elsewhere were eliminated as a classification grouping, which had the effect of increasing the other collision types. The collision types which remained after 1974 were the following:

- Rear-end
- Head-on
- Broken train
- Side or raking
- RR crossing

2.2.3 Accident Damage

In reviewing the damage associated with particular types of train accidents for the period 1975 through June 30, 1979 (see Tables 2-6 through 2-13), it was observed that rear-end collisions accounted for 16.8 percent of the total number of collision accidents and for 28.5 percent of the total collision damage. Moreover, head-on collisions accounted for 7.2 percent of the total number of collision accidents and 20.9 percent of the total collision damage.

However, for the 20-year period (1960 through 1979), rear-end collisions accounted for 5.9 percent of the total number of collision accidents and 19 percent of the total damage. Head-on collisions accounted for 3 percent of the total number of collision accidents and 21 percent of the total damage.

A review of damage resulting from collision accidents revealed that the average cost per collision accident resulting from a rear-end collision was $40,250; a head-on collision was $87,740; a broken train collision was $20,530; a side or raking collision was $14,160; a railroad grade crossing collision was $39,620; a collision of trains with cars not in the trains was $21,320; a switching collision was $4,840; and a collision not classified elsewhere was $9,740.

Tables 2-14 through 2-18 display the relationship between accident type and damage. Table 2-19 displays the yearly composite history of accident damage for various accident types.

2.2.4 Accident Damage (Constant Dollars)

The total cost per collision accident was analyzed as a function of 1959 constant dollars. 1959 was chosen as the base year; therefore, 1960 data could also be compared to the base figure.

Information concerning cost of living approximations applicable to railroad accidents was obtained from the Department of Labor, Bureau of Labor Statistics.

Table 2-19 and Figure 2-4 display data that illustrate that the average cost in current dollars per collision accident has been increasing rapidly.

Examination of Tables 2-11 through 2-13 shows that even though the current dollar values of collision accidents increased from $6,280 in 1960 to $23,870 in 1979, in terms of constant dollars (1959 base), the costs decreased from $6,180 in 1960 to $3,350 in 1978.

This phenomenon is additionally exemplified in Figure 2-4, where the disparity between current dollars and constant dollars can easily be seen.

2.2.5 Causes of Rear-End and Head-On Collisions

To determine the relationship between accident cause and type of collision accident, causes of accidents for rear-end and head-on collision accidents were examined for the years 1974 through 1978. [7] The resulting fatalities, injuries, and damage attributable to each accident cause were also identified. Information regarding the relationship between accident cause and type of collision accident for the years 1960 through 1973 and 1979 was not available, because the accident data were not compiled in a usable format. However, it was compiled in a format which displays the total number of collision accidents (all subtypes combined) that resulted from each accident cause (see Table 2-20). The data presented in the 1974 through 1978 data format for rear-end and head-on collision accidents were believed to be the most appropriate in the crashworthiness problem, and were therefore reviewed closely.

A review of these data showed that a total of 2,183 rear-end and head-on collision accidents occurred during 1974 through 1978 (see Appendix C). Of these, 1,836 (84 percent) were rear-end collisions and 347 (16 percent) were head-on collisions. Rear-end and head-on collision accidents resulted in combined damages exceeding $65,442,000. Of this total, $40,562,000 (62 percent) is attributed to rear-end collisions and $24,880,000 (38 percent) is attributed to head-on collisions. The total number of injuries that resulted from all rear-end collisions was 271 and from head-on collisions was 157. The total number of fatalities that resulted from all rear-end collisions was 10 and from all head-on collisions was 11.

TABLE 2-6. TYPE OF ACCIDENT VS. COST ($1,000's)
(1960 - 1966)

	1960	1961	1962	1963	1964	1965	1966
Total collisions	6,212	6,002	7,947	7,928	11,608	14,076	12,322
. Rear-end	1,000	1,050	1,736	1,203	1,603	1,374	1,703
. Head-on	786	981	880	708	3,600	4,705	2,553
. Broken train	199	157	102	163	335	717	271
. Side or raking	1,256	834	1,173	1,456	1,000	1,904	813
. At RR crossings	83	89	51	374	320	441	579
. Trains with cars not in trains	268	300	283	706	117	776	844
. Switching	2,306	1,918	2,737	3,079	3,703	3,616	5,145
. Not classified elsewhere	314	673	985	239	930	543	414
Derailments	45,000	41,623	46,539	59,235	57,570	68,581	82,479
Other train accidents	342	2,802	1,875	3,309	2,838	2,870	4,158
Total train accidents cost	51,554	50,427	56,361	70,472	72,016	100,713	98,959

TABLE 2-7. TYPE OF ACCIDENT VS. COST ($1,000's)
(1967 - 1973)

	1967	1968	1969	1970	1971	1972	1973
Total Collisions	11,365	10,994	22,120	16,837	15,780	12,929	21,854
. Rear-end	613	893	4,433	3,437	1,821	1,641	4,666
. Head-on	2,474	1,617	4,780	2,641	4,169	2,425	4,974
. Broken train	517	320	2,387	572	441	1,220	2,310
. Side or raking	1,202	1,146	3,188	2,348	620	434	638
. At RR crossings	96	619	141	223	475	188	--
. Trains with cars not in trains	1,187	38	956	719	822	267	701
. Switching	4,273	5,556	5,505	6,063	6,357	5,698	8,072
. Not classified elsewhere	1,003	805	730	834	1,075	1,056	493
Derailments	82,068	99,472	103,782	101,228	90,531	91,283	121,137
Other train accidents	3,216	3,878	3,626	3,558	3,472	3,309	6,369
Total train accidents cost	96,649	114,344	129,528	121,623	109,783	107,521	149,360

TABLE 2-8. TYPE OF ACCIDENT VS. COST ($1,000's)
(1974 - 1979*)

	1974	1975	1976	1977	1978	1979*
Total Collisions	27,763	17,291	24,750	34,102	33,634	17,236
. Rear-end	1,839	5,963	7,524	9,384	6,391	5,362
. Head-on	6,182	3,352	3,573	7,441	8,049	4,298
. Broken train	766	1,095	1,179	1,111	780	367
. Side or raking	1,068	6,449	12,465	15,489	18,396	7,032
. At RR crossings	--	432	9	677	18	177
. Trains with cars not in trains	181	--	--	--	--	--
. Switching	17,079	--	--	--	--	--
. Not classified elsewhere	648	--	--	--	--	--
Derailments	154,548	147,756	184,274	223,123	133,143	134,999
Other train accidents	5,390	12,351	17,968	22,225	21,054	6,239
Total train accidents cost	187,701	177,398	226,992	279,450	304,955	158,501

*Through June 30, 1979.

TABLE 2-9. TYPE OF ACCIDENT VS. COST TOTALS

	Total Cost, by Type ($K)	Percent of Total Cost	Percent of Collision Cost
Total collisions	332,750	13.14	100.00
. Rear-end	63,636	2.51	19.14
. Head-on	70,188	2.77	21.09
. Broken train	15,009	0.60	4.51
. Side or raking	78,911	3.12	23.71
. At RR crossings	4,992	0.20	1.50
. Trains with cars not in trains	8,165	0.32	2.45
. Switching	81,107	3.20	24.37
. Not classified elsewhere	10,472	0.42	3.23
Derailments	2,068,371	81.69	--
Other train accidents	130,849	5.17	--
Total train accidents cost	2,531,970	100.00	--

TABLE 2-10. TOTAL NUMBER OF COLLISION ACCIDENTS VS. COST

Type of Collision	Number of Accidents	Pct. of Total Collision Accidents	Total Cost ($K)	Pct. of Total Collision Cost	Average Cost ($K)
Rear-end	1581	5.84	63636	19.14	40.25
Head-on	800	2.96	70188	21.09	87.74
Broken train	731	2.70	15009	4.51	20.53
Side or raking	5572	20.60	78911	23.71	14.16
At RR crossings	126	0.47	4992	1.50	39.62
Trains with cars not in trains	383	1.42	8165	2.45	21.32
Switching	16760	61.93	81107	24.37	4.84
Not classified elsewhere	1103	4.08	10742	3.23	9.74

TABLE 2-11. ACCIDENT COST IN CONSTANT DOLLARS* (1960 - 1966)

	1960	1961	1962	1963	1964	1965	1966
Total no. collisions	989	982	999	1092	1229	1380	1552
Total yearly collision cost ($K)	6212	6002	7947	7928	11608	14076	12322
Average cost per accident ($K)	6.28	6.11	7.95	7.26	9.45	10.2	7.94
Percentage decrease in dollar value from preceding year	1.6	1.0	1.1	1.2	1.3	1.7	2.9
Yearly collision cost expressed in 1959 constant dollars ($K)	6113	5846	7653	7540	10888	12964	10991
Average collision cost expressed in 1959 constant dollars ($K)	6.18	5.95	7.66	6.90	8.86	9.39	7.08

*Information supplied by the Bureau of Labor Statistics. January 1980. Reference Base is 1959.

TABLE 2-12. ACCIDENT COST IN CONSTANT DOLLARS* (1967 - 1973)

	1967	1968	1969	1970	1971	1972	1973
Total no. collisions	1522	1727	1810	1756	1529	1348	1657
Total yearly collision cost ($K)	11365	10994	22120	16837	15780	12929	21854
Average cost per accident ($K)	7.47	6.37	12.22	9.59	10.32	9.59	13.19
Percentage decrease in dollar value from preceding year	2.9	4.2	5.4	5.9	4.3	3.3	6.2
Yearly collision cost expressed in 1959 constant dollars ($K)	9808	9026	16966	11920	10494	8171	12457
Average collision cost expressed in 1959 constant dollars ($K)	6.44	5.23	9.37	6.79	6.86	6.06	7.52

*Information supplied by the Bureau of Labor Statistics. January 1980. Reference Base is 1959.

TABLE 2-13. ACCIDENT COST IN CONSTANT DOLLARS* (1974 - 1979)

	1974	1975	1976	1977	1978	1979**
Total no. collisions	1551	1002	1370	1363	1476	722
Total yearly collision cost ($K)	27763	17291	24750	34102	33634	17236
Average cost per accident ($K)	17.90	17.26	18.06	25.02	22.79	23.87
Percentage decrease in dollar value from preceding year	11.0	5.1	5.8	6.5	7.7	N/A
Yearly collision cost expressed in 1959 constant dollars ($K)	12771	7072	8687	9753	4944	N/A
Average collision cost expressed in 1959 constant dollars ($K)	8.23	7.06	6.34	7.16	3.35	--

*Information supplied by the Bureau of Labor Statistics. January 1980. Reference Base is 1959.

**Data available through June 30, 1979.

TABLE 2-14. ACCIDENT TYPES VS. DAMAGE (1975)

Types	Property Damage (All types) ($K)	Property Damage Percent of Total	Property Damage Percent of Collision Damage
Collisions			
Rear-end	5,963	3.36	34.47
Head-on	3,352	1.89	19.39
Broken train	1,095	0.62	6.33
Side or raking	6,449	3.64	37.30
At RR crossing	432	0.24	2.51
Trains with cars not in trains	--	--	--
Switching	--	--	--
Not classified elsewhere	--	--	--
Total collisions	17,291	9.75	100.00%
Total derailments	147,756	83.29	
Total other train accidents	12,351	6.29	
Total train accidents	$177,398	100.00%	

TABLE 2-15. ACCIDENT TYPES VS. DAMAGE (1976)

Types	Property Damage (All types) ($K)	Property Damage Percent of Total	Property Damage Percent of Collision Damage
Collisions			
Rear-end	7,524	3.31	30.40
Head-on	3,573	1.57	14.44
Broken train	1,179	0.52	4.76
Side or raking	12,465	5.49	50.36
At RR crossing	9	0.008	0.04
Trains with cars not in trains	--	--	--
Switching	--	--	--
Not classified elsewhere	--	--	--
Total collisions	24,750	10.89	100.00%
Total detailments	184,274	81.18	
Total other train accidents	17,968	7.93	
Total train accidents	$226,992	100.00%	

TABLE 2-16. ACCIDENT TYPES VS. DAMAGE (1977)

Types	Property Damage (All types) ($K)	Property Damage Percent of Total	Property Damage Percent of Collision Damage
Collisions			
Rear-end	9,384	3.36	27.52
Head-on	7,441	2.66	21.82
Broken train	1,111	0.40	3.26
Side or raking	15,489	5.54	45.42
At RR crossing	677	0.24	1.98
Trains with cars not in trains	--	--	--
Switching	--	--	--
Not classified elsewhere	--	--	--
Total collisions	34,102	12.20	100.00%
Total derailments	233,123	83.42	
Total other train accidents	22,225	4.38	
Total train accidents	$279,450	100.00%	

TABLE 2-17. ACCIDENT TYPES VS. DAMAGE (1978)

Types	Property Damage (All types) ($K)	Property Damage Percent of Total	Property Damage Percent of Collision Damage
Collisions			
Rear-end	6,391	3.40	19.00
Head-on	8,049	4.29	23.93
Broken train	780	0.42	2.32
Side or raking	18,396	9.79	54.69
At RR crossing	18	0.01	0.06
Trains with cars not in trains	--	--	--
Switching	--	--	--
Not classified elsewhere	--	--	--
Total collisions	33,634	17.91	100.00%
Total derailments	133,143	70.88	
Total other train accidents	21,054	11.21	
Total train accidents	$187,831	100.00%	

TABLE 2-18. ACCIDENT TYPES VS. DAMAGE (1979*)

Types	Property Damage (All types) ($K)	Property Damage Percent of Total	Property Damage Percent of Collision Damage
Collisions			
Rear-end	5,362	3.38	31.11
Head-on	4,298	2.71	24.94
Broken train	367	0.23	2.13
Side or raking	7,032	4.44	40.80
At RR crossing	177	0.11	1.02
Trains with cars not in trains	--	--	--
Switching	--	--	--
Not classified elsewhere	--	--	--
Total collisions	17,236	10.87	100.00%
Total derailments	134,999	85.17	
Total other train accidents	6,239	3.96	
Total train accidents	$158,501	100.00%	

*Through June 30, 1979

2.2.6 Accidents Resulting from Operations Versus Track or Vehicle Conditions

The causes of accidents/incidents that resulted in at least 5 percent of the total number of rear-end or head-on collision accidents were reviewed to determine the severity (i.e., measured by the number of resulting fatalities and/or injuries) of each accident cause.

The methodology used in this analysis was similar to the "severity index" (SI) formula examined in Section 2.6, "Locomotive Accident Histories." The only difference between the two formulas was the substitution of the total number of accidents (NOA) that resulted from each cause for the locomotive population (P) as the denominator.

A review of rear-end collision accidents revealed the severity index shown in Table 2-21.

A review of head-on collision accidents revealed the severity index shown in Table 2-22.

It appeared that vandalism and unauthorized people in the proximity of rail facilities caused the most severe rear-end collisions. Conversely, it appeared that excessive speed caused the most severe head-on collisions.

2.2.7 Comparison of the Leading Causes of All Collision Accidents Versus Rear-End and Head-On Collision Accidents Exclusively

An analysis was performed regarding major causes of accidents versus types of collision to examine the similarities and differences between the major causes of all collisions compared to head-on and rear-end collisions exclusively. Table 2-23 displays the leading causes of collision accidents for the years 1975 through 1979.

In addition, the significant causes of accidents, for all collision types, expressed as operations and track or vehicle conditions for 1975 through 1979 data were examined. The results of this analysis are shown in Table 2-24.

2.2.8 Fatalities and Injuries Resulting from Train Accidents

A total of 3,147 fatalities resulted from train accidents during 1960 through 1979 (see Table 2-25). Of these, 354 (11.3 percent) resulted from collision accidents; 728 (23.1 percent) resulted from derailment accidents; 2,065 (66 percent) resulted from other train accidents. In general, the number of fatal-

TABLE 2-19. TYPE OF ACCIDENT VS. DAMAGE ($1,000's) (1960 - 1979*)

Year	Type of Accident											
	Collisions									Derailments	Other	Total
	Rear-End	Head-On	Broken Train	Side or Raking	At RR Crossing	Trains W/Cars Not In Trains	Switching	NCE	Total			
1960	1,000	786	199	1,256	83	268	2,306	314	6,212	45,000	342	51,554
1961	1,050	981	157	834	89	300	1,918	673	6,002	41,623	2,802	50,427
1962	1,736	880	102	1,173	51	283	2,737	985	7,947	46,539	1,875	56,361
1963	1,203	708	163	1,456	374	706	3,079	239	7,928	59,235	3,309	70,472
1964	1,603	3,600	335	1,000	320	117	3,703	930	11,608	57,570	2,838	72,016
1965	1,374	4,705	717	1,904	441	776	3,616	543	14,076	68,581	2,870	100,713
1966	1,703	2,553	271	813	579	844	5,145	414	12,322	82,479	4,158	98,959
1967	613	2,474	571	1,202	96	1,187	4,273	1,003	11,365	82,068	3,216	96,649
1968	893	1,617	320	1,146	619	38	5,556	805	10,994	99,472	3,878	114,344
1969	4,433	4,780	2,387	3,188	141	956	5,505	730	22,120	103,782	3,626	129,528
1970	3,437	2,641	572	2,348	223	719	6,063	834	16,837	101,228	3,558	121,528
1971	1,821	4,169	441	620	475	822	6,357	1,075	15,780	90,531	3,472	109,783
1972	1,641	2,425	1,220	434	188	267	5,698	1,056	12,929	91,283	3,309	107,521
1973	4,666	4,974	2,310	638	---	701	8,072	493	21,854	121,137	6,369	149,360
1974	1,839	6,182	766	1,068	--	--	--	--	27,763	154,548	5.390	187,701

TABLE 2-19. TYPE OF ACCIDENT VS. DAMAGE ($1,000's) (1960 - 1979*) (Continued)

Year	Type of Accident											
	Collisions									Derailments	Other	Total
	Rear-End	Head-On	Broken Train	Side or Raking	At RR Crossing	Trains W/Cars Not In Trains	Switching	NCE	Total			
1975	5,963	3,352	1,095	6,449	432	--	--	--	17,291	147,756	12,351	177,398
1976	7,524	3,573	1,179	12,465	9	--	--	--	24,750	184,274	17,968	226,992
1977	9,384	7,441	1,111	15,489	677	--	--	--	34,102	223,123	22,225	279,450
1978	6,391	8,049	780	18,396	18	--	--	--	33,634	133,143	21,054	304,955
1979	5,362	4,298	367	7,032	177	--	--	--	17,236	134,999	6,239	158,501
Total Damage	63,636	70,188	15,009	78,911	4,992	8,165	81,107	10,472	332,750	2,068,371	130,849	2,531,970
Pct. of Total Damage	2.51	2.77	0.60	3.12	0.20	0.32	3.20	0.42	13.14	81.69	5.17	100
Pct. of Collision Damage	19.14	21.09	4.51	23.71	1.50	2.45	24.37	3.23	100			

*Through June 30, 1979

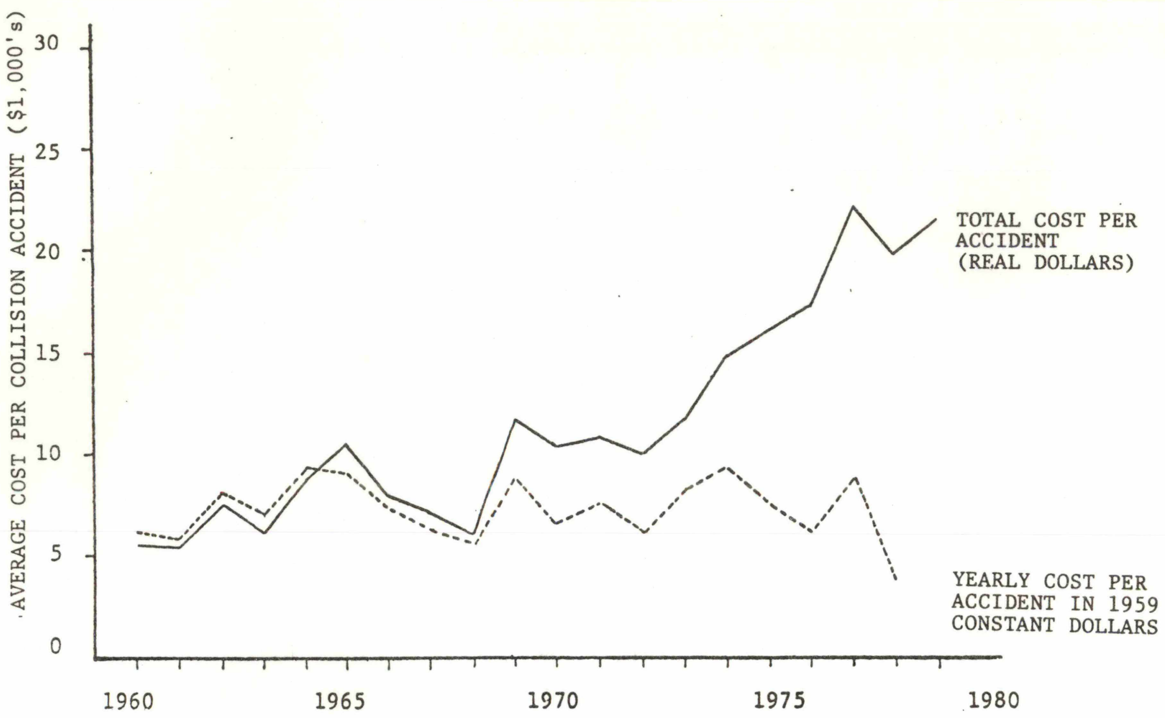


FIGURE 2-4. ACCIDENT COST (1959 CONSTANT DOLLARS)

ities by accident type for any given year remained rather constant. Any significant yearly increase in the number of fatalities was basically the result of one or two catastrophic passenger accidents/incidents during the year.

A total of 20,716 injuries resulted from train accidents during 1960 through 1979 (see Table 2-26). Of these, 7,161 (34.6 percent) resulted from collisions; 9,612 (46.4 percent) resulted from derailments; 3,943 (19 percent) resulted from other train accidents. Again, the number of train injuries by type of accident for any given year remained rather constant.

In this survey of rear-end and head-on locomotive collision accidents for 1974 through 1978, it appeared that a total of 21 fatalities occurred; 10 (48 percent) resulted from a rear-end collision and 11 (52 percent) resulted from a head-on collision. Moreover, review of the accident data showed that a total of 428 injuries occurred: 271 (63 percent) resulted from rear-end collisions and 157 (37 percent) resulted from head-on collisions.

2.2.9 Impact of Speed on Accidents

An analysis was made of some 761 train-to-train collision accidents for the years 1975 through 1978 [8] to determine at what speed the greatest number of fatalities, injuries, and damage occurred. Data indicated that all fatalities in the sample resulted from accidents that occurred at 35 mph or less; moreover, at 35 mph or less, 96 percent of all injuries occurred. The total damage incurred as a function of locomotive speed, prior to accident, indicated that 96 percent of all damage occurred at speeds of 50 mph or less. The distribution of accidents with respect to speed is shown in Table 2-27.

2.3 UTILIZATION OF AVAILABLE DATA

Examination of train accidents for the years 1960 through 1979 concentrated on the review of numerous sources of information. Unfortunately, not all of the reviewed information presented data in a format that was usable in this analysis. Consequently, not all desired information was obtained. To further illustrate the situation, the following subsections display some of the problems associated with the information as obtained.

2.4 STANDARIZED DATA BASE

A meaningful and concise data base format was developed; however, it was limited in its comprehensiveness for the following reasons.

For the years 1960 through 1973, the FRA "Accident Bulletins" provided only the total number of collisions that resulted from each accident cause, and did not

TABLE 2-20. TOTAL NUMBER OF COLLISIONS BY CAUSE (ICC & FRA ACCIDENT BULLETINS)

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979*	TOTAL
Hand brakes, brake rigging and appurtenances	13	17	17	13	19	13	19	18	26	28	22	23	13	15	29						285
Bridges, trestles, culverts and tunnels		0	0	0	0	0	0	0	0	0	0	0	0	0	0						0
Frogs and switches		2	2	4	3	8	3	1	1	3	4	7	1	8	4						51
Interlocking and block signal systems		0	2	0	2	2	0	0	1	1	2	2	2	0							14
Other causes														811	298						1109
Locomotives other than steam														1	0						1
Couplers														61	45						106
Employee physical condition																2	1	3	3	1	10
Flagging, fixed, hand and radio signals																42	51	53	68	30	244
Other rules and instructions																380	490	528	607	292	2297
Speed																106	145	79	99	39	468
Brakes (mechanical)																18	26	28	35	14	121
Trailer or container on flatcar																1	2	3	3	1	10
Body																3	4	4	6	3	20
Coupler and draft system																53	40	33	21	10	157
Truck components																2	2	2	3	0	9

*1979 Data through June 30.

TABLE 2-20. TOTAL NUMBER OF COLLISIONS BY CAUSE (ICC & FRA ACCIDENT BULLETINS) (Continued)

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979*	TOTAL
Rails and joints		0	0	0	0	0	0	1	2	2		0	0	0	1						6
Rail joints and fastenings	0																				1
Special work	1																				1
Roadway structures	0																				0
Ties and tie plates	0	0	0	0	0	0	0	0	0	0	1	0		0	2						3
Rail	0																				0
Other way and structure items	7	4		4	7	12	26	32	51	58	63	64	53	52	48						481
Signal systems	1																				1
Improper loading	0	0	1	1	2	0	0	1	1	1	1	1	0	0	2						11
Negligence of nonemployees	8	14	16	7	2	15	19	13	18	15	15	23	26	26	17						260
Malicious acts or other misbehavior of nonemployees	5	4	5	7	6	8	5	9	6	17	14	10	9	16	15						136
Obstructions, extraordinary forces of nature	1	0	2	3	2	4	1	2	0	0	4	4	3	2	3						31
Rail-highway grade crossing	0	0	0	0	0	0	0	0	0	0	0	0	0		0						0
Unascertained causes	6																				6
Combination of two or more causes	3	5	0	0	3	2	0	0	0	1	3	0	0	4	2						23
Other ascertained causes	29	34	36	32	35	44	33	31	54	47	60	53	51	60	56						655
Locomotives other than steam including propulsion equipment of rail motor cars		0	1	0	2	0	1	1	2	1	0	3	0								11

*1979 Data through June 30.

TABLE 2-20. TOTAL NUMBER OF COLLISIONS BY CAUSE (ICC & FRA ACCIDENT BULLETINS) (Concluded)

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979*	TOTAL
Use of brakes (human)																141	194	192	184	91	802
Axles and journal bearings																1	0	0	2	2	5
Wheels																1	3	9	6	1	20
Locomotives																0	4	0	3	5	12
General mechanical and electrical failure																6	2	2	2	2	14
Miscellaneous causes																92	85	124	122	73	496
Track geometry defects																	19	9	17	5	50
Miscellaneous (human)																30	48	41	81	55	255
Doors																	0	1	3	2	6
Roadbed defects																	3	1	3	4	11
Rail and joint bar defects																	16	8	7	5	36
Frogs, switches and track appliances																	59	45	56	27	187
Signal and communications failures																	6	7	91	2	106
Switches																73	107	133	178	58	549
Other way and structure items																0	1	2	0	0	3

*1979 Data through June 30.

TABLE 2-21. REAR-END COLLISIONS - SEVERITY INDEX

Cause	Fatalities	Injuries	Severity Index
Operations			
Vandalism/unauthorized person	0	43	398
Improper use of switches	0	2	10
Track or Vehicle Conditions			
Rail or joint bar defects	0	18	58
Wide gage or irregular track alignment	0	15	72
Frogs/switches	0	3	18

TABLE 2-22. HEAD-ON COLLISIONS - SEVERITY INDEX

Cause	Fatalities	Injuries	Severity Index
Operations			
Excessive speed	0	11	500
Improper instructions given to train crew	0	14	483
Improper use of switches	0	11	289
Failure to comply with motor car or on-track equipment rules	0	19	1,017
Track or Vehicle Conditions			
A number of reported unsafe conditions resulted in at least 5 percent of the total number of head-on collisions.			

indicate the specific collision types that made up the total. (See Tables 2-28 and 2-29.) As a result, accident causes could not be correlated to specific collision types (i.e., head-on and rear-end) for 1960 through 1973. Cause-collision correlations for the year 1979 were not available at the time as the accident/incident reports had not yet been coded for the year. See Table 2-20 for accident causes that resulted in collision accidents for 1960 through 1973 and 1979.

Accident data for 1974 through 1978 were standardized. See Appendix C for causes of rear-end and head-on collision accidents for 1974 through 1978.

2.5 CAUSE RELATIONSHIPS

To determine the relationship between specific types of collisions and particular causes of accidents, an examination of 1977 accidents/incidents was conducted. This investigation involved a review of some 226 rear-end and head-on collisions of which 130 (57.5 percent) were rear-end collisions.

TABLE 2-23. MAJOR CAUSES OF COLLISION ACCIDENTS

	Number	Percent
1975 (951 Total)		
Other rules and instructions	380	11
Speed	105	40
Coupler and draft system	53	6
Use of brakes (human)	141	15
Miscellaneous causes	92	10
Switches	73	8
1976 (1308 Total)		
Other rules and instructions	490	37
Speed	145	11
Use of brakes (human)	194	15
Miscellaneous causes	85	7
Switches	107	8
1977 (1307 Total)		
Other rules and instructions	528	40
Speed	79	6
Use of brakes (human)	192	15
Miscellaneous causes	124	9
Switches	133	10
1978 (1600 Total)		
Other rules and instructions	607	38
Speed	99	6
Use of brakes (human)	184	12
Miscellaneous causes	122	8
Miscellaneous (human)	81	5
Signal and communication failures	91	6
Switches	178	11
1979 (722 Total)		
Other rules and instructions	292	40
Speed	39	5
Use of brakes	91	13
Miscellaneous causes	73	10
Miscellaneous (human)	55	8
Switches	58	8

TABLE 2-24. ACCIDENTS DUE TO OPERATIONS AND TRACK OR VEHICLE CONDITIONS

	Number	Percent
Operations		
Failure to comply with rules and instructions of road	2,297	39
Failure to control speed of car and/or excessive speed	468	8
Improper use of or failure to secure brakes	802	14
Improper use of switches	549	9
Miscellaneous human causes	496	8
Track or Vehicle Conditions		
A number of "unsafe condition" accidents resulted in at least 5 percent of the total collision accidents		

TABLE 2-25. FATALITIES RESULTING FROM TRAIN ACCIDENTS

Year	Collision	Derailment	Other Train Accidents
1960	6	66	84
1961	6	41	111
1962	15	75	111
1963	8	37	107
1964	24	34	133
1965	19	41	131
1966	11	52	151
1967	17	36	117
1968	3	27	112
1969	35	50	118
1970	29	53	128
1971	24	44	103
1972	60	21	90
1973	35	41	73
1974	13	40	86
1975	16	2	65
1976	19	15	124
1977	4	8	96
1978	3	41	82
1979*	7	4	43
Total 1960-1979	354	728	2,065
Percent of Total	11	23	66
Total Fatalities = 3,147			
Total Percent = 100			

*Through June 30, 1979

NOTE: In 1975, the classification "RR Grade Crossing was created out of "Other Train Accidents." For the purpose of consistency, however, the two categories have been re-combined into "Other Train Accidents after 1975."

TABLE 2-26. INJURIES RESULTING FROM TRAIN ACCIDENTS

Year	Collision	Derailment	Other Train Accidents
1960	252	485	110
1961	239	694	129
1962	368	899	127
1963	861	575	144
1964	344	522	162
1965	302	446	116
1966	233	489	178
1967	239	365	150
1968	580	540	173
1969	352	594	227
1970	223	262	142
1971	194	381	119
1972	376	302	99
1973	220	402	136
1974	247	520	144
1975	723	234	266
1976	256	626	400
1977	232	399	354
1978	803	625	316
1979*	117	252	451
Total 1960-1979	7,161	9,612	3,943
Percent of Total	35	46	19
Total Injuries = 20,716			
Total Percent = 100			

*Through June 30, 1979

NOTE: In 1975, the classification "RR Grade Crossing was created out of "Other Train Accidents." For the purpose of consistency, however, the two categories have been re-combined into "Other Train Accidents after 1975."

An examination of those causes that contributed at least 5 percent of the total number of head-on collision accidents, showed that nine causes accounted for 68 percent of all head-on collisions. These accident causes were categorized as operations or track or vehicle conditions.

Head-on collisions due to operations were comprised of the following causes: hand signals, 5 percent; failure to properly secure engine, 5 percent; excessive speed while attempting to couple locomotive with car, 5 percent; failure to stop in time, 6 percent; excessive speed outside yard, 6 percent; failure to comply with operating instructions, 9 percent; failure to comply with motor car on track at night, 11 percent; and other human error, 6 percent. The only accident cause attributed to track or vehicle conditions with over 5 percent of the total head-on collision accidents, was improperly lined switches. This comprised 13 percent of the total head-on collision accidents in 1977.

An examination of those causes which accounted for at least 5 percent of the total number of rear-end collision accidents showed that nine causes comprised 59 percent of all rear-end collisions. The rear-end collision accidents that resulted from operations accounted for 53 percent of all rear-end collisions, and track or vehicle conditions, 6 percent.

Those rear-end collisions that resulted from operations included such accident causes as excessive speed during coupling, 9 percent; failure to stop in clear, 8 percent; failure to comply with motor car on track at night, 5 percent; improper flagging, 7 percent; failure to comply with fixed signal, 7 percent; failure to comply with operating instructions, 5 percent; excessive speed during road service, 6 percent; and absence of man in cab, 5 percent. Improperly lined switches was the only accident cause attributed to track or vehicle conditions, accounting for 6 percent of the total rear-end collisions in 1977.

2.6 LOCOMOTIVE ACCIDENT HISTORIES

A review and analysis of information concerning population of locomotive models and accident histories of specified locomotive models were conducted to identify locomotive models and service types with the highest accident frequencies and severities. However, the data has not been normalized for ton-miles, speeds, etc.

TABLE 2-27. BREAKDOWN OF SPEED VERSUS NUMBER OF INJURIES/FATALITIES FOR TRAIN-TO-TRAIN COLLISION ACCIDENTS (HEAD-ON AND REAR-END)

	Collisions		Fatalities		Injuries	
Speed	Number	Percent of Total Head-On and Rear-End	Number	Percent of Total Head-On and Rear-End	Number	Percent of Total Head-On and Rear End
0-5	380	50	4	27	120	32
6-10	122	16	0	0	71	19
11-15	89	12	5	33	91	25
16-20	55	7	2	13	33	9
21-25	33	4	0	0	21	6
26-30	30	4	4	27	9	2
31-35	17	2	0	0	11	3
36-50	35	5	0	0	14	4
Total	761	100	15	100	370	100

2.6.1 Population of Locomotive Models

The population of in-service locomotives as of January 1979 was compiled. It consisted of all models of rolling stock locomotives that were classified as road-freight, passenger, general-purpose, or switching locomotives. General-purpose locomotives were further subdivided as general-purpose/diesel-electric and general-purpose/electric. The total locomotive population was approximately 28,000 locomotives. Of these 7,112 (25 percent) were road-freight; 303 (1 percent) were passenger; 15,715 (56 percent) were general-purpose/diesel-electric; 266 (1 percent) were general-purpose/electric; 3,137 (11 percent) were switcher exclusively; and 1,467 (3 percent) were other locomotive service types, including multiple purpose.

Tables 2-30 through 2-33 were prepared to display the locomotive models that were used in determining the total number of road-freight, passenger, general-purpose, switcher, and other locomotive service types that comprised the composite locomotive population.

Table 2-30 shows that of the total road-freight locomotives manufactured, approximately 5,752 (80 percent) were EMD; 1,210 (17 percent) were GE; and 150 (3 percent) were MLW. Also, road-freight locomotives comprised 24 percent of the total locomotive population.

Table 2-31 shows that of the total passenger locomotives manufactured, approximately 272 (90 percent) were EMD and 31 (10 percent) were GE. The most common passenger locomotive model was the SDP40, with 119 locomotives (39 percent) of the total passenger locomotive population.

Table 2-32 shows that general-purpose locomotives acounted for 15,981 (57 percent) of the total locomotive population. Of these, 15, 715 (98 percent) were general-purpose/diesel-electric and 266 (2 percent) were general-purpose/electric. The EMD-manufactured general-purpose/diesel-electric locomotives accounted for 80 percent of the total general-purpose locomotive population. The most common general-purpose/diesel-electric locomotive was the GP38, which comprised 2,999 (19 percent) of the total general-purpose locomotive population. The most common general-purpose/electric locomotive was the GG1, with 139 locomotives.

Table 2-33 shows that the SW1200 and SW1500 switching locomotives accounted for 1,322 locomotives (42 percent) of the total switching locomotive population. The accident histories of switching locomotives were not included in this analysis because switching accidents usually result in only minor damage because of low-speed yard operation.

The 1,467 other locomotives not classified elsewhere included such locomotive types as Boosters and Metroliners.

2.6.2 Accident Histories of Locomotive Models

An analysis of locomoitive accidents for the years 1975 through 1978 was conducted and showed that a total of 1,264 rear-end and head-on collision accidents occurred. Of these, 653 (52 percent) of the total rear-end and head-on collisions were examined. Through a process of identifying a locomotive number with a locomotive type through published railroad rosters, model types in 162 of the accidents were identified. Thus, 162 (13 percent) of the rear-end and head-on collision accidents that occurred during 1975 through 1978 were correlated with locomotive type.

Table 2-34 details the results of the investigation. As can be seen, six

TABLE 2-28. CAUSAL FACTORS OF 1960 COLLISION ACCIDENTS

Cause	Number of Accidents	Percent of Total
Negligence of Employees		
Air brakes	14	1.42
Switches	88	8.92
Hand brakes	152	15.40
Other forms of negligence	523	52.99
Train orders	4	0.41
Cab signals	2	0.20
Automatic train control	0	0.00
Fixed signals	33	3.34
Hand signals	61	6.18
Train flagging	2	0.20
Defects or Failures of Equipment		
Trucks	0	0.00
Wheels and axles	0	0.00
Steam locomotives	0	0.00
Air brakes and appurtenances	3	0.30
Hand brakes, brake rigging and appurtenances	13	1.32
Couplers, draft gear and related parts	30	3.04
Car structure	0	0.00
Other parts of equipment	1	0.10
Improper Maintenance of Way and Structures		
Rail joints and fastenings	0	0.00
Special work	1	0.10
Roadway structures	0	0.00
Ties and tie plates	0	0.00
Rail	0	0.00
Other way and structure items	7	0.71
Signal systems	1	0.10
Miscellaneous Causes		
Improper loading	0	0.00
Negligence of nonemployees	8	0.81
Malicious acts of other misbehavior of nonemployees	5	0.51
Obstructions, extraordinary forces of nature	1	0.10
Rail-highway grade crossings	0	0.00
Unascertained causes	6	0.61
Combination of two or more causes	3	0.30
Other ascertained causes	29	2.94
Total	987	100.00

TABLE 2-29. CAUSAL FACTORS OF 1961 TO 1979 COLLISION ACCIDENTS

Cause	Number of Accidents	Percent of Total
Negligence of Employees		
Air brakes	169	0.88
Hand brakes	3435	17.95
Switches	2608	13.63
Other forms of negligence	7747	40.49
Train orders	155	0.81
Cab signals	7	0.04
Automatic train control	3	0.02
Fixed signals	420	2.20
Hand signals	848	4.43
Train flagging	88	0.46
Defects or Failures of Equipment		
Trucks	7	0.04
Wheels and axles	1	0.005
Steam locomotives	0	0.00
Locomotives other than steam including propulsion equipment of rail motor cars	11	0.06
Air brakes and appurtenances	73	0.38
Hand brakes, brake rigging and appurtenances	272	1.42
Couplers, draft gear and related parts	418	2.18
Improper Maintenance of Way and Structures		
Rail joints and fastenings	1	0.005
Ties and tie plates	3	0.02
Other way and structure items	474	2.48
Bridges, trestles, culverts and rails and joints	6	0.03
Frogs and switches	51	0.27
Interlocking and block signal systems	14	0.07
Miscellaneous Causes		
Couplers	106	0.55
Steam locomotives	0	0.00
Locomotives other than steam	1	0.005
Improper loading	11	0.06
Negligence of nonemployees	252	1.32
Malicious acts or other misbehavior of nonemployees	131	0.68
Obstructions, extraordinary forces of nature	30	0.16
Rail-highway grade crossings	0	0.00
Combination of two or more causes	20	0.10
Other ascertained causes	1735	9.065
Total	19,097	100.00

locomotive models, each acounting for more than 5 percent of the total rear-end and head-on collision accidents in this sample, totaled approximately 49 percent of all the rear-end and head-on collision accidents. These models represented more than 70 percent of the total locomotive population as shown in Table 2-35. This table compares the variation between a model's percentage of the total population versus is percentage of occurrence in the accident sample.

2.6.2.1 <u>Severity of Locomotive Accidents.</u> The locomotive models that accounted for fatalities in this accident sample were the GP7 (20 percent), GP9 (40 percent), and SD45 (20 percent). One other fatality resulted from an accident involving a GP locomotive not classified elsewhere. It must be noted that out of a total of 162 identified rear-end and head-on collision accidents, only five fatalities occurred.

The locomotive models that accounted for the majority of the total injuries in this accident sample were the GP7 (6 percent), GP9 (10 percent), GP15 (12 percent), GP38 (16 percent), SD40 (8 percent), SD45 (24 percent), and U30-C (10 percent). An additional 6 percent

TABLE 2-30. ROAD-FREIGHT LOCOMOTIVE POPULATION

Manufacturer	Model	Number	Percent of Total Population	Percent of Road-Freight Locomotives
EMD	SD38	46	0	1
	SD39	35	0	0
	SD40	3866	14	54
	SD45	1805	6	25
	Subtotal	5752	20	80
GE	U23-C	47	0	1
	U30-C	585	2	8
	U33-C	253	1	4
	U36-C	73	0	1
	U30-7	220	1	3
	U34-CH	32	0	0
	Subtotal	1210	4	17
MLW	M630 (Canada)	55	0	1
	M636 (Canada)	95	0	2
	Subtotal	150	0	3
	Total	7112	25	100

TABLE 2-31. PASSENGER LOCOMOTIVE POPULATION (Comprises 1 percent of total population)

Manufacturer	Model	Number	Percent of Passenger Locomotive Population
EMD	F40-PH	106	35
	SDP40	119	39
	FP45	47	16
GE	P30-CH	25	8
	U30-CG	6	2
TOTAL		303	100

of the collisions resulted from a GP locomotive not classified elsewhere.

Damage was an important factor in determining the severity of an accident. The damage costs associated with accidents involving particular locomotive models were investigated. Results indicated that only the GP9, SD40, and SD45 model locomotives had damage costs exceeding 5 percent of the total damage cost for all locomotive models. The GP9 had 8 percent, SD40 had 17 percent, and the SD45 had 51 percent of the total damage cost.

2.6.2.2 Accident Severity of Candidate Locomotives. In this study, several candidate locomotive models were required to be evaluated for cab crashworthiness. This required examining susceptibility to damage in rear-end and head-on collision accidents as well as other associated damage, fatalities, and injuries. The candidate models examined

TABLE 2-32. GENERAL-PURPOSE LOCOMOTIVE POPULATION (DIESEL-ELECTRIC/ ELECTRIC)

Manufacturer	Model	Number	Population	Percent General-Purpose Locomotive
EMD (Dies.-Elec.)	GP7	1997	7	12
	GP9	2802	10	18
	GP15	63	0	0
	GP18	5	0	0
	GP38	2999	11	19
	GP39	112	0	1
	GP40	1637	6	10
	GP-other	3229	11	20
	Subtotal	12,844	45	80
GE (Dies.-Elec.)	U18-B	96	0	1
	US23-B	401	1	3
	B23-7	172	1	1
	U30-B	268	1	2
	U33-B	230	1	1
	U-other	1676	6	10
	Subtotal	2843	10	18
MLW (Dies.-Elec.)	M420	28	0	0
	Subtotal	28	0	0
EMD (Elec.)	GM6	1	0	0
	GM10	1	0	0
	Subtotal	2	0	0
GE (Elec.)	GG1	139	0	1
	EP5	6	0	0
	E25-B	7	0	0
	E33	12	0	0
	E44	66	0	0
	E50-C	2	0	1
	E60-CP	7	0	0
	E60-CH	19	0	0
	E60-C	6	0	0
	Subtotal	264	0	2
Total		15,981	57	100.00

TABLE 2-33. EMD SWITCHING LOCOMOTIVE POPULATION (11% of Total Population)

Model	Number
SW1	262
SW7	457
SW8	75
SW9	220
SW10	48
SW12	384
SW15	88
SW900	157
SW1000	45
SW1001	79
SW1200	673
SW1500	649

Total Switching Population 3,137

were the GP18, GP38, GP40, SD40, SDP40, E60, and SD45 locomotives.

Table 2-36 shows accident data for the candidate locomotive models. Examination revealed that these models accounted for 38 percent of the total locomotive population and 37 percent of the accident sample. The three most significant locomotives in the sample,

TABLE 2-34. ACCIDENT HISTORIES OF LOCOMOTIVE MODELS

Model	No. of Accidents in Sample	Percent of Total Accidents in Sample	Fatalities in Sample	Percent of Total Fatalities in Sample	Injuries in Sample	Percent of Total Injuries in Sample	Total Damage to RR Prop. ($1,000's) in Sample	Av. Damage to RR Prop. ($1,000's) in Sample	Total Population	Percent of Total Population
ELECTRO-MOTIVE DIVISION (EMD)										
GP7	19	12	1	20	3	6	169	9	1,997	7
GP9	36	22	2	40	5	10	467	13	2,802	10
GP15	2	1	0	0	6	12	12	6	63	0
GP18	3	2	0	0	0	0	32	11	5	0
GP38	14	9	0	0	8	16	164	12	2,999	11
GP39	2	1	0	0	0	0	36	18	112	0
GP40	5	3	0	0	1	2	26	5	1,637	6
GP-Other	15	9	1	20	3	6	77	5	3,229	12
SD38	4	2	0	0	0	0	5	1	46	0
SD39	0	0	0	0	0	0	0	0	35	0
SD40	15	9	0	0	4	8	1,021	68	3,866	14
SD45	19	12	1	20	12	24	2,984	157	1,805	6
F40-PH	0	0	0	0	0	0	0	0	106	0
SDP40	2	1	0	0	1	2	46	23	119	0
FP45	0	0	0	0	0	0	0	0	47	0
P30-CH	0	0	0	0	0	0	0	0	25	0
Subtotal	136	83	5	100	43	86	5,039	37*	18,893	66
GENERAL ELECTRIC COMPANY (GE)										
U18-B	2	1	0	0	0	0	20	10	96	0
U23-B	2	1	0	0	0	0	60	30	401	1
U30-B	2	1	0	0	2	4	23	11.5	268	1
U33-B	0	0	0	0	0	0	0	0	230	1
U-Other	7	4	0	0	0	0	624	89	1,676	6
B23-7	1	1	0	0	0	0	4	4	172	1
U23-C	0	0	0	0	0	0	0	0	47	0
U30-C	9	6	0	0	0	0	116	13	585	2
U33-C	1	1	0	0	0	0	0	0	253	1
U36-C	0	0	0	0	0	0	0	0	73	0
U30-7	1	1	0	0	0	0	0	0	220	1
U34-CH	0	0	0	0	0	0	0	0	32	0
U30-CG	0	0	0	0	0	0	0	0	6	0
E60	1	0	0	0	0	0	4	4	26	0
Subtotal	26	16	0	0	2	4	851	32.731*	4,085	14
MLW										
M4020	0	0	0	0	0	0	0	0	28	0
M630	0	0	0	0	0	0	0	0	55	0
M636	0	0	0	0	0	0	0	0	95	0
Subtotal	0	0	0	0	0	0	0	0	178	0
Total	162	99	5	100	45	90	$5,890	$36.358*	23,156	80

*Subtotal Average Damage to Railroad Property is Calculated by Dividing the Subtotal of the Number of Accidents in the Sample into the Subtotal for the Total Damage to Railroad Property. The Total Average Damage to Railroad Property is derived in the same manner.

TABLE 2-35. ACCIDENT HISTORIES OF LOCOMOTIVE MODELS (Comprising Major Part of Population)

Models	Population	Percent of Total Accidents In Sample
SD40	14	9
SD45	12	6
GP9	22	10
GP7	12	7
GP38	9	11
GP40	3	6
TOTAL	72	49

when considering frequency of train-to-train collision accidents, were the SD45 (12 percent), SD40 (9 percent), and GP38 (9 percent). Of the candidate locomotive models, only the SD45 was involved in accidents that incurred fatalities. Additional fatalities were associated with other models (see Table 2-34).

A total of 26 injuries was associated with the candidate models under consideration. The three locomotive models that displayed the greatest injury frequency were the SD45, GP38, and SD40. Of these, the number of injuries was distributed by locomotive model as follows: the SD45 , 12 (13 percent); GP38, 8 (6 percent); and SD40, 4 (4 percent). Twenty-four injuries were associated with models other than the candidate locomotives (see Table 2-34).

The aggregate damage and the average accident damage associated with particular locomotive models are identified in Table 2-36. Because the aggregate damage associated with certain models was relatively high, based on its overall population size, a more accurate indicator of the relative damage associated with particular models was the average damage per accident. Examination of the average damage cost per accident showed that the candidate model locomotives had average damage costs that ranged from $4,000 to $68,000 per accident, as shown in Table 2-37.

2.6.2.3 Most-Prevalent Accident Locomotive Models. Subsequent to examining the accident histories of the candidate locomotives, other locomotive models were identified as having a relatively high proportion of the total number of injuries, fatalities, and damage in the accident sample. Specifically, these models included the GP7 and GP9.

A mathematical formula to determine the overall severity index of the specific locomotive models under consideration was formulated. This formula demonstrated the relative frequency of model severity by considering the number of fatalities and injuries associated with specific locomotive model accidents. Specifically, the severity index (SI) was defined to be:

$$SI = \frac{(10 \times F) + I}{P} \times 1{,}000$$

Where:

F = the total number of fatalities that resulted from accidents that involved particular locomotive models.

I = the total number of injuries that resulted from accidents that involved particular locomotive models.

P = total population of locomotive model.

TABLE 2-36. ACCIDENT HISTORIES OF CANDIDATE LOCOMOTIVES

Model	Population	Percent of Total Population	Accidents in Sample	Percent of Total Accidents in Sample	Fatalities in Sample	Percent of Fatalities in Sample	Injuries in Sample	Percent of Injuries In Sample	Total Damage in Sample ($1000)	Percent of Total Damage in Sample
GP38	2999	11	14	9	0	0	8	6	164	3
GP40	1637	6	5	3	0	0	1	1	26	0
F40-PH	106	0	0	0	0	0	0	0	0	0
SD40	3868	14	15	9	0	0	4	4	1021	17
SD45	1769	6	19	12	4	57	12	13	2984	51
SDP40	119	0	2	1	0	0	1	1	46	1
E60	26	0	1	1	0	0	0	0	4	4
GP18	305	1	3	2	0	0	0	0	32	1
Total	10,829*	38	59	37	4	57	26	25	4217	77

*Total population of all locomotives is approximately 28,000.

1000 = per 1000 accidents that involved a specific model. A constant of 1000 accidents was chosen because the average number of collision accidents per year was approximately 1000.

The average damage per accident associated with the candidate locomotives compared to the GP7 and GP9 models are shown in Table 2-38.

Table 2-39 shows accident severity by locomotive type. Results showed that the SD40 and SD45 (i.e., EMD over-the-road freight) locomotives had the greatest number of fatalities and injuries per 1,000 accidents. Furthermore, if the severity ranking of specific locomotive model types were correlated with average accident damage, it was found that the SD40 and SD45 had a combined average damage of $117,794 per accident. This value far exceeded the combined average accident damage for the various other models.

TABLE 2-37. AVERAGE DAMAGE COST FOR ACCIDENTS INVOLVING CANDIDATE LOCOMOTIVES

Model	Average Damage ($)
SD40	68,000
SDP40	23,000
SD45	157,000
GP18	11,000
GP38	12,000
GP40	5,000
F60	4,000
F40-PH	No observed damage

TABLE 2-38. AVERAGE DAMAGE TO CANDIDATE VERSUS SELECTED LOCOMOTIVES

Candidate Locomotive Model	Average Damage ($)	Percent of Total Damage
GP7	8,000	3
GP9	13,000	4
SD40	68,000	23
SDP40	23,000	8
SD45	157,000	52
GP18	11,000	4
GP38	12,000	4
GP40	5,000	1
E60	4,000	1
F40-PH	no observed damage	0

2.6.3 Summary

In summary, it was found that:

(1) The GP38 and GP40 model locomotives displayed a higher percentage of occurrence in the accident sample than they do in the total locomotive population.

(2) The GP9 model locomotive accounted for two of the five fatalities in this sample.

(3) The SD45 model locomotive accounted for 24 percent of all the injuries in this sample.

(4) The SD45 model locomotive accounted for approximately 51 percent of the total damage cost incurred from accidents in this sample.

(5) Data from this accident sample seemed to indicate that all the fatalities and 96 percent of all injuries resulted from accidents occurring at 35 mph or less.

(6) The total damage incurred as a function of locomotive speed, prior to accident, showed that 96 percent of all damage occurred at 50 mph or less.

(7) The SD40 and SD45 model locomotives (i.e., EMD over-the-road freight units) may be regarded as the locomotives associated with the greatest number of fatalities, injuries, and damage costs.

2.7 ANALYSIS OF ACCIDENT DATA (NTSB)

A sample of 45 NTSB railroad collision accident reports [9] for the period 1970 through 1979 were reviewed to determine if there were any similarities between the types of collision accidents and demographic variables. Of these 45 collision accidents, 16 (35 percent) were rear-end collisions and 10 (21 percent) were head-on collisions.

An analysis of this sample was conducted to determine at what time during the day most train accidents occurred. Results of this analysis indicated that 24 percent of all train accidents occurred between the hours of 4:01 p.m. and 8:00 p.m. Other time periods with a relatively high accident frequency included 8:01 p.m. to 12:00 midnight (20 percent); 12:01 a.m. to 4:00 a.m. (18 percent); and 4:01 a.m. to 8:00 a.m. (18 percent). The increased accident rate from 4:01 p.m. to 8:00 p.m. may be due to the fact that it was the peak loading time of the day, and there were more trains on mainline at this time than any other time of the day.

TABLE 2-39. ACCIDENT SEVERITY BY LOCOMOTIVE TYPE

Model		Total Population (28,000)	Fatalities*	Injuries*	Severity Index
SD40 SD45	EMD: Over-the-road freight (Candidate)	5600	4	16	10
SDP40 F40-PH	EMD: Over-the-road passenger (Candidate)	226	0	1	4.42
GP38 GP40	EMD: Medium general-purpose/ diesel-electric (Candidate)	4600	0	9	1.96
E60	GE: Passenger/electric (Candidate)	32	0	0	0
GP18	EMD: Light general-purpose/ diesel-electric (Candidate)	5	0	0	0
GP7 GP9	EMD: Light general-purpose/ diesel-electric	4799	3	8	7.92

*Based on a sample of 162 accidents, 1975-1978

The predominant climatic conditions during the accidents were examined in 147 NTSB Railroad Accident Reports (brief format). Results indicated that 61 percent of all accidents occurred during clear and dry conditions and 29 percent of all accidents occurred during cloudy conditions. The remaining 19 percent occurred during conditions such as rain, snow, or fog.

A further analysis was performed on these 147 accidents to determine the spatial location in which the majority of the accidents occurred. This analysis was based on a state comparison and may be biased due to differences in transportation patterns between the states. More precisely, the state that had the greatest volume of traffic should also have had a relatively high frequency of accidents. Results indicated five states had a total of 42 percent of all the accidents in the sample. These states included New York, 12 percent; Illinois, 10 percent; California, 9 percent; Pennsylvania, 6 percent; and Texas, 5 percent. The exceptionally high frequency of accidents in these states may be due to many factors. It must be noted, however, that these states have extremely large surface areas, have many clusters of metropolitan populations, and contain some of the principal agricultural farmland in this country. Because agricultural commodities transported over long distances are least costly if moved by rail, it would follow that there would be a greater concentration of rail routes in these areas, hence a higher accident rate.

In terms of override frequency and severity factors, a sample of 36 NTSB accident reports for the period 1975 through 1979 was reviewed. It was found that 53 percent of the train collisions resulted in override with accompanying injury or fatality. This confirmed conclusions reached in Boeing Vertol's study* that frequency and severity of the override problem (in terms of injury/fatality) can be most significantly reduced by improving locomotive crashworthiness.

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*Boeing Vertol's study, "A Structural Survey of Classes of Vehicles for Crashworthiness" (FRA-OR&D 79-13), established that locomotives ranked first in benefits to be received in reducing fatalities by improving locomotive crashworthiness. The study covered the eight-year period from 1966 to 1973 and concentrated its analysis on 166 serious accidents. This review of accidents in a period from 1975 through 1979, covering 5,455 accidents (378 fatalities), reached a similar conclusion.

2.8 ANALYTICAL RESEARCH AND DESTRUCTIVE TEST EXPERIENCE REGARDING CRASHWORTHINESS

A review of relevant literature concerning crashworthiness was conducted. The review concentrated on identifying pertinent sources of information on the analytical research and destructive testing that have been iness and override phenomenon. The review revealed that both public and private agencies have been involved in this activity including: (1) Transportation Systems Center (TSC), (2) Calspan Corporation, (3) Dynamic Sciences, (4) Boeing Vertol, (5) Illinois Institue of Technology Research Institute (IITRI), and (6) Stanford Research Institute (SRI).

TSC [10, 11] recommended that, to improve the crashworthiness of locomotives, these causes be eliminated or controlled by a cost-effectiveness approach which included:

- Institute inspection procedures to assure that the coupler alignment of the rail vehicles are within the AAR limits
- Use tempered glass for windshields to reduce lacerations from shattered glass in accidents
- Equip locomotives with top shelf couplers or equip the shorthood end of locomotives with anticlimbers capable of withstanding a vertical strength of 200,000 lb
- Require all the longhood structures to be anchored to the sills with adequate shear strength
- Provide adequate emergency escape routes
- Use high-capacity draft gears for locomotives
- Improve the coupling mechanisms to ensure positive coupling
- Provide soft interiors in the cab and eliminate all sharp interior objects
- Increase the vertical strength of the cab to be able to support the weight of a heavy rail vehicle.

Calspan Corporation, in a 1975 study [12], concluded that the following considerations should be incorporated into the development of a crashworthy cab:

- More control of force deflection characteristics
- A safer interior can be produced by incorporating a one- to two-inch layer of padding in the cab interior.

Dynamic Sciences, in their 1977 two-volume publication series entitled "Train-to-Train Rear-End Impact Tests" [13], concluded that increased vehicle strength, improved occupant safety, and fire protection should be incorporated into the design of a crashworthy cab.

Boeing Vertol performed both research and scale testing in the development of their crashworthy cab design. One of the numerous Boeing Vertol publications concerning this topic is entitled "Locomotive Cab Design: Recommended Design," Volume IV [14]. In this study, Boeing Vertol recommended improved couplers, deflectors, incorporting rollover protection, emergency exits, and interior design features.

Another Boeing Vertol study regarding this topic is entitled, "Rail Safety/ Equipment Crashworthiness, Volume I: A Systems Analysis of Injury Minimization in Rail System."[15] In this study, Boeing Vertol examined the primary and secondary causes of injuries and fatalities along with the locomotive cab hazards and failure mechanisms during collisions. The primary cause of injuries and fatalities, as reported by Boeing Vertol, was cab crushing due to impact and override that resulted in a loss of survivable volume. The secondary cause of injuries and fatalities was due to the occupants being thrown around the cab into fixed objects with protuberances or no padding. The report recommended that improvements in interior design and cab structure would minimize override hazards.

IITRI developed a computer-simulated model to assess the impact that the collision of two consists of transit cars will have upon each other, considering the effects of initial impact, primary collision, and secondary collisions. This model was documented in Edward Hahn's publication entitled "Increased Rail Transit Vehicle Crashworthiness in Head-On Collisions" under Contract Number DOT-TSC-1052.

J. B. Raidt in "A Preliminary Study of Vertical Motion During Impact" [16] developed a computer-simulated model to predict vertical motion during impact.

3 OVERRIDE MITIGATION CONCEPTS REVIEW

The review of existing data on the override problem covered four major areas: (1) operational considerations, (2) nonlocomotive concepts, (3) locomotive structural modifications, and (4) new construction. The following subsections evaluate each proposed override mitigation concept for its applicability to the override problem. All of the proposed approaches are technically feasible, but some approaches are more attractive due to their effect or ease of implementation.

3.1 OPERATIONAL CONSIDERATIONS AND NONLOCOMOTIVE CONCEPTS

Various private railroad management personnel were interviewed to determine operating procedures that may be implemented to mitigate the problem of override during locomotive collisions. These approaches fall into two major categories; i.e., (1) operational or maintenance policies and procedures, and (2) nonlocomotive equipment practices (e.g., car truck retention). The following list outlines the candidate concepts under consideration. Each major category is discussed separately and then is listed by technical benefit and/or ease of implementation.

- Operational Equipment Considerations
  - Locomotive coupler design
  - Safety glass
  - Protective padding
  - Occupant restraint
  - Anticlimb devices
  - Emergency exits
- Operational Procedures Considerations
  - Locomotive coupler maintenance
  - Longhood-forward operations
  - Consist practices and procedures
  - Communications
  - Train dynamics
- Nonlocomotive Concepts
  - Impacted car modifications
  - Freight car modifications
  - Coupler design and maintenance

3.1.1 Operational Equipment Considerations

The operational considerations listed above are discussed below with both the benefits and restrictions covered for each approach. They are not only aimed at preventing an override but, additionallive occupants from the secondary effects of ahese nonlocomotive considerations are discussed in the following paragraphs.

3.1.1.1 Locomotive Coupler Design. When considering the override problem, locomotive coupler design is an area of concern. The use of coupler designs, such as E or F shelf couplers, would tend to prevent climbing at the coupler during a collision. Also, increasing the strength of the coupler/draft gear steel to near that of the locomotive underframe would tend to decrease climbing during impact by containing the collision energy in the couplers and undersill areas.

3.1.1.2 Use of Safety Glass. Extensive use of safety glass throughout the locomotive cab area would reduce the effects of a secondary source of injuries/fatalities due to flying glass. This modification should be considered in conjunction with emergency exits.

3.1.1.3 Protective Padding. Protective padding would provide increased protection for the locomotive occupants from impacting sharp protuberances within the cab. One study [17] has determined that doubling the padding thickness from one inch to two inches decreased the shockload on the body by a factor of 100, which would greatly enhance the occupant's survivability in secondary impacts.

3.1.1.4 Occupant Restraint Systems. Occupant restraint systems, such as seat belts and shoulder harnesses, would protect the occupants from secondary impacts due to uncontrolled movement within the locomotive cab during a collision. However, locomotive restraint systems would probably suffer from lack of use due to requirements for engineers to move about during normal operations. In addition, during emergency situations the engineer must be free to move to a protected area of the cab (survivable volume).

3.1.1.5 Anticlimbers. Anticlimbers are used on locomotives by various railroads to prevent override in low-speed collisions. Since anticlimbers are not standard equipment provided by the locomotive manufacturers, they are designed and ordered by the individual railroads as "custom" equipment. These devices have been partially successful in the low-speed environment, but they seem to be of little value at higher speeds (above 5 mph). Due to the fact that not all railroads use them, their effectiveness has not been accepted industrywide. Their usefulness should be investigated, particularly for switching operations.

3.1.1.6 Emergency Exits. Emergency exits from the locomotive cab area should be considered. During a collision involving a locomotive, the cab usually deforms, jamming the exit doors. Along with the installation of safety glass in the cab area, consideration should be given to mounting the safety glass as an emergency exit similar to rail passenger car installation practices.

3.1.2 Operational Procedures Considerations

3.1.2.1 Coupler Maintenance. Coupler maintenance is an area of concern since the locomotive and freight car couplers are maintained by different people at different intervals. While locomotive coupler height and alignment are frequently inspected by the railroads (every 30 days), the freight car standards allow longer inspection periods (up to 4 years) compared to the locomotive standards. This contributes to the override problem due to possible coupler misalignment at impact. A common maintenance standard for use on all rail vehicles, in addition to the use of E or F shelf couplers on locomotives, would tend to mitigate the frequency of override by improving coupler impact engagement characteristics.

3.1.2.2 Longhood-Forward Operation. Longhood-forward operation provides the operators with protection from override from the front by using the locomotive engines and generators as a cushion between the overriding car and the locomotive cab. This approach would provide more protection for the occupants from front override during a collision, but it does not protect the locomotive cab occupants from rear override during a collision, which is known to occur.

Another drawback to this approach is the fact that forward visibility is restricted by the longhood. At least one railroad does operate their locomotives longhood forward when feasible, but it is not an accepted industrywide practice by either railroad management or operating unions. Adopting this solution would require adding duplicate reverse controls in the cabs of the majority of operating locomotives, since they are presently designed to operate shorthood forward only.

3.1.2.3 Consist Practices and Procedures. Consist practices and procedures involve those areas which may reduce either the frequency of collisions, the override occurrence, or the exposure of the operating crew to a collision incident. The following points should be considered concerning the override problem.

- Consist make-up practices should be reviewed to prevent light railcars from being positioned immediately behind the locomotive, in that they have a tendency to be "squeezed out" of the consist under emergency braking and/or a collision accident, causing possible override from the rear.

- Ensuring that communication is maintained between the consist and the controlling Central Train Control (CTC) is an imperative requirement for reducing the exposure of consists to collisions. For example, a number of collisions investigated by the NTSB were caused when a local service consist without CTC communications was struck by a through revenue consist that did not know that the local consist was on the mainline track. A thorough review of consist operating communications requirements should be undertaken to ensure that the operating crews know of the position of other consists using the same track.

3.1.2.4 Communications. Communications deficiencies were alluded to in a previous paragraph, but the lack of effective communications is one of the major causes of collision accidents. The lack of knowledge by the consist conductor or the locomotive engineer of the existence and progress of other consists using the same track on which they are operating, except by schedule, increases the exposure of these personnel to train-to-train collisions and the resulting devastating effects. Improved communications to ensure that train-to-CTC, train-to-train, and locomotive-to-caboose contact is maintained would reduce the exposure of consist operating personnel and passengers to collisions and their resulting effects.

3.1.2.5 Train Dynamics. With the advent of longer, heavier consists, train dynamics has become an area of concern to the railroads. Improved cab signaling, intra-train dynamics (car-to-car forces), mass distribution of the cars within a consist (light car/heavy car position), and brake performance (stopping distances and wave propagation within long trains) are all areas that cause operational problems. Consideration of the mass distribution within the consist of cars with the same destination block, would result in consists with more predictable braking performance, better intra-train dynamics, and shorter stopping distances. Improved cab signaling would improve the operator's knowledge of the safe progress of his consist. A trade-off of the increased crew costs against the decreased accident costs would have to be conducted to establish whether this is a viable option.

3.1.3 Nonlocomotive Concepts

Nonlocomotive possibilities cover those permanent changes to operating equipment other than locomotives that would tend to reduce the effects of an override during a locomotive collision.

3.1.3.1 Impacted Car Modifications. Impacted car modifications are those changes that may reduce the incidence of override when impacted by a locomotive. They involve the couplers and trucks of the impacted car. The following discussion addresses the truck changes. The couplers will be covered as a separate item. Maintaining the rotational moment of inertia of the impacted car by retaining the trucks appears to be a promising nonlocomotive concept to mitigate override occurrence by decreasing the likelihood of car rotation and subsequent climbing. Therefore, truck retention should be considered. This could be implemented with positive-lock center pins like passenger cars, or simply by adding a safety chain around the truck bolster and fastening it to the car body bolster.

3.1.3.2 Freight Car Modifications. Occasionally, the first car behind the locomotive overrides the cab during collisions. Therefore, truck retention for freight cars should be considered as a method of reducing override occurence.

3.1.3.3 Caboose and Freight Car Couplers. Couplers on cabooses and freight cars are another area of concern in the override problem. As stated before, the couplers on these classes of railcars are maintained by different personnel than locomotive couplers. This may result in coupler height misalignments. Coupler misalignment contributes to the override problem by generating a vertical force at impact that causes the higher coupled car to begin rising and overriding the other car. Installing E or F shelf couplers on these classes of cars and also maintaining them to the same installation standards would tend to mitigate the override tendencies at impact by ensuring that the majority of impact energy is absorbed below the floor level.

3.1.3.4 Strengthening Materials and Mountings. In addition to improving the type and maintenance of caboose and freight car couplers, strengthening their material and mounting should be considered. That is, the coupler and its mounting should be able to absorb an impact load equal to the strength of the freight car coupler sill without braking off, in order to contain the maximum impact energy at the coupler level.

A summary of the operational and nonlocomotive concepts is given in Table 3-1.

TABLE 3-1. SUMMARY OF OPERATIONAL AND NONLOCOMOTIVE CONCEPTS

Concept Area
Operational Equipment
Locomotive coupler design
Safety glass
Protective padding
Occupant restraint
Anticlimb devices
Emergency exits
Operational Procedures
Locomotive coupler maintenance
Longhood forward
Consist practices and procedures
Communications
Train dynamics
Nonlocomotive
Impacted car modifications
Freight car modifications
Coupler design
Coupler maintenance

3.2 LOCOMOTIVE STRUCTURAL MODIFICATIONS

Research and testing conducted to evaluate the locomotive override problem by various organizations such as Calspan, Dynamic Sciences, Boeing Vertol, and Stanford Research Institute has led to similar conclusions and recommendations. The three major conclusions are:

- Ensure that the locomotive cab maintains a survivable volume during the override or rollover

- Eliminate/reduce sources of secondary impact within the locomotive cab
- Establish the force-deflection characteristics of the locomotive frontal area; i.e., collision posts, couplers, shorthood, and undersill areas.

The present analysis concentrates on four major areas of the locomotive cab: (1) structural changes to the cab, (2) underframe modifications, (3) shorthood modifications, and (4) other cab interior safety modifications.

To make these modification concepts more specific, candidate locomotive modification designs have been developed in the following section based on the EMD GP40-2 locomotive.

3.2.1 Structural Changes to the Cab Area

Two areas must be addressed to ensure a survivable cab volume during a locomotive collision. These are (1) override protection and (2) rollover protection. Override protection must ensure that the locomotive cab is not crushed by the overriding vehicle, either in a longitudinal or a vertical direction. Concurrently, rollover protection must prevent cab crushing from the lateral and vertical directions. The obvious implication of these requirements is that some method must exist to deflect or absorb the longitudinal crush load of the overriding vehicle (the objective of existing collision posts), and that some method must exist to prevent vertical and lateral crush loads (such as a roll cage).

NTSB accident reports covering fatal locomotive collisions established that the present collision posts fail in shear under override load at speeds as low as five miles per hour. Also, the overriding vehicles usually crushed the cab under lateral and vertical loads. This collision phenomenon (cab crushing) usually reduced the cab volume below survivable limits for the occupants, which was a primary cause of the fatalities reported.

Improving the strength and integrity of the locomotive collision posts should be a major objective of any improvement program to reduce cab crushing resulting from override. Careful attention should be paid to the structural attachment of the collision posts. They are presently welded to the locomotive deck plate upper surface, and they exhibit a tendency to fail at these welds under moment loading (longitudinal force at the top of the collision-post-override). Properly attaching the collision posts to the underframe would alleviate this type of failure and should, therefore, be investigated. Also, redundant attachment of the collision posts should be investigated, such as welding them to the sandbox which could be welded to the locomotive deck plate. The collision post should be able to develop the ultimate load of the material to which it is supported.

A roll cage approach (similar to the sports car concept) should be utilized as a back-up support to the collision posts under longitudinal loading, as well as providing a roll cage for the occupied cab area. The roll cage must provide sufficient strength to support an overriding vehicle's vertical load and any lateral or vertical load caused by rollover. This roll cage should be a structure independent of the locomotive cab enclosure, and it should be tied to the underframe when feasible.

3.2.2 Underframe Modifications

Since the underframe areas (couplers/ draft gear, center and side sills, and cushioning unit) receive the initial impact energy during a locomotive collision, attention to their structural designs, material strengths, and failure modes should be considered in any modification design. That is, any methods such as stronger coupler materials that can absorb more impact energy prior to failure would be beneficial in mitigating the override problem. Possible modifications should include increasing the center and side sill cross-sectional areas, better attachment between the center and side sills, and increasing the draft gear strength from the couplers to the bolster. This structure should be designed with failure loads close to the limits of the material to which it is attached.

3.2.3 Shorthood Modifications

The shorthood area is an attractive area for crash attenuation. Judicious selection of the types of equipment housed in this area could greatly enhance the crashworthiness of locomotives. Placing items such as the sandboxes, battery boxes, and other fixed storage containers in this area, plus increasing their wall strength, would provide a crash attenuation feature with a functional utility. Attaching these enclosures to the locomotive deck plate and collision posts would provide both crash attenuation plus structural rigidity to the collision posts.

3.2.4 Occupant Safety Modifications

Other considerations during a locomotive improvement program should address occupant safety by preventing secondary impact sources as causes of injuries or fatalities. Better restraint of equipment (water coolers, fire extinguishers, etc.), repositioning of auxiliary controls (lamps, lights, etc.) out of the operator's frontal area, removing sharp corners, and padding of any probable impact areas would improve the locomotive cab safety environment. Also, either active or passive restraint systems should be investigated as possibilities for protecting locomotive occupants from collision effects.

3.3 CANDIDATE LOCOMOTIVE MODIFICATION DESIGNS

Using the modification considerations discussed above, four candidate locomotive modification designs were investigated that addressed the four major areas of concern in a locomotive collision: (1) structural changes to the cab (ensuring a survivable cab volume), (2) underframe modifications (absorption of the impact energy), (3) shorthood modifications (deflection of the overriding vehicle), and (4) occupant safety (minimizing secondary impacts).

As discussed in subsection 2.6.2, EMD locomotives were the models analyzed for concept recommendations. As a result of that locomotive grouping analysis, a GP40 was selected as the candidate locomotive upon which to model the modifications. The GP40 was chosen largely because of the number in service and the similarity of cab design throughout the EMD series of locomotives.

3.3.1 Design No. 1: Braced Collision/Roll Posts

The major features of this design are as follows:

- Improved collision post mounting
- Incorporation of cab roll cage
- Shorthood crash attenuation design
- Coupler strength improvements
- Undersill strength improvements
- Occupant safety improvements.

Important basic parameters for this design were derived from an analysis of 1975 through 1979 FRA and NTSB accident statistics. These are:

- All fatalities occurred in collisions below 30 mph
- 96 percent of the injuries occurred below 35 mph.

Research and testing on the override problem produced the following design parameters:

- The measured impact force at 30 mph is 500,000 lb ft
- The collision posts are subjected to 40 to 50 percent of the maximum impact force during override.

Thus, this proposed locomotive modification design incorporates the major features of previous research, development, testing, and evaluation.

The following paragraphs outline the major features of this proposed modification design, which is capable of withstanding crash loads for speeds up to 30 mph. The design is based on the following forces:

- Coupler impact force: 1,200,000 lb ft
- Collision post impact force: 500,000 lb ft.

3.3.1.1 Implementation. Major features of the proposed braced collision/roll posts design are shown in the following six figures. This concept was specifically designed to be implemented by a railroad locomotive repair facility.

Figure 3-1	Depicts the GP40 locomotive cab as built by EMD.
Figure 3-2	Shows the disassembly of the GP40 locomotive cab sections required to prepare it for modification.
Figure 3-3	Depicts the parts required to implement the design and their installation positions.
Figure 3-4	Shows the internal structure after assembly.
Figure 3-5	Is a view of the completely assembled cab after the modification is completed.
Figure 3-6	Shows the front, side, and vertical views of the modification.

The locomotive configuration is not dramatically changed from the original design in the areas of internal cab configuration and external clearance profile. This approach should not prohibit unrestricted interchange.

3.3.1.2 Priority of Implementation. The proposed modification design, as outlined above, has the feature of being implemented on various levels. That is,

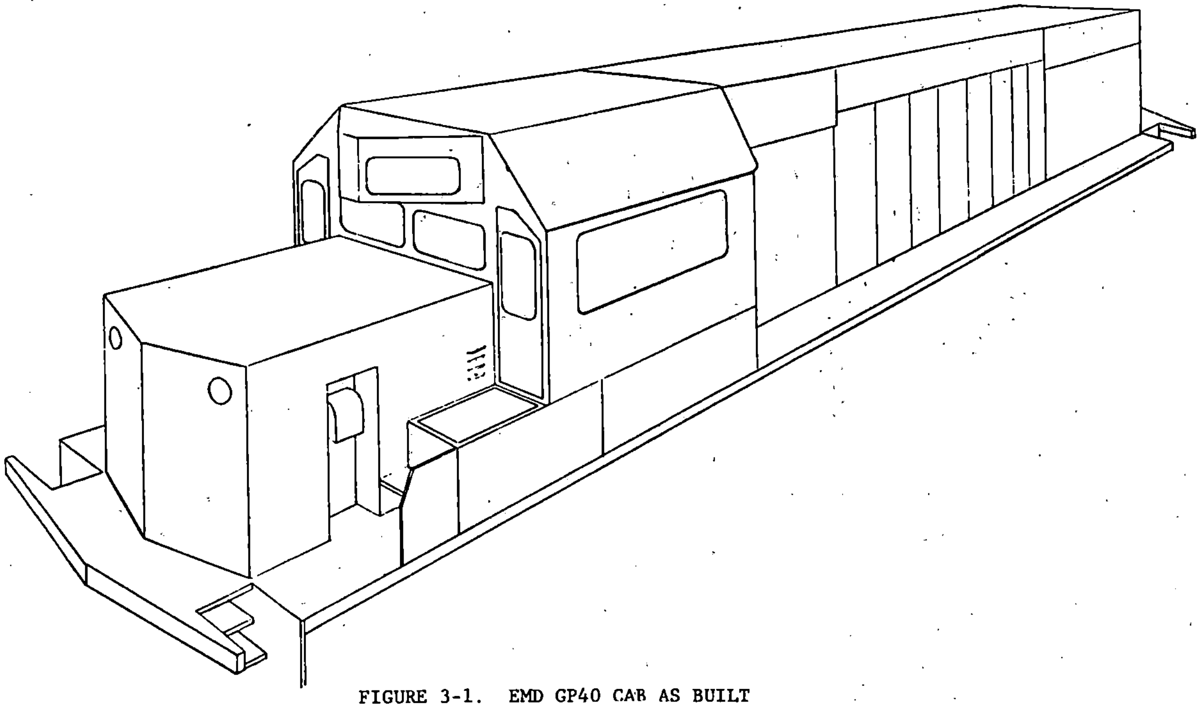

FIGURE 3-1. EMD GP40 CAB AS BUILT

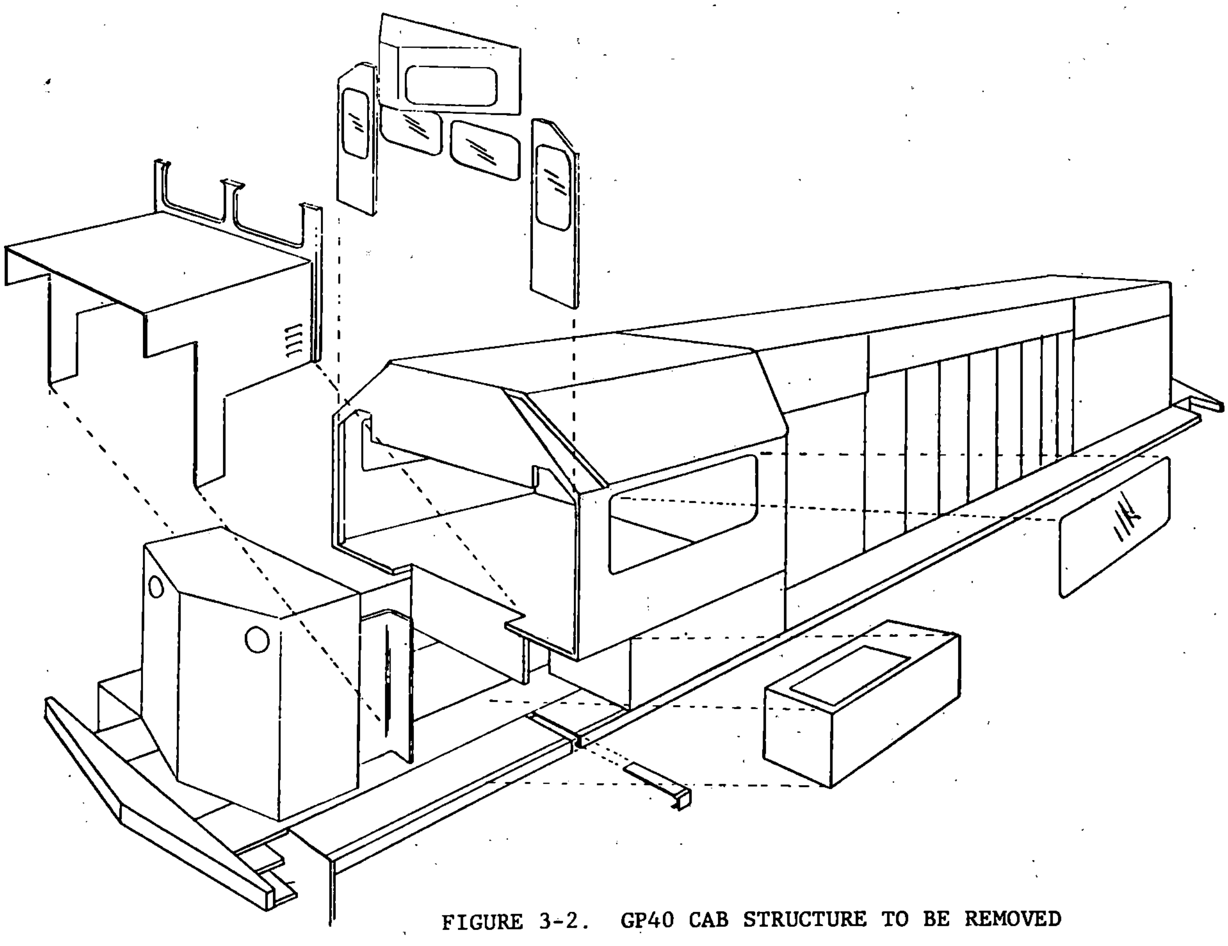

FIGURE 3-2. GP40 CAB STRUCTURE TO BE REMOVED

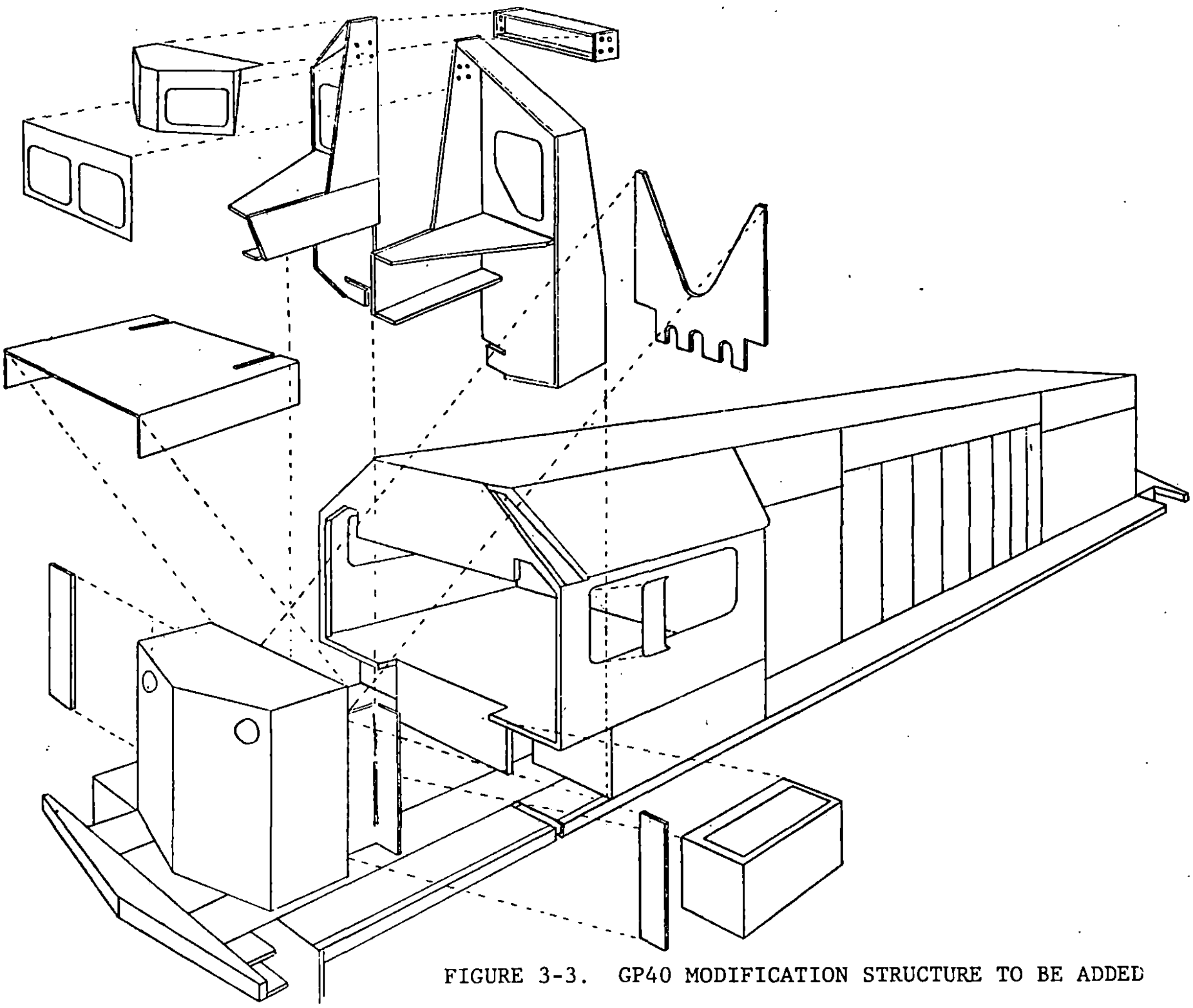

FIGURE 3-3. GP40 MODIFICATION STRUCTURE TO BE ADDED

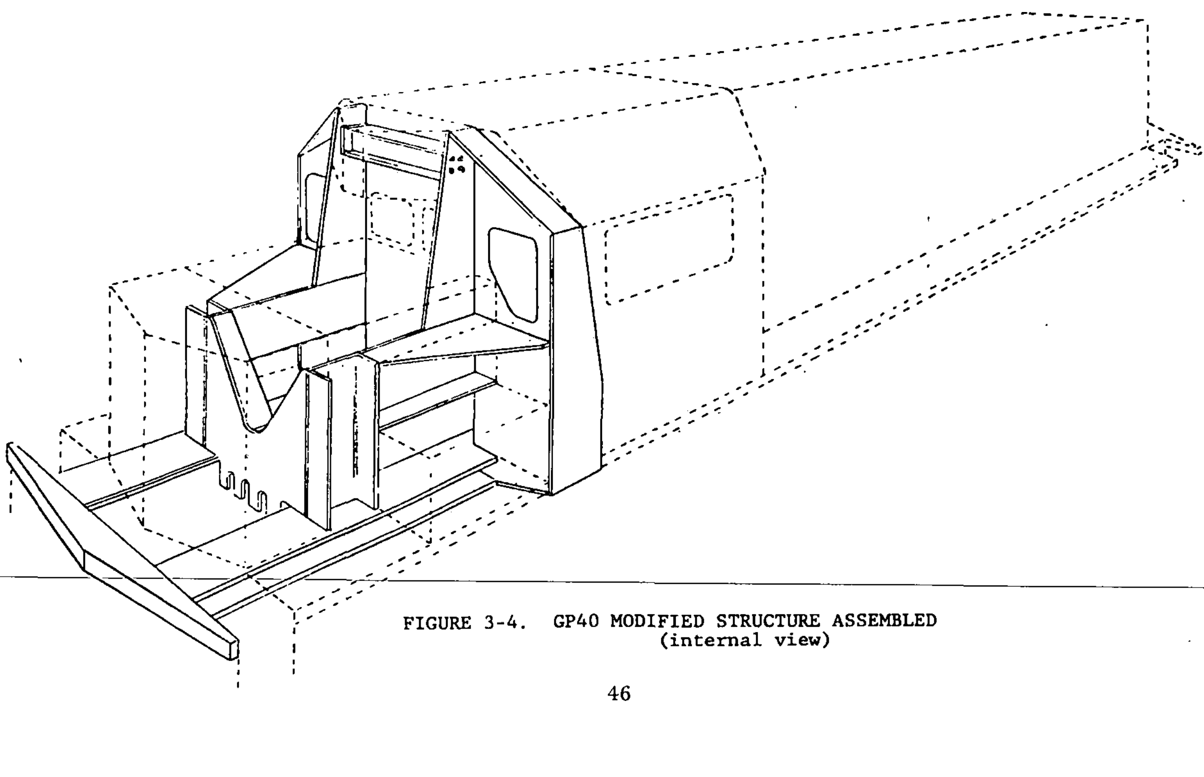

FIGURE 3-4. GP40 MODIFIED STRUCTURE ASSEMBLED
(internal view)

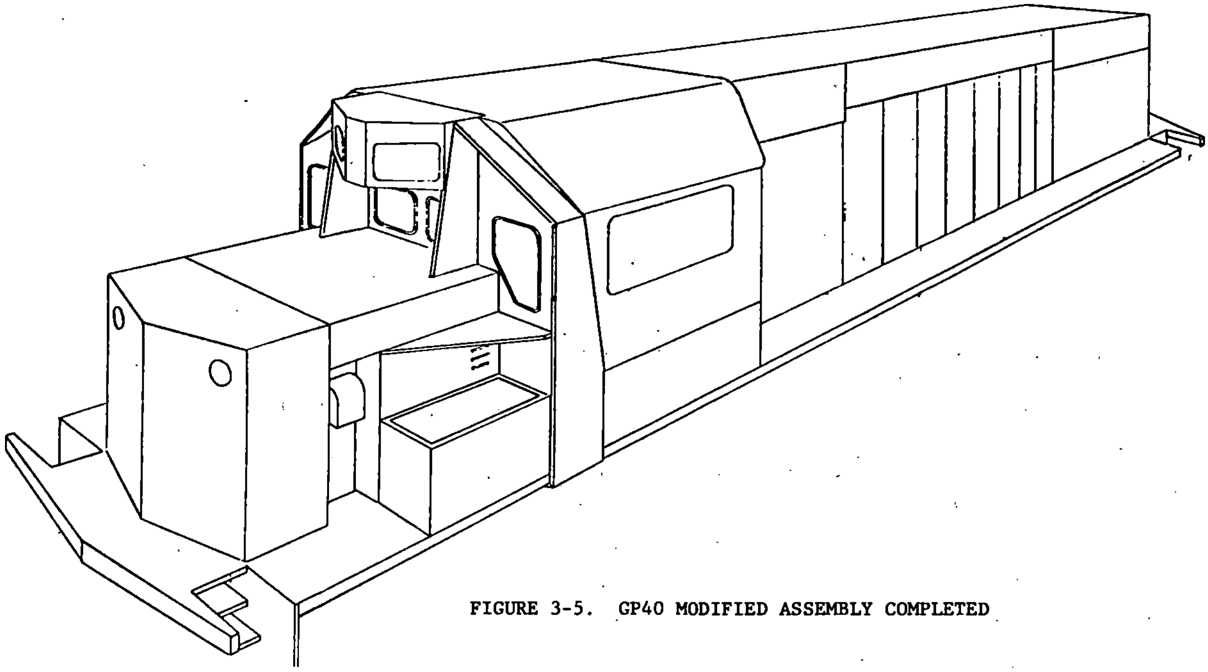

FIGURE 3-5. GP40 MODIFIED ASSEMBLY COMPLETED

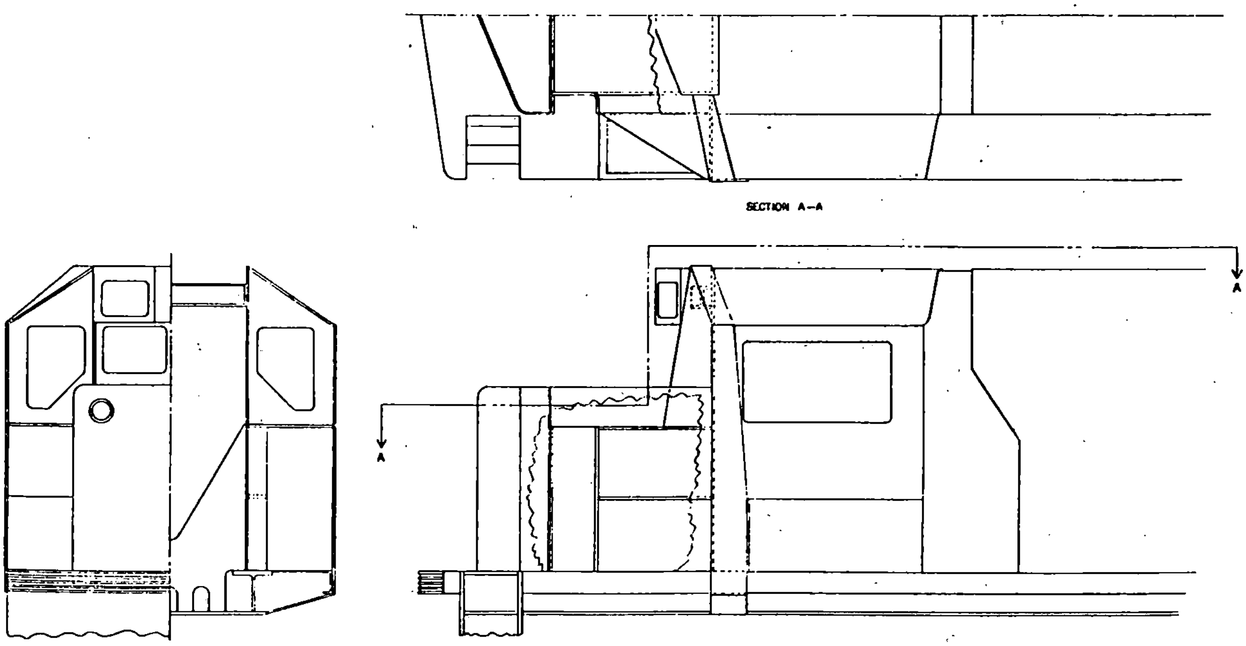

FIGURE 3-6. GP40 FRONT, SIDE, AND VERTICAL VIEWS OF MODIFICATION

the design can be divided into those features which address (1) ensuring a survivable cab volume, (2) impact energy absorption, and (3) occupant safety modifications to the cab.

Prioritizing the features of this design in terms of benefit to the override mitigation problem results in the following list:

(1) Braced collision posts and roll bar (baseline)

(2) Improving the sandbox strength and attaching it to the improved collision posts (Impact Energy Attenuation - Option 1)

(3) Increasing the strength and attachment of the battery boxes (Crash Attenuation - Option 2)

(4) Strengthening the side sills and connecting them to a stronger end sill-plus adding stronger coupler mounting welds (Energy Absorption - Option 3)

(5) Cab Safety Additions (Option 4)

- Stronger equipment tie downs; e.g., water fountain and fire extinguisher
- Cover exposed valves
- Padded impact bar for occupants
- All sharp corners removed.

See Appendix D for a static load analysis of the braced collision/roll posts design.

3.3.2 Design No. 2: Roll Cage

The roll cage shown in Figure 3-7 is a possible approach to ensure a survivable cab volume in an override due to a collision or a locomotive rollover in a derailment or collision. The structure is constructed of 4" x 4" x 3/8" wall steel tubes that are bolted together. This structure is tied to the underframe through the four center columns. It was designed to be manufactured in individual pieces and to be assembled inside the locomotive cab.

The column load carrying capacity of the structure is 800,000 lb, but it does not have this level of load capacity in a longitudinal or lateral direction. Because the roll cage design primarily provides cab structural strengthening (survivable volume), its application to the override problem should be considered. This design has some deficiencies as a modification possibility that must be pointed out:

- Low longitudinal and lateral stiffness
- Underframe connections interfere with the locomotive's airbrake system
- Roof crossbraces interfere with the locomotive's air-conditioning system
- Reduces interior volume
- Restricts the interior lateral visibility.

Because this design is primarily a roll cage and not an override deflector, its applicability to the train-to-train collision problem is not as great as the braced collision/roll posts design, except in a rollover.

3.3.3 Design No. 3: Burlington Northern Collision Nose

Burlington Northern (BN) railroad ordered its 1980 purchased locomotives with an improved collision post design. This safety improvement, as shown in Figure 3-8, is installed by the manufacturer when the locomotives are built. From the description of the design, it represents a possible safety improvement for other locomotives to address the override problem. An analysis of the structure reveals that its stiffness was only in the longitudinal direction, which helps mitigate the override problem, but it does not provide rollover protection at all. Therefore, it does not address the total "survivable volume" issue.

The BN collision nose was designed to address only collision speeds below 15 mph, which covers 76 percent of the reported injuries and 60 percent of the fatalities. This is in comparison to the braced collision/roll posts design which covers the speed range where 96 percent of the injuries and 100 percent of the fatalities were reported.

The Canadian Research Center produced a design, Canadian National Cab (CN), which is similar to the BN design but involved wider reinforcing of the cab. The CN design added somewhat more weight, thus reduced operating fuel efficiency, but did not provide a significantly higher level of occupant safety or impact absorption compared to the BN design.

Details of the CN design are given in Appendix E. Since the design is similar to the BN design it is not considered as a separate modification concept in the current study. A summary of the locomotive modifications is shown in Table 3-2 and discussed in greater detail in Section 4.

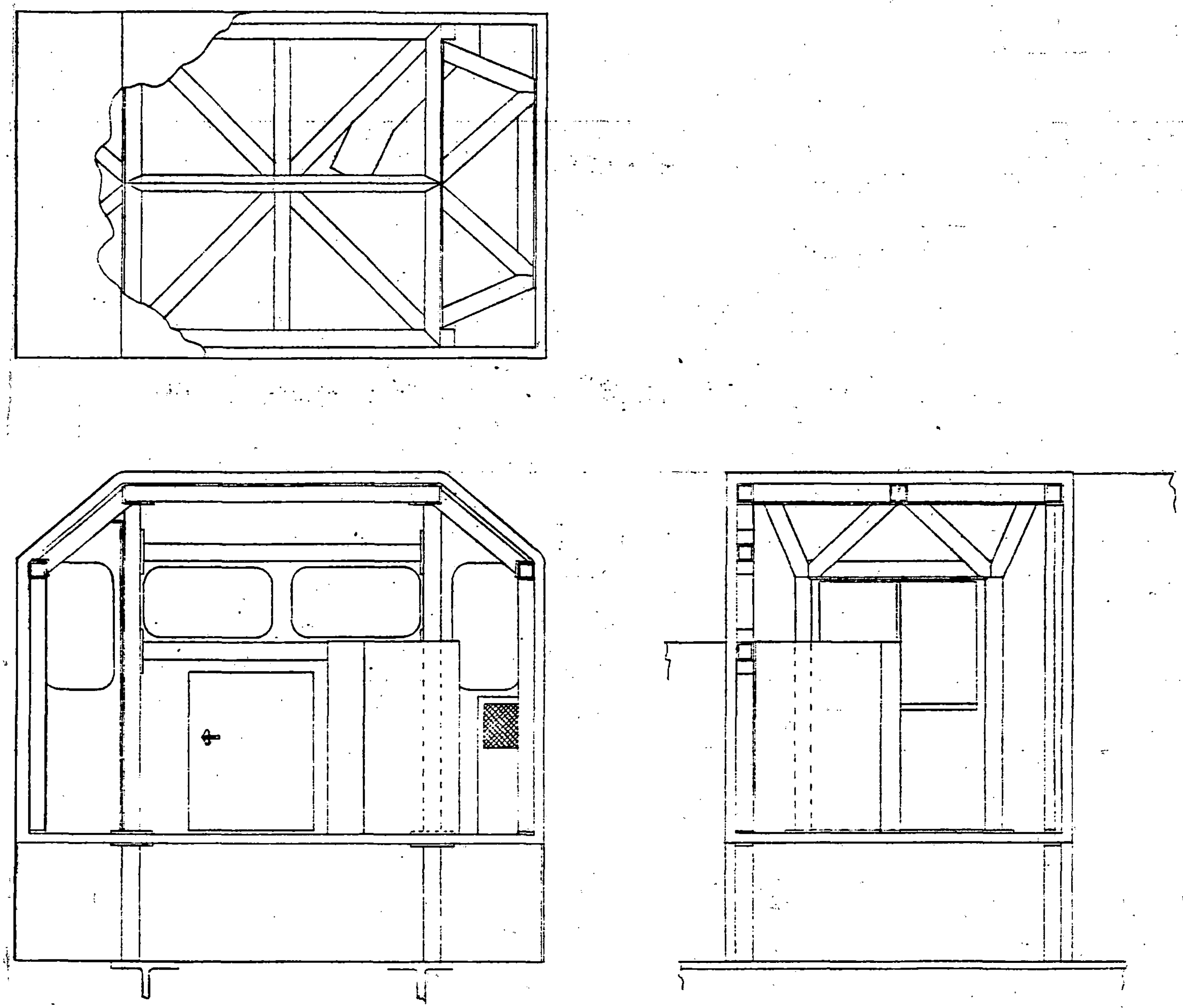

FIGURE 3-7.

DESIGN NO. 2:
ROLL CAGE

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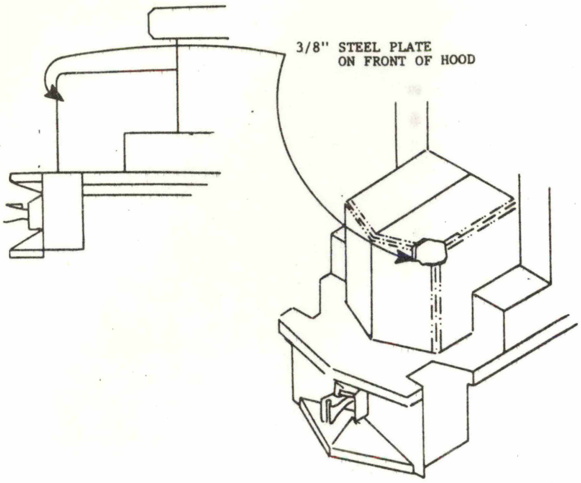


FIGURE 3-8. BN COLLISION NOSE

TABLE 3-2. SUMMARY OF LOCOMOTIVE MODIFICATIONS

Retrofit Design
Braced Collision/ roll post
BN Collision nose
Roll cage

3.4 NEW CONSTRUCTION

New locomotive designs should address the same areas of concern as the modification designs, i.e., controlled force deflection characteristics (impact absorption), survivable cab volume (override deflection and vertical crash protection), and occupant safety. In new locomotive designs, the designer has a greater opportunity to consider crashworthiness and occupant safety in the design process. In this endeavor, the designer has the freedom to select the materials, equipment placement, and structural design to address these concerns. From the accident statistics review, Section 2, and the accompanying review of crashworthiness research, Section 3, the following points should be addressed by the designer to ensure a safe, crashworthy locomotive design.

- From accident statistics:
  - Impact velocity of 30 mph for occupant safety
  - Ultimate locomotive strength to withstand impacts up to 40 mph.
- From crashworthiness research:
  - Impact absorption by collision posts of 500,000 lb
  - Deflectors for overriding vehicles
  - Rollover protection
  - Cab interiors designed for occupant safety.

Further information is contained in the Boeing Vertol reports titled "Locomotive Cab Design Development, Volume IV: Recommended Design" [18] and "A Structural Survey of Classes of Vehicles for Crashworthiness." [19]

Stanford Research Institute (SRI) has conducted a series of scale model tests of some of the new construction recommendations. Their results are summarized below:

- Boeing Vertol Design (Figure 3-9): Couplers engaged cab structure during override. Structure weighs 12,000 lb.
- SRI Modified Design (1) (Shorter, Steeper Ramp): Overriding vehicle developed too much vertical velocity. Light Structure.
- SRI Modified Design (2) (Short ramp and impact attenuation material): Lowered vertical velocity. Light Structure: 4,000 lb.

The braced collision/roll posts design presented in paragraph 3.3.1 could also apply to new construction. It addresses all the same areas as the previous research on crashworthiness. The attractiveness of the design to new construction lies in the fact that the cab and clearance profiles are nearly identical to existing locomotives, which would reduce the impact of operating agreements, interchange procedures, and training costs. This design is comparable in weight to the SRI designs (5,000 lb Versus 4,000 lb).

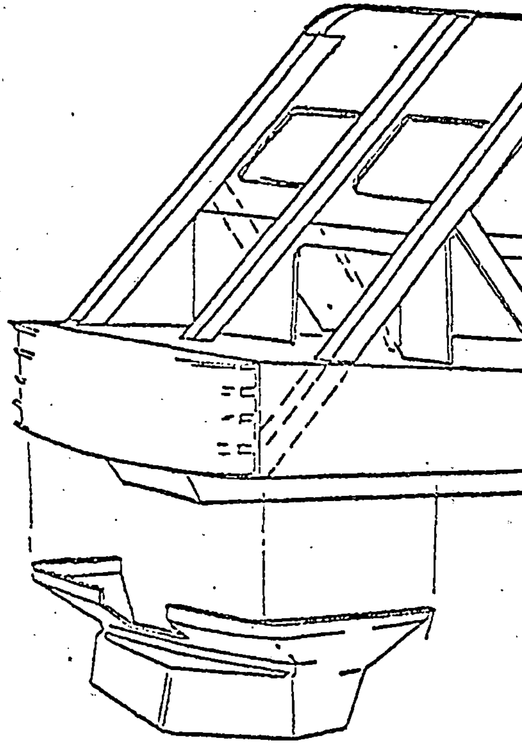
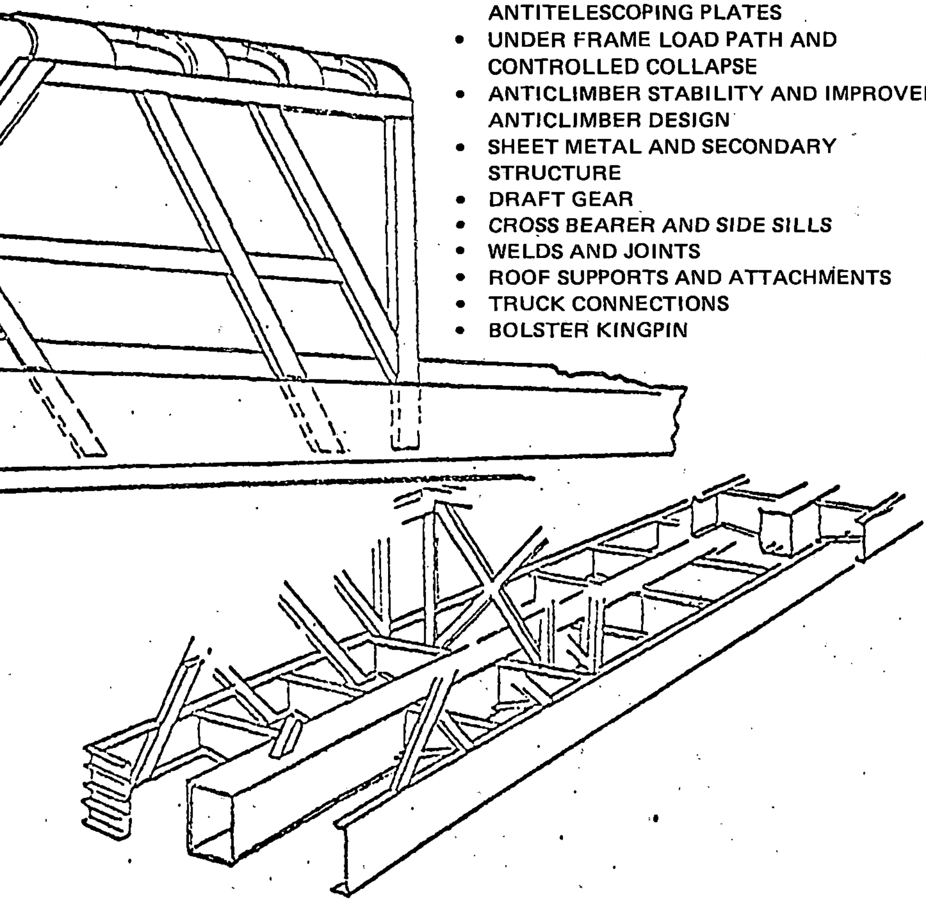


FIGURE 3-9.

REQUIREMENTS

- COLLISION END POSTS ANTITELESCOPING PLATES
- UNDER FRAME LOAD PATH AND CONTROLLED COLLAPSE
- ANTICLIMBER STABILITY AND IMPROVED ANTICLIMBER DESIGN
- SHEET METAL AND SECONDARY STRUCTURE
- DRAFT GEAR
- CROSS BEARER AND SIDE SILLS
- WELDS AND JOINTS
- ROOF SUPPORTS AND ATTACHMENTS
- TRUCK CONNECTIONS
- BOLSTER KINGPIN



BOEING VERTOL CAB DESIGN LAYOUT

4 IMPACT ANALYSIS OF DESIGN CONCEPTS (ENGINEERING ECONOMY)

4.1 INTRODUCTION

In subsection 3.3, three possible designs were discussed. Each had merit since they all addressed the criteria established to evaluate their technical feasibility. Specifically, they all provided some level of structural integrity to ensure a survivable cab volume during an override due to a train-to-train collision. This section evaluates each proposed locomotive modification design for its impact on railroad operations. This analysis will consider the following performance and financial factors to establish the engineering economy of each design.

- Performance
  - Weight and balance
  - Structural penalty
  - Visibility
  - Operational efficiency
  - Cab habitability and access
  - Interchangeability
- Financial
  - Cost of concept (including downtime)
  - Operational cost
  - Maintenance cost
  - Equipment loss and damage cost
  - Unit age, condition, and remaining life
  - Funding source(s) and availability

After the performance and financial impact of the three designs are covered, they are ranked in order of their benefit to crew safety and equipment survivability.

4.1.1 Performance Factors of the Three Modification Designs

Table 4-1 compares the three locomotive modification designs and the performance factors. The following discussion covers each performance factor and the three designs.

4.1.1.1 Weight and Balance. The three designs add 1 to 2 percent to the locomotive weight over and forward of the

TABLE 4-1. LOCOMOTIVE MODIFICATION PERFORMANCE FACTORS

	Modification Design		
Performance Factors	Braced Collision/ Roll Posts	Roll Cage	BN Collision Nose
Weight and balance	- Adds 5,000 lbs. wt. CG moves forward	- Adds 2,500 lbs CG moves forward	- Adds 1,000 lbs. CG moves forward
Structural penalty	Must move equipment in short nose	Reduces interior room	None
Visibility	- Vertical no change - Shifts lateral vision	- Vertical no change - Restricts laterals	No change
Operational efficiency (wt. and drag)	- Increases wt. - 4 axle + 2% - 6 axle + 1%	- Increases wt. - 4 axle +1% - 6 axle + 0.5%	- Increases wt. - 4 axle + 0.1% - 6 axle + no change
Maintenance and reliability	- Fixed installation - No change	- Fixed installation - No change	- Fixed installation - No change
Cab habitability	Removes front door - no walk-through access	Reduces interior room	No change
Interchangeability	Should not affect interchange	May restrict interchange different interior	Should not affect interchange
Union agreements	R/R capital equipment - not addressed in union agreements	R/R capital equipment - not addressed in union agreements	R/R capital equipment - not addressed in union agreements

front truck. This additional weight shifts the center of gravity of the locomotive forward slightly.

In the case of the 6-axle EMD locomotives, this increase in weight is negligible, approximately 1 percent. Also, some railroads add ballast to improve wheel adhesion, which means that judicious selection of the design weight and the ballast weight would result in a locomotive with the same operating wieght.

Four-axle locomotives present a different problem. Since they are already at 98 percent to 99 percent of their maximum designed axle loads, the addition of the modification must be carefully planned to maintain the locomotive weight within these axle load limits. The tolerance on design loads is ±5 percent, which is larger than the modification increase. Therefore, the modification may be accommodated on a 4-axle locomotive without violating the axle load limits.

4.1.1.2 Structural Penalty. Each design has some effect on the basic locomotive structure. The braced collision/roll posts and BN collision nose designs require the movement of some equipment in the shortnose of the locomotive, while the roll cage design reduces the interior floor space of the locomotive cab by 1.5 percent.

4.1.1.3 Visibility. The braced collision/roll posts and roll cage designs restrict the existing visibility. The braced collision/roll posts design does not alter the vertical visibility, but it does shift the lateral visibility (see Figure 4-1). The roll cage design, being an internal structure, does not change the forward visibility, but it does block some of the lateral visibility since one must look around the structure for full lateral visibility. The BN collision nose design does not alter the existing visibility since the structure is inside the shortnose.

4.1.1.4 Operational Efficiency. All three designs affect operational efficiency of the locomotive when installed. They all increase the operating weight which increases the rolling resistance, and, therefore, the fuel consumption. This is especially true for 4-axle locomotives where very little weight trade-off is available. Those railroads that ballast their 6-axle locomotives have an opportunity to minimize this impact by off-loading ballast equivalent to the modification weight, which would not alter the locomotive's operating weight. In any case, the addition is less than 2 percent of the operating weight and should not significantly increase the locomotive's fuel consumption.

4.1.1.5 Maintenance and Reliability. Since all three designs are fixed installations, once installed they should not require additional maintenance. They are constructed of heavier materials than the basic cab structure, which should make them more reliable than the existing locomotive cab designs.

4.1.1.6 Cab Habitability and Access. The three designs have different impacts on the cab habitability and access. The braced collision/roll posts and BN collision nose designs are both exterior to the cab, and they have minimal impact on cab habitability. On the other hand, the roll cage design adds structure to the cab interior, reducing the floor space and headroom, which reduces the cab interior size. This reduction in interior size may cause more problems than it solves by creating new secondary impact injury sources.

Access to and from the cab is altered by both the braced collision/roll posts design and the roll cage design. That is, the braced collision/roll posts design fills the left front door area with a steel plate to act as a web between the braced collision/roll posts and the side roll bar. This design restricts access between locomotives in a multiple-unit operation. Access may be restored in this design by altering the gusset design and installing a structural (load-carrying) door. The roll cage reduces access throughout the cab in which it is installed by reducing the head room and door widths. The BN collision nose has no impact on cab access.

4.1.1.7 Interchangeability. The braced collision/roll posts and BN collision nose designs do not alter the interior of the locomotive cab, and, therefore, they should not affect the interchange of locomotives between railroads, which is a prevalent practice on coast-to-coast long-haul trains. The roll cage design does alter the cab interior, which may affect the acceptance of this design for unrestricted interchange.

4.1.1.8 Procurement. Locomotives are purchased by the individual rail-roads as captial equipment. The railroads are concerned with cab habitability and safety. Safety (crashworthiness) is addressed by these concepts. Cab habitability is covered under operational solutions.

4.1.2 Financial Factors

In Table 4-2 each design is investigated

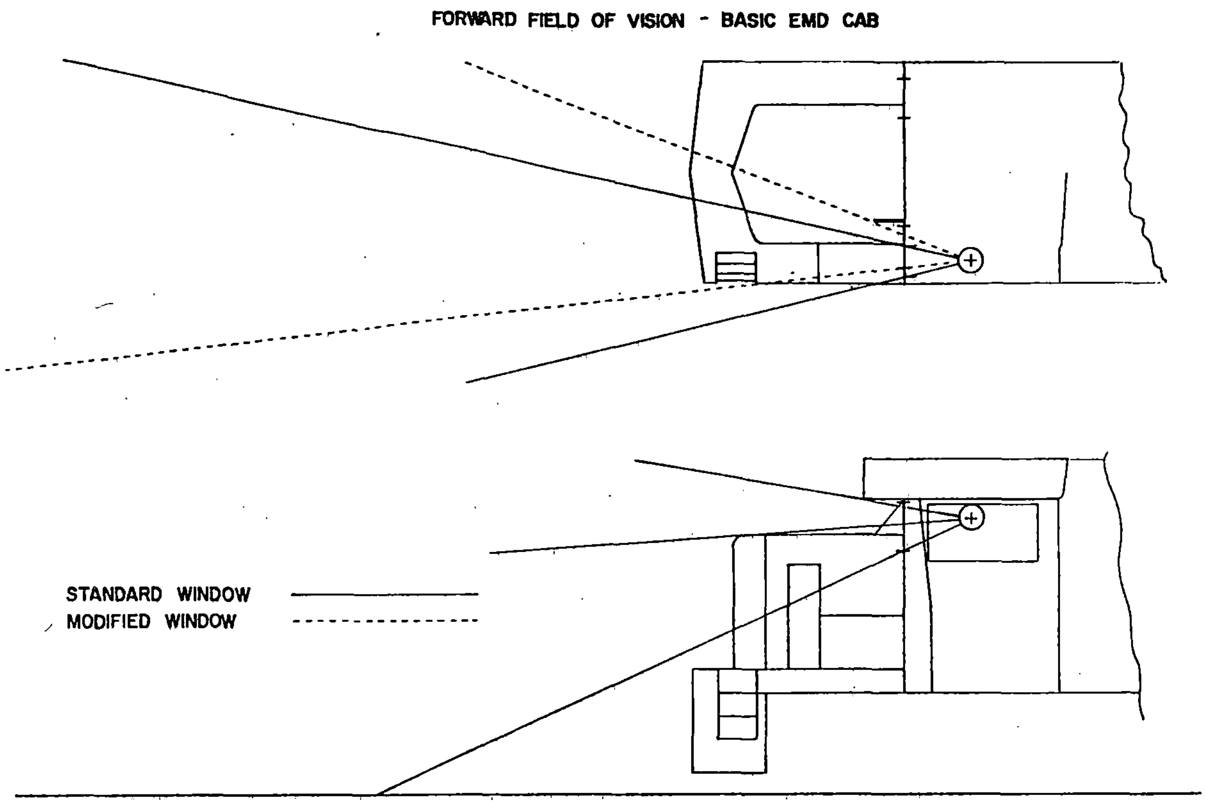


FIGURE 4.1 GP40 LOCOMOTIVE MODIFICATION VISIBILITY

TABLE 4-2. LOCOMOTIVE MODIFICATION COST FACTORS

	Retrofit Design		
Cost Factors	Braced Collision/ Roll Posts	Roll Cage	BN Collision Nose
Cost of solution	- Retrofit $16,100 - Downtime $360/day	- Retrofit $7,150 - Downtime $360/day	- $10,000 - Downtime $360/day
Operational costs/year	- Increase fuel cost 1-2% - +$600-$1200/yr.	- Increase fuel costs approximately 1½% - +$900/yr.	- No impact - $ 0
Maintenance costs	Negligible	Negligible	Negligible
Equipment loss or damage cost	- Loco $360/day - Rebuild retrofit $16,100	- Loco $360/day - Rebuild retrofit $7,100	- Loco $360/day - Rebuild retrofit $10,000
Labor and productivity cost factors	- Always lead loco - $100 total	- Always lead loco - $100 total	- Always lead loco - $100 total
Unit age, condition and remaining life	- Avg. age 12 yrs. - Salvage age 20-25 yrs. - Retrofit limit 12½ yrs.	- Avg. age 12 yrs. - Salvage age 20-25 yrs. - Retrofit limit 12½ yrs.	- Avg. age 12 yrs. - Salvage age 20-25 yrs. - Retrofit limit 12½ yrs.
Funding source(s) and survivability	- Competes for R/R maintenance budget funds	- Competes for R/R maintenance budget funds	- Competes for R/R maintenance budget funds

for its financial impact; e.g., installation costs, operational costs, maintenance costs, and factors associated with unit age, which affects the decision to do the modification in the first place.

4.1.2.1 Cost of Concept. Two factors are considered in the cost of the modification: (1) the cost of the concept in terms of labor and materials, and (2) the cost of the locomotive downtime from revenue service.

Since the locomotive downtime cost is a constant, $360/day in interest cost, the only variable is the length of time for the modification. It is estiamted that the V-shield would take one day to install, the roll bar two days, and the collision post and nose designs five days to complete. The major difference in time between the designs is the fact that the roll bar may be fabricated without requiring the locomotive to be present, while the braced collision/roll posts design takes longer since the locomotive must be present for disassembly and reassembly. The following downtime cost is associated with each design:

- Braced collision/roll posts
  @ 14 days $5,040
- BN collision nose
  @ 5 days $1,800
- Roll cage design
  @ 2 days $720

Each design has been discussed with various railroad personnel to get their input on the skills, time, and materials required for implementation. These inputs were applied to a range of labor costs to establish the cost range of the designs.

The braced collision/roll posts design requires 107 mandays of sheet metal workers, machinists, and pipefitters to accomplish the disassembly, fabrication, and installatin. This equates to 864 manhours at an averge of $14/hr (wages and benefits) which results in a labor cost of $12,000. Material costs are estimated at $4,000 for a total cost of $16,000.

The BN collision nose design added about $5,000 to the delivery price of their new locomotives (this design is manufacturer-installed). It is estimated that to disassemble and install this design would double this price to $10,000 for both material and labor costs.

The roll cage design requires 48 mandays or 384 manhours to manufacture and install. This results in a cost for labor of $5,400. Adding $1,750 for materials brings this design cost to $7,150.

4.1.2.2 Operational Cost. All the modification designs add some weight to the basic locomotive, which adds to its rolling resistance. This increase in weight will cause an increase in fuel consumption comparable to the weight increase of 1 to 2 percent for 4-axle and unballasted 6-axle locomotives. There will be no changes in the operating weight or fuel consumption of the ballasted 6-axle locomotives. Using an estimated fuel consumption of 3,000 gallons/year, a 1 to 2 percent increase at $.50/gallon for diesel fuel would increase operating costs by $1,500 a year.

4.1.2.3 Maintenance Cost. Since all three designs are fixed installations and require no scheduled maintenance, the maintenance costs associated with these designs would be limited to preventive maintenance (e.g., rust proofing, painting, etc.).

4.1.2.4 Equipment Loss and Damage Cost. The proposed modifications, which vary in cost between $7,150 and $16,000, are all engineered to absorb impact energy by deforming under load. Any collision with sufficient energy to impact one of the modifications should damage it. Therefore, it is estimated that costs associated with a train-to-train collision would probably increase since the modification must be repaired along with the basic locomotive damage. The major cost benefit of these proposed modifications is train crewmember safety and not equipment damage avoidance. Equipment damage avoidance is addressed under subsection 4.3, "Impact Analysis of Operational Concepts."

4.1.2.5 Unit Age, Condition and Remaining Life. The average age of in-service road locomotives is 12 years. Depending on their intended use, locomotives are retired for salvage at 20 to 25 years of life, with yard locomotives having the longest service because of low-speed operation. The modifications, each with a different cost, would have different periods for which the modification has economic value. The braced collision/roll posts design would not be considered for locomotives over 12 years old or with less than 10 years of useful life remaining. Locomotives are usually overhauled every two to three years, and adding the modification at this time should reduce the downtime costs since the locomotive is already scheduled out-of-service and the modification may be done in parallel with the overhaul.

4.1.2.6 Funding Source(s) and Availability. Two sources of funding were investigated for the designs - railroad funds and government assistance. In the case of railroads, the modifications would compete with other maintenance programs in their budget cycle. At least one study by the National Transportation Policy Study Commission recommended in 1979 that the government fund safety improvements for all modes of transportation, but the government has taken no actions at this time. The NTSB has also recommended safety programs to the FRA for research on safety issues; one of which, Locomotive Crashworthiness, is the basis for this report. The NTSB did not recommend government funding for implementing their recommendations. The 3R Act and 4R Act also do not specifically address government funding of safety improvements for railroads.

4.2 IMPACT ANALYSIS OF NONLOCOMOTIVE CONCEPTS

Three nonlocomotive concepts to mitigate the override problem were discussed in paragraph 3.1.3. The objective of these modifications is to reduce the tendency of the impacted car to override the locomotive in a train-to-train collision.

4.2.1 Performance Factors of the Three Nonlocomotive Override Mitigation Concepts

In Table 4-3 each of the proposed nonlocomotive override concepts is evaluated against the performance factors listed in subsection 4.1. Some of these factors do not apply to these concepts, and where they do not apply is indicated by an "N/A" (Not Applicable).

4.2.1.1 Weight and Balance. None of the proposed nonlocomotive concepts would add over 100 lb of weight to the modified car. Locking center pins or safety chains weigh less than 50 lb each. Improving the coupler material (stronger steel) and mounting would not significantly alter the weight of the coupler system. However, the use of E or F shelf couplers would add additional weight. Again, this increase should be less than 100 lb per 45,000-lb car, or less than 0.2 percent of the total weight.

4.2.1.2 Structural Penalty. The only structural penalty involved with these proposed concepts is the locking center pin. If a locking center pin is used to retain the trucks on a caboose or freight car, an access door must be cut in the car's floor over the center of the bolster to provide access to the center pin to install and remove the lock. This has no significant effect on the structural strength of the railcar. Improving the coupler mounting strength and material will induce higher loads into the underframe of the impacted car, which may cause more structural damage to the car's underframe than before the modification.

4.2.1.3 Visibility. None of the proposed modifications for affects the visibility of the modified car.

4.2.1.4 Operational Efficiency. Since the proposed three concepts add so little weight to the railcar, they should have no impact on the operational efficiency of the railroads.

4.2.1.5 Maintenance and Reliability. Both the truck retention schemes and the recommended coupler improvements affect the maintenance and reliability of the subject railroad cars. The use of locking center pins requires the additional task of removing the lock to remove the trucks for maintenance. Since this is not a normal car configuration, proper identification on the car plus additional maintenance crew qualifications will be required to ensure proper car maintenance. This should not be a problem for railroads with passenger cars because the locking center pin is normal passenger car equipment. Similarly, a safety retaining chain around the bolsters would require car marking and also proper disassembly for truck removal. Again, this task should be well within the normal maintenance capability of the railroads.

Coupler improvements in material strength (higher grade steels) and mounting techniques should not affect the railroad maintenance cycle since these improved items would look identical to the original equipment. Reliability of these items should be improved (require less maintenance) because of their improved strength.

4.2.1.6 Cab Habitability and Access. The proposed railcar modifications do not affect the locomotive configurations and, therefore, they do not affect cab habitability and access.

4.2.1.7 Interchangeability. The proposed railcar modifications have a minor effect on interchangeability. Basically, the modified cars need special identifiers, such as stenciled information that the car is modified with a locking center pin, safety chain, or a special-strength coupler. Unless the railroad industry adopts these proposed changes industrywide, a car "bad ordered" for a deficiency in these parts may have to be returned to the owning railroad for repair. This would be especially true of spare parts for a modified car in interchange services.

TABLE 4-3. NONLOCOMOTIVE PERFORMANCE FACTORS

	Nonlocomotive Modification		
Performance Factors	Caboose Truck Retention	Freight Car Truck Retention	Coupler Modifications
Weight and balance	- Adds negligible weight	- Adds negligible weight	- Shelf couplers add weight - Stronger material and mounting
Structural penalty	- Floor access required to release locking center pin	- Floor access required to release locking center pin	- None - Improves mounting
Visibility	N/A	N/A	N/A
Operational efficiency	N/A	N/A	N/A
Maintenance and reliability	- Requires release of retention device to remove truck for maintenance	- Requires release of retention device to remove trucks for maintenance	- Increases reliability due to use of stronger material
Cab habitatility and access	N/A	N/A	N/A
Interchangeability	Caboose must indicate that trucks are restrained	Freight car must indicate that trucks are restrained	- If shelf used, coupler may not be compatible with some tank cars
Union agreements	- Addresses their safety concerns	- Addresses their safety concerns	- Addresses their safety concerns

4.2.1.8 Freight Car Configuration. Freight car configuration is established by the car manufacturer, the purchasing railroad, and AAR interchange standards that the car must meet. The proposed modifications addressed by this study do, however, cover the concerns about the safety aspects of a locomotive override in a collision environment.

4.2.2 Financial Factors of the Nonlocomotive Concepts

The modifications covered in this report are evaluated for various financial considerations as shown in Table 4-4. Those financial factors which do not apply to any or all of the concepts are indicated by N/A.

4.2.2.1 Cost of Concept (including downtime). Modifications for proposed nonlocomotive concepts amount approximately $1,000 per car. These modifications include truck retention, use of E or F shelf couplers, and improved materials. When considering the freight car fleet (approximately 1,652,000), the total cost becomes prohibitive for the railroads. The use of shelf couplers on locomotives seems to be of more value since the locomotive is always the vehicle of concern.

Listed below are the costs associated with each modification. Each modification takes less than 8 hours of labor. Average railroad labor rates including benefits are approximately $12.50 per hour. Consequently, this should cost less than $100 per modification.

	Material Cost Per Item ($)	Labor Cost Per Car ($)
Caboose truck retention		
- Locking center pin	60	100
- Safety chain	50	50
Freight car truck retention		
- Locking center pin	60	100
- Safety chain	50	50
Coupler modifications		
- E or F shelf coupler cost increase over standard coupler)	207	50
- Mounting improvements	50	50

For example, adding a locking center pin, shelf coupler, and improved coupler mounting would add $874 per car to selected cars.

4.2.2.2 Operational Cost. Once installed, the modifications should be transparent to normal railroad operations and they would not increase operational costs.

TABLE 4-4. NONLOCOMOTIVE COST FACTORS

	Nonlocomotive Modification		
Cost Factors	Caboose Truck Retention	Freight Car Truck Retention	Coupler Modifications
Cost of solution	- Locking center pin - $60 each - Safety chain - $50 each	- Locking center pin - $60 each - Safety chain - $50 each	- Shelf coupler - $620 each - Improved mounting - $100 each
Operational costs	N/A	N/A	N/A
Maintenance cost	- Adds 1 hr/truck removal $< \$15$ - Spares add $40 each	- Adds 1 hr/truck removal $< \$15$ - Spares add $60 each	- Strength - no change - Shelf increases spares by $200 each
Equipment loss and damage costs	- Replace locking pin - $60 each - Replace safety chain - $50 each	- Replace locking pin - $60 each - Replace safety chain - $50 each	- Replace shelf coupler $200 each - Strengthen coupler pocket - $100 each
Labor and productivity cost factors	N/A	N/A	N/A
Unit age, condition and remaining life	- Average age over 20 years - Salvage 35-40 yrs.	- Average age over 20 years - Salvage 35-40 yrs.	- Average age over 20 years - Salvage 35-40 yrs.
Funding sources and availability	- Competes for railroad car maintenance budget	- Competes for railroad car maintenance budget	- Competes for railroad car maintenance budget

4.2.2.3 Maintenance Cost. Maintenance costs associated with these nonlocomotive modificatons fall into two categories. , there is an increased labor required to maintain extra components on each car, and second, there is the cost of spares due to three modifications.

4.2.2.4 Equipment Loss and Damage Cost. Repair of the modification due to collision damage should cost the same as the original modification. Using this fact as a basis for estimating equipment loss and damage costs results in the following material cost. Here it has been assumed that the labor for the modification repair would not be separable from the overall car repair labor.

	Estimated Material Cost Per Item ($)
Replace truck retention devices	
- Locking center pin	60
- Safety chain	50
Replace coupler	
- E or F shelf coupler	207
- Coupler strengthening	50

4.2.2.5 Labor and Productivity Cost Factors. These proposed modifications are essentially imperceptible to the general railroad operations; therefore, they would not increase or decrease the existing railroad productivity or labor cost.

4.2.2.6 Unit Age, Condition, and Remaining Life. Cabooses have a longer lifetime than locomotives, typically lasting up to 35 to 40 years. The present average age of the caboose fleet is approximately 20 years. Consequently, based on remaining life, all of the fleet is eligible for modifications up to the decision to salvage.

4.2.2.7 Funding Source(s) and Availability. These modificatons would compete with other railroad car maintenance programs for funding. Although various studies and government acts address safety research and railroad funding, none of these sources specifically set aside funds for safety improvements for railcars.

4.3 IMPACT ANALYSIS OF OPERATIONAL CONCEPTS

The operational concepts to mitigate the override problem in train-to-train collisions were presented in subsection 4.1. These concepts fall into two categories: (1) operational equipment and (2) operational procedures. The two categories are listed below and are discussed separately in this report on the impact analysis.

- Operational Equipment
  - Locomotive coupler design
  - Safety glass
  - Protective padding
  - Occupant restraints
  - Anticlimb devices
  - Emergency exits
- Operational Procedures
  - Coupler maintenance
  - Longhood-forward operations
  - Consist practices and procedures
  - Communications
  - Train dynamics

These concepts are evaluated with respect to the following performance and financial factors stated in subsection 4.1.

- Performance and Financial Factors
  - Weight and balance
  - Structural penalty
  - Visibility
  - Operational efficiency
  - Maintenance and reliability
  - Cab habitability and access
  - Interchangeability
  - Union agreements

4.3.1 Operational Equipment Concepts

Table 4-5 shows an evaluation of each operational equipment concept compared against the specified performance factors. Where a performance factor does not apply, this is indicated by an N/A.

4.3.1.1 Weight and Balance. Only two operational equipment concepts have any impact on a locomotive's weight and balance. They are: (1) the addition of shelf couplers (including increase of coupler mounting strength) and (2) the addition of anticlimb devices to the

TABLE 4-5. PERFORMANCE FACTORS OF OPERATIONAL EQUIPMENT CONCEPTS (All Applied to Locomotive)

Financial Factors	Equipment					
	Shelf Coupler	Safety Glass	Protective Padding	Occupant Restraint	Anticlimb Device	Emergency Exits
Weight and balance	Negligible increase	N/A	N/A	N/A	Adds a little	N/A
Structural penalty	N/A	N/A	N/A	N/A	Extends deck plate which may cause deck bending under impact load	N/A
Visibility	N/A	Must use proper type of safety glass	N/A	N/A	N/A	N/A
Operational efficiency	Reduces coupler problems	N/A	N/A	Decreases operator mobility	Prevents low speed collision override <5 mph	N/A
Maintenance and reliability	Increases coupler reliability	Increased installation complexity	Increases inspection and repair	Increases inspection and repair	Increased repair due to more structure	Same as safety glass
Cab habitability and access	N/A	Improves operator confidence	Improves operator confidence	N/A	N/A	Improves emergency exits
Interchangeability	Must be marked as a shelf coupler	N/A	N/A	N/A	N/A	N/A
Union agreements	Addresses union safety concerns	Addresses union safety concerns	Addresses union safety concerns	A union recommendation	Addresses union safety concerns	Addresses union safety concerns

locomotive (e.g., the BN V-shield). Since both the coupler improvements and anticlimb devices are added to both ends of the locomotive, the locomotive balance is maintained. Consequently, the only consideration under this performance factor is the added weight.

In the case where both modifications are added, the increase in weight would be 1,200 lb or a little over 0.1 percent of a 4-axle locomotive's weight, and even less for a 6-axle.

4.3.1.2 Structural Penalty. Of the proposed operational equipment concepts, only the anticlimb devices have a structural penalty implication. Because they are attached to and are extensions of the locomotive deck plate, impact loading on the anticlimb device may result in bending of the deck plate. Most railroad locomotive shops are capable of frame straightening, so this would not be considered a severe penalty for this operational equipment modification.

4.3.1.3 Visibility. The only modification which may affect visibility from the locomotive is the change in glazing associated with safety glass. The type of safety glass selected must be distortion-free to ensure proper visibility from the locomotive during normal operations.

4.3.1.4 Operational Efficiency. In general, the applicable proposed concepts are intended to improve the operational efficiency of the locomotive crew by reducing both operational problems and by providing a safer operating environment. Both the coupler improvements and anticlimb devices are installed to prevent override, especially in low-speed collisions. Occupant restraint systems may reduce the operator's mobility and as such may not be used. They do, however, provide protection for the operator in a collision environment. These proposed concepts would increase the operator's confidence in the safety of the locomotive cab in a low-speed collision.

4.3.1.5 Maintenance and Reliability. All of the equipment concepts affect the maintenance and reliability of the locomotives. They increase the number of parts to maintain and to inspect, thereby increasing the manhours required to maintain the locomotive. In the case where increased parts are used (e.g., seat belts) the requirement for increased spare parts is evident. For the present analysis, a 10 percent spares complement is assumed.

Each component recommended to be added has a relatively high reliability but, because it means more parts, it would reduce the overall locomotive reliability from a maintainability standpoint. Since these additions are not essential to the operation of the locomotive, their addition should not affect the day-to-day operational availability of the locomotive.

4.3.1.6 Cab Habitability and Access. The safety additions of safety glass, protective padding, and emergency exits improve the cab habitability from an operator's confidence viewpoint. They provide a protective environment when considering both vandalism and secondary impact sources. Installing the safety glass as an emergency exit also improves operator confidence by ensuring emergency egress through these portals.

4.3.1.7 Interchangeability. None of the proposed equipment concepts to mitigate the override problem should affect the interchangeability of the locomotive. Each device or equipment that is recommended is self-explanatory in its operation or intended use. However, in unrestricted interchange, the leasing railroad may not have spare parts to repair a deficiency in one of the equipment concepts. The lack of spare parts for any of the proposed equipment concepts, except the shelf coupler, should not affect the normal operations of the locomotive. In the case of the coupler, the locomotive should be properly marked (stenciled notice) stating that the coupler is a shelf variety. This ensures proper replacement if the coupler is damaged in any way during interchange service.

4.3.1.8 Procurement. Locomotives are purchased by the railroads as capital equipment. Their design and accessory equipment is determined by the purchasing railroad and the locomotive manufacturer. All of the proposed equipment concepts covered by this report address union safety concerns about locomotive operations. As a matter of fact, the proposed occupant restraint system is even a union recommendation.

4.3.2 Financial Factors of Operational Equipment Concepts

Each operational equipment concept is evaluated against the applicable financial factors as summarized in Table 4-6.

4.3.2.1 Cost of Concept (including downtime). The operational equipment concepts vary in cost from $65 to $2,500 per set of equipment. Listed in Table 4-7 are the individual costs per locomotive. At the bottom of this listing is the total cost per locomotive if all

TABLE 4-6. FINANCIAL FACTORS OF OPERATIONAL EQUIPMENT CONCEPTS

Financial Factors	Equipment					
	Shelf Coupler	Safety Glass	Protective Padding	Occupant Restraint	Anticlimb Devices	Emergency Exits
Cost of solution	Adds $400 per coupler	Cost-$51 per square foot more than reg. glazing	Cost-$1,000 to install	Cost-$65 to install per seat	Costs as much as $2500 to install per locomotive	Adds 20% to the cost of safety glass installation
Operational Costs	N/A	N/A	N/A	N/A	N/A	N/A
Maintenance Costs	Increases spares cost $400 per coupler	Increases repair cost by $2,000	N/A	Increases spares cost by $65 each seat	- Permanent install - Only preventative maintenance costs	Increases spares cost by 10%
Equipment loss and damage costs	Increases replacement cost $400 per coupler	Cost $51 per square foot to repair	Costs $1,000 to replace if damaged	Costs $240 to replace if damaged	Costs up to $2500 to replace damaged anticlimb device	Adds 20% to the cost of safety glass replacement
Labor and productivity cost factors	N/A	Improves Operator confidence	N/A	Slightly restricts operator movement within locomotive cab	N/A	Improves operator confidence
Unit age, condition and remaining life	N/A	N/A	N/A	N/A	N/A	N/A
Funding sources and availability	Competes for railroad equipment maintenance budget	Competes for railroad equipment maintenance budget	Competes for railroad equipment maintenance budget	Competes for railroad equipment maintenance budget	Competes for railroad equipment maintenance budget	Competes for railroad equipment maintenance budget

TABLE 4-7. COST OF OPERATIONAL EQUIPMENT CONCEPTS MODIFICATION FOR LOCOMOTIVE

Modification	Estimated Material Cost ($)	Estimated Labor Cost per Installation ($)	Installation per Locomotive	Estimated Modification Cost ($)
Shelf coupler	400 each	15 per hour	2	830
Safety glass	6 per window	See emergency exits	12	1,000
Protective padding	500	500	1	1,000
Occupant restraints	65 each	15 per hour	3	240
Anticlimb device	2500 each	Included in cost	2	5,000
Emergency exists	See safety glass	20 per window	---	240
Total				$8,310

concepts are adopted. Since these equipment concepts are relatively minor, their installation should not increase a scheduled locomotive rebuild cycle; therefore, no downtime is included in the cost figures. If the locomotive is taken out of service for only these modifications, the cost would be approximately $360 per day, which is the interest cost on purchase of a typical $800,000 locomotive.

4.3.2.2 Operational Cost. None of the proposed equipment modifications add sufficient weight or drag to substantially affect the efficiency of locomotives during operation.

4.3.2.3 Maintenance Cost. Each of the equipment modifications has an impact on maintenance. Protective padding and anticlimb devices are considered permanent installations and, therefore, their impact is covered under "Equipment Loss and Damage Cost." The rest of the modifications, which are easily replaceable, have their greatest impact on the spares cost for a locomotive. Shelf couplers, safety glass, seat belts, and emergency exit installations all increase the cost of the individual items, and similarly their spares complement. The total impact of this increase in spares cost based on a 10 percent spares complement, is approximately $800 per modified locomotive.

4.3.2.4 Equipment Loss and Damage Cost. It is reasonable to expect that all operational equipment modifications except occupant restraint systems, would be damaged to some extent in an override due to a collision, and they would have to be repaired to their original condition. Under this assumption, it would cost as much to repair these equpment modifications as it did to install them originally, i.e., $8,310 (see Table 4-7).

4.3.2.5 Labor and Productivity Cost Factors. Only the installation of safety glass and emergency exits would tend to improve productivity of the locomotive crew by improving the safety of their work areas. That is, they would be less concerned about external vandalism and more confident that they would not be injured by flying glass in a collision. The addition of seat belts would also increase their safety, but they do restrict the movement within the locomoitive cab. The safety benefits of seat belts may well outweigh the reduction in occupant mobility, and, therefore should be installed. There is no way to accurately establish a cost factor for this increase in confidence by the operators, but it would be evidenced by a reduction in equipment repair due to vandalism.

4.3.2.6 Unit Age, Condition, and Remaining Life. Due to the simplicity of these proposed operational equipment concepts and the fact that most of them could be transferred from one locomotive to another (e.g., shelf couplers, seat belts, etc.), they should be considered as viable modifications on locomotives up to the time it is decided to salvage them.

4.3.2.7 Funding Source(s) and Availability. The only established funding source for these modifications is the individual railroad's equipment maintenance budget. These would be competing with the modifications proposed under subsections 4.1 and 4.2, plus the regularly scheduled railroad maintenance. Due to the expected shortfall in capital equipment funds through 1985, modifying existing equipment may be more attractive than locomotive replacement, which should support these recommendations. Various government-sponsored studies have recommended that the government fund safety improvements in the transportation industry. However, at the time of this report, no action has been taken on these recommendations for the railroads.

4.3.3 Operational Procedures Concepts Performance

The applicable operational procedures concepts to mitigate the override problem are listed in Table 4-8. These are evaluated against their effect on the various performance factors as discussed below.

4.3.3.1 Weight and Balance. The operational procedures concepts do no affect the locomotive's weight and balance. However, one point about the weight and balance of the make-up of a total consist must be pointed out since it affects the locomotive's stopping distance, which is a prime factor in avoiding collisions. A manifest consist (as opposed to a unit train) is made up of a mixture of light, empty, and heavy cars. Although certain cars (categorized by size, cargo, or weight) are restricted from certain positions in the consist (e.g., hazardous cargos are required to be at least 10 cars behind the locomotive), the consist make-up is largely established by convenience and destination. It is this make-up that gives rise to unpredictable train dynamics, especially in long consists. To avoid these problems, consists can be made up with an even distribution of heavy and light cars within a destination block. This action would add approximately 20 percent to both the clerical and train crew tasks per day to ensure the proper consist make-up.

4.3.3.2 Structural Penalty. The only operational procedures concept that has any structural penalty is the longhood-forward operation. Operating in this configuration would require changes in the internal cab structure.

4.3.3.3 Visibility. Again, the only operational procedures concept that affects visibility is longhood-forward operation. Operating the locomotive with the high longhood up front restricts the operator's view to just that of the window in front of the operator's seat. As stated before, this is not a generally accepted practice throughout the railroad industry.

4.3.3.4 Operational Efficiency. The major point here is that operational

TABLE 4-8. PERFORMANCE FACTORS OF OPERATIONAL PROCEDURES CONCEPTS

	Operational Procedures				
Performance Factors	Coupler Maintenance	Longhood Forward Operations	Consist Practices and Procedures	Communication	Train Dynamics
Weight and balance	N/A	N/A	Improved train dynamic through better consist make-up	N/A	Only as applies to the whole consist
Structural penalty	N/A	Cab structure modified for installing redundant controls	N/A	N/A	N/A
Visibility	N/A	Restricted by the longhood	N/A	N/A	N/A
Operational efficiency	N/A	Improved - dual controls reduce wye or turntable moves	Should provide more predictable train handling	Improved intra-, inter-train communications	Improves efficiency by better train handling
Maintenance and reliability	Increases coupler maintenance cycles	Redundant controls must be maintained	N/A	Increases communication maintenance	N/A
Cab habitability and access	N/A	Additional controls restrict cab floor space	N/A	Improves intra-train communications	N/A

efficiency can be improved in terms of more predictable train handling and better braking characteristics. Each proposed operational procedures concept is discussed in terms of effects on operational efficiency.

Longhood-forward operations in one direction and shorthood-forward operations in the other direction increase operating efficiency by reducing the number of wye or turntable operations required to build a consist. This is especially true in areas where wyes or turntables are not readily available, thereby requiring long travel times to reverse the locomotive's operating direction. At least one major railroad operates in this manner.

Consist practices and procedures, as discussed in subsection 3.2, involve both consist make-up and crew complement practices. Both concepts affect operational efficiency and the railroad's operating cost. In the case of consist make-up practices, proper positioning of cars within a destination block improves train handling and, thereby, increases fuel efficiency. The crew make-up per consist exposes a greater number of personnel than necessary to the collision environment. It is recognized that crew complements are union-negotiated positions; however, reduction of the number of crew members could proportionally reduce the number of casualties in a train-to-train collision.

Intra-train, inter-train, and train-to-dispatcher communications are required for efficient operation of a consist. To ensure that communication is maintained would require an increase in the number of radios on a consist. Right now, lack of operational radios is a major problem. The aviation industry, to ensure positive control of commercial traffic, requires redundant radios to be installed on commercial aircraft. On transoceanic traffic, this is increased to three operating radios. A similar approach by the railroads would ensure that efficient operating communications were maintained.

Train dynamics, including intra-train car forces, greatly affect the handling quality of a long consist. To reduce intra-train dynamics problems and improve stopping distances, the use of shorter consists has been investigated. (These have to be evaluated against crew cost implications.) In addition to shorter consists, better cab instrumentation displaying the instantaneous consist dynamics would improve the feedback to the operator and improve his control.

4.3.3.5 <u>Maintenance and Reliability</u>. The three proposed operational procedures concepts that significantly impact maintenance and reliability are (1) coupler maintenance, (2) longhood-forward operations, and (3) communications. All three concepts imply that more maintenance performance on the locomotive equipment is needed. Increasing the coupler maintenance does not necessarily mean increased inspection, which is already performed at 8-hour intervals; but rather, disassembly inspection and repair at 30-day intervals along with the required monthly locomotive inspection and service. Similarly, an increase in communications systems on locomotives implies a proportionate increase in radio maintenance. Present railroad operating rules require operating radios on all consists, but due to a lack of spare equipment and repair, this is not always the case in actual operations.

Adding another control console in the cab to allow for longhood-forward operations would required the same amount of manhours to maintain it as is presently devoted to maintaining the existing control console.

The addition of parts implied by the installation of a duplicate control console would reduce the overall locomotive component reliability, but these additions should not affect the operational availability of the locomotive since the locomotive can be operated with only one operating control console.

4.3.3.6 Cab Habitability and Access. Adding another control console to the locomotive cab would severely restrict the interior floor space within the cab. This loss of floor space may not be acceptable to the operating crews. On the other hand, improved communications within the consist would improve the operator's knowledge of operations that affect safety both within and exterior to his consist. Therefore, improved communications would improve the cab habitability, while dual operating control consoles would decrease the cab habitability.

4.3.3.7 Union Agreements. Each operational procedures concept has a different effect on negotiated operating agreements between the railroads and its operating union. Their effects are listed below:

- Increased coupler maintenance may alter existing task agreements
- Longhood-forward operation is not accepted by some local operating agreements
- Improved consist practices and procedures affect both negotiated crew sizes and consist make-up practices
- Improved communications addresses a union safety concern
- Improved train dynamics addresses the union desire for an engineer training program to ensure better train handling and accident avoidance.

4.3.4 Financial Factors of Operational Procedures Concepts

In Table 4-9 the financial factors are listed against the proposed operational procedures concepts and are evaluated.

4.3.4.1 Cost of Concept (including downtime). The longhood-forward operations has a cost associated with implementation. To implement the longhood-forward would cost $100,000 for a new control console, $1,680 labor to install it (120 hours @ $14/hr), and $1,800 for out-of-service cost (5 days @ $360/day) for a total of $103,480 per modified locomotive.

4.3.4.2 Operational Cost. Two operational cost impacts are analyzed in this section. They are: (1) consist make-up practices and procedures and (2) train dynamics. Each has an opposite effect. That is, the consist practices and procedures add $24 to the make-up of each consist ($8.8 million annually), while train dynamics considerations have a tendency to reduce operating costs by 2 percent or $1,200/year per locomotive.

4.3.4.3 Maintenance Cost. The three applicable operational procedures concepts have an impact on maintenance cost. First, coupler maintenance would require two men for 4 hours to disassemble, inspect, and repair a coupler at a cost of $120 in labor, excluding parts cost. Since this inspection is not presently conducted, an estimate of parts cost could not be established.

Installing a second control console would add $10,000 in spares cost to ensure proper maintenance of the console. Since maintenance on the control console is rarely accomplished, the spares cost would outweigh the labor cost to maintain it.

4.3.4.4 Equipment Loss and Damage Cost. The longhood-forward operation concept would increase the equipment loss and damage cost by an amount required to replace it if damaged. Using its initial installation cost as a basis, it would cost $10,000 per locomotive to replace it if damaged.

4.3.4.5 Labor and Productivity Cost Factors. Allowing the locomotive to operate longhood-forward would eliminate numerous turntable or wye operations. The estimated saving is $100 per locomotive switching operation.

Improving communications would improve the efficiency of railroad operations by ensuring positive control of consist operations.

4.3.4.6 Unit Age, Condition, and Remaining Life. Only the addition of a second control console for longhood-forward operation is a consideration under this factor. The other concepts do not require permanent changes to the

TABLE 4-9. FINANCIAL FACTORS OF OPERATIONAL PROCEDURES CONCEPTS

	Procedure			
Financial Factors	Coupler Maintenance	Longhood Forward Operations	Consist Practices and Procedures	Train Dynamics
Cost of solution	N/A	Installation cost is $103,000	Covered under operational costs	Covered under operational costs
Operational costs	N/A	Covered under labor and production cost	Adds $114 per consist make up	Reduced operating costs by $1200/ consist
Maintenance costs	8 hours/locomotive ≃ $120	Increases repair by $10,000	N/A	N/A
Equipment loss and damage costs	N/A	Replacement cost is $103,000	Reduces equipment loss by 10%	N/A
Labor and productivity cost factors	Covered under maintenance costs	Reduces switching or wye costs by $100 operation	N/A	N/A
Unit age, condition and remaining life	N/A	Requires at least 10 yr. of remaining life	N/A	N/A
Funding source(s) and availability	N/A	Competes for railroad equipment maintenance budget	Increases the operating budget by $114/train	Increases operating budget by $4.1M

locomotive and, consequently, do not require amortization. Since the addition of a second control console is a major modification to a locomotive, it is not recommended unless the locomotive to be modified has at least ten years of remaining life.

4.3.4.7 Funding Source(s) and Availability. Two different railroad budgets are affected by the proposed concept. An additional control console competes with other railroad maintenance projects for the individual railroad's maintenance funds. On the other hand, the consist practices and procedures or train dynamics concepts compete for railroad operating budgets. Maintenance budgets are expected to be tight through 1985 (along with investment capital); therefore, the use of these funds would be carefully controlled by the railroads. Improving consist handling and intra-train dynamics tend to increase the operating efficiency of the railroad (increased revenues) along with reducing equipment loss and damage cost by addident avoidance. Consequently, this operational procedures concept should be more attractive to a railroad to implement.

4.4 OVERALL ASSESSMENT AND COST-BENEFIT ANALYSIS

In the preceding three subsections, locomotive modifications, nonlocomotive and operational concepts for mitigating the override problem were presented. Each concept was evaluated against specific performance and financial factors. This subsection is a compilation of all of the proposed concepts and forms an overall assessment of those concepts in terms of:

- Depth, reliability and measurability of the information
- Rank order by performance and financial benefits/detriments
- Viability for current railroad operations.

The concepts are rank-ordered by their cost-benefit and by their inherent safety benefit to the operating crew. Another characteristic of the concepts is to classify them as one-time-investment concepts (such as modifications) compared to annual operating cost-type concepts (such as consist practices and procedures).

4.4.1 Consideration of Cost-Benefit Analysis

Cost-benefit analysis is a special case of a broader technique called cost-effectiveness analysis. This field, being relatively recent and still developing, uses a scientific approach to economic problems that will provide a decision maker with an understanding of the economic impact of various decisions. Due to the fact that this technique has certain limitations, it should be viewed as one of the tools brought to bear in the decision process. The technique is limited to the degree that the parameters of a problem can be identified and reliably costed within the time frame of the analysis. Consequently, the information contained in this report, which is used as a basis for the analysis, must be addressed for its depth, reliability, and measurability.

4.4.1.1 Depth, Reliability, and Measurability of the Information. Table 4-10 shows each override mitigation concept previously developed in terms of the quality of the information. Since the measure of the depth, reliability, and measurability of the information is by its very nature somewhat subjective, the following categories were chosen to reflect the relative nature of the information:

- Very High - Detailed data is available
- High - Sufficient data is available
- Low - Information computed from available data
- Estimate - Exact data not available and has been estimated from similar projects.

From the information shown in Table 4-10, it can be seen that most of the structural modifications were extensively investigated, and that the strength, depth, reliability, and measurability of the data supporting these modifications are very high. The data supporting the operational equipment concepts have a similar depth and reliability. However, since implementation of some of the operational equipment concepts has never been tried by the railroads, the measurability of the cost data in some cases is low and could only be estimated from similar railroad improvement programs or product quotes. The operational procedures concepts generally lack sufficient railroad program experience to allow very reliable data to be developed. In most cases a "best estimate" was derived from conversations with railroad management and operating personnel.

Each structural modification was independently costed to determine the man-hours and material required for its implementation. The braced collision/roll posts and roll cage designs were discussed in detail with a railroad locomotive shop to establish their costs. Due to the fact that they have never been implemented by a railroad, their measurability had to be considered lower when compared with the other structural modifications. While the roll cage was understood by the railroad, since it was of a tubular steel design with which railroads had little experience in welding and assembly, its measurability was reduced to an estimate. On the other hand, the BN design is presently implemented by that railroad and the measurability is very high since its implementation cost can be derived from actual installation cost.

The two nonlocomotive concepts presented in this study are relatively simple and are presently implemented on either passenger cars (truck retention) or tank cars (coupler improvements). In the case of truck retention, the reliability of the data supporting this concept was slightly downgraded to account for undetermined physical access problems in installing either a locking center pin or welding a safety chain to the car body bolster. While improving the couplers on cabooses was initially addressed, it was determined that improving the locomotive coupler was a more lucrative alternative. Therefore, this concept was not as deeply investigated as locomotive coupler improvements.

All of the operational procedures concepts were investigated in some depth, but there was little actual railroad experience in these areas except for the use of safety glass; therefore, careful estimating was required to determine

TABLE 4-10. RATING OF INFORMATION QUALITY OF OVERRIDE CONCEPTS

	Structural Retrofits				Nonlocomotive			Operational Equipment						Operational Procedures			
Information	Braced Collision/ Roll Post	Light Roll Cage	BN Collision Nose	BN V-Shield	Truck Retention	Coupler Mounting	Coupler Design	Coupler Design	Safety Glass	Protective Padding	Occupant Restraint	Anticlimb Device	Emergency Exits	Coupler Maintenance	Longhood Forward	Communications	Train Dynamics
Depth	++++	+++	++++	++++	+++	++	++	+++	+++	++	+++	+++	+++	++	++	+++	+++
Reliability	+++	+++	++++	++++	++	+++	+++	+++	+++	++	++++	++	+++	++	++	+++	++
Measurability	+++	+	++++	++++	+++	+++	+++	+	++++	+	+++	+	+++	+++	+	+++	+

Key:

+ Estimate
++ Low
+++ High
++++ Very High

their implementation costs. The information for both the protective padding and anticlimb device concepts had to be downgraded slightly in this analysis. In the case of protective padding, there were no actual designs to cost; whereas, in the case of anticlimb devices, there were so many varying, untested designs in use by the railroads that their effectiveness was questionable. That is, the most effective anticlimb device design could not be reliably determined due to the lack of test data.

The area of the operational procedures concepts is the weakest in terms of the depth, reliability, and measurabiity of the supporting information. Since they would represent a continuing operational cost to the railroads, as opposed to the one-time investment cost of the previous concepts, their long-term cost could only be estimated at this time. Also, the willingness of railroads and unions to implement some of these concepts, such as longhood-forward operations, is questionable. Because of the difficulty in estimating the continuing impact of these concepts on the railroads, except for communications, they all received a lower rating relative to the previous concepts.

4.4.1.2 <u>General Approach to Costing of Benefits</u>. The activity associated with costing the benefits of a particular override mitigation concept involves estimating the reduction in cost associated with a locomotive collision accident should a particular concept be successful. Obviously, this approach requires some knowledge of the cost associated with this type of accident and the possible reductions in this cost associated with each concept. This is discussed in more detail in paragraph 4.4.2.

The benefit of any concept and its effect on this problem must reduce the cost accumulated over a given time period by a value equivalent to the cost-of-the-concept to qualify as being effective. Also, the most viable concepts must both reduce the cost associated with the human suffering (injury and/or fatality) as well as the loss in equipment cost associated with the collision/override phenomenon.

One of the issues associated with safety improvements is that, all things being equal, the cost associated with installing one or more of the override mitigation concepts on a new locomotive/railcar will increase the capital cost of that vehicle. Also, where it is required to modify an existing locomotive/railcar to provide an increased level of crew safety protection, the cost of this capital item would be even greater. Another implication of this approach is that, if damaged in a train-to-train accident, then the expected repair cost of a modified locomotive/railcar would increase due to the complexity of the new structure.

4.4.1.3 <u>Safety Assessment of Concepts</u>. Understanding that all of the proposed concepts have some cost impact on the railroad industry, the task of costing the benefits, then, requires some estimate of the expected reduction in cost presently paid by the railroad industry for fatality and injury claims, lost-time, and compensation. These are the primary areas where cost can be reduced using the proposed concepts. It is not expected that the concepts will greatly reduce railroad assets damage cost. The measure of effectiveness for a given concept will be the expected reduction in injury and/or fatality cost.

In ranking the effectiveness of concepts, it is advantageous to place them in certain categories so that those that ensure ultimate safety are given highest rank while those that attempt to avoid the collision in the first place receive the lowest. This is not to say that the proposed concepts that address collision avoidance (e.g., improve communications) are less important than the structural modification recommendations. Rather, in this study those concepts that address the situation when an override has actually occurred are given more weight.

From the previous sections the proposed concepts can be listed as follows:

(1) Braced collision/roll posts

(2) Roll cage

(3) BN collision nose

(4) Truck retention

(5) Improved couplers

(6) Shelf coupler (locomotive)

(7) Safety glass

(8) Protective padding

(9) Occupant restraint

(10) Anticlimb devices

(11) Emergency exits

(12) Coupler maintenance (locomotive)

(13) Longhood-forward operations

(14) Improved communications

(15) Train dynamics

These concepts can be put in the following major categories:

- Ensure survivable cab volume
  - Braced collision/roll posts
  - BN collision nose
  - Roll cage
- Low-speed collision control
  - Locomotive shelf couplers
  - Anticlimb devices
- Cab occupant safety
  - Safety glass
  - Emergency exits
  - Occupant restraint
  - Protective padding
- Component improvements
  - Improved communications
  - Truck retention
  - Improved couplers
- Improved operating procedures
  - Train dynamics
  - Longhood-forward operations.

4.4.1.4 Levels of Safety Effectiveness. The following levels of safety effectiveness were used:

- Primary
  - Ensuring survivable volume
- Secondary
  - Low-speed collision control
  - Cab occupant safety
- Tertiary
  - Component improvements
  - Improved operating procedures

Those concepts in the primary category are claimed to have safety effectiveness varying from 50 to 90 percent in reducing numbers of fatalities and injuries associated with train-to-train collisions. Those in the secondary category will have effectiveness varying from 15 to 50 percent, and those in the tertiary category from 5 to 15 percent.

4.4.2 Overall Cost of Concepts

The cost of the various override mitigation concepts is given in individual units, whether it be a locomotive or caboose, as well as cost to modify the total applicable population.

The candidate locomotive population for costing will be limited to road-freight and late-model general-purpose locomotives. The present populations of these locomotives are:

- Road-freight - 7,122
- General-purpose (late-model) - 7,495
- Total population - 14,607.

It is assumed that half of these locomotives would qualify based on number and unit age considerations.

The present caboose population is 13,000. It is assumed that approximately half of these could qualify for modification.

Utilizing the above data leads to the estimated cost of the modifications shown in Table 4-11.

4.4.3 Computation of Benefit

The benefit from crashworthiness and override mitigation concepts arises from reduction in fatalities and injuries that can occur in head-on and rear-end collision accidents. No appreciable change is expected in cost of damage to railroad assets, wreckage clearance, and lading damage associated with head-on and rear-end collisions. The maximum benefit is tied to maximum fatality/injury cost.

4.4.3.1 Fatality and Injury Cost. The cost associated with each fatality is usually based on the combined effects of lost productivity; medical cost; funeral, legal, and various associated costs; and a compensation for the victim's pain and suffering. Based on research conducted by the National Highway Traffic Safety Administration (NHTSA), the total fatality cost in terms of the general population was given as $197,000 using 1971-72 data. Recent research carried out at the Transportation Systems Center has revealed that the fatality cost associated with railroad employees differ from the general civilian population, and that a figure for these individuals is closer to $262,000, based on 1975 data. Updating this for present-day cost, based on cost-of-living increases, leads to a figure of approximately $400,000 for each railroad employee fatality in 1980.

For injury cost, several items factor into the computation. First, there is the hospitalization cost; second, the employee's compensation while recovering from the accident; and third, the cost of replacing the injured employee until he can return to work. Based on accident data for 1975-1979 it is found that:

- Average Hospitalization Cost
= 4.8 days @ $338/day = $1,622

- Employee Lost Time Cost
= 38 hrs @ $32/hr (loaded) = $1,216

- Total Personal Injury, Lost Time, and Compensation Cost = $4,054 per accident.

TABLE 4-11. ESTIMATED COST OF CONCEPTS

Category	Cost Per Locomotive	Total Cost
Ensure survivable cab volume		
Braced collision/roll posts	$16,000	$114 M
BN collision nose	10,000	71 M
Roll cage	7,150	50 M
Low-speed collision control		
Locomotive shelf coupler improvements	830	5.7 M
Anticlimb devices	2,500	18 M
Cab occupant safety		
Safety glass	2,000	14 M
Emergency exits	240	1.7 M
Occupant restraint	240	1.7 M
Protective padding	1,000	7 M
Component improvements		
Improved communications	2,400	17 M
Truck retention	200	1.4 M
Improved caboose/car couplers	400	2.8 M
Improved operating procedures		
Train dynamics*	$114,000/day	---
Longhood-forward operations	103,000	$732 M

* This is based on rearranging consists in a total of 1,000 trains/day for the total U.S. in order to improve train dynamics.

4.4.3.2 Number of Fatalities and Injuries Occurring in Collisions. In order to compute the maximum benefit associated with reducing fatalities and injuries, a meaningful estimate of the present occurrence rate of these fatalities and injuries was needed. Although the accident analysis conducted in section 2 identified accident rates for the period 1975-1978, in the present cost-benefit analysis it would be more meaningful to use the more recent information relating to 1979. This was obtained from the FRA Office of Safety, Reports and Analysis Division, and revealed the following averages for all collision accidents (including head-on, rear-end, side and raking):

- Average number of fatalities is 15/year

- Average number of injuries is 800/year.

4.4.3.3 Computation of Maximum Benefit to be Obtained. In computing the maximum benefit or, as it were, the greatest opportunity for cost saving through improved cab crashworthiness and override mitigation concepts, it is assumed that these proposed concepts will be effective in reducing injuries and fatalities not only in head-on and rear-end collisions but also in side and raking collisions. Consequently, the maximum opportunity for cost saving is:

- Maximum Benefit =
15 x $400,000 + 800 x $4,054 = $9.24M/yr.

4.4.4 Cost-Benefit Ratios (CBR)

In order to compute the cost-benefit ratio for each concept, the total cost of the concept based on the population to be modified is required (see Table 4-11) together with the benefit to be realized in terms of reducing fatalities and injuries (see paragraph 4.4.3).

In the case of braced collision/roll posts the cost of modification is:

Braced collision/roll post modification cost

= No. of locomotives x cost per locomotive to be modified

= 7,112 x $16,100

= $ 114M

The maximum benefit that can be obtained in reducing accident injuries and fatalities is computed in 4.4.3.3 as $9.24M/year, so that if the braced collision/roll posts were 100 percent effective, the cost-benefit ratio would be:

Braced collision/roll posts

$$= \frac{\$114M}{\$9.24M}$$

Cost-Benefit Ratio
= 12.33

Although this CBR parameter is useful ultimately for ranking the concepts, more practical interpretation is that if the braced collision/roll posts concept were 100 percent effective in reducing injuries and fatalities, then this concept will pay for itself in benefits within approximately 12 years.

Since none of the concepts is going to be 100 percent effective in reducing the fatalities and injuries, and in view of the fact that no test data presently exist, ranges of cost-benefit ratios as a function of effectiveness are provided. As was pointed out in subparagraph 4.4.1.4, the concepts are expected to vary in their effectiveness. For example, those with primary effectiveness will reduce injuries and fatalities by an amount between 50 to 90 percent, those with secondary between 15 to 50 percent, etc. With this in mind, cost-benefit graphs for the various concepts have been prepared in Figures 4-2, 4-3, 4-4, and 4-5. In preparing these figures, it was found that the cost ratios for the improved operating procedures concepts were substantially higher than other concepts, so they were dropped from further consideration. Also, emergency exits were not analyzed separately but included as part of the safety glass concept. Consequently, the safety glass concept is considered to have a total cost of \$14M + \$1.7M = \$15.7M (see Table 4-11).

4.4.5 Ranking of Concepts by Cost-Benefit

In Figures 4-2 through 4-5 the cost-benefit ratios (CBR) for the various concepts are plotted against effectiveness. In order to rank the concepts, some measure of safety effectiveness is required to be assigned to each solution. These measures cannot be exact, so ranges have been assigned through engineering evaluation of the various concepts in terms of their ability to reduce fatalities and injuries.

This results in the following ranking of concepts by cost-benefit as follows:

(1) Occupant restraint

(2) Locomotive shelf couplers

(3) Truck retention

(4) Improved couplers

(5) Protective padding

(6) Safety glass

(7) Anticlimbers

(8) Improved communications

(9) Roll cage

(10) BN collision nose

(11) Braced collision/roll posts

This particular ranking shows that use of occupant restraints, such as seat belts, offers the most benefit in terms of the cost outlays; whereas, the braced collision/roll posts offers the least. It should be noted, however, that the latter has much more capability in crew survivability, which is not emphasized in the above ranking (see paragraph 4.4.6).

4.4.6 Selective Grouping of Concepts that are Viable for Railroad Implementation

4.4.6.1 Viability Criteria for Railroad Operations. The proposed override mitigation concepts are only viable as options to a specific railroad if that railroad deems them necessary based on their own needs and accident history. That is, if the type of operation in which the railroad is involved and its accident history cannot support the need for override mitigation concepts, then it may not be interested in these concepts. This is especially true of shorthaul lines which have little or no interchange of power assignment equipment (locomotives) with the larger Class I railroads. Therefore, the implementation of the proposed override mitigation concepts by a particular railroad must be based on need and not based on an arbitrary rule.

Once the railroad, in reviewing its operational needs and accident statistics, has determined that implementing any or all of the proposed override mitigation concepts is to its benefit, that railroad must also determine the following:

- What equipment is a candidate for modification?
- When is the most advantageous time to modify this equipment?
- Where will these modifications be implemented?

As to what equipment is a candidate for modification, the railroad must determine which equipment is exposed to the most hazardous conditions based on their own experience. As a general

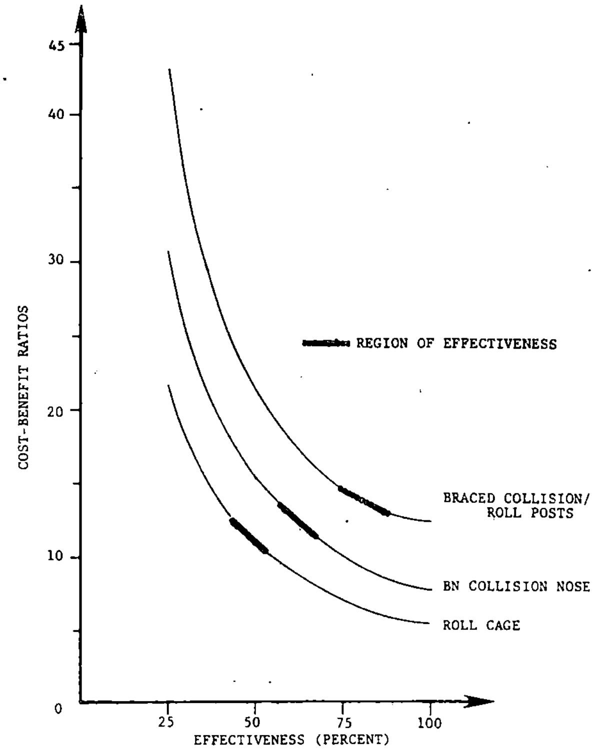


FIGURE 4-2. COST-BENEFIT RATIO VS. EFFECTIVENESS FOR STRUCTURAL RETROFITS

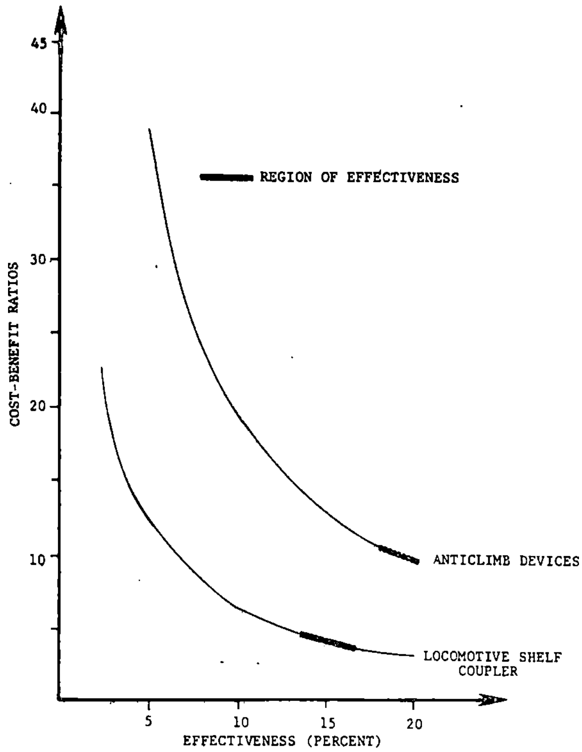


FIGURE 4-3. COST-BENEFIT RATIO VS. EFFECTIVENESS FOR LOW SPEED COLLISION CONTROL

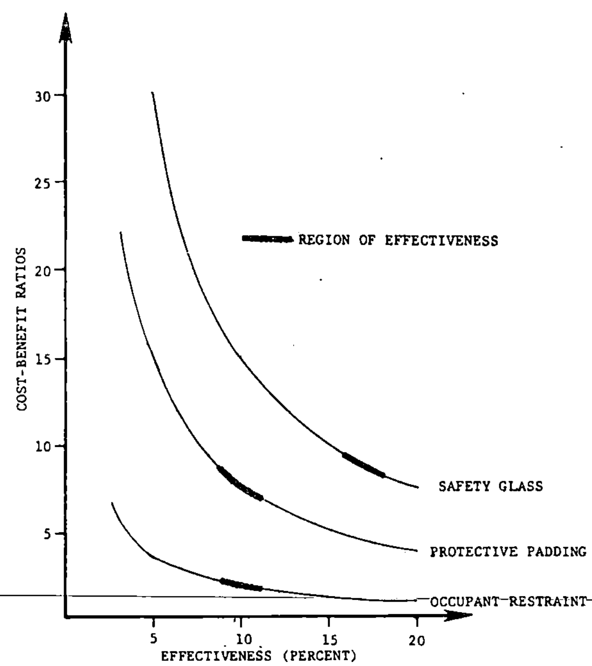


FIGURE 4-4. COST-BENEFIT RATIO VS. EFFECTIVENESS FOR CAB OCCUPANT SAFETY

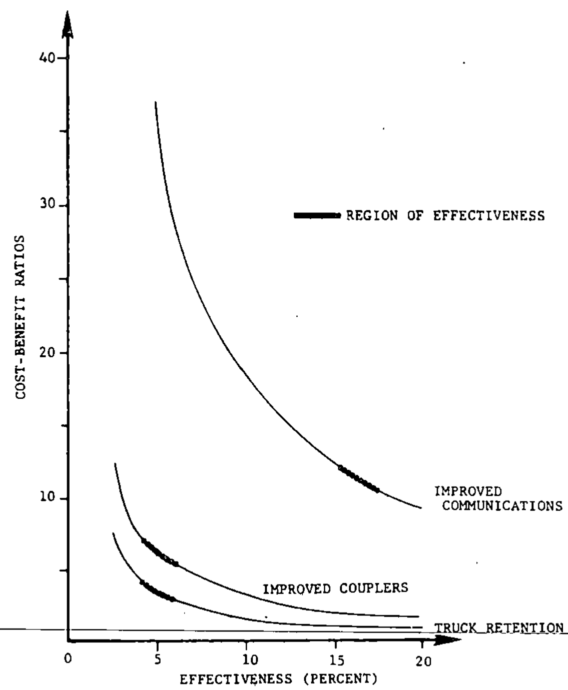


FIGURE 4-5. COST-BENEFIT RATIO VS. EFFECTIVENESS

rule, the most likely candidates are road-freight locomotives, some late-model general-purpose locomotives used in road-freight service, and cabooses.

To make the modifications more attractive in terms of locomotive downtime, the modifications should be planned during scheduled, heavy locomotive maintenance cycles or any time a locomotive is in to repair cab damage.

Finally, to ensure that the locomotives are efficiently modified, a centralized modification site should be selected by the railroad which would provide a core of stabilized manpower and provide for material availability.

In essence, for the proposed override mitigation concepts to be viable for an individual railroad, these concepts must address the railroad's needs as determined by the railroad's operating requirements and accident statistics. Once the need is established for that railroad, an efficient and centralized modification program for the identified equipment must be established, whether it be a road-freight/general-purpose locomotive or a caboose.

4.4.6.2 <u>Viable Concept</u>. From the preceding discussion, it appears that some of the override mitigation concepts are more beneficial than others in solving the problem. Also, in terms of railroad operating cost, some of the concepts are more attractive since they represent a one-time investment (e.g., modifications) as opposed to a continuing operating cost (e.g., consist practices). On this basis, it appears that the override mitigation concepts that are most viable in terms of railroad operations are:

- Braced collision/roll posts
- BN collision nose
- Locomotive shelf couplers
- Truck retention
- Anticlimb devices
- Improved communications
- Safety glass
- Emergency exits
- Occupant restraints
- Protective padding

4.4.7 Selective Concepts Ranked by Benefit to Crew Safety and Equipment Survivability

This is a very important ranking because it emphasizes the selected concepts that produce the maximum benefit in terms of crew safety and/or equipment survivability.

4.4.7.1 <u>Concept Package for Maximum Crew Safety</u>.

- Braced collision/roll posts - ensures survivable volume
- Truck retention - reduces override tendency
- Locomotive coupler design - shelf couplers reduce override
- Communications - avoids accidents due to signal error
- Safety glass - provides interior safety
- Emergency exits - provides exits for crew during impending impact
- Occupant restraint - avoids secondary impact
- Protective padding - protects against secondary impact
- Anticlimb devices - provides low-speed collision control

It may be noted that all the structural modifications are reduced to the braced collision/roll posts design, which has the highest impact load carrying capability. The use of anticlimb devices and shelf couplers on locomotives are both considered to be beneficial in terms of crew safety and equipment survivability in a low-speed collision environment. The two surviving concepts in the component improvements category are improved communications and caboose/freight car truck retention. Both of these concepts provide some measure of override mitigation through collision impact force control (truck retention) or reduction of impact speeds (communications). It must be noted that none of the operatonal procedures concepts are included in this list, although improved train dynamics and, therefore, improved stopping distances have some promise as possible override mitigation concepts by avoiding collisions. Their implementation cost appears to outweigh any operating cost saving available due to their implementation. Because of this, they are not considered as viable concepts in terms of crew safety and equipment survivability.

4.4.7.2 <u>Override Cost-Benefit Ratios of Concepts Package for Optimum Crew Safety</u>. Even though the concepts selected in subparagraph 4.4.6.1 do not individually have the best cost-benefit ratios, as a package to be implemented on locomotives and railcars, they represent a very attractive improvement in safety for the investment. Indeed, based on the previous effectiveness ranges for each of the individual concepts, it can be argued that as a package they would be close to 100 percent in reducing fatalities and injuries. Consequently, this leads to a benefit or cost saving of up to $9.24M/year. The overall cost of the concepts package can be seen from Table 4-5 to be less than $180M, so that the cost-benefit ratio is approximately 19.

4.4.8 Short-Term - Long-Term Concepts

The override mitigation concepts listed in subparagraph 4.4.6 may be divided into two implementation phases that, for this discussion, will be classified as short-term and long-term. Since they represent elements of the total program, these concepts should be considered in terms of their order of implementation, since they require the least amount of modification to the existing locomotive design. Another way to make this distinction is those candidate concepts that should be implemented without a structural modification are designated short-term solutions, and those that should be implemented with a structural modification are designated long-term. Using this distinction, the following two lists are presented:

- Short-term
  - Locomotive shelf couplers
  - Improved communications
  - Occupant restraint
- Long-term
  - Braced collision/roll posts
  - Truck retention
  - Safety glass
  - Emergency exits
  - Anticlimb devices

In the following section, performance guidelines are developed for the selected set of concepts for crashworthiness and override mitigation.

5 DEVELOPMENT OF PERFORMANCE GUIDELINES

5.1 PERFORMANCE GUIDELINES

In this section, performance guidelines are developed for the most promising override control and mitigation concepts developed in sections 2 and 3 of this report. (The designation "most promising" is based upon those concepts that are technically most feasible, economically most viable, and provide the greatest potential safety benefit.) These guidelines establish the minimum performance requirements that a particular concept must meet to be considered effective or beneficial. Additionally, these guidelines are applicable to both new equipment designs as well as to modifications to existing rolling stock, given that the basic locomotive cab designs are not substantially altered by the manufacturers.

It is anticipated that the performance guidelines developed from this crashworthiness project will be useful in formulating new guidelines to improve the safety features of a locomotive should it be involved in a rear-end or head-on collision.

Following the establishment of performance guidelines for the override concepts, the guidelines are prioritized with regard to the current economic and operating railroad environment in section 5.2 Their soundness and practicability is discussed in terms of the engineering fundamentals involved, as well as the pragmatic aspects of the implementation of guidelines.

5.1.1 Performance Versus Design Guidelines

Regulations can typically be based on two types of safety guidelines - design guidelines and performance guidelines. Design guidelines detail features and material specifications for a particular piece of equipment. On the other hand, performance guidelines specify what kind of performance capability the equipment will have under certain circumstances. The key aspect of a performance guideline is its emphasis on what a system should do rather than how it should be designed, thus allowing industry to develop different designs that meet all of the minimum performance specifications. Therefore, innovative safety improvements are continually encouraged.

The performance guidelines developed in this task are concerned with how the system should perform, not how the concept should be designed or what specific products should be used. This deliberate lack of specific product definition is intended to keep the concept from being associated with any specific manufacturer.

5.1.2 Components of Performance Guidelines

In developing performance guidelines, the following items must be considered:

- Performance to be expected
- Appropriate design practices for a typical concept
- Tests required for validation.

The performance to be expected must be stated in definite quantitative terms. For example, in the case of the performance of a structure, it is necessary to state the type of load the structure must withstand and what deformation is acceptable.

The design practices item identifies what design procedures should be used in developing a typical concept. For example, in the case of a structure which is expected to undergo fairly large deflection under impact (as would be expected for a locomotive cab in an override situation), a typical solution should be based on plastic design assumptions rather than elastic. Additionally, design practices, particularly for structural fixes, should specify what detailed design practices are acceptable, such as how welds or other structural attachments should behave. Validation tests should be included in performance guidelines to allow proper verification that a particular concept meets the required performance.

5.1.3 Background

In sections 1 through 3, a number of possible concepts to mitigate the override problem were evaluated for their technical feasibility and implementation cost and reviewed for their safety benefit. The results of these tasks have established that a majority; (over 90 percent) of railroad injuries and fatalities occur at speeds of 30 mph (50 kph) or less. Another conclusion was that the most serious accidents involved road-freight locomotives; e.g., the SD45. Previous research conducted by various organizations established that any concept to the override problem should be effective in three areas:

- Ensures a survivable volume
- Controls impact forces
- Provides for occupant safety.

5.1.3.1 Concepts Ranked by Cost-Benefit. Using safety effectiveness measures, the various concepts were analyzed for cost-benefit in section 4 which resulted in the following ranking:

(1) Occupant Restraint

(2) Locomotive Shelf Couplers

(3) Truck Retention

(4) Improved Couplers

(5) Protective Padding

(6) Safety Glass/Emergency Exits

(7) Anticlimbers

(8) Improved Communications

(9) Roll Cage

(10) BN Collision Nose

(11) Braced Collision/Roll Posts

In this particular listing the emergency exits have been incorporated as a concept with safety glass. The operational procedures concepts involving longhood-forward operations and train dynamics offered such poor cost-benefit ratios in relation to the other concepts that they were dropped from further consideration.

5.1.3.2 Concepts Ranked by Benefit to Crew Safety and Equipment Survivability. Following the identification of those concepts that were the most cost-effective as well as viable for railroad implementation, they were specifically evaluated in terms of their ability to provide for crew safety and equipment survivability. This study resulted in the selection of nine override mitigation concepts as being critical to improved crashworthiness and override mitigation. These are:

(1) Braced Collision/Roll Posts

(2) Truck Retention

(3) Locomotive Coupler Design

(4) Improved Communications

(5) Safety Glass

(6) Emergency Exits

(7) Occupant Restraint

(8) Protective Padding

(9) Anticlimb Devices

Performance guidelines for each concept are now developed that, if implemented, will lead to a safer operating environment for locomotive crews.

5.1.4 Performance Guidelines

The guidelines developed in this section establish the minimum performance requirements for a concept to mitigate the override problem that occurs in train-to-train collisions.

5.1.4.1 Braced Collision/Roll Posts. The performance guidelines developed for this concept are aimed at ensuring some measure of structural integrity for the locomotive cab to reduce its tendency to crush completely during override. A cut-away view of this type of modification as applied to an EMD general-purpose locomotive is shown in Figure 5-1.

- Overall Expected Performance: Since the overall expected performance is defined in terms of ensuring certain length, width, and height dimensions, it is more meaningful to state the performance guidelines in terms of cab side, front, and roof intrusion.

Relative speed at impact is another important consideration in developing these performance guidelines. Analysis of a sample of 761 train-to-train collisions over a four-year period (1975 through 1978) shows that 100 percent of the fatalities and 96 percent of the injuries occurred at impact speeds of 30 mph or less. While this appears to be an unusually low speed, it should be noted that just prior to impact the operating crews are probably in an emergency braking mode, attempting to prevent the collision. Still, even at these low speeds, the momentum of the total consist is so great that coupler impact forces on the order of one million pounds or greater are not uncommon. One million pounds of force is the design limit of a standard locomotive frame in buff, and two million pounds is the level required to cause gross buckling. The problem at these high levels of impact forces is controlling this energy to prevent an override. If the override occurs, it has been estimated that 40 to 50 percent of the impact energy is expected to impinge on the locomotive cab, implying that the cab structure should be designed to withstand forces of approximately 400 to 500 thousand pounds.

- Expected Performance for Cab Front Intrusion: The locomotive cab and shorthood assembly should be designed to absorb the impact of another locomotive or car during a head-on or rear-end collision at speeds up to 30 mph. To accomplish this, the combined shorthood and cab assembly should be able to withstand a load of 400,000 lb applied hori-

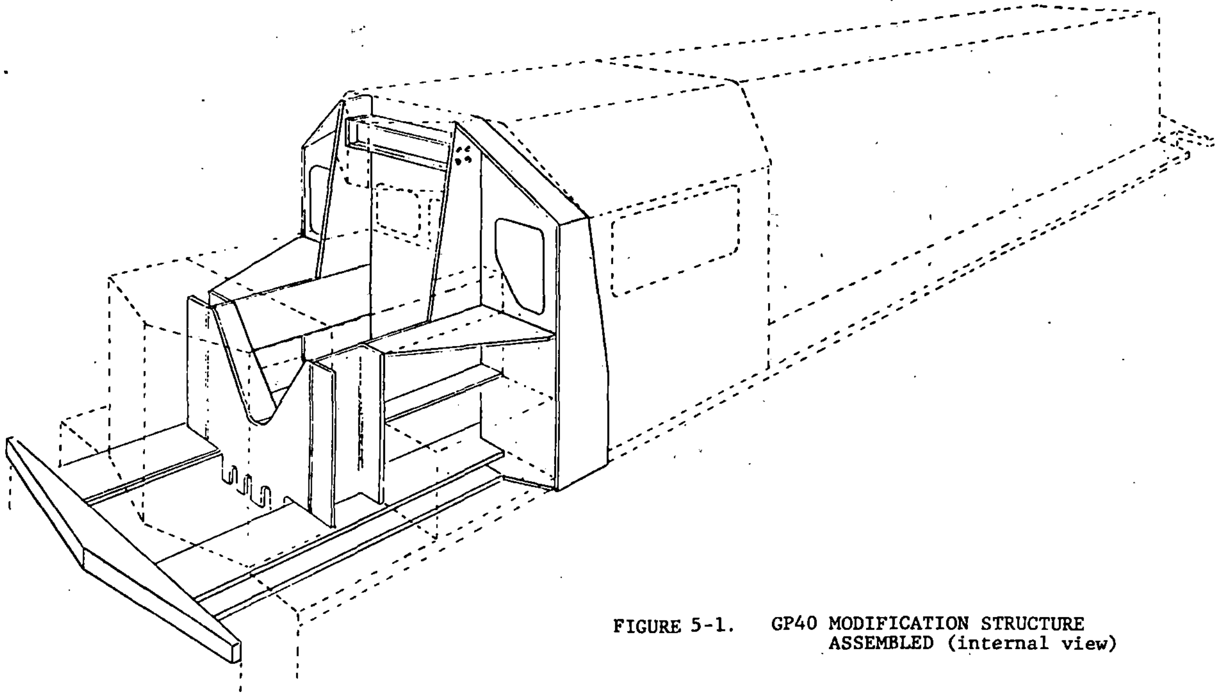


FIGURE 5-1. GP40 MODIFICATION STRUCTURE ASSEMBLED (internal view)

zontally by a rigid bar at a height of 3.5 feet above the locomotive deck with less than 12 inches of resulting cab intrusion. The locomotive cab must also be capable of withstanding independently a horizontal line load of 250,000 lb applied at a height of seven feet above the locomotive deck with less than 12 inches of resulting cab intrusion.

- Expected Performance for Cab Roof Intrusion: The locomotive cab roof should be designed to absorb the impact of a falling train car or the weight of the locomotive during a rollover. This is to be accomplished by designing the cab so that it can support the weight of the entire locomotive when applied over the horizontal projection of the roof with not more than 20 inches of resulting roof deflection.

- Expected Performance for Cab Side Intrusion: The locomotive cab side walls should be designed to prevent intrusion into the passenger compartment during a side collision. To accomplish this, the locomotive cab shall be designed to withstand a static load equal to the weight of the locomotive applied by a rigid non-rotating bar horizontally to the side of the cab at a height of seven feet above the locomotive deckplate. This load shall result in no more than six inches of cab intrusion.

- Appropriate Design Assumptions: Plastic design methods should be used for sizing the structural members of any particular modification utilizing the concept of collision posts. This is based on the fact that a collision post structure exhibits progressive failure during crushing of the cab going through elastic, plastic, and finally fracture phases. Similarly, metals that are used in the structure should have the necessary ductility and strain hardening properties. See Appendix F for general design considerations for locomotive structural modifications.

- Tests Required: The ability of the cab that has been modified with braced collision/roll posts must be demonstrated to withstand the prescribed loads through a static load application such as a squeeze test; a dynamic impact of a bogie type vehicle into the candidate structure; or by use of modern analytical techniques for computing structural strength.

A compression test on the locomotive underframe shall also be performed by applying the test load of 1,000,000 lb in five equal test steps with each load being held for 1 minute.

5.1.4.2 Truck Retention. This concept provides for override mitigation through collision impact force control where the tendency of the railcar to rotate on impact and subsequently override the cab is induced. For this, trucks are required to be locked to the body. This is to retain the rotational moment of inertia of the railcar during impact.

- Expected Performance: The truck

safety mechanism should be provided to produce a connection between the body and trucks that cause the trucks to be raised with the car body, unless intentionally detached. The retention device should maintain truck/railcar connection under separation acceleration of between 2 and 3g. The retention device should not interfere with the kinematics of the truck and railcar.

- Design Practices: In the case of using a safety chain, such as used on locomotives to retain the trucks, the load capacity of the chain should be 2.5 times the weight of the truck. In the case of using a locking center pin, it should have a strength in single shear of 250,000 lb. This horizontal loading capability is designed to force the truck to function as an anti-telescoping device in the case of the rear-end collision into the end car of the train.

- Testing: The safety chain can be tested through normal tensile tests or structural analysis techniques. The locking center pin should be tested using a squeeze test. The force shall be applied at the interface of the truck, car body, and center plate connection in a plane parallel to the cab floor at angles of 0 to 45 degrees to the longitudinal centerline of the railcar.

5.1.4.3 Locomotive Coupler Design. The coupler and draft gear assembly of the locomotive are usually the initial impact point in a train-to-train collision. If the coupler is able to withstand the vertical separation forces, then override can be prevented. One promising candidate concept that is determined to be technically acceptable and economically feasible involves the installation of shelf couplers on locomotives.

- Expected Performance: The coupler should be capable of automatic coupling for speeds up to 20 mph. In the engaged position, the coupler system should be capable of withstanding separation forces up to 250,000 lb.

- Design Practices: The couplers should be designed according to specifications for AAR Standard E and F shelf couplers with respect to materials, coupler bodies, and coupler parts. The design should be capable of providing the vertical load capability through the complete angle of swing. An example of a shelf coupler as fitted to a tank car is shown in Appendix G.

- Testing: A shelf coupler properly mated to another coupler or dummy coupler should be tested by applying at least 200,000 lb of vertical force in both the upward and downward directions while the coupler is in buff load. The applied force will be held for at least five minutes in each direction.

5.1.4.4 Improved Communications. Proper communications between locomotive engineers/conductors and railroad operations personnel can improve control of consists and thereby avoid collisions. Improved communications between locomotive engineers and conductors can increase braking efficiency, particularly in emergency situations.

- Expected Performance: An improved radio link shall be provided in each lead locomotive in a consist to ensure that the consist always retains positive communications with the railroad operations personnel.

- Design Practices: Radio links should conform to standards specified in 49 CFR 220, Parts B and C.

5.1.4.5 Safety Glass. Installation of safety glass in all windows of the locomotive cab will provide improved cab interior occupant protection against the intrusion of foreign objects into the cab area and also prevent sharp glass fragments from being spalled off the windows in the event of an intense impact.

- Expected Performance: Safety glass installed in the locomotive windows should meet the requirements of 49 CFR, Part 223, Safety Glazing Standards - Locomotives, Passenger Cars, and Cabooses.

- Design Practice: Several manufacturers presently make safety glass which meets the performance requirements.

- Tests: To test the intrusion capability, the glass should withstand penetration by a heavy object, such as a concrete block (24 lb), when impacted at 12 ft/sec. To test the prevention of flying glass within the cab, the glass shall not spall when impacted by a 0.22 caliber bullet fired into the outside. Details of certification tests are given in 49 CFR 223, section 223.17.

5.1.4.6 Emergency Exits. To enable cab occupants to escape from the locomotive following a collision, pop-out windows should be provided as emergency exits.

- Expected Performance: Windows should incorporate a quick-release mechanism for easy removal of the window in the event of an accident. Quick-release mechanisms should not activate under normal operation of locomotives, including travel over rough track, action of wind forces, or other inclement weather conditions. In the event the window is struck with a heavy block, the window should not pop inward.

• Design Practice: Installation of these emergency exits will be done in conjunction with the installation of safety glass and will be done according to present rail passenger car installation practices.

5.1.4.7 Occupant Restraint. Occupant restraints in the form of lap seat belts may prevent the locomotive cab occupant from being thrown around the cab in the event of a collision and suffering injuries from impacting objects within the cab. However, the shoulder harnesses or lap seat belts may restrict the mobility of the operator so much that he may not properly carry out his functions.

• Expected Performance: If a lap belt system is used, it should meet the requirements found in 49 CFR 571, 209-210 for lap-type seat belt systems. The seat belt assembly shall be capable of withstanding at least a 5,000 lb force.

5.1.4.8 Protective Padding. As stated in the previous section, in locomotive collisions large decelerations of the locomotive cab occur causing the occupants to be tossed around the interior of the cab. In general, all exposed corners and handles should be free of sharp protrusions and rounded or padded whenever possible.

• Expected Performance: All exposed corners, handles, and other potentially dangerous devices should be free of sharp protrusions and rounded or padded whenever possible. If padding is used, the depth of the padding should be such that the deceleration of a 15-pound, 6.5-inch-diameter head form, impacting at a relative velocity of 15 mph, shall not exceed 80g continuously for more than 3 milliseconds (49 CFR 571.201, 3.1).

• Design Practice: This can be based upon practices typically used in the automobile industry for padding instrument panels.

• Tests: Tests should be performed according to the guidelines found in the Society of Automotive Engineers Recommended Practice (SAERP) J921, "Instrument Panel Laboratory Impact Test Procedure," June 1965, using instrumentation that meets the performance requirements specified in SAERP J977, "Instrumentation for Laboratory Impact Tests," November 1966. Automotive-to-locomotive adaptations should be made as necessary.

5.1.4.9 Anticlimb Devices. Performance guidelines are developed for low-speed collision control to prevent override in low-speed impacts (5-10 mph) and to act as a first stage energy absorber for the high-speed impacts where the overriding vehicle impacts the locomotive cab. Since the coupler, associated draft gear, and the locomotive form the initial impact point in the locomotive collision, adequate vertical restraint capability of the coupler, either through the use of a shelf coupler, anticlimber, or both, must be assured. (See subparagraph 5.1.4.3. for a discussion of shelf couplers.) The guidelines presented below pertain to the minimum performance required of any anticlimb device.

• Expected Performance: Locomotives should be equipped with a device to minimize the likelihood that a coupler from an impacted car or other locomotive will override the locomotive underframe. The device shall be attached to the front end of the locomotive and be operative across the whole width of the locomotive underframe. The device shall extend forward as far as operational constraints will allow. The device shall be capable of sustaining an upward load of 200,000 lb at its forward end without resulting in permanent deformation.

• Design Practice: The load capability for anticlimb devices should be based on plastic design methods.

• Tests: An anticlimber device should be tested by applying an upward vertical force of 200,000 lb to the bottom of the installed anticlimber device at a point directly over the coupler shank. This force will be held for at least five minutes. No permanent deformation of the anticlimber device should result from this test. (NOTE: The locomotive deck plate may have to be restrained to the ground by some means, because it may lift off the ground before the full load is reached.)

5.2 IMPLEMENTATION CONSIDERATIONS

In this subsection, the proposed performance guidelines are assessed and priorized in terms of their ability to be implemented and their ability to provide for improved railroad safety, taking into account the current economic and operating railroad environments. Also identified are the guidelines in terms of those that are able to be accomplished immediately versus those that will require more extensive operations to effectuate.

5.2.1 Practical Ability to Accomplish

All of the nine concepts and the associated performance guidelines are well within the implementation capability of the railroads in their own diesel and car repair shops. Indeed, looking at the proposed concepts:

- Braced Collision/Roll Posts
- Truck Retention
- Locomotive Shelf Coupler
- Improved Communications
- Safety Glass
- Emergency Exits
- Occupant Restraints
- Protective Padding
- Anticlimb Devices,

it is clear that many of them, such as shelf couplers, occupant restraint, improved communications, etc. involve acquisition of purchased parts and do not require excessive amounts of downtime to install. Even the most complicated concepts, such as the braced collision/roll posts, can be done within a period of five days during the major maintenance cycle for the locomotives.

Breaking these concepts down into categories of those concepts which can be implemented immediately (minor) versus those which will require a structural modificatoin of the vehicle (major) results in the following list:

- Minor
  - Locomotive shelf couplers
  - Occupant restraint systems
  - Improved communications
- Major
  - Braced collision/roll posts
  - Anticlimber devices
  - Safety glass
  - Emergency exits
  - Protective padding
  - Truck retention

Note that the structural modifications can be accomplished during regular heavy maintenance cycles and do not warrant the vehicles' withdrawal from revenue operations.

5.2.2 Ordering of Guidelines for Optimal Railroad Implementation

Using the major/minor listing as a baseline, and considering the material, cost per concept as well as the concepts effect on the availability of locomotive power to support railroad operations, the following order for the implementation is proposed:

(1) Occupant restraint systems

(2) Improved communications

(3) Locomotive shelf couplers

(4) Anticlimb devices

(5) Braced collision/roll posts

(6) Safety glass

(7) Emergency exits

(8) Protective padding

(9) Truck retention

If these nine concepts are implemented as a package, they will meet the three basic protection requirements identified for override mitigation and improved crashworthiness as stated previously in subsection 5.1.3.

This comprehensive crashworthiness and override mitigation package is shown as applied to a typical EMD locomotive in Figures 5-2 and 5-3. The estimated cost is approximately $25,000 per locomotive and $200 per caboose. (1980 dollars.)

5.3 RAILROAD CONSIDERATIONS FOR MODIFICATION PROGRAM

5.3.1 Basic Areas of Concern

The total package selected for implementation under a modification program requires that certain guidelines be developed to ensure that the program is practical for the railroads. To ensure this practicability, three basic areas of concern must be addressed by any modification program. These are:

- Needs of the particular railroad based on its own accident experience
- A coordinated program between locomotive modifications and new locomotive purchases
- A modification design accepted by the AAR Mechanical Committee and the FRA.

In addition to these primary concerns, items such as material availability, manpower skills, schedules, and post-

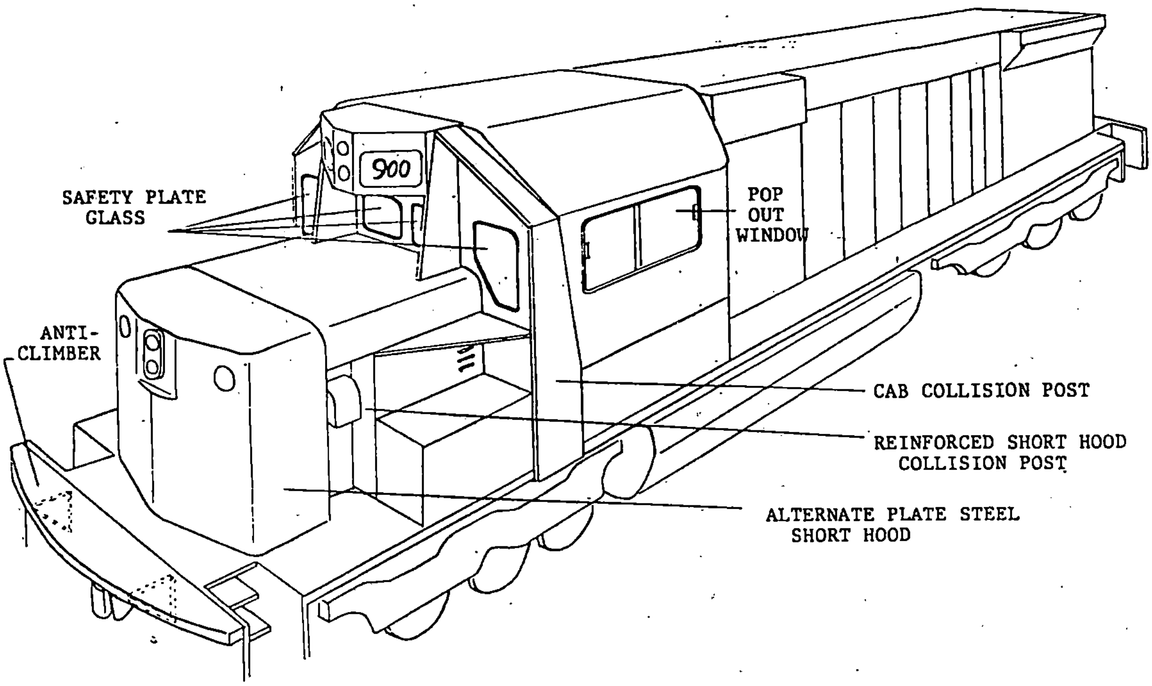


FIGURE 5-2. EXTERIOR VIEW OF MODIFIED EMD SD45 LOCOMOTIVE

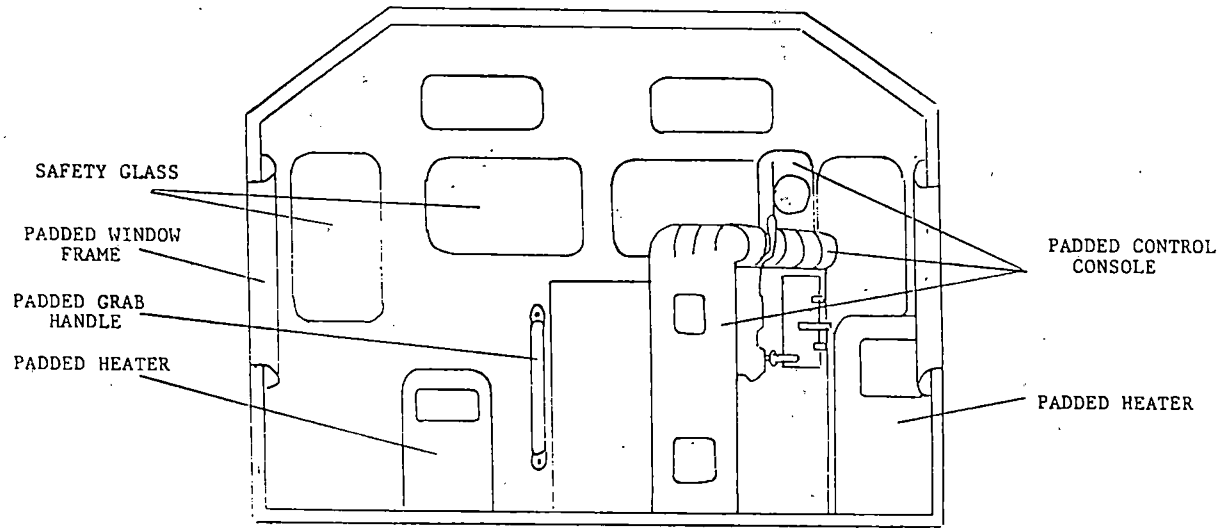


FIGURE 5-3. MODIFIED CAB INTERIOR SHOWING SAFETY MODIFICATIONS

modification use policies must also be considered in developing this program.

The following paragraphs cover each item listed above in more detail and relate these items to the overall modification program. The last paragraph presents an outline of the program.

5.3.2 Railroad Needs

To determine the specific needs of an individual railroad, that railroad must analyze its own accident history to determine its requirements in the area of collision accident prevention. Various railroad equipment, components, and practices should be reviewed to determine their failure modes and resulting contribution to the collision accident statistics. Two categories of accident statistics must be developed. They are (1) those actions by that railroad that would improve collision avoidance and (2) those actions by that railroad that would improve crew safety in a collision environment.

In analyzing the accident data for its equipment, the railroad must investigate those factors that affect train handling characteristics, and, therefore, stopping distance. Since handling characteristics are dependent on train weight and length, system components (brakes and trucks), track characteristics (grade, curvature, stiffness), and vehicle characteristics (rolling resistance, rolling and hunting modes), each must be investigated for their contribution to collision accidents for that railroad. Some of the other train handling considerations that should be reviewed include traffic density, communications, signal spacing, and compliance with operating rules since they all contribute to accident statistics.

Once this review is completed, the railroad's needs in terms of changes to equipment and/or operating procedures can be developed. This report concentrates only on the equipment considerations and, in particular, modification of locomotive cabs to ensure crew safety in a train-to-train collision environment where override may occur.

5.3.3 Modification Program

In implementing a locomotive modification program, a railroad must establish a priority system by locomotive type, a schedule, a centralized modification facility, a policy on the use of modified locomotives, and a coordinated policy on new locomotive purchases. The following criteria should be used in establishing this program.

The first criterium for establishing the priority of a locomotive modification program is the locomotive type based on its intended service (i.e., road-freight, general-purpose, switching). In general, this program should be limited to road-freight locomotives and late-model general-purpose locomotives used in road-freight service. The second criterium to be considered is the locomotive's economic life. As stated before, the locomotive should have 10 to 12 years of remaining economic life. Third, the railroad's locomotive acquisition policy (major modificatins versus new purchases) must be considered when deciding the magnitude of the program. That is, the railroad must decide how much of the program should be devoted to modifications and how much of the program should be devoted to purchasing new locomotives with structural cab improvements.

A fourth criterium for consideration is the railroad's scheduled maintenance program and its effect on the availability of locomotives for modification. The defect or failure history of the candidate locomotives should be reviewed to eliminate those candidates with high defect or failure histories since these particular locomotives may not have a sufficient economic life for the modification. The fifth criterium, and probably the most important, is the modification itself when considering the locomotive type. This criterium implies a decision be made on which of the proposed designs will be implemented on a particular locomotive. This decision must be based on the existing structural integrity of the cab area, based on an analysis of accident damage records, and the interchangeability requirements that will ultimately affect the utilization of the modified equipment.

As a rule, switching engines should not be considered for the cab structural modification program, but they should be considered for anticlimb devices and occupant restraint systems to reduce the severity of collisions in the low-speed realm in which they operate.

5.3.3.1 Schedule. Once the decision is made as to which locomotives to modify, based on the preceding criteria, the actual program must be scheduled for implementation. To implement this program a design package must be developed and a program established that addresses the engineering requirements, production plan, and quality assurance of the package.

This plan should include all the approved engineering drawings, material lists, and skills required to effect the modification. With these items identified, a centralized site must be selected that possesses the necessary fabrication facilities, manpower skill levels, and material availability. To ensure efficiency of the program, it should be conducted in conjunction with other scheduled locomotive maintenance activities. Some opportune times to modify the locomotives include scheduled heavy locomotive maintenance (over 250 manhours) or any time a locomotive is in for repair due to cab damage.

To ensure that the locomotive modification program will be ultimately successful, two actions should be initiated. First, the initial modification should be tested for visibility constraints, impact load capacity, and compatibility with normal railroad operations. Due to the cost of a test program like this, a number of affected railroads might join together to conduct the test program. Secondly, the program, after some experience, should be reviewed to improve the productivity of the modification and possibly reduce its cost. The modification procedure should be changed according to the results of this review. Another consideration should be manpower stability to ensure that the modification procedures do not have to be relearned due to a change in personnel. Finally, to be cost-effective, the program must have an established completion date.

5.3.3.2 Power Assignment of Modified Units. Once a locomotive has been modified, its use must be established by some railroad policy. As a minimum, this policy should require that these units be used as the lead unit on all trains with nonequipped locomotives in the consist. These units should also be limited to road-freight operations in territories determined to be hazardous by the previous review of that railroad's accident statistics.

During the initial introduction of modified locomotives into road-freight service, members of the locomotive engineers union should be asked to evaluate the new cab. This evaluation would establish a feedback to the designers to verify its acceptability in terms of visibility, operability, and compatibility with normal railroad operations.

5.3.4 New Construction

The designs selected for implementation by a railroad should also be specified to the locomotive manufacturers so that newly purchased locomotives are compatible with the modified locomotives in terms of crashworthiness and crew safety. Just as the design was evaluated to ensure that this design is cost-effective. Some considerations during this review should include the design's effect on railroad operations and maintenance. Operating personnel should be consulted on the design to establish employee acceptance before embarking on a new locomotive acquisition program.

As the modification program is limited to road-freight service, the design for newly purchased locomotives should be limited to this class of equipment. This approach will ensure that the proper equipment is modified to increase crew safety in hazardous operating areas. Also, to ensure interchange compatibility of modified equipment and new locomotives purchased with improved crashworthy designs, the design should be approved by the AAR Mechanical Committee and the FRA as an acceptable standard design for a crashworthy locomotive with improved crew safety.

5.3.5 Modification Upgrades

After some experience is gained by the railroads in operating modified locomotives, the design should be reviewed to determine if any improvements will increase the acceptability of the modified equipment. For example, high maintenance cost, design weaknesses, safety issues, and employee complaints should all be considered when reviewing the program for possible upgrade. Finally, the program should be periodically reviewed (at least yearly) to ensure that the design still meets existing government regulations.

5.3.6 Modification Program Outline

The following outline presents the steps that will be necessary in developing a modification program.

I. Determine the railroad's needs from accident data.

1. Analysis of accident data on a given railroad with respect to:
    - A. Train size (weight and length)
    - B. System components
        - a. Brakes
        - b. Trucks
        - c. Longitudinal shock absorbers
    - C. Track characteristics
        - a. Grades
        - b. Curvature
        - c. Longitudinal and lateral track stiffness
    - D. Vehicle characteristics
        - a. Rolling resistance
        - b. Geometry (car dimensions)
        - c. Critical speeds (roll and hunting modes)
    - E. Signal spacing, traffic density and communication systems
    - F. Compliance with operating rules
        - a. Surveillance
        - b. Enforcement.

II. Determine priorities for modifying locomotives using the following criteria:

1. Locomotive type (service requirements) based on performanace characteristics.

2. Locomotive's economic life.

3. Locomotive acquisition policy (major modifications versus new purchases).

4. Scheduled maintenance program and its effect on availability, taking into consideration defect or failure history.

5. Locomotive (type) modification requirements.

6. Structural integrity of cab from analysis and accident damage records.

7. Interchangeability which is a key factor in forecasting utilization.

8. Switch engines should not be considered. This project should be limited to road-freight units.

III. Modification schedule

1. Design package and develop program:

   A. Engineering

   B. Production plan

   C. Quality performance.

2. Select location to perform work:

   A. Centralized fabrication facility

   B. Manpower skill level

   C. Material availability.

3. Work to be performed in conjunction with:

   A. Heavy 3-year maintenance program (1000 manhours)

   B. Heavy non-scheduled maintenance (over 250 manhours)

   C. Accident damage to locomotive cab.

4. Prototype to be tested:

   A. Visibility

   B. Impact

   C. Compatibility.

5. Improve productivity and reduce cost:

   A. Change procedure as required

   B. Manpower stability

   C. Establish target date for completion.

IV. Power assignments of modified units

1. Lead units on all trains with non-equipped locomotives in the consist.

2. Limit usage to road-freight operations in hazardous territories.

3. Invite union participation in evaluating the new cab.

V. New locomotives

5.4 APPLICATION TO MOST-PREVALENT SITUATIONS

In paragraph 5.1.4 performance guidelines were developed to establish the performance requirements of the proposed override mitigation concepts. The purpose of this subsection is to apply these performance guidelines to the most-prevalent accident situations and most-prevalent locomotive examples.

In paragraph 2.6.2, the EMD SD45 was identified as being involved in the most accidents and, therefore, is considered the top candidate for modification. The most-prevalent accident situations are identified as those involving a rear-end collision, rollover collision, and high deceleration impact. The proposed performance guidelines will be applied to each scenario to examine their ability to provide for occupant safety.

5.4.1 Most-Prevalent Accident Situations

There is no single, most-prevalent accident situation since there are several collision modes that can have equally disastrous results. Therefore, three most-prevalent accident scenarios are presented, each of which involves a different set of performance goals. There will, however, be certain similarities in the accident scenarios, such as the type of locomotive (SD45) and the speed at impact (30 mph).

5.4.1.1 Accident Scenario A - Rear-End Collision. A train consist pulled by an SD45 locomotive collides into the caboose at the rear end of a stalled train because of a signal malfunction. The impact speed of the train is 30 mph. The caboose coupler impacts the locomotive coupler. The caboose, being compressed between the loaded hopper car ahead of it and the impacting locomotive, is then forced upward onto the locomotive, impacts and overrides the short nose, and then impacts the front cab window area.

The following subsections show how example modifications that meet the performance guidelines would have given the engineer and crew the best chance for survival with the least injuries.

- Override Prevention: As described in the accident scenario above, the caboose overrides the locomotive following coupler impact. Had an anticlimber been intalled, it may have prevented this override. If it could not have prevented the override, it would have served to absorb a portion of the impact energy and thus lessened the cab impact severity.

The concept behind the anticlimber is that it catches the coupler of the impacted car and holds it down, thus preventing the car from overriding the locomotive underframe. The device must be able to resist the upward force component of the coupler generated during the collision. This has been estimated to be up to 200,000 lb since it consists of only the vertical component of the impact load.

The anticlimber can be fabricated from a 1-inch plate that is welded onto the leading edge of the underframe deck. It is gusseted to the centersills for support. The anticlimber has a radius equal to 20 ft to allow the locomotive to negotiate curves when coupled at this location.

- Protection Against Cab Front Intrusion: Assuming that the anticlimber does not prevent override when the caboose impacts the front of the locomotive, two things should happen. First, energy should be absorbed in deformation of the shorthood and cab; and second, the caboose must be prevented from penetrating into the cab.

To absorb the needed energy, the existing shorthood must be strengthened. The existing hood is presently too weak and will crush without absorbing an adequate amount of energy. This energy is calculated utilizing energy principles. Assuming that the 50,000 lb caboose is traveling at 25 mph with respect to the locomotive (it is assume that a 5 mph velocity reduction occurred during impact), the energy to be absorbed is given by:

$$E = 1/2\ MV^2$$

$$= \frac{(50,000)\quad(36.6)^2}{(2)\quad(32.2)}$$

$$E = 1,044,000 \text{ ft lb},$$

where M is the caboose mass and V equals the impact velocity.

If the shorthood collision posts are designed to yield longitudinally at 250,000 lb, then a force-deflection curve can be assumed as shown in Figure 5-4.

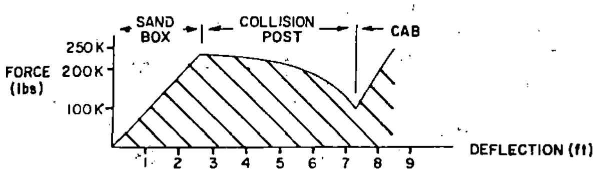


FIGURE 5-4. SHORTHOOD FORCE-DEFLECTION CHARACTERISTIC

To absorb this amount of energy, the existing collision posts were braced with a member that connects the top of each post to a cab collision post. The existing collision posts are also connected to each other with a plate that also ties to the underframe. This plate prevents progressive shearing of the base weld and also provides strength during angular collisions.

The crosshatched area under the curve in Figure 5-4 shows the energy absorption capability of the shorthood. This area, in this case, is equal to approximately 1,400,000 ft lb. It is assumed that only 60 percent or 840,000 ft lb of energy will actually be absorbed in the impact.

To achieve this force-deflection capability, the collision posts would be braced and gusseted as discussed and shown in section 3.3.1 of the candidate designs. The BN collision nose is an alternate approach that could be used if properly designed.

The remaining energy in the locomotive must be absorbed by the cab structure. In order to maintain a survivable volume, the existing cab structure must be strengthened. This could be accomplished most effectively using the braced collision/roll posts as discussed in paragraph 3.3.1.

These cab collision posts are attached to the outside of the cab at the two forward corners. The posts are steel plate weldments which are welded to the underframe and tied together at the top by a beam member. The posts are designed to conform to the shape of the cab to avoid taking up valuable cab space.

These collision posts will yield at about 250,000 lb, neglecting the cab contribution. It is assumed that cab side walls add at least another 20,000 lb. The cab should be able to absorb the remaining 200,000 ft lb of energy in less than one foot of deflection as desired.

5.4.1.2 Accident Scenario B - Rollover Collision. An EMD SD45 locomotive derails on a curve due to defective track or after impacting another train. The track is located on a fill area with a steep side slope, so the locomotive consequently rolls over as it traverses the slope. This section discusses how example concepts which meet the performance guidelines would provide maximum protection for the locomotive crew.

- Protection During Rollover: As the locomotive rolls over, the cab is subjected to the greatest side load since it extends past the hoods on either side. An unmodified cab will be crushed due to its light construction and the very large forces. The forces will be at least equal to the weight of the locomotive (400,000 lb) and possibly higher. The cab will more than likely crush the greatest at the ridge between the roof and side. It will crush back until contact is made with the hoods and the load can be distributed over a large area as shown in Figure 5-5. Thus, the area where the engineer sits will be crushed during a rollover.

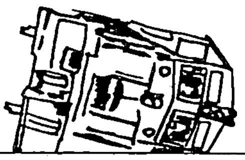


FIGURE 5-5. LOCOMOTIVE CAB SIDE CRUSH DURING ROLLOVER

To prevent this occurrence, the locomotive must be equipped with a strengthening framework that can carry a much greater load. The braced collision/roll posts, as described in paragraph 3.3.1, is one way to accomplish this (an internal roll cage is an alternate method). The posts are mounted to the outside of the cab for easier installation. They are installed on the front of the cab since they also serve as override collision posts. This allows the rear of the cab to crush. However, this crushing would be restricted by the collision posts and the longhood rear edge, which means that crushing is minimal.

The strength of the collision posts and cab combined in the lateral direction should be equal to 400,000 lb to support the weight of the SD45 locomotive.

When rollover continues to 180 , as it did in the scenario, the roof structure of the cab is subjected to crushing. This load could be spread over the entire longhood and cab roof. However, it is also possible for the entire weight of the locomotive to be applied to the leading edge of the cab roofline, assuming the locomotive does not contact the ground squarely. Here again the cab collision posts serve to protect the leading edge of the roof from crushing. As in the side crushing situation, the collision posts and cab combination must be designed to hold 400,000 lb for the SD45 locomotive.

5.4.1.3 Accident Scenario C - High Decerleration Impact. An EMD SD45 locomotive traveling at 40 mph comes upon a fully loaded tractor trailer stalled on a grade crossing. The engineer throws the brakes into emergency but is not able to stop before hitting the truck. Assuming impact speed is 30 mph, the locomotive will experience an average deceleration of 2g for over half a second as it impacts the truck and finally stops.

The 2g deceleration is sufficient to throw the crew about the cab and is, therefore, a dangerous situation for occupant injury. This section describes how example concepts which meet the performance guidelines make the cab environment safer for the crew in this type of situation.

- Occupant Protection: During this violent collision, the occupants of the locomotive cab would be tossed around the cab and could possibly impact a series of dangerous objects.

First of all, the windows could shatter or be impacted by the occupants. The use of safety glass is a concept for reducing the hazard of being cut by flying glass. Installation of pop-out glass windows at the side window locations would also provide for escape following a collision.

Seat belts for the locomotive engineer and brakeman would provide some means of protection provided they were worn. Improved protection could be accomplished by padding or moving dangerous handles and switches on the control console and in the cab as well as padding the console itself. Improved restraint or storage of such items as fire extinguishers, water coolers, and tool boxes is also imperative to prevent these objects from flying around during the collision.

5.4.2 The Modified Locomotive

Figure 5-6 shows the exterior view of an SD45 locomotive following modification with safety devices that meet the proposed performance guidelines required in the situations discussed above. Starting in the front, there is the anticlimber coupler override prevention device, which is welded to the front of the locomotive underframe. The anticlimber is gusseted to the center sills as shown by the hidden lines.

The standard collision posts are reinforced with a cross brace (not seen) and braces back to the cab collision posts. An alternative to this approach is a short-nose skin fabricated from steel plate rather than sheet metal.

The cab collision posts are attached to the underframe and cover the front outboard surfaces of the cab. The posts are made from 1-inch plate and have a hole cut in them for a forward observation window. Both the reinforced shorthood collision post and the cab collision posts are designs which were discussed in detail in paragraph 3.3.1.

The four windows on the front of the cab and the two on the rear are replaced with safety plate glass. The side windows are also safety glass but have been designed with pop-out frames similar to those found on train passenger cars and on buses. These windows allow for exit following a collision if other exits are blocked.

Figure 5-7 shows the interior of the cab viewed from the rear. The operator's control console has been padded on the top with a dense foam covered in vinyl. The pad overhangs the console in a manner similar to an automobile padded dash. The rear facing side is also padded with the pad going around each corner.

Both heaters are padded as are the grab handles. The surface around each side window is also padded in a manner similar to the control console.

The water cooler (not shown), in the rear of the cab is padded and secured to the wall with steel straps. The fire extinguisher (also not shown), is equipped with a more secure quick-release wall mount.

Controls such as the heater valve and the sander switch, which do not require quick access, are equipped with padded hinged covers to make them less hazardous.

5.5 CONCEPT APPLICATION ON OTHER LOCOMOTIVE MODELS

In North America, locomotives built by the Electro-Motive Division of General Motors Corporation (EMD) and General Electric Company (GE) comprise the majority of the locomotives in use today. The 4- and 6-axle EMD locomotives used in revenue service include the GP and SD models. Since the construction of the shorthood and cab assembly of these locomotives is quite similar, the proposed concepts are applicable to almost all the EMD models used in revenue service. Proposed concepts can easily be adopted for other EMD models. These include the E8, F40-PH, F40-G, SDP40-F, etc.

Although the shorthood assemblies of the GE locomotives are not identical to the EMD locomotive's shorthood assemblies, there are many similarities between the two. The proposed concepts can also be adopted for the GE locomotives, with minor modifications. While the GE Q (quarters) cab is an entirely different design, it can still utilize a somewhat similar approach.

5.5.1 Application to Other EMD Locomotives

Most EMD road locomotives for freight use are broken into two general categories; GP, or light (4-axle) road switchers and SD, or heavy (6-axle) road switchers. The differences are mainly in the engines, frames, and truck and not in the cab or shorthood assembly. Essentially, they all use the same basic cab and shorthood assembly. The underframes are also similar on the forward end where the anticlimber is mounted. Therefore, the proposed modifications can be used in all these models with only minor changes.

The F models (cowl units) have a different cab and shortnose design. The cab and shortnose are designed as a single unit, with the shortnose being full width. There are two front windows instead of four that encompass most of the width of the cab. These differences make application of the braced collision/post more difficult. A proposed design is shown in Figure 5-8. This design is also applicable to similar GE cowl units, such as the U30-CG and the P30-CH.

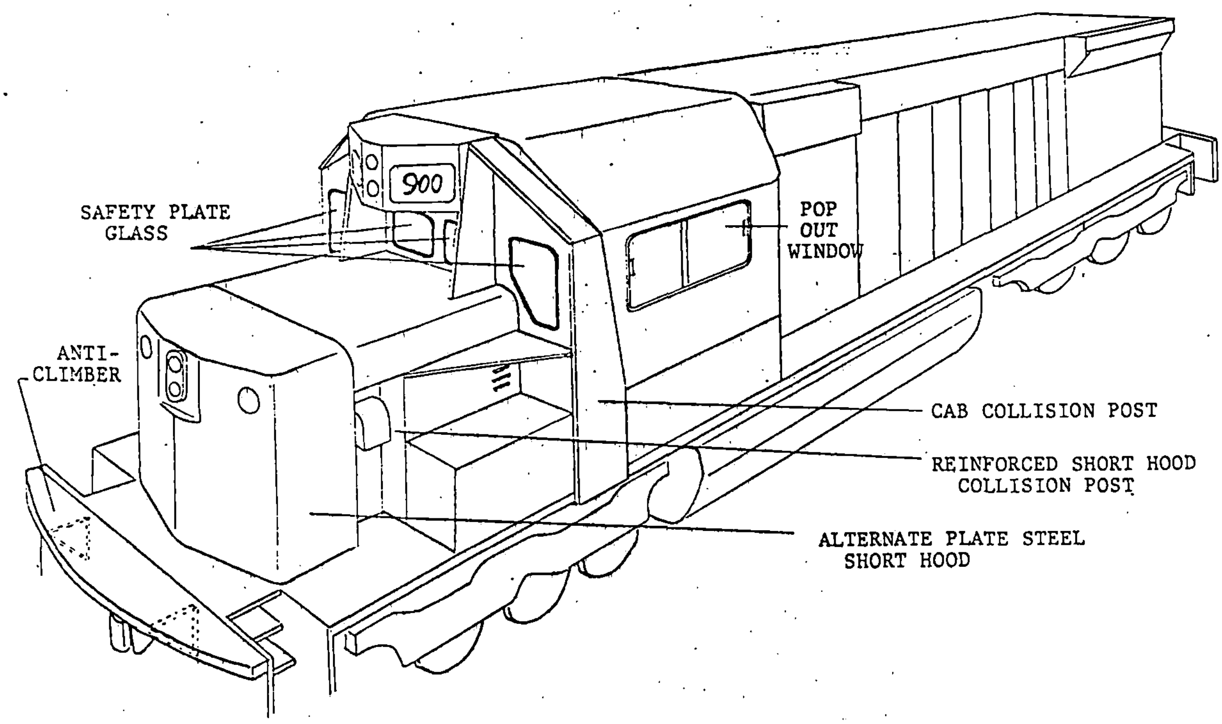


FIGURE 5-6. EXTERIOR VIEW OF MODIFIED EMD SD45 LOCOMOTIVE

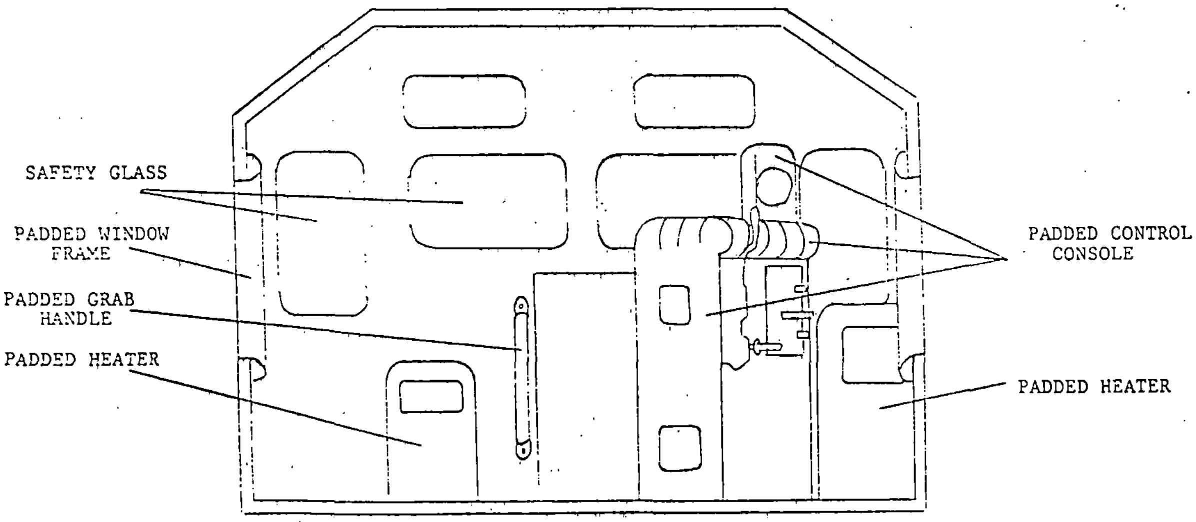


FIGURE 5-7. MODIFIED CAB INTERIOR SHOWING
SAFETY MODIFICATIONS

The phantom drawing in Figure 5-8 shows the SDP40-F locomotive with the braced collision/post modification. The front surface of the cab has been replaced (or covered) with a heavy plate with cutouts for the windows and shorthood access door. This plate is welded to the underframe and has a peripheral plate flange attached to it that surrounds the cab. Attached to the front of the plate are two collision posts that separate the battery boxes from the head. The collision posts are gusseted in the front with plates that go between the sand box and the battery box. The collision posts are cut out in front of the windows to increase the field of view from the cab. The posts are connected at the top by a box brace.

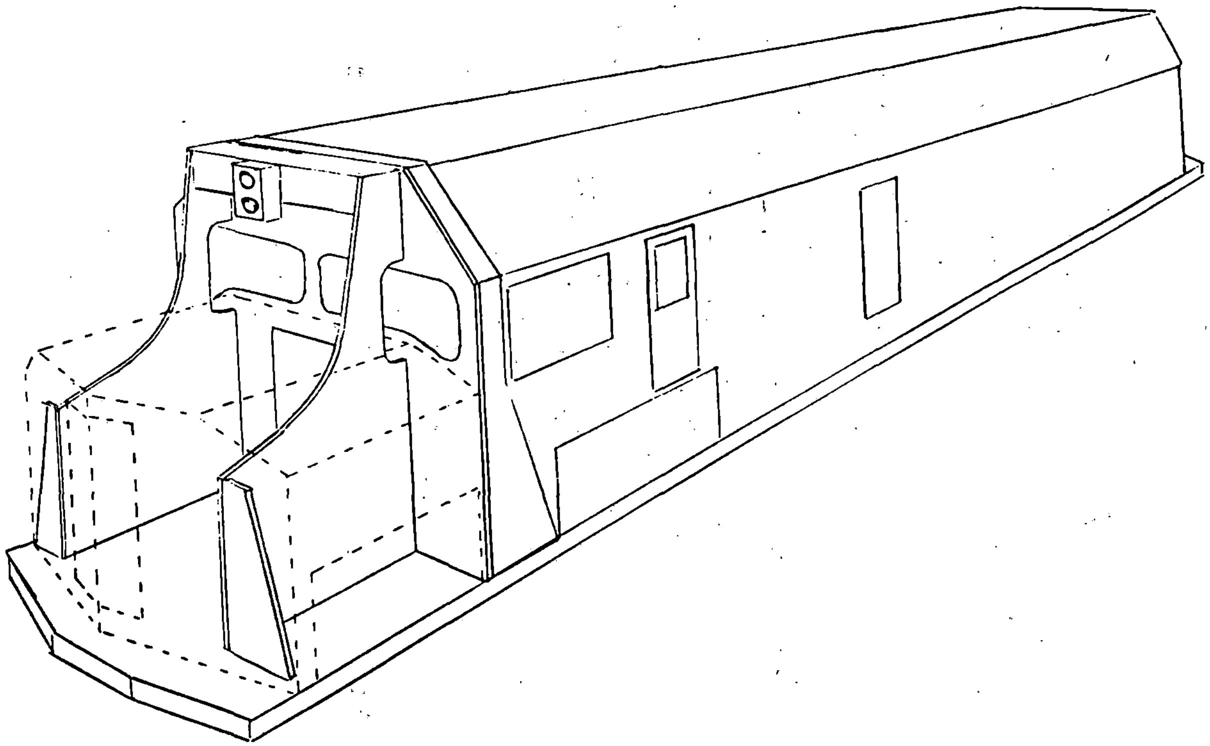


FIGURE 5-8. EMD SDP40-F LOCOMOTIVE MODIFIED WITH BRACED COLLISION POSTS

5.5.2 Application to GE Locomotives

Most General Electric freight locomotives are similar in design to the EMD locomotives and are, therefore, candidates for the proposed modifications. Most of these locomotives have a shorthood and cab that are similar to each other, and the dimensions and construction of the EMD and GE cabs are almost the same. The important difference between the GE and EMD locomotives is in the shorthood. The GE shorthood is shorter and it lacks the collision posts found in the EMD models.

A suggested modification for a GE locomotive consists of the installation of braced collision posts on the exterior of the shorthood as shown in Figure 5-9. The shorter hood length would necessitate stronger braced collision posts in order to absorb the needed energy.

The braced collision posts modification shown in Figure 5-9 is a totally exterior modification that lowers the cost substantially. The front of the cab is covered with heavy plates that cover the area outboard of the shorthood. These plates are strengthened with flanges on the outboard and upper edges and welded to the underframe. A collision post is welded to each plate and the underframe and sits just outboard of the shorthood. The collision posts are tied together at three points; ahead of the shorthood and above and below the front windows. Again, these posts are notched in front of the windows to increase the field of view. Horizontal gussets are connected to the collision posts and the cab front plates.

GE also builds the Q-cab locomotives that have no shorthood at all. On these locomotives, a collision post assembly would be required to maintain a survivable cab volume during a collision. This device is shown in Figure 5-10. A similar approach is also possible with the E series electric locomotives. However, an extension to the underframe and the coupler draft gear would be necessary.

The Q-cab modification shown in Figure 5-10 uses two plates that have the shape of a crooked A for collision posts. These posts are welded to the underframe on either side of the front stairway. The large opening in the collision post allows the crew to use the stairway. A smaller opening is provided to increase peripheral vision. The posts are connected above and below the front windows by braces. The front legs of the posts are gusseted to the underframe for increased strength.

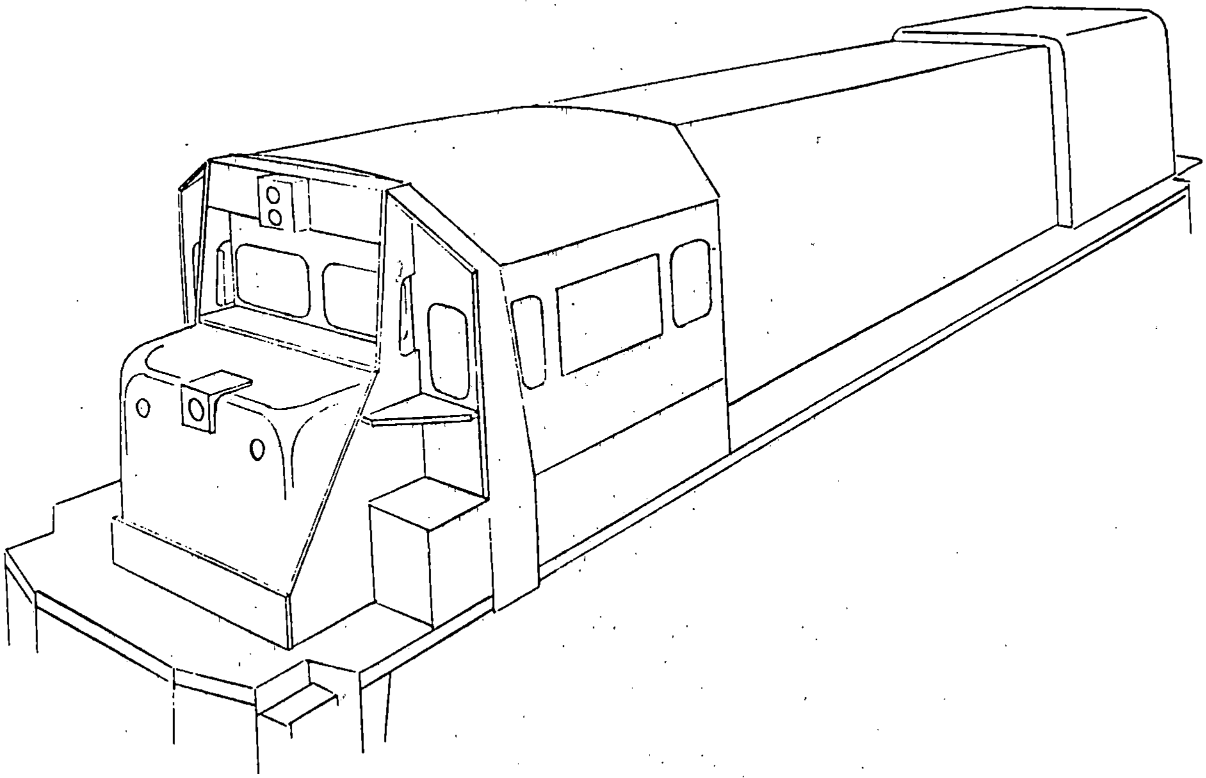


FIGURE 5-9. GE LOCOMOTIVE MODIFIED WITH EXTERIOR BRACED COLLISION POSTS

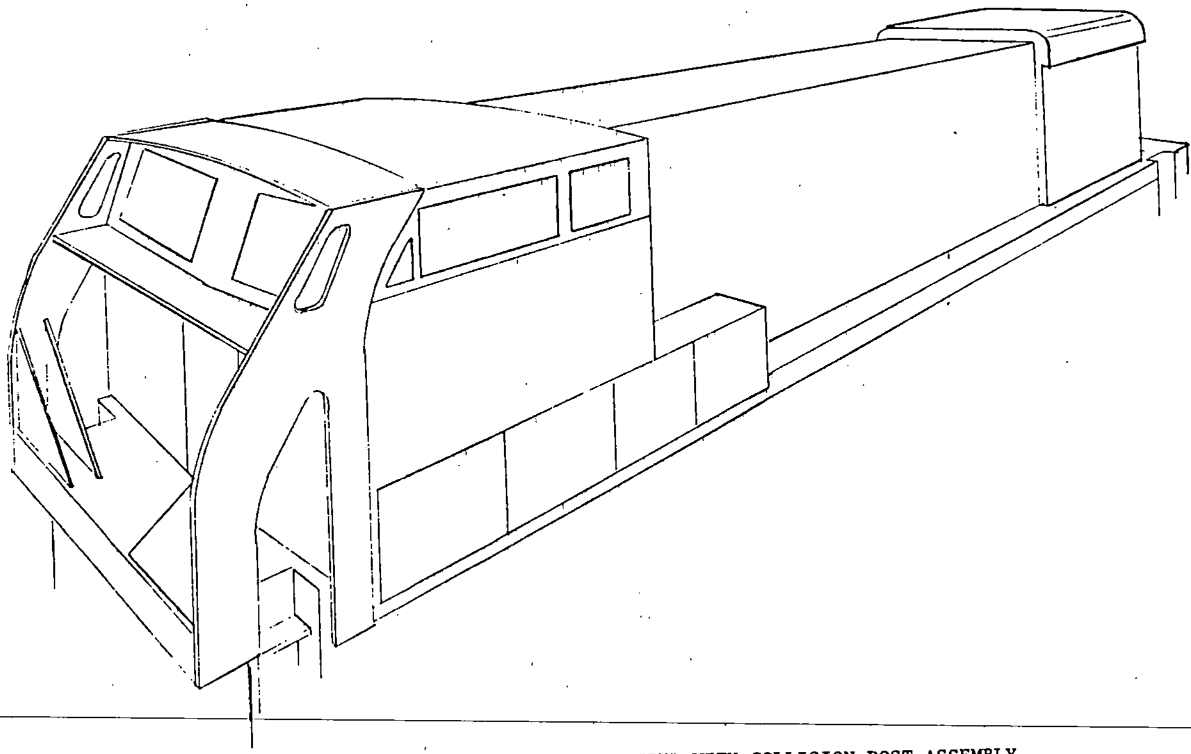


FIGURE 5-10. GE U15BQ LOCOMOTIVE MODIFIED WITH COLLISION POST ASSEMBLY

5.6 PROPOSED PERFORMANCE GUIDELINES FOR SECONDARY BENEFITS

5.6.1 Introduction

This subsection addresses two important concerns: (1) what benefits do the guidelines proposed in paragraph 5.1.4 provide to protect the locomotives in potential railroad grade crossing collisions, and (2) can the proposed performance guidelines be applied to self-propelled passenger car rolling stock; and if they can, do the guidelines need to be modified?

Both of these concerns (grade crossing collisions and protection for self-propelled passenger vehicles) are very real. For example, in 1979, there were 11,800 accidents involving trains and motor vehicles at public grade crossings. Of these accidents, 8,361 occurred when the trains struck the highway vehicles; in 3,191 cases, the highway vehicles struck the trains. Consequently, there is a need to extend the proposed guidelines to include grade crossing protection.

In the case of self-propelled passenger vehicles, this comprises a sizeable portion of the rail vehicle population if the high-speed corridor vehicles and commuter trains are counted. Indeed, the passenger cars rank second (next to locomotives) in terms of number of fatalities resulting from collisions. Consequently, crashworthiness guidelines need to be developed for this type of vehicle. This section describes multi-purpose performance guidelines that apply to the locomotive or self-propelled passenger vehicle while also providing protection for grade crossing accidents.

5.6.2 Multi-Purpose Performance Guidelines for Application to Self-Propelled Passenger Vehicles

The proposed guidelines are applicable to passenger vehicles, with the provision that the braced collision/roll posts structural performance guidelines for ensuring a survivable volume be augmented to define appropriate structural strength for the passenger vehicle. This relates to the fact that for the braced collision/roll posts to be effective it requires that there is a sufficiently strong car body structure to react to the load transmitted from the collision post structure.

This indicates a need to provide guidelines for the following parts of the car body:

- Longitudinal frame
- Side posts and braces
- Sheathing to prevent buckling
- Vertical end members
- Roof

Guidelines applicable to these are taken from AAR specifications and are listed in Appendix H.

The multi-purpose performance guidelines incorporating application to self-propelled passenger vehicle stock include the preceding performance guidelines for car body performance, in addition to the peformance guidelines from paragraph 5.1.4, and are modified as follows:

- Braced collision/roll posts (to be incorporated at both ends of the vehicle)
- Truck retention
- Locomotive coupler design
- Improved communications
- Safety glass
- Emergency exits
- Occupant restraint
- Protective padding
- Anticlimber devices

6 STRUCTURAL ANALYSIS OF LOCOMOTIVE CABS

6.1 INTRODUCTION

The purpose of the structural analysis task was to evalute the abilities of representative locomotive cabs from the operational railroad fleet to support a static load. The static load could be characterized as the weight of a freight car atop the cab. These structural analyses provide a baseline for development of improved cab structures aimed at guaranteeing adequate survivable space within each cab in the event of a rear-end collision with rear car override.

This section presents the results of structural analyses performed on typical locomotive cabs from the operational railroad fleet. Recommendations are presented for modifications to existing cabs, redesign of future cabs, and proposed areas of further research. Initially, eight locomotive models were identified as being representative of the operational fleet: GP18, GP38, GP40, SD40, SDP40, E60, SD45, and F40. The inability to obtain industry drawings and resource limitations dictated that the study by limited to five cabs that were accessible (within a 100-mile radius of NSTL) for inspections and measurements. The three cabs that were deleted from the original list were the GP18, E60, and SD45. They were deleted not only because of their lack of availability for measurement purposes but also because the other five locomotives were in wider use, and their study had a more extensive applicability. The five locomotives that were chosen for study were all manufactured by the Electro-Motive Division of General Motors (EMD).

6.2 APPROACH

6.2.1 Organization of Structural Analysis

The structural analysis was organized into three activities:

- Data collection
  - Establish a reference library of documentation
  - Measure cab structural details
  - Assemble analysis tools
- Determination of the structural design characteristics of existing cabs
  - Structural drawings
  - Determine member properties
  - Structural idealization
- Analysis of cab structures
  - Determine locomotive cab maximum load without margin
  - Conduct locomotive cab post-yield analyses
  - Establish maximum load with safety margin.

As indicated above, five locomotives were analyzed. These were representative of the operational fleet and are classified as follows:

- 4-Axle
  - Road-Switches

    GP38-2

    GP40-2
  - Passenger

    F40-PH
- 6-Axle
  - Road-Switches

    SD40-2
  - Passenger

    SDP40

6.2.2 Data Collection

A literature search was conducted to locate and obtain existing documentation concerning railroad crashworthiness and related subjects. Numerous documents were obtained from the Department of Transportation and other government sources, commercial sources, railroad companies, and consultants. A bibliography containing all the references obtained during the course of this study is included as a part of this report (following the Appendices).

The NSTL/EL exercised the alternative of making field trips to perform the required measurements on the various locomotive cabs. Arrangements, permission, and clearances were obtained from accessible railroad yards in New Orleans, Louisiana, and various other locations to inspect the locomotives. The locomotives studied were available frequently enough in the railroad yards to allow measurement/inspection. once the information was gathered through field trips, engineering representations were drawn for use in the analysis of each locomotive cab structure.

Typically, four trips were required to document a locomotive cab. The first trip was directed toward identifying the locomotive, taking general photographs, and sketching gross features and overall dimensions. The second and third trips were to examine a particular model locomotive by sketching interior and exterior features, determining details of joint connections, and identifying location, type, and extent of cab structural welds. The fourth trip was to verify measurements and sketches made on the previous three trips. The data and measurements of the locomotive cab structures were obtained by removing panels, opening component covers, employing probes, conversing with employees, examining wrecked vehicles, and making references to literature. Photographic coverage included exterior and interior shots as well as closeup shots of details.

The final steps in the data collection activity were the assembly of the tools needed to perform the analyses and the identification of a structural engineering consultant. At the recommendation of the structural consultant, the Sperry-Univac's ICES-STRUDL II (Integrated Civil Engineering Structural Design Language) computer program was obtained. The program was modified and installed on a Univac 1108 at the NASA Slidell Computer Center. STRUDL was chosen over NASTRAN and numerous other computer programs for its simplicity and flexibility as an analysis and design tool. Also, the structural consultant had written significant parts of the program and was familiar with its use in similar analysis projects. Example problems from the structural consultant were exercised to verify procedures, techniques, operation, and formats. Other analysis tools, such as charts for plasticity reduction factors applicable to elastic-plastic buckling analysis, were obtained from the reference library.

6.2.3 Structural Design Characteristics

Engineering representations of the main structural components of the locomotive cab were developed from the data gathered on each cab. Isometric representations to a scale of 1:10 were made of the right side of each cab. The outer skin of the locomotive cab's framework was deleted to clearly show the structural members. The locomotive cabs were assumed symmetric about the longitudinal centerline. The locomotive cabs examined during this analysis represent two styles of locomotive cab roofs, the hatched roof and the non-hatched roof. Figures 6-1 and 6-2 are examples of these cab roofs.

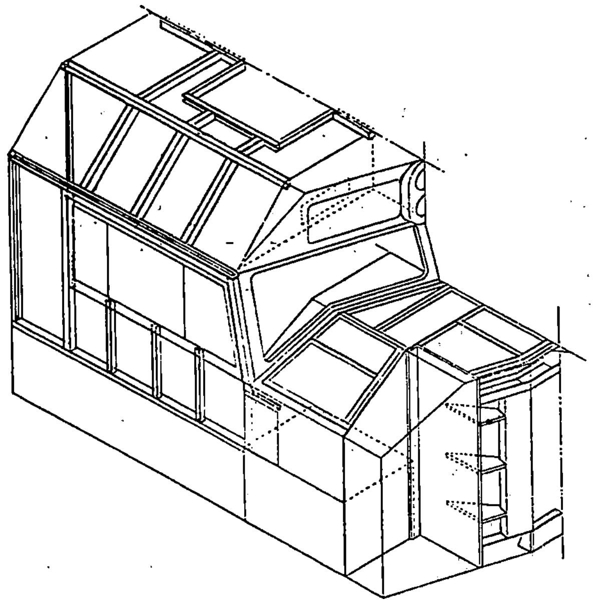


FIGURE 6-1. ISOMETRIC OF A LOCOMOTIVE CAB FRAMEWORK WITH HATCH

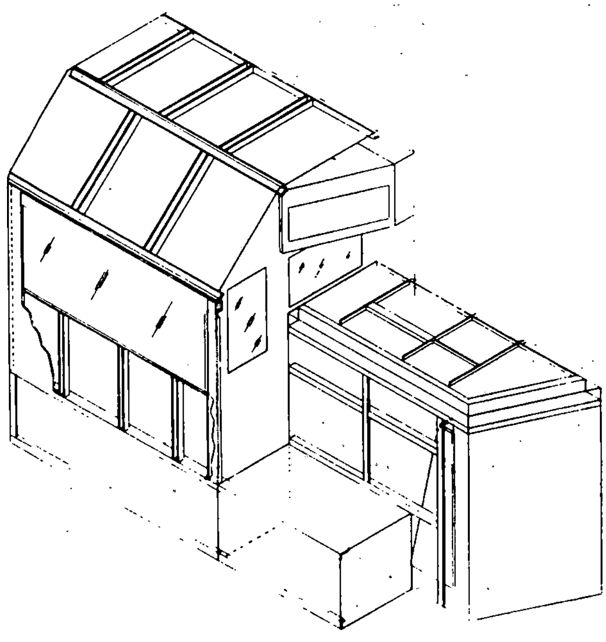


FIGURE 6-2. ISOMETRIC OF A LOCOMOTIVE CAB FRAMEWORK WITHOUT HATCH

Each locomotive cab required approximately ten different representations to describe the various types of cross-sections of structural members. Some of the member cross-sections were open shapes, closed shapes, multiple closed shapes, and combinations of the preceding (Figures 6-3, 6-4, 6-5, and 6-6 illustrate this description).

The cross-sectional representations were used for calculations to determine member properties for various effective skin widths. In some cases the effective skin width allowed otherwise open shapes to become closed shapes. For example, an angle iron shape might become a tee or channel shape, a channel iron might become a closed rectangular shape, and so on. Figure 6-7 shows the contribution of a few properties of member cross-sections due to effective skin width variation.

A majority of the members had to be graphically integrated due to their complex shape. In those cases where graphic integration was required, the member was divided into elemental pieces and numbered. The cross-sectional area, centroids, moments of inertia, section moduli, and torsional constants were then calculated and summations were performed on the results.

Idealizations were made for calculating the section properties of members. Fillets and radii were generally assumed square. The typical member was 11-gage (Manufacturer's Standard Gage, 0.1196-inch thick) steel that was approximately 0.12-inch thick. Built-up cross-sections were assumed to work together fully as one member. The thin, perforated metal attached to some interior members was ignored. No reduction in member strength due to tolerance variation was included.

Predominantly, the members were not standard structural shapes, such as angle iron or channel sections. Typically, the structural members were formed or cold-worked press-brake sections. Skip welding, track welding, and spot welding were common with very little full-penetration welding evident.

Some members were almost completely hidden from view and would have required an abrasive saw or cutting torch to enable more accurate determination of the structural member configuration. At these points, the top assembly and general arrangement drawings of the locomotive cabs aided in the idealization of the basic shape of the section. The shape of each section was then confirmed, as much as possible, through measurements and direct inspection on the vehicle.

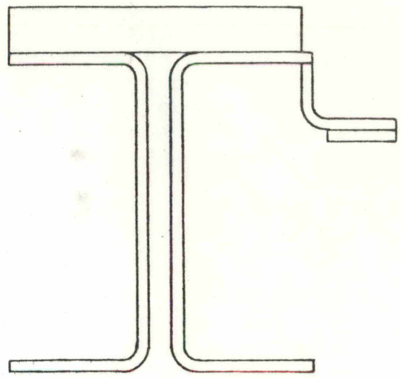


FIGURE 6-3. OPEN SHAPE MEMBER CROSS-SECTION

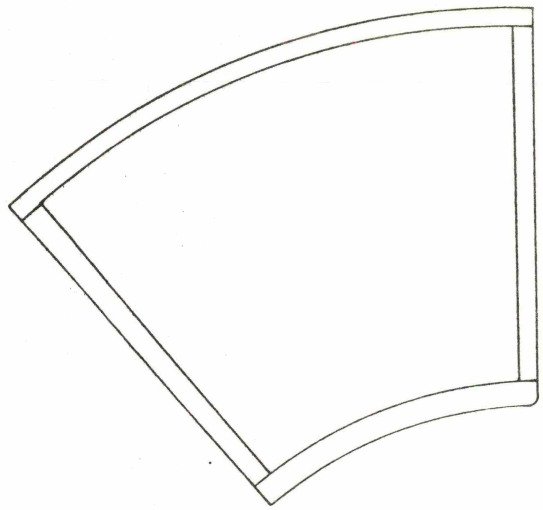


FIGURE 6-4. CLOSED SHAPE MEMBER CROSS-SECTION

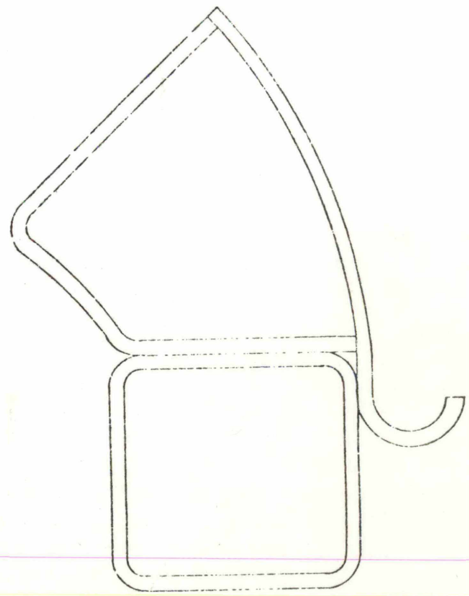


FIGURE 6-5. MULTIPLE CLOSED SHAPE MEMBER CROSS-SECTION

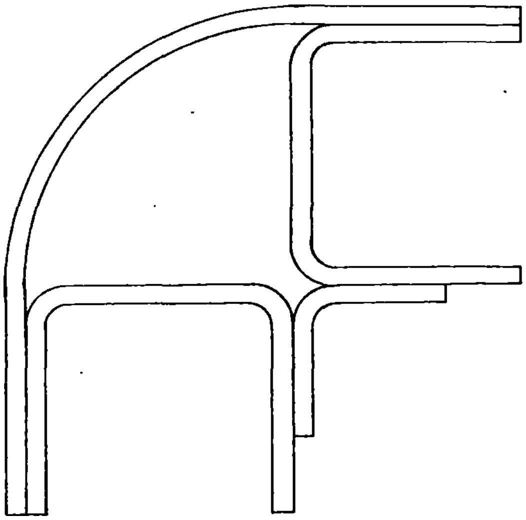


FIGURE 6-6. COMBINATION SHAPE MEMBER CROSS-SECTION

I. Member Without Skin Effect

	AX	*IX	IY	IZ
2 1/2"x2"x2 1/2"x.12"	0.8112	0.00389	0.534	0.585
1 5/8"x1 5/8"x.12"	0.3756	0.001796	0.0962	0.0962

II. Same Member With Effective Skin Width of 1B

	AX	*IX	IY	IZ
2 1/2"x2"x.12 RECT. TUBE	1.0224	1.1267	0.911	0.6399
1 5/8"x1 5/8"x.12"	0.5562	0.002669	0.24788	0.1520

III. Same Member With Effective Skin Width of 2B

	AX	*IX	IY	IZ
2 1/2"x2"x2 1/2"x4"x.12 (SHAPE)	1.2624	1.1278	1.32	1.199
3 1/4"x1 5/8"x1 5/8"x.12 (SHAPE)	0.7512	0.003605	0.347	0.717

* TORSIONAL CONSTANT

FIGURE 6-7. CONTRIBUTION OF EFFECTIVE WIDTH OF SKIN TO MEMBER PROPERTIES

The idealized member section representations were the basis of all calculations of member properties. For use in both hand calculations and computer structural analyses, the section property calculations consisted of calculating the following:

- Cross-sectional area
- Weight
- Centroid
- Moment of inertia
- Product of inertia
- Principal axes spatial orientation
- Extreme fiber distance
- Elastic section modulus
- Plastic section modulus
- Radius of gyration
- Torsion constant.

At least one single-line isometric representation of each locomotive cab was prepared to idealize the locomotive cab for computer modeling purposes. Centerlines and neutral axes were used to idealize the cab structure. These sketches assisted in identifying space frame topology, joints, members, end conditions, loadings, and support points. The idealized model allowed identification of primary structural members. Figure 6-8 shows an example that demonstrates this idealization and modeling approach.

The single-line isometric allowed the assignment of a three-axes coordinate for each member connection point. Once coordinates were determined for each joint, the interconnecting members could be defined through their respective

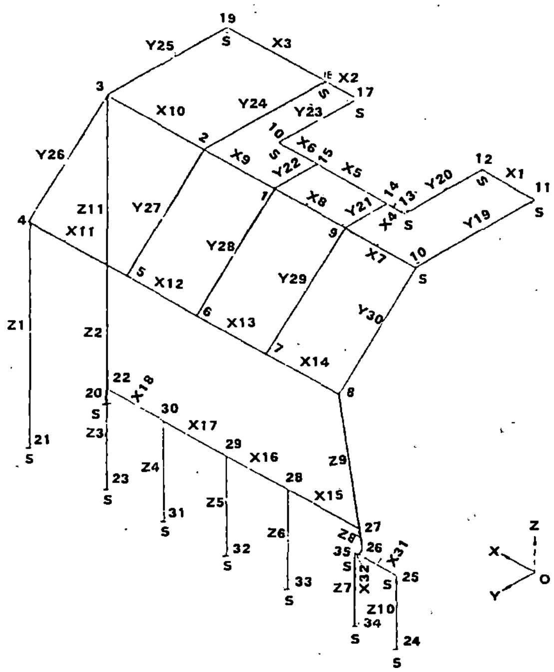


FIGURE 6-8. SINGLE-LINE COMPUTER MODEL ISOMETRIC

joint numbers. Local coordinates of specific members were labeled, thus fixing the particular member section properties in tensor notation in relation to the global (three-dimensional space) coordinates of the structure. Each member had a local coordinate system that ensured properly oriented section properties.

6.2.4 Analysis of Cab Structures

The single-line isometric was also used to calculate the uniform vertical load on the locomotive cab roof. This calculation was used to determine the distribution and load intensity on each member. The technique for calculating the roof line was first to divide the roof into various rectangular areas. The rectangles were next divided into triangles using diagonals of the rectangles. The vertical projected area for each triangular area was calculated. A vertical uniformly distributed load of unity (one pound per square inch) was applied to the thus calculated surface area. A distributed load of unity was for preliminary analysis so that later it could be easily factored. Loads adjacent and contributing to an underlying support member were summed and then applied to the proper roof member as a line load along the axis of the member. The contribution due to dead load (the weight of the load carrying members) was assumed not significant. It represented only a small percentage of a uniformly distributed unity load.

6.2.4.1 Hand Calculations Analysis. Hand calculations were carried out at different levels of complexity to gain insight into the overall structural response of the cab structures. The more basic analyses entailed assumptions that made the structures statically determinant. The cabs were also modeled as space frames, and statically indeterminant analyses were performed. The roof grid of transverse and longitudinal beams covered by the outer skin was analyzed using a pseudo-bending plate analysis to take into account the effect of the total outer skin. [20] Variability in member end constraints was also considered in the hand calculations.

Elaborate stress redistribution and shakedown analyses were not carried out since the uncertainties associated with joint constraints and member end fixities were of such magnitude as to make the use of highly theoretical, elastic-plastic strain models unjustifiable. Rather, the sensitivity of the structural response was studied as a function of the likely structural variation, such as integrity of certain welds, to determine the degree of confidence in the idealized structural model configuration. The collapse mechanisms were determined by use of classical plastic design techniques. The elastic-plastic progression was followed iteratively based upon the relative stiffness of the remaining elastic portion of those sections where plastic hinges had begun to form.

Buckling was checked using Euler buckling theory and classical plate buckling equations. Plasticity reduction factors were also considered to account for elastic-plastic buckling. The NACA Handbook of Structural Stability was used as a principal reference source. The wall panels were analyzed as stiffened plates and were checked for buckling. However, complex buckling computations were seldom necessary since the buckling loads of stifffened panels and plates were quite high, as illustrated by the fact that individual stiffening elements (if isolated by broken welds) generally had Euler buckling loads corresponding to roof load levels much higher than those required to cause roof collapse.

6.2.4.2 Elastic Computer Analysis. Numerous computer runs with the STRUDL program were made for each locomotive to investigate the effects of joint and member fixity, as well as support releases. These computer runs aided the hand calculations by allowing numerous permutations and combinations to verify the assumptions made by the hand calculations.

The key to effective computer structural analysis was the judgement in assigning support points, support releases, joint fixity, and member fixity for the three-dimensional space frame cab structure. Because of the uncertainty of joint restraints, several different analyses were performed with different member end fixities to determine the sensitivities of the load response to such variability. Runs were also made varying the effective width of the outer skin that is utilized by the framed channel and angle sections. The results of the study were in agreement with the AISI specification for the Design of Cold-Formed Steel Structural Members, that the effective width of the outer skin welded to the cold-formed sections under analysis should be taken as the width of the cold-formed sections themselves. Then, the elastic computer analyses basically model the structure as a three-dimensional space frame where the roof sections are hollow rectangular tubes formed by the welding of channel legs to the outer skin.

6.2.4.3 Correlation of Hand Calculation and Elastic Computer Analysis. The hand calculations were correlated with the computer-generated elastic analysis results. Some pseudo-elastic analyses were performed on the computer with secant moduli to simulate elastic-plastic responses. The results were generally consistent and, given the uncertainty of the type of construction and its variations, the analyses of the cab load levels provided a reasonably high confidence level in their accuracy.

6.3 RESULTS

6.3.1 Structural Analyses Results

Results of the structural analyses were based upon the modeling idealizations attained from the inspection/measurements and upon the results of sensitivity studies performed to assess the applicability of what was considered the best modeling idealization. Structural detailed drawings of the cabs were not available; the cabs could best be described as "shop contructed." This means that rigid standards with respect to weld spacing and other tolerances were apparently not applied and the actual cab construction varied somewhat from shop to shop and from time to time. Determination of the structural details was made by project personnel who actually measured the cabs and individual structural elements on the locomotives. Access to all joints and welds was not possible, but the inspections and measurements clearly indicated the variabilities associated with this type of shop construction. Enough variation was found among locomotives of the same model number to warrant creating a "typical" locomotive cab of a particular model number for analysis purposes.

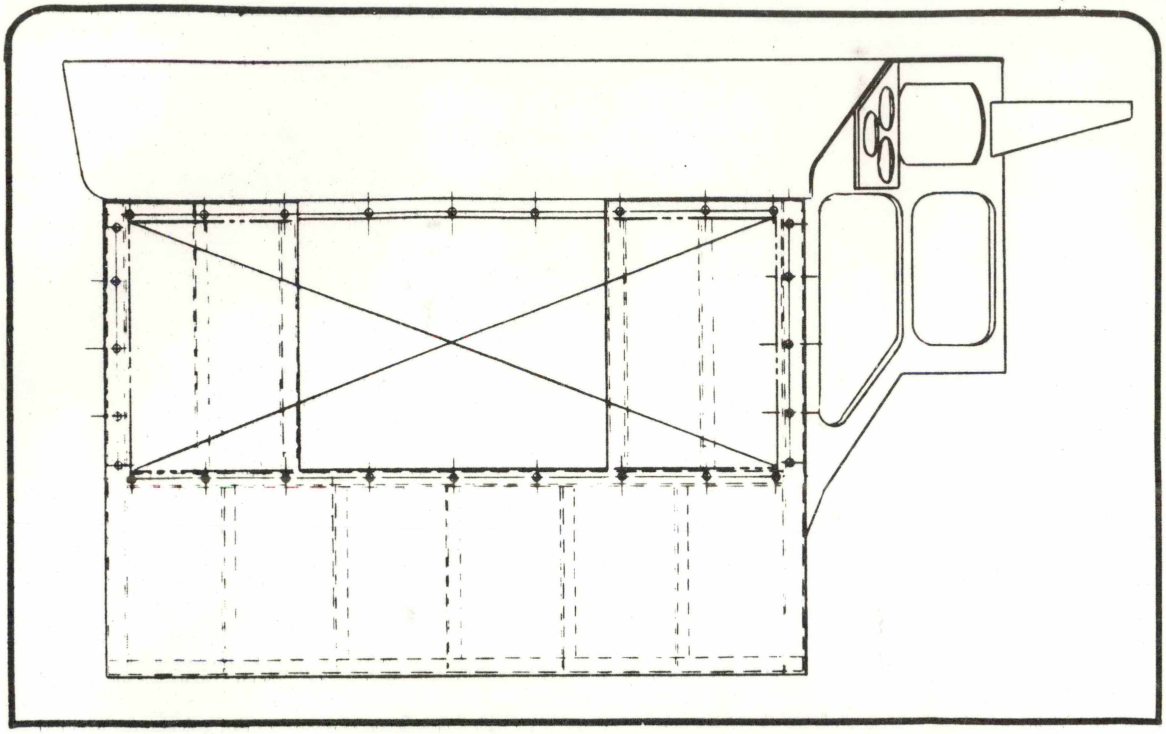
All the locomotive vehicles had the appearance of "custom built" as opposed to "mass produced." Each vehicle was slightly different from others of the same model. The cab structures generally consisted of a 0.12-inch-thick outer skin over a framework of cold-formed structural steel sections. The cold-formed sections were also generally 0.12-inch thick. The primary roof framing elements were channel sections as shown in the isometric drawings developed for each vehicle's cab. The inner cab was thin perforated metal sheeting that was deemed to be insignificant in providing structural resistance to loading. The inner skin was ignored in the structural analyses. The yield stress of the steel was approximately 36,000 psi.

The primary roof members of all cab structures, with the exception of the GP40-2, consisted of 2.5-inch-deep channels spot welded to the 0.12-inch-thick outer skin. The GP40-2 had 1.5-inch-deep channels similarly welded to the outer skin for the primary transverse and longitudinal roof members.

The cab sidewalls generally consisted of angle sections spot welded to the outer skin. The side window units consisted of glass and steel plate that bolt on as an integral unit over the window opening. The cab sidewalls were welded to the channel section floor joints, but the joint flexibility was such that they should be considered pinned end connections. The floor was supported on short pipe columns that extended to the locomotive sill structure. The interstitial space between the floor and sill was occupied by ancillary equipment.

The cold-formed framing sections were spot welded to the outer skin. Inspection of the locomotive cabs indicated that the distance between welds was variable, but generally was on the order of six inches. Joint rigidity was also dependent upon the continuity provided by the spot welds. In most instances, the joint rigidity could be characterized as low, since exact tolerances and consistent welding practices at the intersection of structural framing members were apparently not attained. In fact, the intersection of the transverse roof members with the longitudinal member at the edge of the flat portion of the roof had a gap between the ends of the transverse members and the longitudinal channel which, according to maintenance personnel, was large enough in some instances to accommodate wiring cable approximately 0.38-inch in diameter. Such a joint transfers loads primarily through the short sections of outer skin spanning the distances between the members. A joint such as this must be considered to have essentially no moment transfer capacity and should be modeled as a pinned (no rotational resistence) joint.

Variations were frequently found and documented when different units of the same model locomotive cab were inspected. In one case, the sidewall of the locomotive contained vertical members, but inspection and photographs showed that the entire window was a bolted-on panel (see Figure 6-9). The vertical load transmission capacity for vertical structural members compared to a bolted-on panel are obviously different. In another case, the hood/nose of a locomotive demonstrated differences within a particular model number locomotive (Figure 6-10). One vehicle contained several heavy plate gussets to stiffen a vertical section, whereas, another vehicle of the same model number did not contain this feature.



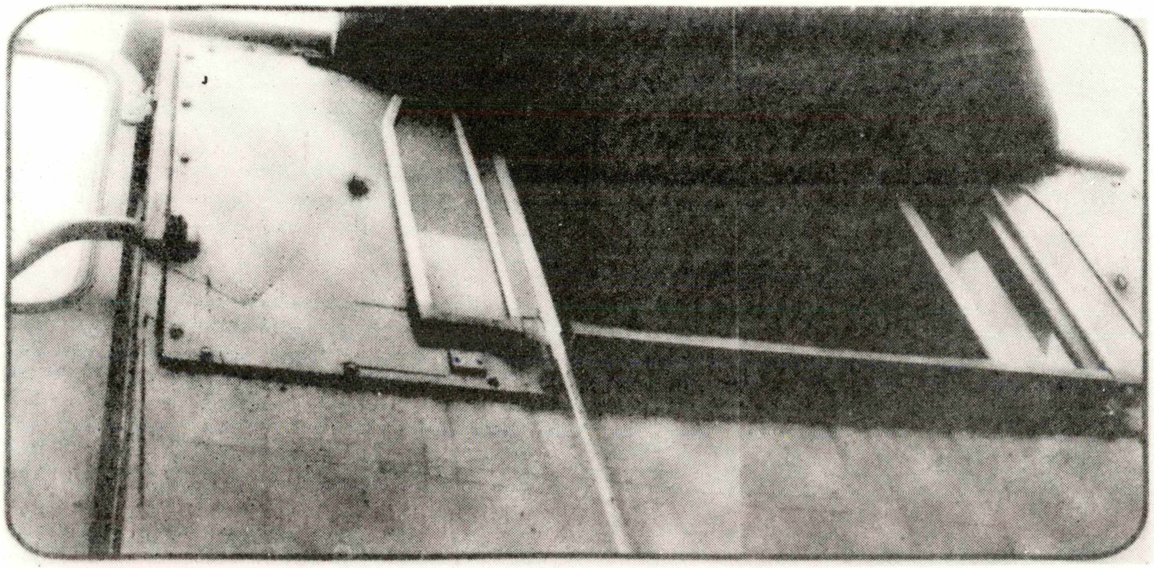


FIGURE 6-9. LOCOMOTIVE CAB STRUCTURAL VARIATIONS, FRONT BULKHEAD

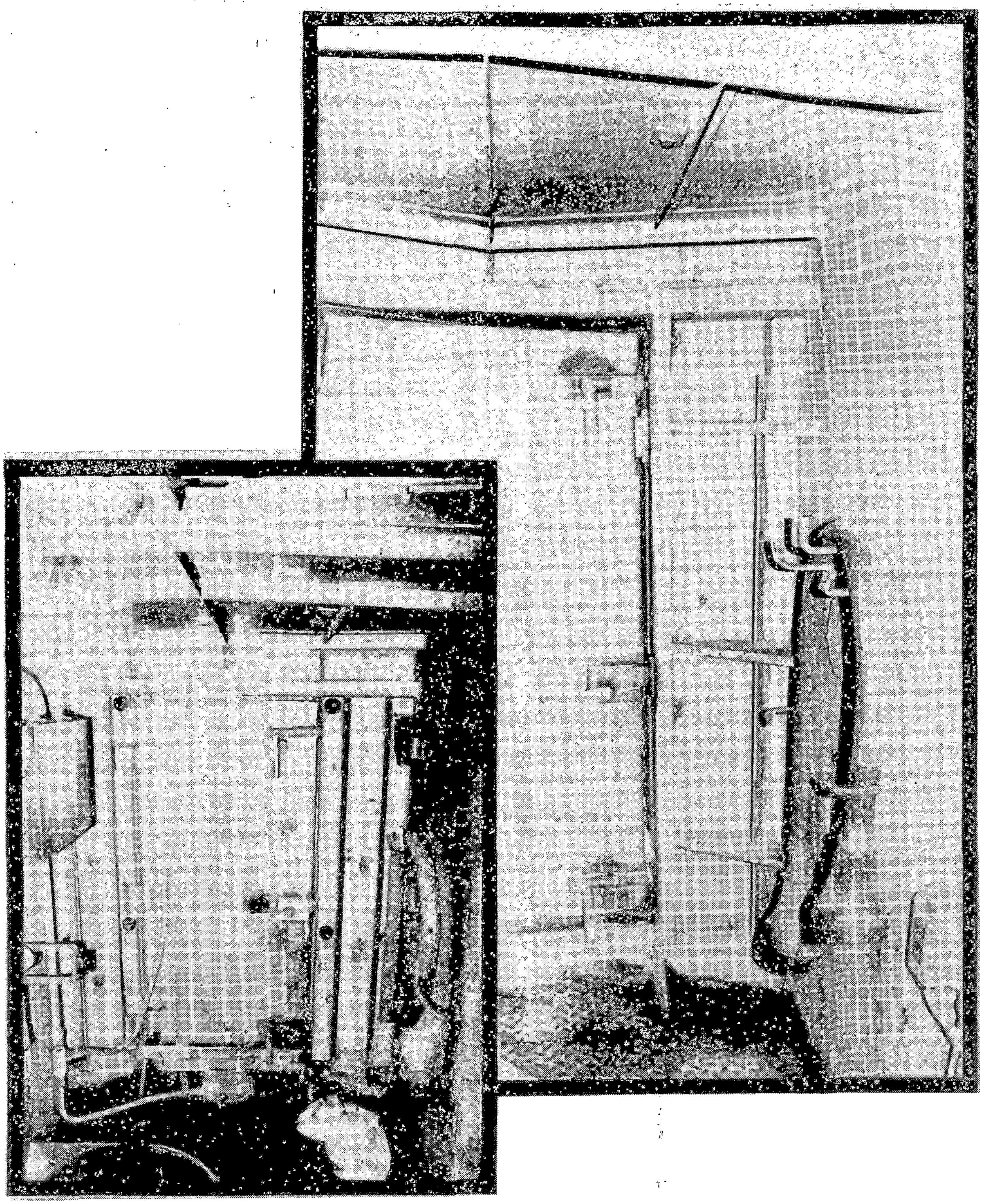


FIGURE 6-10. LOCOMOTIVE CAB STRUCTURAL VARIATIONS, SIDE WINDOW.

6.3.2 Structural Response and Maximum Loads for Locomotive Cabs

The restraint of the transverse members was such that pinned end conditions existed at their intersection with the longitudinal members that form the edge of the flat roof portion. Very little moment capacity was anticipated at these points, even for loads above the yield load level after which large strains and stress redistribution could possibly cause some pinned ends to begin to develop some moment resistance. For the most part, the longitudinal roof members also had pinned ends at the lower load levels, but the structural inspections and analyses indicated that the higher load levels were accompanied by moment resistance at the longitudinal member ends. The magnitude of such resistance was on the order of 10 to 20 percent of the ultimate plastic moment capacity of the cross-section.

Buckling and local member instabilities proved not to be a major factor on the limiting loads for any of the cabs. If unsupported, the roof channel legs would undergo some buckling near the elastic yield stress; but, given that the spot welds to the outer skin remain intact, only minor lateral buckling (waves) between the welds is likely to occur. Although some limited yielding in the side window lintels may occur, the principal yield points occur in the transverse and longitudinal roof members. These yield points develop at the center of the flat roof spans (longitudinal and transverse). The end result is the development of plastic hinges at the center span points, with simple beam collaspe mechanisms developing in both directions. The roof collapse is generally associated with the flat portions of the roof, but some large deflection of the sidewalls does occur.

All cab models had limiting load levels that were controlled by the yielding of the roof members. The uniformly distributed load and total loads at first yield are shown in Table 6-1 for the five locomotives.

TABLE 6-1. UNIFORMLY DISTRIBUTED LOAD

Loco.	Load Intensity at First Yield (psi)	Roof Area (sq in)	Approx. Tot. Load at first Yield (lb)
GP38-2	3.3	9,134	30,000
GP40-2	1.1	9,243	10,000
SD40-2	4.2	8,562	36,000
SDP40	2.5	10,230	26,000
F40-PH	2.8	9,200	26,000

First yield occurred in the longitudinal roof members of all cabs except the SDP40 for which a transverse roof member yielded first. The SDP40 and F40-PH had hatches in the roof and experienced yield at lower load levels than the GP38-2 and SD40-2 which did not have hatch openings. The lower load capacity of the GP40-2 with respect to the other cabs is directly attributed to the 1.5-inch-deep roof channels as compared to the 2.5-inch-deep channels in the other cabs.

The post-yield behavior of three locomotives (GP38-2, GP40-2, SD40-2) was analyzed to determine their collapse load. Failure sequence and modes due to uniform vertical load were established and are presented in Figures 6-11, 6-12, and 6-13. The total load on the roof was equal to the uniform load intensity multiplied by the horizontal projected roof area denoted on the schematic sheets.

Note that the load considered was in all cases a uniformly distributed pressure. The same total load applied at one or several points would cause higher bending moments and greater likelihood of localized web crippling. Therefore, a locomotive cab capable of supporting a uniformly distributed load, approximately equal to that of a freight car, would not be expected to perform as satisfactorily under the dead weight of a freight car because of the concentration of loading. The analyses also did not take into account the higher loads associated with the impact of a freight car falling upon the roof. The analyses did, however, illustrate the general inability of any of the cabs to support a freight car with an adequate margin of safety.

Adequate research data were not available for the independent establishment of a factor of safety for locomotive cabs. Significant work has been performed in other types of steel design to indicate that a safety factor of 1.5 to 1.8 applied to the yield stress was adequate for most designs. The in-depth analysis of variability of the structures, fatigue, impact loading, and so on, was beyond the scope of this study. Given the similarity of the cold-formed cab structures to other common steel structures, the use of the traditional 1.5 to 1.8 factor of safety was reasonable. The experience in the successful use of these margins of safety without overdesign provided a particularly strong empirical argument for the application of the same margins of safety to the structures under study. For steel with a yield stress of 36,000 psi, a maximum design working stress of 20,000 to 24,000 psi would result.

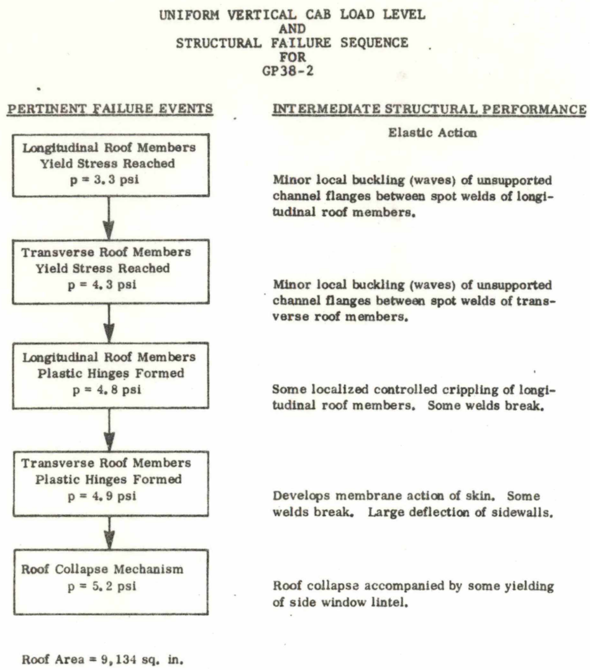


FIGURE 6-11. GP38-2, STRUCTURAL FAILURE SEQUENCE, YIELD THRU POST-YIELD

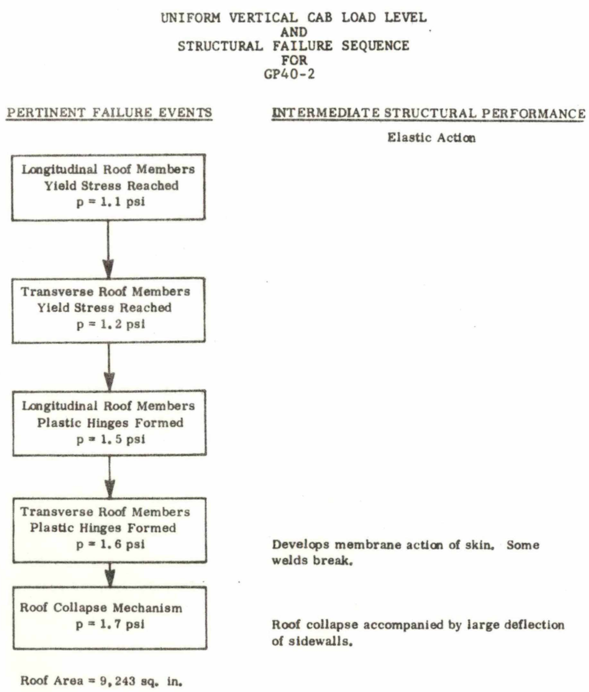


FIGURE 6-12. GP40-2, STRUCTURAL FAILURE SEQUENCE, YIELD THRU POST-YIELD

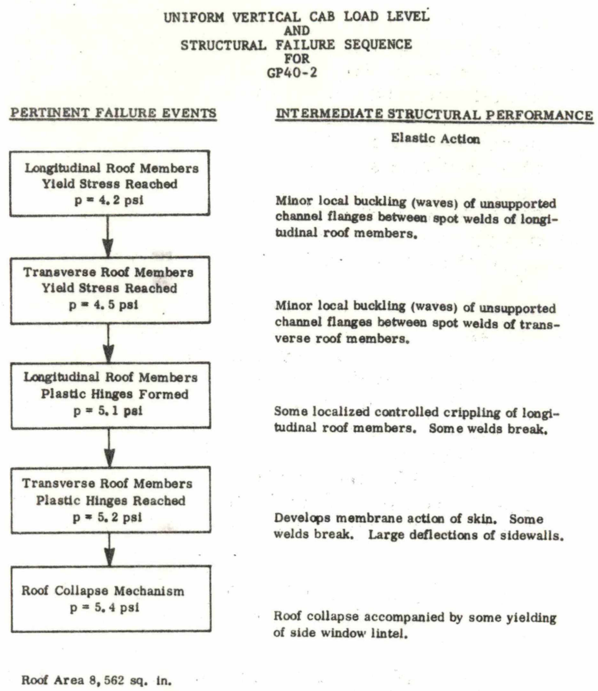


FIGURE 6-13. SD40-2, STRUCTURAL FAILURE SEQUENCE, YIELD THRU POST-YIELD

Larger factors of safety should be considered if buckling appears to be a problem, but the mode of failure for the cab roofs was elastic yielding so that the 1.5 to 1.8 factor of safety was deemed adequate.

The maximum deflection of the roof structure at first yield was small, generally less than 0.5 inch for all cab structures. Given this and the fact that the greatest uncertainty (member and restraints) was accounted for in the analyses and by sensitivity studies, a factor of safety of 1.5 appeared generally acceptable. However, for cab structures with a smaller reserve capacity beyond the elastic yield load and for hatch cabs with their greater number of joints (and correspondingly greater uncertainty in tolerances and welds), the use of the larger factor of 1.8 was advisable. Inspection of the three schematic sheets indicated that the ratio of the collapse load to the yield load was approximately 1.6 for the GP38-2 and GP40-2. The same ratio for the SD40-2 was about 1.3, which indicated a more narrow range between first yield and collapse for the SD40-2. The more rapid advancement of pertinent failure events for the SD40-2, and therefore smaller reserve beyond first yield, suggested the need for the larger factor of safety of 1.8 for this locomotive. The greater number of members joints associated with the hathes of the F40-PH and SDP-40 models introduced an added uncertainty that also substantiated the use of the 1.8 factor of safety. The allowable working loads for the cab models are shown in Table 6-2, using a 1.5 factor of safety for the GP38-2 and GP40-2 and a 1.8 factor of safety against first yield for the remaining three cabs.

It should also be noted that the choice of safety factors as applied to the elastic yield load was substantiated by the consistency in the ratio of the collapse load to the allowable load for the three models for which the collapse load was determined. For the GP38-2, GP40-2, and SD40-2 the ratio of collapse load to the allowable load (or safe working load) was approximately 2.3 to 2.4.

TABLE 6-2. THE ALLOWABLE LOADS USING SAFETY FACTOR OF 1.5 AND 1.8

Loco.	Safety Factor	Load Intensity (psi)	Roof Area (sq in)	Allow. Tot. Load (lb)
GP38-2	1.5	2.2	9,134	20,000
GP40-2	1.5	0.7	9,243	6,800
SD40-2	1.8	2.3	8,562	20,000
SDP40	1.8	1.4	10,230	14,000
F40-PH	1.8	1.6	9,200	14,000

7 CONCLUSIONS

7.1 DATA ANALYSIS

Analysis of train accident data for the years 1960 through 1979 revealed that a total of 2,381 rear-end and head-on collision accidents occurred. Of this total, 1,581 (66 percent) were rear-end collisions and 800 (34 percent) were head-on collisions. Rear-end and head-on collisions resulted in combined damages of over $133,824,000. Rear-end collisions accounted for $63,636,000 (48 percent) and head-on collisions for $70,188,000 (52 percent) of the combined damages.

For years 1974 through 1978, the number of injuries that resulted from combined rear-end and head-on collision accidents was 428. Fatalities for both collision types totaled 21. Rear-end collisions were responsible for 48 percent of the fatalities and 63 percent of the injuries. Head-on collisions caused 52 percent of the fatalities and 37 percent of the injuries. An analysis of the causes of train collisions demonstrated that most accidents were caused by operations rather than by track or vehicle conditions.

A study of the impact of speed upon accident severity for a large accident sample indicated that all fatalities occurred in accidents at 35 mph (56 km/hr) or less. Likewise, 96 percent of all injuries in this accident sample occurred in accidents in the same speed range. In terms of damage cost, 96 percent of all damage occurred at speeds of 50 mph (80 km/hr) or less. Thus accidents occur most often at speeds less than 50 mph with most of the fatalities and injuries occurring at less than 35 mph.

7.2 CONCEPTS REVIEW

Investigation of a sample of 162 accidents involving rear-end and head-on accidents revealed that the SD40, SD45, GP7 and GP9 models have the highest injury and fatality rates. The SD40 and SD45 locomotives seemed to sustain the greatest amounts of physical damage of all the models. Consequently, models targeted for override mitigation concepts are EMD-manufactured.

The investigation into past and present research and development of override mitigation concepts defined three concept areas: (1) operational considerations, (2) nonlocomotive concepts, and (3) locomotive structural modifications. The following operational and nonlocomotive concepts were identified for further analysis in terms of cost-benefit and viability:

- Locomotive anticlimbers
- Safety glass
- Protective padding in interior
- Occupant restraint
- Improved communications
- Shelf couplers
- Truck retention.

Three modification designs were developed and evaluated for technical feasibility and crashworthiness capability. Of the three, the braced collision/roll posts appeared to provide the greatest level of crew protection in the event of car overriding in a locomotive rear-end collision. The braced collision/roll posts design was also applicable to new locomotive designs.

7.3 IMPACT ANALYSIS OF CONCEPTS

The impact analysis of the proposed override mitigation concepts in terms of their effect on railroad operations, showed that the implementation of the structural modifications would only marginally affect locomotive weight, balance, visibility, and cab habitability. The braced collision/roll posts design, which provided the greatest crew protection, was costed out in consultation with railroad personnel and found to be implementable for approximately $16,000 per locomotive, including downtime. For the nonlocomotive concepts such as improved caboose/freight car couplers and truck retention, there were some minor implementation problems due to increased maintenance complexity and interchange considerations. In terms of the operational equipment concepts, such items as shelf couplers, occupant restraints, and protective padding in the interior of the cab, may be implementable without major impact on the railroad operations. Of the operational procedures concepts, the only attractive one dealt with effective communications by provision of an improved radio link between the locomotive engineer and railroad operations personnel. Other override mitigation concepts, such as longhood-forward operations and consist make-up practices, were found to have major implementation and financial penalties that made them unattractive for further analysis.

Ranking of the proposed override mitigation concepts showed that improved interior design, end-of-train truck retention, and shelf couplers were high on the list. On the other hand, when ranking was carried out of the basis of benefit to crew safety and equipment survivability, the structural modifications such as the braced collision/roll posts and BN collision nose rank high.

Based on considerations of both crew safety and cost effectiveness, a modification package was selected for implementation as the optimum set of concepts for providing the maximum crew safety at the least price. The modification package consists of a sturdy cab structure such as the braced collision/roll posts, shelf couplers, and anticlimbers, and secondary impact protection such as improved interior design, safety glass, and emergency exits together with improved communications. In addition, the use of truck retention deices appeared effective.

7.4 PERFORMANCE GUIDELINES

Performance guidelines for the modification package were developed that can be used by railroads to develop their own override mitigation designs along the lines of the specific concepts developed in the study. The performance guidelines incorporated three aspects; (1) the performance expected, (2) the design practices to be used, and (3) the validation test required. It is noted that implementation of all the override mitigation package presented is well within the capabilities of the railroads' own diesel and car repair shops. Additionally, the various modifications are broken into major and minor categories to help the railroads implement a modification program. The performance guidelines are shown to apply to the most-prevalent accident situations. Methods of modifying the locomotive structural modification designs to types of locomotives other than EMD are also presented.

7.5 STRUCTURAL ANALYSIS OF LOCOMOTIVE CABS

7.5.1 Design Concepts for Strengthening Cab Structures

The structural analyses performed on available locomotives have verified that the existing fleet has very limited load carrying capability. Strengthening of the cab structures to withstand vertical load is definitely indicated but must be viewed with respect to the longitudinal and lateral loads that almost certainly will be imposed on an impacted cab. The longitudinal forces are so obviously large that design of a collision post/frame system to withstand substantial horizontal loading should consequently satisfy vertical support requirements also.

Two basic alternatives exist for strengthening the locomotive cabs: (1) a full structural cage and (2) a roll bar at the forward section of the cab. The full structural cage concept includes all designs that provide a framework extending from the front of the cab to the rear bulkhead just forward of the engine compartment.

Any modification to increase occupant safety and crashworthiness would have to be accomplished with minimal changes to the exterior clearance of the locomotive. As is evident from the clearance diagrams depicting the GP38-2 locomotive passing through the AAR clearance envelopes (Figure 7-1), little space remains. Construction of a full cage within the AAR clearance envelope would result in diminished interior space and significant modification problems. The roll bar concept offers a much simpler approach and little intrusion into the existing interior space, while keeping the modified lines within the clearance requirements. A significant weight savings in the choice of the roll bar over the full cage can also be anticipated if the roll bar is tied rigidly into the shorthood/collision post structure to provide a highly redundant vertical and horizontal force-carrying system. Since the distance from the front to the back of the cab is approximately eight feet in most cases, a caboose would be supported vertically by the roll bar and the longhood/engine section to the rear of the cab. This section will deal with general design recommendations that have governed the conceptual design to date and which should be integrated into subsequent design optimizations for cab modification.

7.5.2 Energy Dissipation

The forces generated in a locomotive collision, even at moderate speeds, are so large that the theoretical peak impact force exceeds the structural collapse load of the cab superstructure. The actual impact force on the cab is therefore limited by the strength of the cab. The peak deceleration is also limited as a proportional function of the cab collapse load. From this relationship, it is obvious that increasing the cab load capacity will result in even greater peak decelerations. The ultimate theoretical extension of strengthening the locomotive to prevent collapse within its capable speed range would be an almost solid steel projectile. Two locomotives colliding would then rebound elastically (conservative energy system) in a manner similar to two steel ball bearings colliding. However, if such a structure were feasible the deceleration would be so astronomically large at higher speeds that survival of occupants, even properly supported by seat belts and shoulder har-

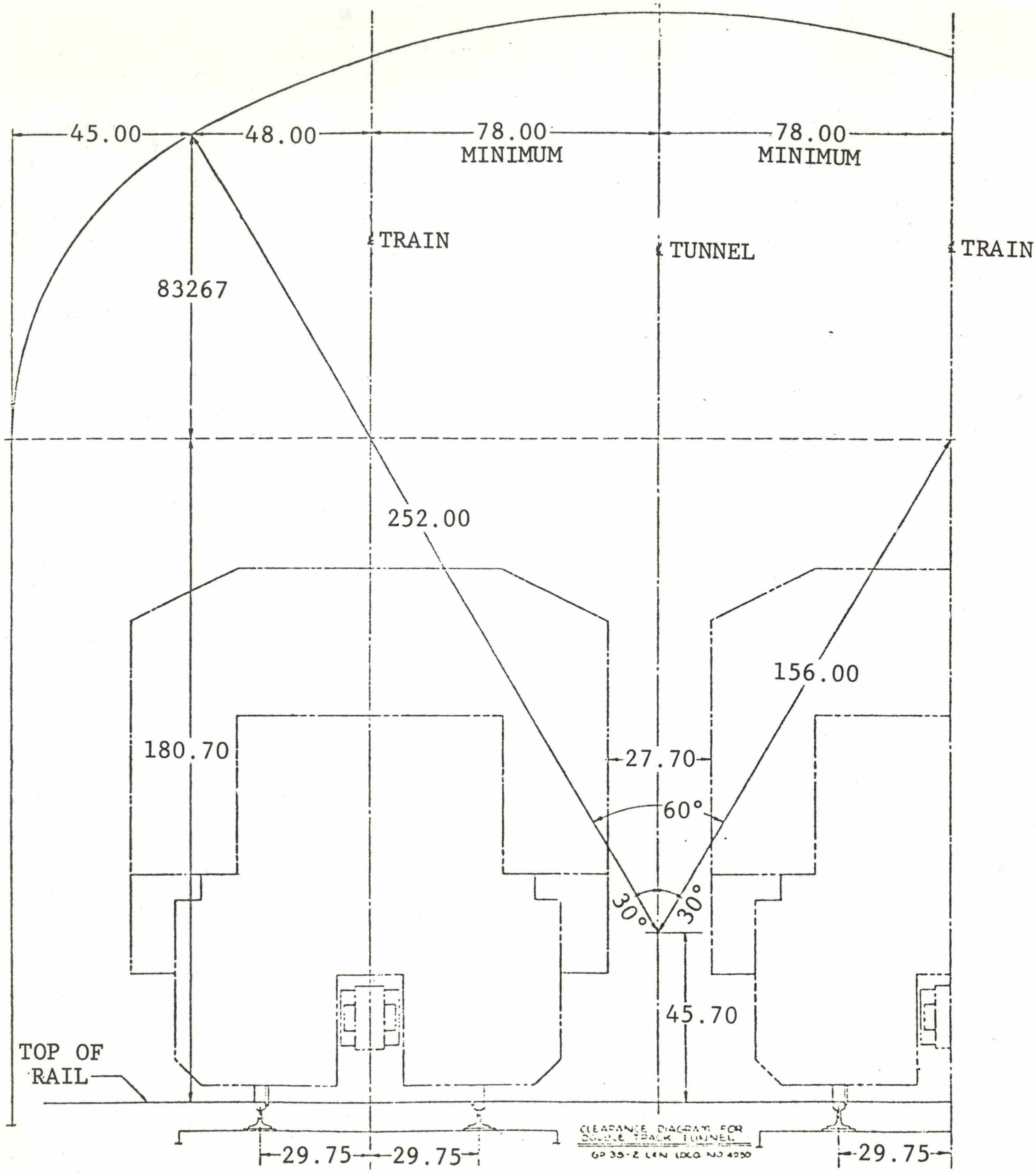


FIGURE 7-1 . AAR CLEARANCE DIAGRAM WITH GP38-2 LOCOMOTIVE nesses, would be highly unlikely. The kinetic energy must be dissipated plastically rather than stored elastically. Controlled nonrecoverable structural deformation to dissipate a portion of the energy is indicated.

Examination of the tremendous amount of kinetic energy involved in a locomotive collision reveals the lack of feasibility of designing a locomotive to dissipate all of the kinetic energy. A deflector system must also be utilized to divert some of the kinetic energy away from the cab structure. The general concept of a deflector has been thoroughly researched in other studies. Treatment of the deflection concept was not a part of this structural study of the existing cabs and cab modification. However, the deflection shield must be considered in conjunction with the roll bar when design optimization is performed. This is because a cost-effective modification requires that a balance be achieved between the deflector and roll bar as to their relative structural benefit with respect to added weight.

A design approach is recommended wherein nonrecoverable deformation is accepted above a certain design impact force level. The emphasis of the design would be the maximization of the plastic dissipative capacity occurring beyond the design impact force level.

7.5.3 Choice of Structural Steel

A predominantly bending mode of plastic energy dissipation is desirable to provide a controlled collapse associated with the progressive spreading of the plastic regions. It appears feasible to provide the plastic dissipative reserve required for a caboose impact, but a steel with an exaggerated strain-hardening range is desirable to ensure involvement of the entire structure material in the dissipative process. The reasons for this are discussed in Appendix I. The required strain-hardening characteristics could be satisfied by a low carbon steel with a high toughness index. Conversely, a higher carbon content and higher impact resistance would be necessary for any type of deflection shield.

Several different steels were investigated to determine their relative suitability with respect to the above requirements and with respect to their availability in closed structural section forms. The best candidate for steel with these properties and for the modification is ASTM A-500 Grade B, Normalized Steel. The steel must be normalized to attain the desired strain-hardening and toughness characteristics. Samples of A-500 Grade B steel were obtained by project personnel. After normalizing the specimens at 1650-1700 F for 0.5 hour, straps were machined and tested by the project team members. Specimens thus prepared showed an average yield stress of 33,259 psi and an average ultimate stress of 59,433 psi. The raio of the ultimate to yield stress is approximately 1.79, and the percent elongation at rupture was approximately 37 percent. It is therefore recommended that A-500 Grade B Normalized Steel, as tested, be considered. However, it would be desirable to consider more testing with variable normalization procedures in order to optimize the desired material properties.

7.5.4 Multi-Tiered Structural Modification

The most significant design concept for the roll bar (or full cage if later utilized) is the incorporation of a tiered failure sequence. In addition to the need for a steel with exaggerated strain-hardening characteristics, the involvement of more than just a few plastic hinges, which are limited in extent, requires a tiered structure. In such a structure the lower levels, or tiers, provide greater load capacity and energy dissipative ability than do the upper levels. A single tier structure collapses by the formation of the required set of plastic hinges that may extend over only a small percentage of the structural material. A two-tiered structure, designed so that the lower tier has a higher collapse load than the upper, allows the selective formation of additional hinges, which in turn provide additional plastic energy dissipation. A larger percentage of the structural material is therefore involved in the energy dissipation process by designing each tier to participate with its own plastic mechanism.

For a front roll bar cantilevered up from the locomotive sill, impact at the upper lead corner of the cab/roll bar could cause maximum stresses at the base of the roll structure resulting in complete collapse. If impact occurs only at the upper corner, the structure should be designed to fail in this area first, thereby allowing the overriding car to continue its rearward movement while the lower sections of the roll structure remain intact. For a three-tiered failure sequence, the upper-level sacrifical structure would extend above the window line and would generally consist of vertical structural tubing acting as the backbone of the roll bar modification. The second stronger tier would extend from the upper line of the windows to the top of the battery boxes. This tier would also contain the continuous vertical backbones stiffened by rigid structural framing into the collision posts. Impact at this level would utilize the full capacity of the collision posts/roll bar structure such that bending of the sill behind the front bolster also would become an active plastic dissipative mechanism. The battery boxes on either side of the short hood would be constructed of heavy plate to form, in conjunction with the collision posts/roll bar integral structure, an almost rigid third tier. This lowermost tier would be the final defense and as such would provide a survivable volume. A minimum of three tiers is indicated, but more tiers could possibly be formulated into the final design when structural details are treated by the particular cab undergoing modification.

7.5.5 Integral Collision Posts and Roll Bar Structure

For maximum structural efficiency the collision posts and roll bar should be tied rigidly together to allow a truss type action to develop after large deformations have occurred. At lower load levels the integral structure would act as a stiffened frame in bending. Large deformations and plastic flow due to frontal impact should result in a truss type action, whereby tension occurs in the collision posts and compression in the vertical roll bar members. The redistribution of stresses in the pseudo-truss should result in full development of the collision posts/roll bar structure load capacity. This may cause the bending moment capacity of the sill to the rear of the front bolster to be exceeded. The sill in this area may require strengthening to provide a balanced design, particularly if the truss action does fully develop.

7.5.6 Closed Structural Sections

The use of closed structural sections, such as square or rectangular tubing, is recommended to reduce the problems associated with local buckling of free flanges and angle elements. Any use of wide flange or similar shapes should consider the closing of the section with steel plates connecting the outer edges of the flanges. The use of closed sections also reduces the problems attributed to a preferable direction of buckling of a section and, in turn, makes design against lateral buckling of beam elements easier. Perhaps even more important is the greater resistance of closed sections to biaxial bending and torsion over that of an equally heavy flat plate stock section. After the initial impact of a caboose on a locomotive cab, the loading geometry changes to an extent that significant biaxial bending and torsion occurs. A section such as a wide flange beam would resist the initial planar bending but would be clearly inferior to a structural tube when the geometry changes cause the bending to become biaxial and torsion to be introduced. In addition, structural tube sections generally have higher values of shape factors than do comparable wide flange sections and thus offer a broader range of contained plastic flow. Narrow tubing, two to three inches in width, should be used in lieu of flat plate stock for gussets. Although designed for the impact load path, the thine plate stock gussets could be bent as much as 90 degrees upon impact such that their weak axis would be aligned to resist the subsequent dynamic loads.

7.5.7 Design Concepts Summary

Optimization of the strengthening of the cab structures must await the choice of the locomotive to be tested. However, the following concepts should be incorporated into the design process:

- Emphasis on energy dissipation
- Low carbon steel with high toughness index
- Multi-tiered structural configuration
- Integral collision posts and roll bar structure
- Use of closed structural sections.

7.6 AREAS FOR FURTHER RESEARCH

7.6.1 Override Control and Mitigation Concepts

In view of the high promise of the concepts for improving locomotive cab crashworthiness and mitigating car override during rear-end collisions, it is recommended that a more detailed analysis of the various concepts be carried out and specific designs developed. These designs should be implemented on a specific locomotive and testing performed to verify their crashworthiness performance.

7.6.2 Structural Analysis of Locomotive Cabs

From this project, it is obvious that the areas of greatest uncertainty lie in the cab modeling and not in the methods of analysis. More sophisticated elastic/plastic analysis techniques cannot be justified unless more specific information is obtained by inspection/measurement and load testing of the cabs. Recommendations for areas of further study deal principally with determining the actual load-deformation response of selected cab structures.

Since the cab inspection/measurement program for this study precluded the dismantling of any portion of the cab structures, not all joints and welds could be fully viewed. An inspection/measurement program for which the inner skin is removed would provide much more information regarding the actual cab construction. A possible source for such accessibiity may be locomotive overhaul shops.

As stated earlier, the load considered in all cases was a uniformly distributed pressure. The concentration of loads by a railcar would result in higher bending moments and greater likelihood of web crippling. The response of selected cabs to specific point loads is therefore of interest. Further structural analyses could include the application of point loads at one, two, four, or more locations atop the cab to simulate the actual support of a railcar. Most important is the experimental determination of the structural response. As a parallel study to the above analyses and to the further inspection/measurement of additional locomotive cabs, a program of determining the load deflection characteristics of the locomotive roofs should be undertaken. Jack loads of one, two, four, or more points could be much more easily applied to trains in service then could a uniformly distributed load. The jack loads could be released almost immediately if portions of the structures show signs of overloading. A uniform load, applied by sand or water, could not be removed as quickly. Loading would be within the elastic range and the applied load would be correlated with deflections and strains measured for members of primary interest. Specific flexibility terms (the deflection at one joint due to an applied load at another joint) could then be directly obtained. Such information would be invaluable in substantiating the validity of past and future analyses. Of utmost importance would be the information obtained from the tests indicating the actual degree of end fixity and joint continuity, which is presently the greatest source of uncertainty in the analyses performed. Loading to collapse would not be necessary although it would be informative to obtain experimental collapse loads for at least two cabs. The test program should include elastic load testing of several similar cabs to check variability in their stiffness and structural response under point loads.

Future structural analyses on other locomotives should concentrate on those locomotives which, in addition to those analyzed for this project, are in wide use. The additional analyses should include the GP7 or GP9, U23-B, and the SD45 locomotive models.

As stated previously, a low carbon steel with a high toughness index is desirable for the cab to plastically dissipate the energy of impact. Conversely, a higher carbon content and higher impact resistance would be necessary for any type of deflection shield. More work should be done on the best choice of materials for the cab, cab modification, and shield construction.

Since readily available steels are desirable for cost-effective implementation, it is recommended that avenues of research be explored which deal with normalization or other means of altering commonly available steels. A specific research project worthy of consideration would be the variation of the modulus of resilience and toughness index as a function of normalization temperatures and times.

More research should be done on the required factors of safety for the cab structures. perhaps even more important is the determination of dynamic impact factors to be applied to the dead weight of the freight car to simulate the dynamic loading experienced in an actual rear-end crash. During impact, such as in a rear-end collision, complex static and dynamic interactions are taking place:

- Longitudinal loads and lateral loads are present in addition to vertical loads
- Loading is not static (but might be idealized as pseudostatic for theoretical analyses)
- The loading is a combination of complex point loads and various types of uniformly distributed loads
- The loading intensity varies with time.

More information about the magnitude of both horizontal and vertical loads is needed.

APPENDIX A
NTSB ACCIDENT REPORT

Date	Location	Type of Accident	Report No.
28 Dec. 1966	Everett, MA	Collision	N/A
22 Feb. 1967	Sacramento, CA	Grade Crossing	N/A
22 May 1967	New York, NY	Head-On Collision	N/A
2 Oct. 1967	Waterloo, NE	Grade Crossing	N/A
1 Jan. 1968	Dunreith, IN	Derailment/Coll.	N/A
25 Jan. 1969	Laurel, MS	Derailment	N/A
28 June 1969	Glen Dale, MD	Derailment	RAR-70-1
11 Sept. 1969	Glendora, MS	Derailment	RAR-70-2
20 Aug. 1969	Darien, CT	Collision	RAR-70-3
24 Jan. 1970	Loda, IL	Collision	RHR-71-1
27 Jan. 1970	Franconia, VA	Derailment	RAR-71-3
18 Feb. 1969	Crete, NE	Coll./Derailment/ Hazardous Materials	RAR-71-2
8 Sept. 1970	Riverdale, IL	Collision	RAR-71-3
5 April 1971	Collinsville, OK	Collision	RAR-72-1
8 Oct. 1970	Sound View, CT	Derailment/Coll.	RAR-72-2
21 June 1970	Cresent City, IL	Derailment	RAR-72-2
14 May 1971	Washington DC	Electrocution of Individual	RAR-72-3
28 March 1971	Sheridan, WY	Derailment	RAR-72-4
10 June 1971	Salem, IL	Derailment	AAR-72-5
19 Oct. 1971	Houston, TX	Derailment	RAR-72-6
24 March 1972	Congers, NY	Collision	RHR-73-1
22 Jan. 1972	East St. Louis, IL	Hazardous Materials	RAR-73-1
27 April 1972	Arlington, VA	Derailment/Coll.	RAR-73-2
12 March 1972	Herndon, PA	Head-On Collision	RAR-73-3
24 May 1972	Maquon, IL	Head-On Collision	RAR-73-3
30 Oct. 1972	Chicago, IL	Collision	RAR-73-4
21 Feb. 1973	Taft, LA	Head-On Collision	RAR-73-6
25 June 1973	Indio, CA	Rear-End Collision	RAR-74-1
11 Aug. 1973	Pueblo, CO	Collision	RAR-74-2
1 Dec. 1973	Cotulla, TX	Collision	RAR-74-3
12 Feb. 1974	Oneonta, NY	Derailment	RAR-74-4
23 Oct. 1974	Aragon, GA	Collision	RHR-75-1

Date	Location	Type of Accident	Report No.
5 July 1974	Melvern, KS	Derailment	RAR-75-1
24 May 1973	Benson, AZ	Hazardous Materials	RAR-75-2
8 May 1974	Cleveland, OH	Collision	RAR-75-3
19 July 1974	Decatur, IL	Hazardous Materials	RAR-75-4
1 Dec. 1974	Huntington Station, NY	Equipment Failure	RAR-75-5
1 Sept. 1974	Mustang, OK	Collision	RAR-75-6
21 Sept. 1974	Houston, TX	Hazardous Materials	RAR-75-7
2 Jan. 1975	New York, NY	Collision	RAR-75-8
30 May 1975	Meeker, LA	Rear-End Collision	RAR-75-9
6 Aug. 1974	Wenatchee, WA	Hazardous Materials	RAR-76-1
6 June 1975	Leetonia, OH	Collision	RAR-76-2
5 July 1975	Hurricane, AK	Rear-End Collision	RAR-76-3
5 June 1975	Wilmington, DE	Collision	RAR-76-7
1 Sept. 1975	Des Moines, IA	Derailment	RAR-76-8
4 Feb. 1976	Pettisville, OH	Head-On Collision	RAR-76-10
5 May 1976	Jarratt, VA	Derailment	RAR-76-11
7 Feb. 1976	Beckemeyer, IL	Collision	RHR-76-3
19 Nov. 1975	Elwood, IL	Collision	RHR-76-2
8 Aug. 1976	Stratton, NE	Collision	RHR-77-1
1 July 1976	Des Moines, IA	Collision	RHR-77-2
15 Dec. 1976	Marland, OK	Collision	RHR-77-3
2 Aug. 1976	Hasting, NE	Derailment	RAR-77-1
16 May 1976	Glen Ellyn, IL	Derailment/Collision	RAR-77-2
30 June 1976	Goodman, MS	Derailment	RAR-77-3
19 Oct. 1976	New Haven, IN	Head-On Collision	RAR-77-6
26 Nov. 1976	Belt, MT	Derailment	RAR-77-7
28 Dec. 1977	Goldonna, LA	Collision	RHR-78-1
12 June 1977	Baltimore, MD	Rear-End Collision	RAR-78-1
2 Oct. 1977	Plant City, FL	Collision	RHR-78-2
8 Oct. 1977	Spencer, NC	Side Collision	RAR-78-3
9 Nov. 1977	Pensacola, FL	Derailment/ Hazardous Materials	RAR-78-4
10 Feb. 1978	Pittsburgh, PA	Collision	RAR-78-5
24 Feb. 1978	Florence, SC	Derailment	RAR-78-6
26 Feb. 1978	Youngstown, FL	Derailment	RAR-78-7

Date	Location	Type of Accident	Report No.
29 March 1978	Lewisville, AR	Hazardous Materials	RAR-78-8
22 Feb. 1978	Waverly, TN	Derailment	RAR-79-1
18 Sept. 1978	Florence, AL	Head-On Collision	RAR-79-2
9 June 1978	Seabrook, MD	Rear-End Collision	RAR-79-3
3 Dec. 1978	Elma, VA	Derailment	RAR-79-4
31 Jan. 1979	Muncy, PA	Rear-End Collision	RAR-79-6
12 Dec. 1979	New York, NY	Derailment	RAR-79-8
29 March 1979	Ramsey, WY	Rear-End Collision	RAR-79-9
20 April 1979	Edison, NJ	Head-On Collision	RAR-79-10
8 April 1979	Crestview, FL	Derailment/ Hazardous Materials	RAR-79-11

APPENDIX B

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION

RAIL EQUIPMENT ACCIDENT/INCIDENT REPORT

FORM APPROVED
OMB NO. 04R4008

1. NAME OF REPORTING RAILROAD — Amtrak ☐ Autotrain ☐	1a. Alphabetic Code	1b. Railroad Accident/Incident No.	
2. NAME OF OTHER RAILROAD INVOLVED IN TRAIN ACCIDENT/INCIDENT	2a. Alphabetic Code	2b. Railroad Accident/Incident No.	
3. NAME OF RAILROAD RESPONSIBLE FOR TRACK MAINTENANCE *(single entry)*	3a. Alphabetic Code	3b. Railroad Accident/Incident No.	
4. U. S. DOT-AAR GRADE CROSSING IDENTIFICATION NUMBER	5. DATE OF ACCIDENT/INCIDENT — month / day / year	6. TIME OF ACCIDENT/INCIDENT — am ☐ pm ☐	

7. TYPE OF ACCIDENT/INCIDENT *(enter number in code box, single entry)* — CODE
1. Derailment 2. Head on collision 3. Rear end collision 4. Side collision 5. Raking collision 6. Broken train collision 7. Rail-Hwy crossing 8. RR grade crossing 9. Obstruction 10. Explosion-Detonation 11. Fire or violent rupture 12. Other *(specify)*

HAZARDOUS MATERIALS *(number of)*

8. CARS CARRYING	9. CARS DAMAGED OR DERAILED	10. CARS WHICH RELEASED HAZ. MAT.	11. PEOPLE EVACUATED *(est.)*

LOCATION

12. DIVISION	13. NEAREST STATION	14. MILEPOST *(to nearest tenth)*	15. STATE *(two letter code)*	CODE

ENVIRONMENTAL CONDITIONS

16. TEMPERATURE *(specify if minus)*	17. VISIBILITY *(single entry)*	CODE	18. WEATHER *(single entry)*	CODE
°F	1. Dawn 2. Day 3. Dusk 4. Dark		1. Clear 2. Cloudy 3. Rain 4. Fog 5. Sleet 6. Snow	

OPERATIONAL DATA

19. METHOD *(place X in appropriate box(es))*
1 ☐ Manual block 2 ☐ Interlocking 3 ☐ Cab signal 4 ☐ Automatic block 5 ☐ Traffic control 6 ☐ Auto. train stop 7 ☐ Yard rules 8 ☐ Time table 9 ☐ Radio 10 ☐ Auto. train control 11 ☐ Verbal permission 12 ☐ Train orders 13 ☐ Other *(specify)*

20. SPEED *(recorded speed, if available)* MPH — Est. / Recorded	21. TRAIN NUMBER	22. TIME TABLE DIRECTION — 1. North 2. South 3. East 4. West	CODE

EQUIPMENT

23. TRAILING TONS *(gross tonnage, excluding power units)*	24. TYPE OF EQUIPMENT CONSIST *(single entry)* 1. Freight train 2. Passenger train 3. Mixed train 4. Work train 5. Single car 6. Cut of cars 7. Yard/switching 8. Light loco(s)	CODE	25. WAS THE EQUIPMENT IDENTIFIED IN ITEM 24 UNATTENDED? 1. Yes 2. No	CODE
26. TRACK NUMBER OR NAME	27. FRA TRACK CLASSIFICATION	28. ANNUAL TRACK DENSITY *(gross tons in millions)*	29. TYPE OF TRACK 1. Main 2. Yard 3. Siding 4. Industry	CODE

30. PRINCIPLE CAR/UNIT	30a. Initial and Number	30b. Position in Train	30c. Loaded *(yes or no)*
(1) First Involved *(derailed, struck, striking, etc.)*			
(2) Causing *(mechanical failures)*			

31. LOCOMOTIVE UNITS *(no. of)*	a. Head End	Mid Train b. Manual	Mid Train c. Remote	Rear End d. Manual	Rear End e. Remote	32. CARS *(no. of)*	Loaded a. Freight	Loaded b. Pass.	Empty c. Freight	Empty d. Pass.	e. Caboose
(1) Total in Train						(1) Total in Equipment Consist					
(2) Total Derailed						(2) Total Derailed					

PROPERTY DAMAGE *(estimated cost, including labor, to repair or replace)*

33. EQUIPMENT DAMAGE *(to be reported for this equipment consist only)*	$	34. TRACK, SIGNAL, WAY AND STRUCTURES DAMAGE *(to be reported by railroad in item 3 only)*	$

ACCIDENT/INCIDENT CAUSE CODE

35. PRIMARY CAUSE	CODE	36. CONTRIBUTING CAUSE	CODE	37. If no code available, explain cause.

CASUALTIES

38. NUMBER OF PERSONS INJURED	39. ESTIMATED TOTAL DAYS DISABILITY	40. NUMBER OF FATALITIES

CREW *(no. of)* / HOURS ON DUTY

41. ENGINEERS	42. FIREMEN	43. CONDUCTORS	44. BRAKEMEN	45. ENGINEER Hrs: Mins:	46. CONDUCTOR Hrs: Mins:

47. TYPED NAME AND TITLE	48. SIGNATURE	49. DATE

50. NARRATIVE DESCRIPTION – *Describe the cause, nature and circumstances of accident/incident*

FORM FRA F 6180-54 (12-74) REPLACES FORM FRA F 6180-15 (11-72) WHICH IS OBSOLETE

GPO 880-965

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION

RAIL-HIGHWAY GRADE CROSSING ACCIDENT/INCIDENT REPORT

FORM APPROVED
OMB NO. 04R4033

1. NAME OF REPORTING RAILROAD — Amtrak / Autotrain
1a. Alphabetic Code
1b. Railroad Accident/Incident No.

2. NAME OF OTHER RAILROAD INVOLVED IN TRAIN ACCIDENT/INCIDENT
2a. Alphbetic Code
2b. Railroad Accident/Incident No.

3. NAME OF RAILROAD RESPONSIBLE FOR TRACK MAINTENANCE *(single entry)*
3a. Alphabetic Code
3b. Railroad Accident/Incident No.

4. U.S. DOT-AAR GRADE CROSSING IDENTIFICATION NUMBER
5. DATE OF ACCIDENT/INCIDENT — month / day / year
6. TIME OF ACCIDENT/INCIDENT — am / pm

LOCATION

7. NEAREST RAILROAD STATION
8. COUNTY
9. STATE *(two letter code)* — CODE
10. CITY *(if in a city)*
11. HIGHWAY NAME OR NUMBER *(if private crossing, so state)*

ACCIDENT/INCIDENT SITUATION

HIGHWAY USER INVOLVED

12. TYPE — 1. Auto 2. Truck 3. Truck-Trailer 4. Bus 5. School Bus 6. Motorcycle 7. Pedestrian 8. Other *(specify)* — CODE
13. SPEED *(estimated mph at impact)*
14. DIRECTION *(geographical)* — 1. North 2. South 3. East 4. West — CODE
15. POSITION — 1. Stalled on crossing 2. Stopped on crossing 3. Moving over crossing — CODE

RAILROAD EQUIPMENT INVOLVED

16. EQUIPMENT — 1. Train *(units pulling)* 2. Train *(units pushing)* 3. Train *(standing)* 4. Car(s) *(moving)* 5. Car(s) *(standing)* 6. Light loco(s) *(moving)* 7. Light loco(s) *(standing)* 8. Other *(specify)* — CODE
17. POSITION OF CAR/UNIT IN TRAIN — CODE
18. CIRCUMSTANCE — 1. Train struck highway user 2. Train struck by highway user — CODE

19. Was the highway user and/or rail equipment involved in the impact transporting hazardous materials? 1. Highway user 2. Rail equipment 3. Both 4. Neither — CODE

ENVIRONMENT

20. TEMPERATURE *(specify, if minus)* °F
21. VISIBILITY *(single entry)* — 1. Dawn 2. Day 3. Dusk 4. Dark — CODE
22. WEATHER *(single entry)* — 1. Clear 2. Cloudy 3. Rain 4. Fog 5. Sleet 6. Snow — CODE

TRAIN AND TRACK

23. TYPE OF TRAIN — 1. Freight 2. Passenger 3. Mixed 4. Work 5. Yard/Switching 6. Light Locomotive(s) — CODE
24. TRACK TYPE USED BY TRAIN INVOLVED — 1. Main 2. Yard 3. Siding 4. Industry — CODE
25. TRACK NUMBER OR NAME
26. FRA TRACK CLASSIFICATION
27. NUMBER OF LOCOMOTIVE UNITS
28. NUMBER OF CARS
29. TRAIN SPEED *(recorded speed, if available)* — MPH — Est / Recorded
30. TIME TABLE DIRECTION — 1. North 2. South 3. East 4. West — CODE

CROSSING WARNING

31. TYPE *(place X in appropriate box(es))*
1 Gates
2 Cantilever FLS
3 Standard FLS
4 Wig Wags
5 Hwy. Traffic Signals
6 Audible
7 Crossbucks
8 Stop Signs
9 Watchman
10 Flagged by crew
11 Other *(specify)*
12 None

32. SIGNALED CROSSING WARNING — Was the signaled crossing warning identified in item 31 operating? 1. Yes 2. No — CODE
33. LOCATION OF WARNING — 1. Both sides 2. Side of vehicle approach 3. Opposite side of vehicle approach — CODE
34. CROSSING WARNING INTERCONNECTED WITH HIGHWAY SIGNALS — 1. Yes 2. No 3. Unknown — CODE
35. CROSSING ILLUMINATED BY STREET LIGHTS OR SPECIAL LIGHTS — 1. Yes 2. No 3. Unknown — CODE

MOTORIST ACTION

36. MOTORIST PASSED STANDING HIGHWAY VEHICLE — 1. Yes 2. No 3. Unknown — CODE
37. MOTORIST DROVE BEHIND OR IN FRONT OF TRAIN AND STRUCK OR WAS STRUCK BY SECOND TRAIN — 1. Yes 2. No 3. Unknown — CODE
38. MOTORIST — 1. Drove around or thru the gate 2. Stopped and then proceeded 3. Did not stop 4. Other *(specify)* 5. Unknown — CODE
39. VIEW OF TRACK OBSCURED BY *(primary obstruction)* — 1. Permanent structure 2. Standing railroad equipment 3. Passing train 4. Topography 5. Vegetation 6. Highway vehicles 7. Other *(specify)* 8. Not obstructed — CODE

HIGHWAY VEHICLE PROPERTY DAMAGE/CASUALTIES

40. HIGHWAY VEHICLE PROPERTY DAMAGE *(est. dollar damage)*
41. DRIVER WAS — 1. Killed 2. Injured 3. Uninjured — CODE
42. WAS DRIVER IN THE VEHICLE? — 1. Yes 2. No — CODE
43. TOTAL NUMBER OF OCCUPANTS KILLED
44. TOTAL NUMBER OF OCCUPANTS INJURED
45. TOTAL NUMBER OF OCCUPANTS *(include driver)*

46. IS A RAIL EQUIPMENT ACCIDENT/INCIDENT REPORT BEING FILED? 1. Yes 2. No — CODE

47. TYPED NAME AND TITLE
48. SIGNATURE
49. DATE

FORM FRA F 6180-57 (12-74) REPLACES FORM FRA F 6180-13 (10-67) WHICH IS OBSOLETE

GPO 880-562

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION

RAILROAD INJURY AND ILLNESS SUMMARY

Form Approved
OMB No. 04-R4009

1. NAME OF REPORTING RAILROAD	2. ALPHABETIC CODE	3. REPORT MONTH & YEAR	4. STATE ALPHABETIC CODE	5. COUNTY

NAME OF REPORTING OFFICER	OFFICIAL TITLE
ADDRESS	**TELEPHONE** *(Area Code) (Number)*

6.

I, ______________________________ , being first duly sworn, do say upon my oath that I
(Name of Affiant)
am ______________________ , of the railroad aforesaid and as such officer of the said railroad it is my duty to have supervision
(Title of Office held by affiant)
over the record of reportable incidents arising from the operation of the said railroad, and that I have caused to be compiled from the said record and to be carefully examined the annexed report of such incidents occurring during the month named at the head of this sheet; and that the said report is true and complete to the best of my knowledge and belief.

Subscribed and sworn to before me, a notary public in and for the State and County aforesaid, this ______ day of ______________ , 19 _____ .

(Use an im-
[L.S]
pression seal) ______________________________ ______________________________
(Notary Public) *(Signature of affiant)*

7. MILES RUN DURING MONTH			
A. LOCOMOTIVE TRAIN MILES	B. MOTOR TRAIN MILES	C. YARD SWITCHING MILES	D. TOTAL

8.		
A. EMPLOYEE MANHOURS WORKED	B. PASSENGER MILES OPERATED	C. NUMBER OF PASSENGERS TRANSPORTED

TOTAL TRAIN ACCIDENTS	TOTAL FRA FORMS 6180-55A	TOTAL FRA FORMS 6180-54	TOTAL FRA FORMS 6180-57

SECTION A—RECAPITULATION OF ALL CASUALTIES *INCLUDING* HIGHWAY GRADE CROSSING ACCIDENT/INCIDENT CASUALTIES								CLASS OF PERSON FOR SECTIONS A AND B	SECTION B—RECAPITULATION OF ALL HIGHWAY GRADE CROSSING ACCIDENT/INCIDENT CASUALTIES							
TRAIN ACCIDENTS		TRAIN INCIDENTS		NONTRAIN INCIDENTS		TOTAL			TRAIN ACCIDENTS		TRAIN INCIDENTS		NONTRAIN INCIDENTS		TOTAL	
Kld	Inj	Kld	Inj	Kld	Inj	Kld	Inj		Kld	Inj	Kld	Inj	Kld	Inj	Kld	Inj
								1. Employees on duty								
								2. Employees not on duty								
								3. Passengers on trains								
								4. Other nontrespassers								
								5. Trespassers (all classes)								
								6. Contractor Employees								
								7. GRAND TOTAL								

SECTION C—MEMORANDUM—SUBSEQUENT FATALITIES DEVELOPED FROM REPORTED CASUALTIES

LINE NO.	ACCIDENT/INCIDENT NUMBER	TYPE PERSON OR JOB CODE	DATE OF INJURY	DATE OF DEATH	STATE
1.					
2.					
3.					
4.					

FORM FRA F 6180-55 (8-76) REPLACES FORM FRA F 6180-55 (12-74) WHICH IS OBSOLETE.

This report is required by law (45 USC 40). Failure to report can result in the imposition of civil penalties.

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION

RAILROAD INJURY AND ILLNESS SUMMARY
(CONTINUATION SHEET)

FORM APPROVED
OMB NO. 04R4035

SHEET ____ OF ____

1. NAME OF REPORTING RAILROAD	2. ALPHABETIC CODE	3. REPORT MONTH

9.

CASUALTIES *(Cont.)*

a. INCIDENT NUMBER	b. TYPE PERSON OR JOB CODE	c. INJURY OR ILLNESS CODE	d. OCCURRENCE CODE	e. AGE	f. NUMBER OF DAYS AWAY FROM WORK	g. NUMBER OF DAYS OF RESTRICTED ACTIVITY	h. CASES WITHOUT LOST WORK DAYS	i. STATE ALPHABETIC CODE

FORM FRA F 6180-55a (8-74)

GPO 880-564

APPENDIX C

REPORT FOR ACCIDENT TYPE CODE 3 INVOLVING LOCOMOTIVES - REAR-END

CODE	SUM	COST	INJURED	KILLED	CAUSE EXPLANATION
	512	14664900.00	174	12	Total sums for all accident cases.
101	0	0.00	0	0	Roadbed settled or soft
102	2	15700.00	1	0	Washout/rain/slide/flood/snow/ice damage to track
109	0	0.00	0	0	Cause code not listed; enter code 109 in Item 35 and explained in Item 50.
110	0	0.00	0	0	Wide gage (defective or missing crossties)
111	0	0.00	0	0	Wide gage (defective or missing spikes or other rail fasteners)
112	0	0.00	0	0	Wide gage (loose, broken, or defective gage rods)
113	0	0.00	0	0	Wide gage (worn rail)
114	0	0.00	0	0	Track alignment irregular
115	0	0.00	0	0	Track alignment irregular (buckled)
116	0	0.00	0	0	Track profile improper
117	0	0.00	0	0	Superelevation improper, excessive or insufficient
118	0	0.00	0	0	Superelevation runoff improper
119	0	0.00	0	0	Cross level of track irregular (at joints)
120	0	0.00	0	0	Cross level of track irregular (not at joints)not listed; enter code 129 in Item 35 and explain in Item 50
130	0	0.00	0	0	Bolt hole crack or break
131	0	0.00	0	0	Broken base of rail
132	0	0.00	0	0	Broken weld, field
133	0	0.00	0	0	Broken weld, plant
134	0	0.00	0	0	Detail fracture from shelling or head check
135	0	0.00	0	0	Engine burn fracture
136	0	0.00	0	0	Head and web separation (outside joint bar limits)
137	0	0.00	0	0	Head and web separation (within joint bar limits)
138	0	0.00	0	0	Horizontal split head
139	0	0.00	0	0	Piped rail
140	0	0.00	0	0	Rail defect with joint bar repair
141	0	0.00	0	0	Transverse/compound fissure
142	0	0.00	0	0	Vertical split head
143	0	0.00	0	0	Worn rail
144	0	0.00	0	0	Mismatched rail-head contour
145	0	0.00	0	0	Joint bar broken, compromise
146	0	0.00	0	0	Joint bar broken, insulated
147	0	0.00	0	0	Joint bar broken, noninsulated
148	0	0.00	0	0	Joint bolts, broken or missing
149	0	0.00	0	0	Cause code not listed; enter code 149 in Item 35 and explain in Item 50
160	0	0.00	0	0	Guard rail loose/broken, or mislocated
161	1	54050.00	0	0	Switch damaged or cut out of adjustment
162	0	0.00	0	0	Switch, hand operated, stand mechanism broken, loose or worn
163	0	0.00	0	0	Switch connecting or operating rod, broken or defective
164	0	0.00	0	0	Stock rail worn, broken or disconnected
165	0	0.00	0	0	Switch point worn or broken
166	0	0.00	0	0	Switch rod worn, bent, broken or disconnected

167	0	0.00	0	0	Frog, rigid, worn or broken
168	0	0.00	0	0	Frog, spring, worn or broken
169	0	0.00	0	0	Frog, self guarded, worn or broken
171	0	0.00	0	0	Derail, defective
172	0	0.00	0	0	Expansion joint failed or malfunctioned
173	0	0.00	0	0	Retarder worn, broken or malfunctioning
174	0	0.00	0	0	Spring/power switch mechanism malfunction
175	0	0.00	0	0	Retarder yard skate defective
176	0	0.00	0	0	Switch out of adjustment due to insufficient rail anchoring
179	0	0.00	0	0	Cause code not listed; enter code 179 in Item 35 and explain in Item 50
180	0	0.00	0	0	Bridge misalignment or failure
181	0	0.00	0	0	Flangeway clogged
189	0	0.00	0	0	Cause code not listed; enter code 189 in Item 35 and explain in Item 50
200	1	10000.00	0	0	Fixed signal improperly displayed (defective)
201	1	0.00	1	0	Radio communication equipment failure
202	0	0.00	0	0	Other communication equipment failure
209	2	30000.00	0	0	Cause code not listed; enter code 209 in Item 35 and explain in Item 50
400	0	0.00	0	0	Air hose uncoupled or burst
401	0	0.00	0	0	Hydraulic hose uncoupled or burst
402	3	395000.00	2	0	Broken brake pipe or connections
403	1	7800.00	0	0	Obstructed brake pipe (closed angle cock, ice, etc.)
404	3	35000.00	0	0	Other brake components damaged, worn, broken, disconnected
405	0	0.00	0	0	Brake valve malfunction, undesired emergency
407	0	0.00	0	0	Rigging down or dragging
408	3	10400.00	0	0	Hand brake (including gear) broken or defective
409	0	0.00	0	0	Hand brake linkage and/or connections
410	1	0.00	0	0	Cause code not listed; enter code 410 in Item 35 and explain in Item 50
411	0	0.00	0	0	Broken or defective tiedown equipment
412	0	0.00	0	0	Broken or defective container
413	0	0.00	0	0	Broken or defective trailer
419	0	0.00	0	0	Cause code not listed; enter code 419 in Item 35 and explain in Item 50
420	0	0.00	0	0	Body bolster broken or defective
421	0	0.00	0	0	Center sill broken or bent
422	0	0.00	0	0	Draft sill broken or bent
423	0	0.00	0	0	Center plate broken or defective
424	1	11511.00	0	0	Center plate disengaged from truck (car off center)
425	0	0.00	0	0	Center pin broken or missing
426	0	0.00	0	0	Center plate attachment defective
429	0	0.00	0	0	Cause code not listed; enter code 429 in Item 35 and explain in Item 50
430	0	0.00	0	0	Knuckle broken or defective
431	1	550.00	0	0	Coupler mismatch, high/low
432	1	400.00	0	0	Coupler drawhead broken or defective
433	0	0.00	0	0	Coupler retainer pin/cross key missing
434	0	0.00	0	0	Draft gear/mechanism broken or defective (including yoke)
435	0	0.00	0	0	Coupler carrier broken or defective
436	0	0.00	0	0	Coupler shank broken or defective
439	0	0.00	0	0	Cause code not listed; enter code 439 in Item 35 and explain in Item 50
440	0	0.00	0	0	Side bearing clearance improper
441	0	0.00	0	0	Side bearing(s) broken
442	0	0.00	0	0	Side bearing(s) missing
443	0	0.00	0	0	Truck bolster broken

444	0	0.00	0	0	Side frame broken
445	0	0.00	0	0	Truck, stiff, improper lateral or improper swivelling
446	0	0.00	0	0	Defective snubbing
447	0	0.00	0	0	Broken, missing, or otherwise defective springs
449	0	0.00	0	0	Cause code not listed; enter code 449 in Item 35 and explain in Item 50
450	0	0.00	0	0	Broken or bent between wheel seats
451	0	0.00	0	0	Journal (plain) failure from overheating
452	0	0.00	0	0	Journal (roller bearing) failure from overheating
453	0	0.00	0	0	Journal fractured, new cold break
454	0	0.00	0	0	Journal fractured, new cold break (previously overheated)
459	0	0.00	0	0	Cause code not listed; enter code 459 in Item 35 and explain in Item 50
460	0	0.00	0	0	Broken flange
461	0	0.00	0	0	Broken rim
462	0	0.00	0	0	Broken plate
463	0	0.00	0	0	Broken hub
464	0	0.00	0	0	Worn flange
465	0	0.00	0	0	Worn tread
466	0	0.00	0	0	Damaged flange or tread, thermal/flat
467	0	0.00	0	0	Loose wheel
469	0	0.00	0	0	Cause code not listed; enter code 469 in Item 35 and explain in Item 50
470	0	0.00	0	0	Running gear failure
471	0	0.00	0	0	Traction motor failure
472	0	0.00	0	0	Crank case or air box explosion
473	0	0.00	0	0	Oil filter
474	0	0.00	0	0	Electrically caused fire
475	0	0.00	0	0	Current collector system
476	0	190000.00	2	0	Remote control equipment inoperative
477	0	0.00	0	0	Broken or defective swing hanger or spring plank
479	1	80000.00	1	0	Cause code not listed; enter code 479 in Item 35 and explain in Item 50
480	0	0.00	0	0	Box car plug door open
481	0	0.00	0	0	Box car plug door, attachment defective
482	0	0.00	0	0	Box car plug door, locking level not in place
483	0	0.00	0	0	Box car door, other than plug, open
484	0	0.00	0	0	Box car door, other than plug, attachment defective
485	0	0.00	0	0	Bottom outlet car door open
486	0	0.00	0	0	Bottom outlet car door attachment defective
489	0	0.00	0	0	Cause code not listed; enter code 489 in Item 35 and explain in Item 50
499	2	2000.00	0	0	Cause code and device not listed; enter code 499 in Item 35 and explain in Item 50
500	2	167800.00	0	0	Automatic brake, improper use
501	0	0.00	0	0	Dynamic brake, improper user
502	14	162490.00	3	0	Failure to properly secure engine(s) (railroad employee)
504	1	71000.00	0	0	Failure to apply sufficient number of hand brakes on car(s) (railroad emp)
505	1	1500.00	0	0	Failure to apply hand brakes on car(s) (railroad employee)
507	0	0.00	0	0	Independent (engine) brake, improper use
508	2	28910.00	1	0	Failure to control speed of car using hand brake (railroad employee)
509	9	110425.00	3	0	Cause code not listed; enter code 509 in Item 35 and explain in Item 50
510	2	21500.00	0	0	Impairment of efficiency and judgement due drugs or alcohol or illness

511	0	0.00	0	0	Incapacitation due to death or illness
512	0	0.00	0	0	Employee restricted in work or motion
513	1	30000.00	0	0	Employee falling asleep
519	0	0.00	0	0	Fixed signal improperly displayed
520	30	4223090.00	36	1	Fixed signal, failure to comply
521	8	200677.00	34	2	Flagging, improper or failure to flag
522	7	30231.00	0	0	Flagging signal, failure to comply
523	4	5500.00	1	0	Hand signal, failure to comply
524	5	6108.00	2	0	Hand signal improper
525	4	301905.00	2	0	Hand signal, failure to give/receive
526	2	45763.00	3	0	Radio communication, failure to comply
527	2	3200.00	0	0	Radio communication, improper
528	2	5075.00	0	0	Radio communication, failure to give/receive
529	3	1151910.00	0	0	Cause code not listed; enter code 529 in Item 35 and explain in Item 50
530	2	2100.00	0	0	Car(s) shoved out and left out of
531	0	0.00	0	0	Car(s) left foul
532	18	556991.00	3	3	Derail, failure to apply or remove
533	12	236019.00	2	0	Failure to stop train in clear
534	4	17650.00	1	0	Hazardous materials regulations, failure to comply
535	32	109927.00	5	4	Instruction to train/yard crew
536	48	178775.00	3	0	Motor car or on-track equipment rules, failure to comply
537	16	244850.00	2	0	Movement of engine(s) for car(s) without authority (railroad employee)
538	9	207249.00	1	0	Shoving movement, absence of man on or at leading end of movement
539	10	140539.00	1	0	Shoving movement, man on or at leading end of movement, failure to comply
540	7	75733.00	2	0	Skate, failure to remove or place
541	15	421604.00	2	0	Special operating instruction, failure to comply (instruction in Item 50)
542	5	15560.00	0	0	Train order or timetable authority, failure to comply
543	1	0.00	0	0	Train orders, radio, error in preparation, transmission or delivery
544	2	37772.00	1	0	Train orders, written, error in preparation, transmission or delivery
550	22	613201.00	2	0	Coupling speed excessive
553	20	239675.00	3	0	Switch movement, excessive speed
554	36	1113590.00	9	1	Train inside yard limits, excessive speed
555	5	38100.00	0	0	Train outside yard limits under clear block, excessive speed
559	17	355540.00	15	0	Cause code not listed; enter code 559 in Item 35 and explain in Item 50
560	0	0.00	0	0	Spring switch not cleared before reversing
561	40	635544.00	5	1	Switch improperly lined
562	1	2750.00	0	0	Switch not latched or locked
563	0	0.00	0	0	Switch previously run through
570	2	3300.00	0	0	Buffing or slack action excessive
571	2	15056.00	0	0	Failure to couple
572	0	0.00	0	0	Lateral drawbar force on curve excessive
573	0	0.00	0	0	Moving cars while loading ramp or bridge plate not in proper position
574	0	0.00	0	0	Passed couplers
575	0	0.00	0	0	Retarder, improper manual operation
576	0	0.00	0	0	Retarder yard skate improperly applied
599	16	235655.00	6	0	Other train operation/human factors

700	0	0.00	0	0	Collision with highway user at grade crossing
701	0	0.00	0	0	Emergency brake application to avoid accident
702	20	1453040.00	12	0	Vandalism
703	2	5452.00	0	0	Interference with railroad operations by persons nonrailroad employees
704	0	0.00	0	0	Load shifted
705	0	0.00	0	0	Load fell from car
706	2	16416.00	0	0	Overloaded car
707	0	0.00	0	0	Improperly loaded car
708	0	0.00	0	0	Oversized load, misrouted
709	1	900.00	0	0	Object on or fouling track
710	2	0.00	0	0	Equipment on or fouling track
711	0	0.00	0	0	Trailer or container tiedown equipment improperly applied
712	0	0.00	0	0	Overloaded or improperly loaded container or trailer or flatcar
713	0	0.00	0	0	Interaction of lateral/vertical forces to brake (non-railroad employee)
715	0	0.00	0	0	Snow, ice, or mud on track
716	0	0.00	0	0	Other acts of God
799	11	199183.00	6	0	Cause code not listed; explain in narrative

REPORT FOR ACCIDENT TYPE CODE 2 INVOLVING LOCOMOTIVES - HEAD-ON

CODE	SUM	COST	INJURED	KILLED	CAUSE EXPLANATION
	347	12374800.00	157	11	Total sums for all accident cases.
101	0	0.00	0	0	Roadbed settled or soft
102	0	0.00	0	0	Washout/rain/slide/flood/snow/ice damage to track
109	0	0.00	0	0	Cause code not listed; enter code 109 in Item 35 and explain in Item 50
110	0	0.00	0	0	Wide gage (defective or missing crossties)
111	0	0.00	0	0	Wide gage (defective or missing spikes or other rail fasteners)
112	0	0.00	0	0	Wide gage (loose, broken, or defective gage rods)
113	0	0.00	0	0	Wide gage (worn rail)
114	0	0.00	0	0	Track alignment irregular
115	0	0.00	0	0	Track alignment irregular (buckled)
116	0	0.00	0	0	Track profile improper
117	0	0.00	0	0	Superelevation improper, excessive or insufficient
118	0	0.00	0	0	Superelevation runoff improper
119	0	0.00	0	0	Cross level of track irregular (at joints)
120	0	0.00	0	0	Cross level of track irregular (not at joints)
129	1	0.00	0	0	Cause code not listed; enter Code 129 in Item 35 and explain in Item 50
130	0	0.00	0	0	Bolt hole crack or break
131	0	0.00	0	0	Broken base of rail
132	0	0.00	0	0	Broken weld, field
133	0	0.00	0	0	Broken weldture
135	0	0.00	0	0	Engine burn fracture
136	0	0.00	0	0	Head and web separation (outside joint bar limits)
137	0	0.00	0	0	Head and web separation (within joint bar limits)
138	0	0.00	0	0	Horizontal split head
139	0	0.00	0	0	Piped rail
140	0	0.00	0	0	Rail defect with joint bar repair

141	0	0.00	0	0	Transverse/compound fissure
142	0	0.00	0	0	Vertical split head
143	0	0.00	0	0	Worn rail
144	0	0.00	0	0	Mismatched rail-head contour
145	0	0.00	0	0	Joint bar broken, compromise
146	0	0.00	0	0	Joint bar broken, insulated
147	0	0.00	0	0	Joint bar broken, noninsulated
148	0	0.00	0	0	Joint bolts, broken or missing
149	0	0.00	0	0	Cause code not listed; enter Code 149 in Item 35 and explain in Item 50
160	0	0.00	0	0	Guard rail loose/broken, or mislocated
161	1	200.00	0	0	Switch damaged or out of adjustment
162	0	0.00	0	0	Switch, hand operated, stand mechanism broken, loose or worn
163	0	0.00	0	0	Switch connecting or operating rod, broken or defective
164	0	0.00	0	0	Stock rail worn, broken or dis-connected
165	0	0.00	0	0	Switch point worn or broken
166	0	0.00	0	0	Switch rod worn, bent, broken or disconnected
167	0	0.00	0	0	Frog, rigid, worn or broken
168	0	0.00	0	0	Frog, spring, worn or broken
169	0	0.00	0	0	Frog, self guarded, worn or broken
171	0	0.00	0	0	Derail, defective
172	0	0.00	0	0	Expansion joint failed or malfunc-tioned
173	0	0.00	0	0	Retarder
174	0	0.00	0	0	Spring/power switch mechanism malfunction
175	0	0.00	0	0	Retarder yard skate defective
176	0	0.00	0	0	Switch out of adjustment due to insufficient rail anchoring
179	0	0.00	0	0	Cause code not listed; enter code 179 in Item 35 and explain in Item 50
180	0	0.00	0	0	Bridge misalignment or failure
181	0	0.00	0	0	Flangeway clogged
189	0	0.00	0	0	Cause code not listed; enter code 189 in Item 35 and explain in Item 50
200	4	994000.00	21	0	Fixed signal improperly displayed (defective)
201	0	0.00	0	0	Radio communication equipment failure
202	0	0.00	0	0	Other communication equipment failure
209	0	0.00	0	0	Cause code not listed; enter code 209 in Item 35 and explain in Item 50
400	0	0.00	0	0	Air hose uncoupled or burst
401	0	0.00	0	0	Hydraulic hose uncoupled or burst
402	0	0.00	0	0	Broken brake pipe or connections
403	0	0.00	0	0	Obstructed brake pipe (closed angle cock, ice, etc.)
404	1	0.00	0	0	Other brake components damaged, worn, broken, disconnected
405	0	0.00	0	0	Brake valve malfunction, undesired emergency
407	0	0.00	0	0	Rigging down or dragging
408	2	30000.00	0	0	Hand brake (including gear) broken or defective
409	1	5000.00	0	0	Hand brake linkage and/or connections broken or defective
410	1	5000.00	0	0	Cause code not listed, enter code 410 in Item 35 and explain in Item 50
411	0	0.00	0	0	Broken or defective tiedown equipment
412	0	0.00	0	0	Broken or defective container
413	0	0.00	0	0	Broken or defective trailer
419	0	0.00	0	0	Cause code not listed; enter code 419 in Item 35 and explain in Item 50
420	0	0.00	0	0	Body bolster broken or defective
421	0	0.00	0	0	Center sill broken or bent
422	0	0.00	0	0	Draft sill broken or bent

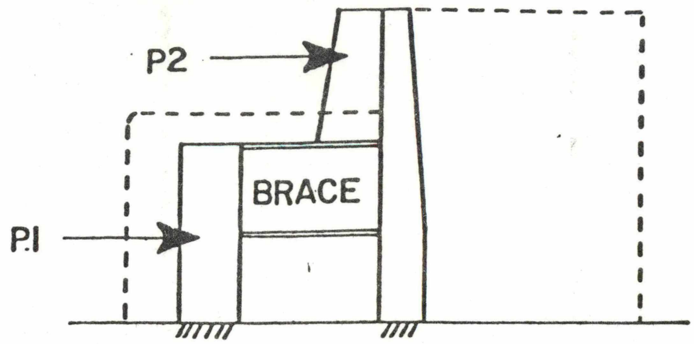
423	0	0.00	0	0	Center plate broken or defective
424	0	0.00	0	0	Center plate disengaged from truck (car off center)
425	0	0.00	0	0	Center pin broken or missing
426	0	0.00	0	0	Center plate attachment defective 429
429	0	0.00	0	0	Cause code not listed; enter code 429 in Item 35 and explain in Item 50
430	0	0.00	0	0	Knuckle broken or defective
431	0	0.00	0	0	Coupler mismatch, high/low
432	0	0.00	0	0	Coupler drawhead broken or defective
433	0	0.00	0	0	Coupler retainer pin/cross key missing
434	0	0.00	0	0	Draft gear/mechanism broken or defective (including yoke)
435	0	0.00	0	0	Coupler carrier broken or defective
436	0	0.00	0	0	Coupler shank broken or defective
439	0	0.00	0	0	Cause code not listed; enter code 439 in Item 35 and explain in Item 50
440	0	0.00	0	0	Side bearing clearance improper
441	0	0.00	0	0	Side bearing(s) broken
442	0	0.00	0	0	Side bearing(s) missing
443	0	0.00	0	0	Truck bolster broken
444	0	0.00	0	0	Side frame broken
445	0	0.00	0	0	Truck, stiff, improper lateral or improper swivelling
446	0	0.00	0	0	Defective snubbing
447	0	0.00	0	0	Broken, missing, or otherwise defective springs
449	0	0.00	0	0	Cause code not listed; enter code 449 in Item 35 and explain in Item 50
450	0	0.00	0	0	Broken or bent between wheel seats
451	0	0.00	0	0	Journal (plain) failure from overheating
452	0	0.00	0	0	Journal (roller bearing) failure from overheating
453	0	0.00	0	0	Journal fractured, new cold break
454	0	0.00	0	0	Journal fractured, cold break (previously overheated)
459	0	0.00	0	0	Cause code not listed; enter code 459 in Item 35 and explain in Item 50
460	0	0.00	0	0	Broken flange
461	0	0.00	0	0	Broken rim
462	0	0.00	0	0	Broken plate
463	0	0.00	0	0	Broken hub
464	0	0.00	0	0	Worn flange
465	0	0.00	0	0	Worn tread
467	0	0.00	0	0	Loose wheel
469	0	0.00	0	0	Cause code not listed; enter code 469 in Item 35 and explain in Item 50
470	0	0.00	0	0	Running gear failure
471	0	0.00	0	0	Traction motor failure
472	0	0.00	0	0	Crank case or air box explosion
473	0	0.00	0	0	Oil filter
474	0	0.00	0	0	Electrically caused fire
475	0	0.00	0	0	Current collector system
476	0	0.00	0	0	Remote control equipment inoperative
477	0	0.00	0	0	Broken or defective swing hanger or spring plank
479	0	0.00	0	0	Cause code not listed; enter code 479 in Item 35 and explain in Item 50
480	0	0.00	0	0	Box car plug door open
481	0	0.00	0	0	Box car plug door, attachment defective
482	0	0.00	0	0	Box car plug door, locking lever not in place
483	0	0.00	0	0	Box car door, other than plug, open
484	0	0.00	0	0	Box car door, other than plug, attachment defective
485	0	0.00	0	0	Bottom outlet car door open
486	0	0.00	0	0	Bottom outlet car door attachment defective

489	0	0.00	0	0	Cause code not listed; enter code 489 in Item 35 and explain in Item 50
499	0	0.00	0	0	Cause code and device not listed; enter code 499 in Item 35 and explain
500	2	78500.00	1	0	Automatic brake, improper use
501	0	0.00	0	0	Dynamic brake, improper user
502	11	1708330.00	2	0	Failure to properly secure engine(s) (railroad employee)
504	5	30762.00	0	0	Failure to apply sufficient number of hand brakes on car(s) (railron car(s) (railroad employee)
507	0	0.00	0	0	Independent (engine) brake, improper use
508	0	0.00	0	0	Failure to control speed of car using hand brake (railroad employee)
509	2	34211.00	0	0	Cause code not isted; enter code 509 in Item 35 and explain in Item 50
510	2	12000.00	0	0	Impairment of efficiency and judgement due drugs or alcohol
511	0	0.00	0	0	Incapacitation due to death or illness
512	0	0.00	0	0	Employee restricted in work or motion
513	0	0.00	0	0	Employee falling asleep
519	4	89500.00	2	0	Fixed signal improperly displayed
520	8	1248540.00	7	4	Fixed signal, failure to comply
521	7	428092.00	6	0	Flagging, improper or failure to flag
522	0	0.00	0	0	Flagging signal, failure to comply
523	2	6000.00	1	0	Hand signal, failure to comply
524	5	14176.00	1	0	Hand signal improper
525	1	2400.00	0	0	Hand signal, failure to give/receive
526	0	0.00	0	0	Radio communication, failure to comply
527	0	0.00	0	0	Radio communication, improper
528	3	103500.00	2	0	Radio communication, failure to give/receive
529	2	18949.00	0	0	Cause code not listed; enter code 529 in Item 35 and explain in Item 50
530	0	0.00	0	0	Car(s) shoved out and left out of clear
531	2	13500.00	1	0	Cars left foul
532	5	132100.00	0	2	Derail, failure to apply or remove
533	16	1398160.00	6	0	Failure to stop train in clear
534	4	110750.00	8	0	Hazardous materials regulations, failure to comply
535	22	269647.00	11	0	Instruction to train/yard crew improper
536	38	291155.00	11	0	Motor car or on-track equipment rule, failure to comply
537	10	87391.00	9	0	Movement of engine((railroad employee)
538	2	16923.00	0	0	Shoving movement, absence of man on or at leading end of movement
539	7	375933.00	12	0	Shoving movement, man on or at leading end of movement, failure to comply
540	4	71560.00	0	0	Skate, failure to remove or place
541	9	39503.00	5	0	Special operating instruction, failure to comply (instruction in Item 50)
542	9	973025.00	7	0	Train order or timetable authority, failure to comply
543	2	3550.00	0	0	Train orders, radio, error in preparation, transmission or delivery
544	0	0.00	0	0	Train orders, written, error in preparation, transmission or delivery
550	15	210950.00	2	0	Coupling speed excessive
553	8	68645.00	2	0	Switch movement, excessive speed
554	34	1762510.00	13	4	Train inside yard limits, excessive speed
555	1	3000.00	2	0	Train outside yard limits under clear block, excessive speed

APPENDIX D

D.1 ANALYSIS OF MODIFIED LOCOMOTIVE CAB LOADING STRENGTH

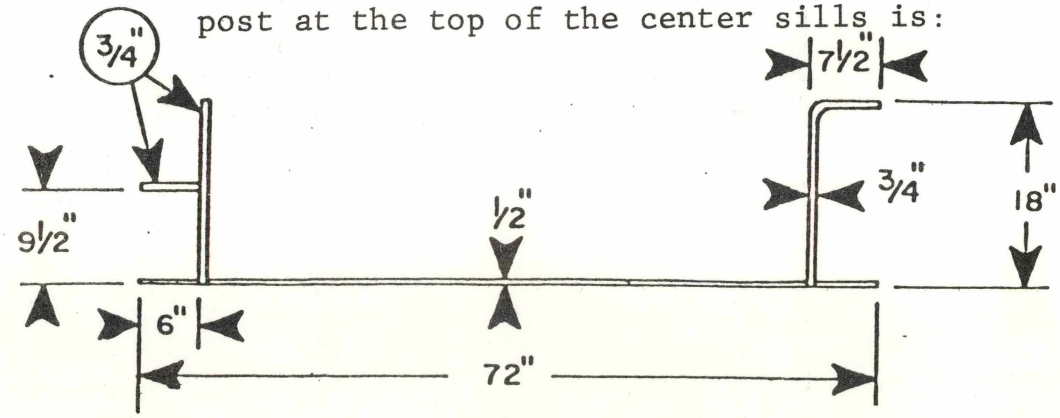
Longitudinal Load on Short Hood End



For simplification, the analysis will consist of two loading conditions of the modified collision posts and of the roll posts, neglecting the additional strength obtained from other structures such as the cab, the sandbox, and the shorthood. It will be assumed that single-point loads are applied at a height 75 percent of the total height of each respective structure. The analysis will be further simplified by assuming that the brace acts as a simple supported beam and acts merely to transfer tensile or compressive load and does not increase the bending strength of the attached structures. These simplifying assumptions make the analysis more conservative; therefore, the actual strength will be greater.

D.1.1 Calculation of the Moments of Inertia of the Posts in Longitudinal Bending (P_1)

Collision Posts - The cross-section of the collision post at the top of the center sills is:



Location of Centroid:

$$72(\tfrac{1}{2})(X-\tfrac{1}{4}) + 2(X-\tfrac{1}{2})(3/4)\left(\frac{X-\frac{1}{2}}{2}\right) = 2(18-X)(3/4)\left(\frac{18-X}{2}\right)$$

$$+ (6\ 3/4)(3/4)(17\ 5/8-X)$$

$$+ (6\ 3/4)(3/4)(9\ 7/8-X)$$

$$36X - 9 + 3/4X^2 - 3/4X + 3/16 = 243 - 27X + 3/4X^2 +$$

$$89.23 - 5.06X + 49.99 + 5.06X$$

$$X = \frac{391.03}{72.37} = 5.40'' \qquad C = 18-5.4 = 12.6''$$

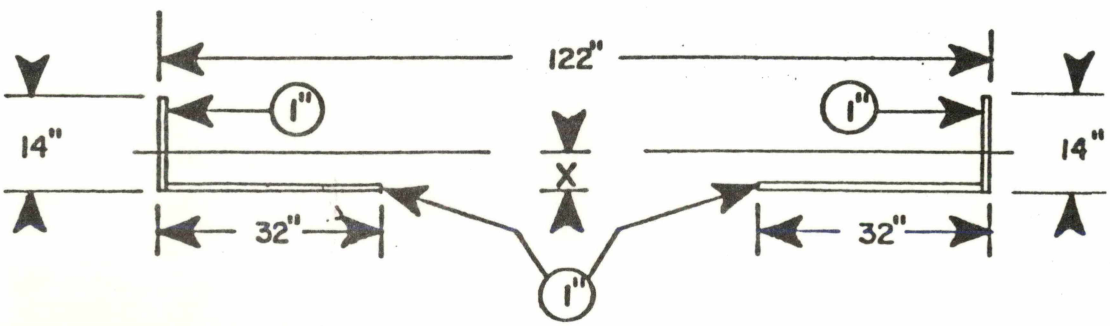
Moment of Inertia:

$$I = \frac{72(.5)^3}{12} + 72(.5)(5.15)^2 + 2\left[\left(\frac{.75(16.75)^3}{12}\right) + (16.75)(.75)(3.48)^2\right] + 2\left(\frac{7\tfrac{1}{2}(.75)^3}{12}\right) + 7\tfrac{1}{2}(.75)(12.23)^2 + 6.75(.75)(4.48)^2$$

$$= .75 + 954.81 + 587.43 + 304.27 + .53 + 841.35 + 101.61$$

$$= 2790.75 \text{ in}^4$$

<u>Roll Posts (at base)</u>



Location of Centroid:

$$32(X-\tfrac{1}{2}) + (X-1)\left(\frac{X-1}{2}\right) = (14-X)\left(\frac{14-X}{2}\right)$$

$$32X-16 + \frac{X^2}{2} - X + \tfrac{1}{2} = 98-14X + \frac{X^2}{2}$$

$$X = \frac{113.5}{45} = 2.52 \text{ in}$$

$$C = 11/48 \text{ in}$$

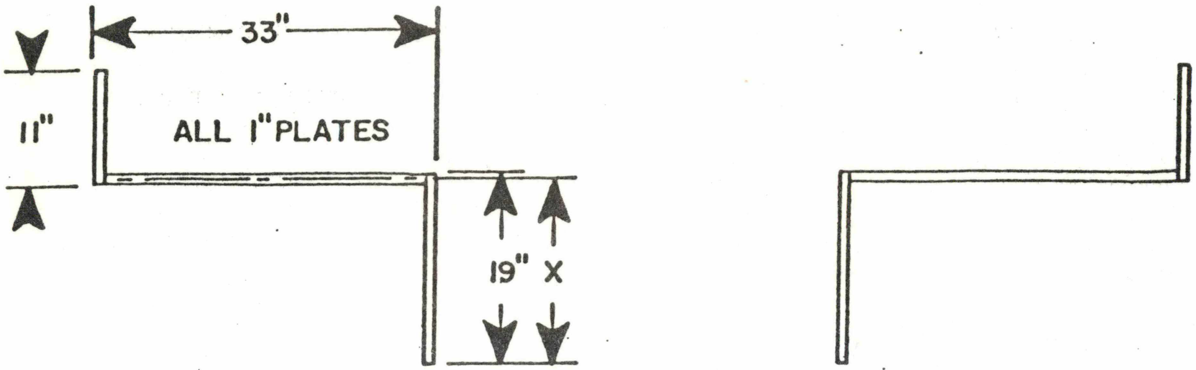
Moment of Inertia:

$$I = 2\left[\frac{32(1)^3}{12} + 32(2.02)^2 + \frac{(13)^3(1)}{12} + 13(4.98)^2\right]$$

$$= 2\left[2.67 + 130.57 + 183.08 + 322.41\right]$$

$$= 1277.45 \text{ in}^4$$

Roll Posts (at top of collision posts)



Location of Centroid:

$$18 + 33a = 10 + 33(1-a)$$

$$66a = 25$$

$$a = .38$$

$$X = 18 + .38$$

$$X = 18.38 \text{ in} \qquad C = 18.38 \text{ in}$$

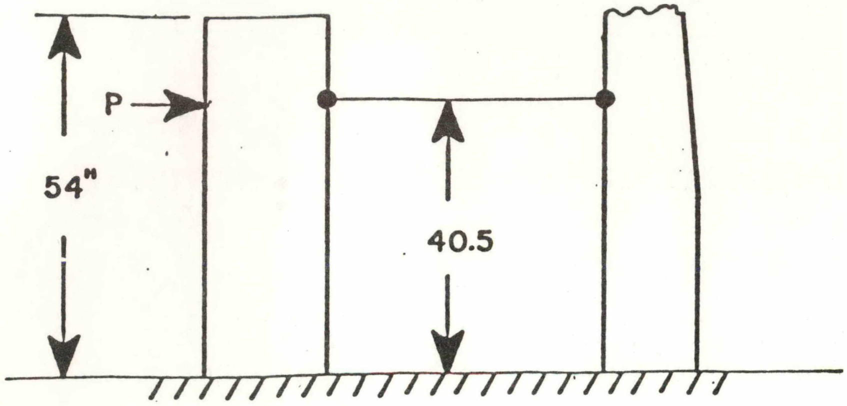
Moment of Inertia:

$$I = 2\left[\frac{(19)^3}{12} + 19(8.88)^2 + \frac{(11)^3}{12} + 11(5.13)^2\right]$$

$$= 2\left[571.58 + 1498.23 + 110.92 + 289.49\right]$$

$$= 4940.43 \text{ in}^4$$

Loading of Collision Post



In calculating the yield load for the collision posts, the yield loads of the collision posts and roll posts at a load height of 40.5" will be added.

$$S \text{ yield} = \frac{MC}{I} = \frac{Plc}{I}$$

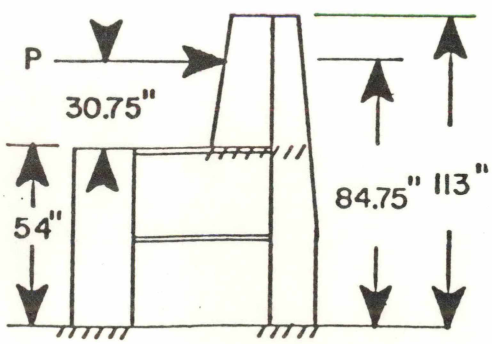
$$P_1 = \left(\frac{SI}{lc}\right)_{\text{collision post}} + \left(\frac{SI}{lc}\right)_{\text{roll post}}$$

$$P_1 = \frac{36{,}000\ (2790.75)}{40.5\ (12.60)} + \frac{36{,}000\ (1277.45)}{40.5\ (11.48)}$$

$$P_1 = 196878 + 98912$$

$$P_1 = 295{,}790 \text{ lb.}$$

D.1.2 Loading of Roll Post (P_2)



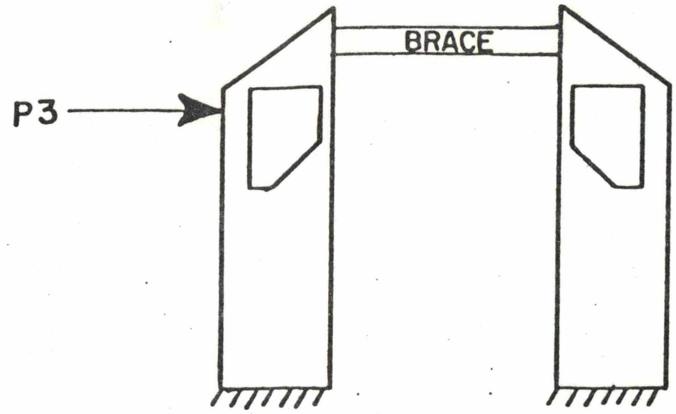
To determine the loading of the roll post, it will be assumed that the weakest point is at the height of the top of the collision post (for longitudinal loading).

$$P_2 = \frac{SI}{lc}$$

$$P_2 = \frac{36,000\ (4940.43)}{30.75\ (18.38)}$$

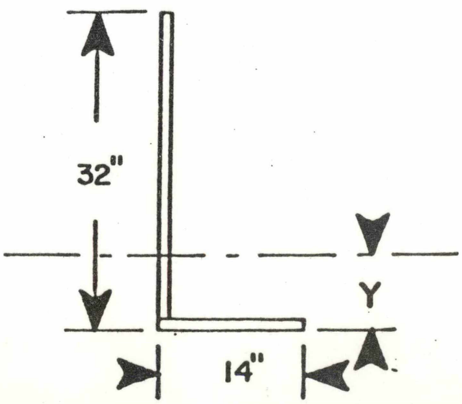
$$P_2 = 314,685 \text{ lb.}$$

D.1.3 Lateral Load on Roll Post (P_3)



As in the previous analysis, it will be assumed that the two roll posts act without aid from the cab structure and are connected by a simple support brace that carries a compressive load connecting the two.

Calculation of Moment of Inertia



Cross-section of one post at top of center sill

Location of Centroid:

$$14(y-\tfrac{1}{2}) + (y-1)\,\frac{y-1}{2} = (32-y)\left(\frac{32-y}{2}\right)$$

$$14y - 7 + \cancel{\frac{y^2}{2}} - y + \tfrac{1}{2} = 512 - 32y + \cancel{\frac{y^2}{2}}$$

$$y = \frac{518.5}{45} = 11.52''$$

$$C = 20.48''$$

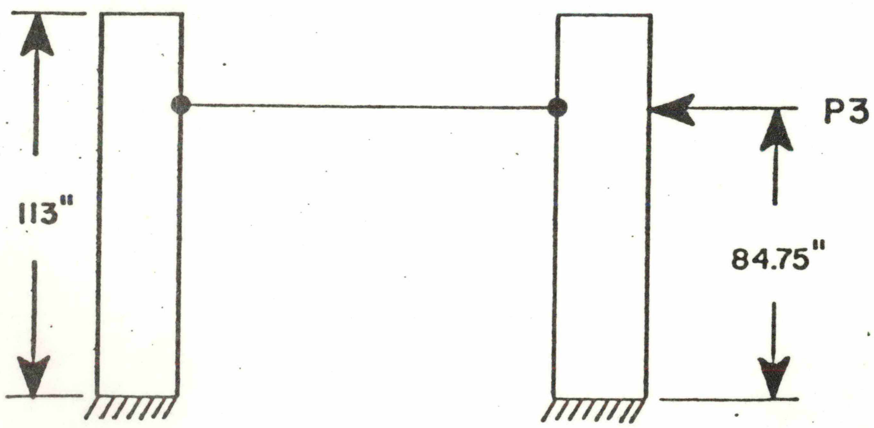
Moment of Inertia:

$$I = \frac{14}{12} + 14(11.02)^2 + \frac{(31)^3}{12} + 31(4.98)^2$$

$$= 1.17 + 1700.17 + 2482.58 + 768.81$$

$$= 4952.73 \text{ in}^4$$

<u>Lateral Loading of Roll Posts</u>



$P_3 = 2\,\frac{SI}{lc}$ collision post-lateral

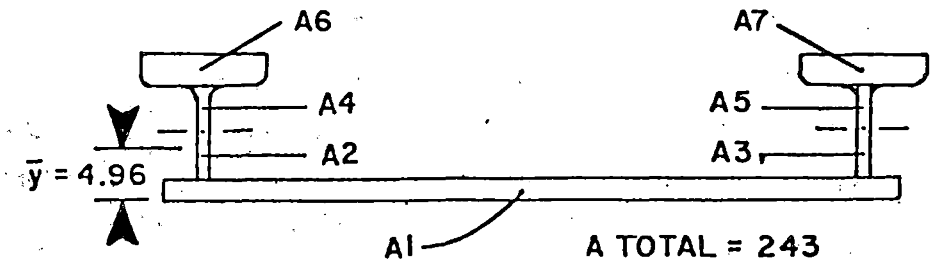
$$P_3 = 2\,\frac{36{,}000(4952.73)}{84.75 \quad 20.48}$$

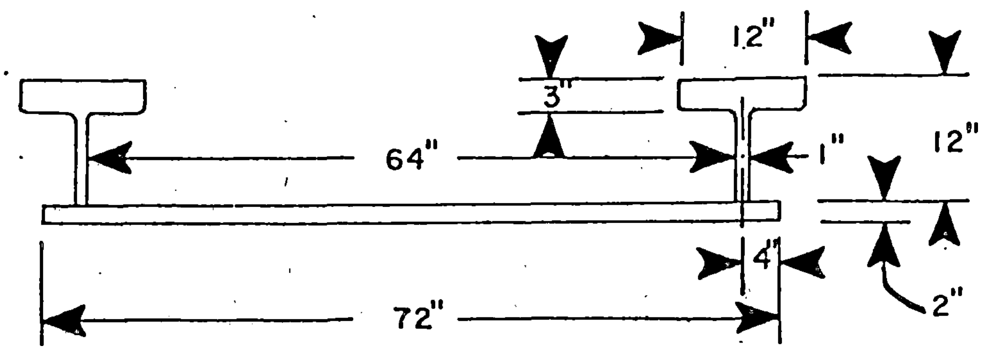
$P_3 = 205{,}450$ lb.

D.2 CALCULATION OF BENDING MOMENT OF DECK PLATE UNDER IMPACT LOAD

To calculate the moment loading of the structure covered in the discussion immediately preceeding on the locomotive deck plate, the following information is presented. Shown in the figure below is the cross-section of the GP40 locomotive deck plate. To compute the bending moment of this structure under impact loading at the top of the collision posts, three calculations are required. They are:

- Location at locomotive deck plate centroid
- Moment of inertia at the deck plate
- Applied torque load.





From the dimensions shown in the figure above, the centroid of the locomotive deck plate is computed as follows:

Location of Centroid

$$A_T x\bar{y} = A_1 x_1 + 2\ A_2 x_2 \quad + 2\ A_3 x_3$$

$$A_T \bar{y} \quad = 144(1) + 2\ 9(6.5) \quad + 2\ 36(12.5)$$

$$234\bar{y} = 144 + 2(58.8) + 2\ 450$$

$$234\bar{y} = 144 + 117 + 900$$

$$\bar{y} = \frac{1161}{234} = 4.96\ ''$$

$$c = 14 - 4.96 = 9.04\ ''$$

To compute the moment of inertia of the deck plate the seven separate areas identified as A, through A_7 are computed. Then their contribution to the stress capability is computed using these areas and the previously computed centroid.

Moment of Inertia

$$I\bar{y}1 = \frac{72 \times (2)^3}{12} + 144(3.96)^2 = 48 + 2258.15$$

$$I\bar{y}1 = 2306.15\ in^4$$

$$I\bar{y}2 = \frac{1 \times (2.25)^3}{12} + 4.5(11)^2 = .9492 + 2.268$$

$$I\bar{y}2 = 3.21765\ in^4 = I\bar{y}3$$

$$I\bar{y}4 = .9492 + 4.5(3.79)^2 = .9492 + 14.3641$$

$$I\bar{y}4 = 13.63\ in^4 = I\bar{y}5$$

$$I\bar{y}6 = \frac{12(3)^3}{12} + 36(7.54)^2$$

$$= 27 + 36(56.85) = 27 + 2046.6576$$

$$I\bar{y}6 = 2073.6576 \text{ in}^4 = I_7$$

$$I_{total} = I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7$$

$$= (2306.15 + 3.22 + 3.22 + 13.63 + 13.63 + 2073.66 + 2073.66)\text{in}^4$$

$$I_{total} = 6487.17 \text{ in}^4$$

Finally, the loading of the locomotive deck plate is calculated using a 300,000 lb impact load at 84" above the deck plate, which results in a moment load (M) of 25.2×10^6 in lbs. Using this load, the maximum moment load induced in the deck plate is:

$$f_{max} = \frac{M\bar{y}_{max}}{I} = \frac{25.2 \times 10^6 \text{ in lbs} \times \bar{y}_{max} \text{ in}}{6.487 \times 10^3 \text{ in}^{4\ 2}}$$

$$f_{max} = 3.885 \times 10^3 \text{ lbs/in}^2 (y_{max})$$

$$f_{max} = 3885 \times 9.04 \text{ lbs/in}^2 = 35,120 \text{ lbs/in}^2$$

The deck plate is made of mild A-36 steel, which has a stress capability of 51,000 lbs/in^2; therefore, bending of the deck plate under this load should not occur.

APPENDIX E

DETAILS OF CN MODIFIED CAB DESIGN

The Canadian National Cab was based on a design of an English engineering firm and put into service in October of 1978. Features of the design include:

- Elimination of front doors (doors placed in rear)

  Front doors were eliminated and placed in rear to reinforce the front end of the cab. The design with the exception of being wider with doors placed to the rear of the cab is similar to the design of the EMD-GP40 locomotive.

- Solid steel front

  A solid steel front below the cab windows produces a more collision-worthy front.

- Nose wider - yield load of cab 400,000 lb.

  The nose front of the locomotive is wider stretching - full width of the cab. This allows a double collision understructure post which greatly increases the structural integrity of the nose and the strength of the locomotive cab at the deck plate level. The joint stress level of the double collision post of the CN locomotive is 400,000 lbs impact load.

- Front end V-shield anticlimber and snow plow

  The BN and CN anticlimber are quite similar with the exception that the CN front-end anticlimber is a wrap-around type, 0.5-inch thicker than the current EMD model in service by the BN, making the plate 2-inch thick.

- Snow plow design

  The Snow Plow design is the usual snow removal type with the exception that the reinforced steel plate of the design is thicker than the standard design of the northern railroads in the United States.

- Sandbox placement

  The Sandbox, which supplies sand to the wheels for traction, is located outside the front nose on the sides at the deck plate level of the locomotive. The reinforced steel sandbox acts as an inhibitor with the weight of the sand lending added support to the deck-level of the cab. This design differs from the BN in that it places the sandboxes to the side of the nose and cab as an added collision factor.

  In October 1979, a CN locomotive experienced a collision at 12 mph entering the yard limits, hitting the corner of a boxcar - total damage to the locomotive equipped with the new design was $300, showing the effectiveness of the new design.

APPENDIX F

GENERAL DESIGN CONSIDERATIONS FOR LOCOMOTIVE STRUCTURAL MODIFICATION

An example of the structural modification design that meets the performance guidelines for ensuring a survivable volume and that is suitable for application to a GP40 or similar EMD locomotive was given in paragraph 3.3.1. It is expected that slight variations of this type of braced collision post design will be applicable to other types of locomotives. The following general design practices and approaches are to assist those designated to develop specific designs.

F.1 LOCOMOTIVE UNDERFRAME

The locomotive underframe structure should resist a minimum static end load of 1,000,000 lbs. applied along the centerline of the draft without developing any permanent deformation in any member of the locomotive structure. In meeting this requirement, it is important that maximum vertical deflection, measured at the center of the locomotive, shall not exceed L/720 inches, where L represents the distance between truck centers in inches.

The locomotive must be designed to resist a horizontal load of 500,000 lbs. applied on the buffer beam at a point 10 inches above the centerline of the draft.

In the event the locomotive underframe does not have the proper static load capacity,additional reinforcing of the underframe would have to be accomplished in order to make the braced collision type of structure effective in preventing excessive crushing of the cab and ensuring a survivable volume.

F.2 COLLISION POSTS

Collision posts can be channel, Z, or hat section members and must be properly welded to all horizontal members. They should be located in the shorthood of the locomotive and should be fastened securely to a suitable structure at the top, developing the appropriate reactions at this point), tied into an underframe structure at the bottom, and welded to the upper floor.

The welding of the collision post to the center sill should carry the end reaction developed by the collision posts under the prescribed loads. The torsional strains developed in the collision post shall be resisted by the center sill and a transverse beam constructed into the end frame 18 inches above the center sill.

The attachment of the collision posts at the top shall be adequate to resist the simultaneous loads from both posts and sufficient to develop the ultimate strength of the posts when loaded at 18 inches above the top of the floor; the top support shall resist these loads at stresses not exceeding the ultimate strength of the supporting members.

The two main vertical collision posts should have an ultimate shear value on the order of 300,000 lbs. each at a point even with the top of the underframe to which they are attached. In addition, a collision post shall withstand a horizontal load of the order of 300,000 lbs. applied at an angle of 15° either side of a line parallel to the horizontal centerline of the car at any height up to 18 inches above the center sill, without exceeding the ultimate strength of its attachments.

F.3 MATERIAL SPECIFICATIONS

Strength members of the modification structure shall be of all-metal construction. Castings may be used as parts of the strength members but such castings must have a carbon content of 0.25 percent or more and must be annealed.

Where built-up welded metal parts are substituted in place of castings, the unit should be stress relieved before application. Any structural material having a yield strength greater than 80 percent of the tensile strength shall not be used since this material would be too brittle in the plastic collapse mode.

All weld connections shall be identified on the construction drawing for the modified locomotives. The description shall cover the type and pattern for each weld.

Welders should be properly qualified and meet the MIL specifications "Welding and Bracing Procedure and Performance Qualification" (MIL-STD-50248).

It is recommended test welds as per ASME "Boiler and Pressure Vessel Code," Section IX, be used in performing the tests of the welds in question.

A proper method for inspecting welds at the base of the collision posts should be used.

F.4 PLASTIC DESIGN ANALYSIS

In the design of the collision posts, plastic design analysis should be used and be carried out in the following steps:

- Determine the dimension of the member, working load, and ultimate load.
- Assume the relative size of the member, type of steel, type of connection, etc.
- Analyze the tentative structural member and modify the relative size so that the member will fail under the critical combination of the ultimate load.

The design should then be checked for adequacy against local buckling, lateral buckling, excessive deflection, and shear.

- Maximum shear (V) should not exceed

$$V = 0.55\,\sigma_y\,wd$$

where d = depth of member
w = web thickness
σ_y = yield strength.

To prevent local buckling, the width to thickness ratios of the plate members which comprise the member must meet the following requirements:

(1) Projecting elements (flanges of rolled shapes or similar outstanding elements, stiffeners, etc.) b/t $\overline{<}$ 8.5 (b = width of element and t its thickness)

(2) Flange plates in box sections and similar elements, b/t $\overline{<}$ 32

(3) Web of rolled or built shapes

$\frac{d}{w} \not< 43$, where

d = depth

w = web thickness

The overall specifications for the welded joints are as follows:

(1) The effective stress area of a fillet weld should be taken equal to the throat thickness multiplied by the weld length, regardless of the direction of load.

(2) The minimum size of fillet weld to avoid cracked welds should be used as given below:

Thickness of Thicker Part Jointed, in.	Minimum Size of Fillet Weld, in.
to 1/2 incl	3/16
over 1/2 to 3/4	1/4
over 3/4 to 1-1/2	5/16
over 1-1/2 to 2-1/4	3/8
over 2-1/4 to 6	1/2
over 6	5/6

(3) The allowable shear stress in fillet welds should be as follows:

Welding Grade or Electrode Class	Steel Type Being Joined*	Allowable Shear Stress
SAW-1, GMAW-1, E60 XX		
SAW-2, GMAW-2, E70 XX	A36, A441	12,400
SAW-2, GMAW-2, E70 XX	A36	12,400
SAW-2, GMAW-2, E70 XX	A441,A514	14,700
SAW-3, GMAW-3, E90 XX	A514	18,000
SAW-4, GMAW-4, E110 XX	A514	22,000

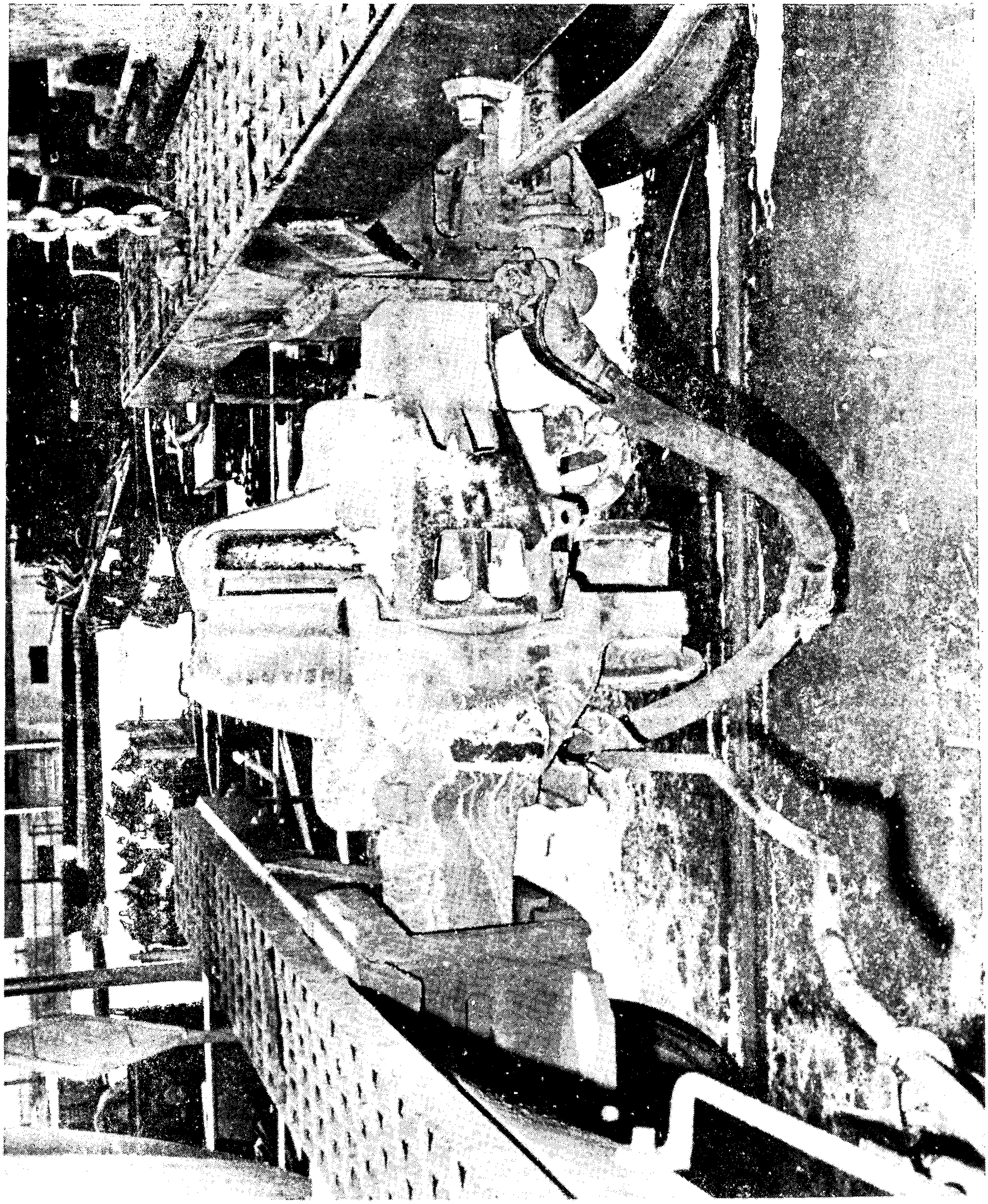
(4) Connections for a collision post which is prepositioned on the basis of the theory of plastic design must be capable of resisting the moment, shear, and axial loads which are acting on the connection as a result of the applied ultimate loads. The welds must be proportioned to resist the forces produced at ultimate load using stresses which have been increased accordingly. For fillet-weld stresses, the assumption is made that the weld is capable of developing at least the shearing yield stresses of the weld metal on the minimum throat area. A safe design value is obtained by multiplying the elastic design allowable stress value for the weld by the ratio of σ_y/σ_w, where σ_y is the yield strength and σ_w is the allowable tensile stress of the base material.

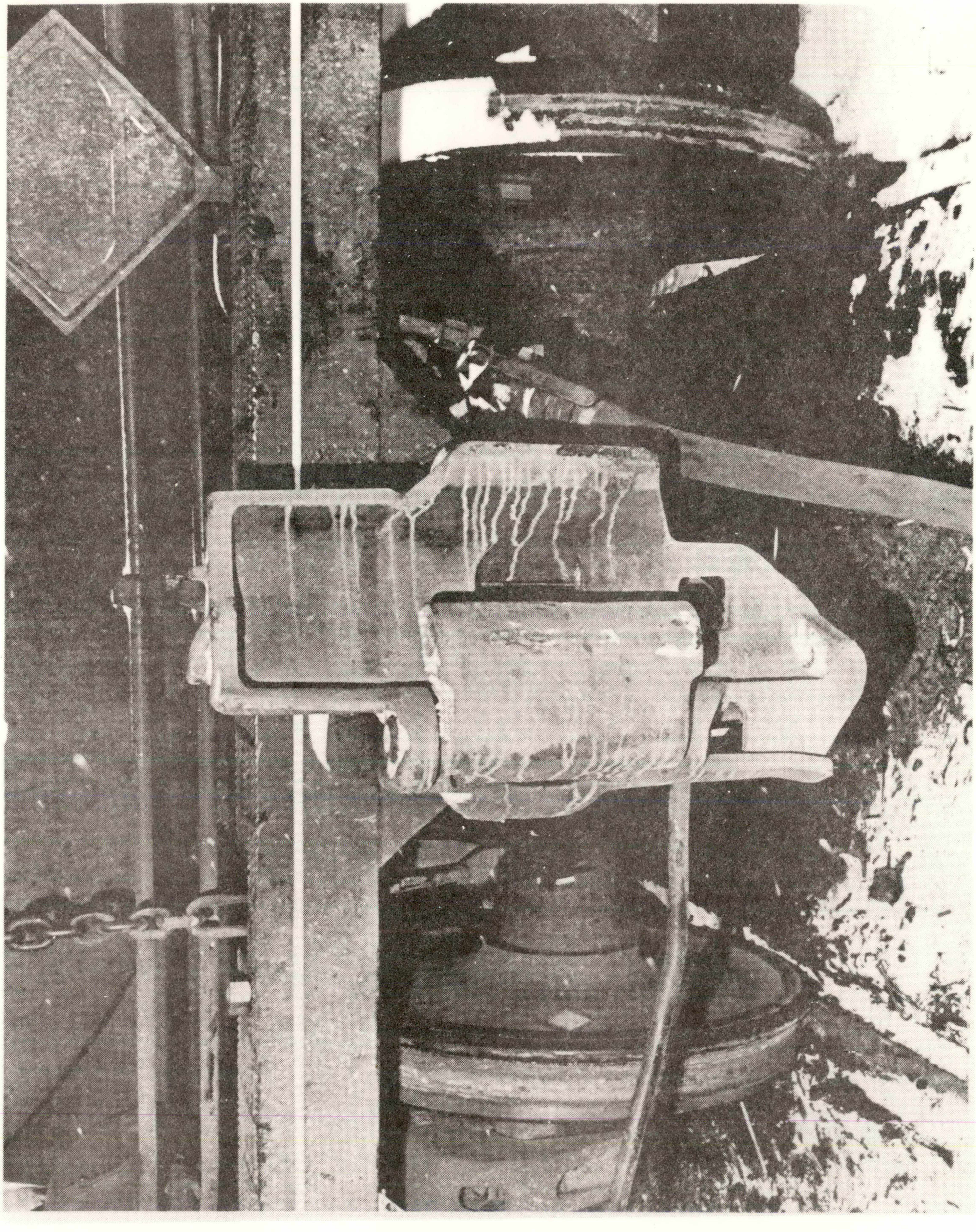
(5) All loads acting on a fillet weld should be considered as shears, independent of their actual direction.

* If two different steels are joined, electrodes or welding grades for the lower strength steel should be used.

APPENDIX G

EXAMPLES OF SHELF COUPLERS





APPENDIX H

GUIDELINES FOR PASSENGER CAR BODY STRENGTH
(AAR Specifications)

Longitudinal Frame Or Truss Framing Members

In calculating the stresses in side frame, its effective depth when designed as a truss or girder may be taken either as the distance between centers of gravity of side plate and side sill or as the distance between centers of gravity of bottom and top chords of the girder. In the latter case the bottom member may be taken as the section comprising side sill, belt rail, and intervening side sheet; the top member may include side plate and letter board, provided connections are such that all members will act together. Piers connecting the top and bottom chords above described must be of sufficient strength to withstand the shear loads imposed upon the, with stresses not to exceed the specified values. At side door openings the bending moment caused by the vertical shear at door posts shall be considered as being resisted by the section above and below door opening, and the sum of the direct stresses and those due to bending at such sections shall not exceed the specified stresses. A sufficient proportion of any reinforcing members addressed to these sections shall be extended far enough beyond the door posts at each side to transmit their reactions to the side frame without exceeding the limit specified for stresses. The roof and underframe systems may be considered as load carrying members to the extent of their connection to the side frame.

Side Posts and Braces

(a) For girder construction or truss construction the sum of the section moduli about a longitudinal axis, taken at the weakest horizontal section between side sill and side plate, of all posts and braces on each side of the car located between the body corner posts shall be not less than 0.30 multiplied by the distance in feet between the centers of end panels.

(b) For girder construction only the sum of the section moduli, about a transverse axis, taken at the weakest horizontal section between side sill and side plate, of all posts, braces and pier panels, to the extent available, on each side of car located between body corner posts shall be not less than 0.20 multiplied by the distance in feet between the centers of end panels.

(c) The center of the end plane is to be considered as the point midway between the center of the body corner post and the center of the adjacent side post.

(d) Side frame members shall also meet the stress requirements.

Sheathing

(a) Outside sheathing of mild open hearth steel when used flat without reinforcement (other than side posts) in a side frame of girder construction must be not less than 0.125-inch nominal thickness. Other metals may be used of a thickness in inverse proportion to their yield strengths.

(b) Outside metal sheathing of a lesser thickness may be used provided it is reinforced so as to produce at least an equivalent sectional area at right angle to reinforcements as flat sheathing specified above.

(c) For truss construction where sheathing serves no load carrying function, minimum thickness shall be not less than 40% of that specified above.

Vertical End Members

(a) The sum of the section moduli of all vertical end members at each end of the car shall be not less than 65.

(b) The outside end of each car shall be provided with two main vertical members, one at each side of the diaphragm opening. Each of these members shall have a section modulis of not less than 24.375. Each main member shall also have an ultimate shear value of not less than 300,000 lbs. at a point even with the top of the underframe member to which it is attached. The attachments of these members at bottom shall be sufficient to develop their full shear value.

(c) This shear value shall be based on the area of the web, which is the depth of the member times the web thickness times the shear strength of the material used.

(d) If reinforcement is used to provide the shear value such reinforcement shall have a full value for a distance of 18" up from the underframe connection, then taper to a point approximately 30" above the underframe connection.

(e) The attachment of the vertical members at the top shall be adequate to resist without failure the reactions of the members, without shear reinforcements, when assumed to be simple beams with free supports at their ends and loaded at a point 18" above the connection to the underframe member to which they are attached with a load sufficient to develop the yield point of the material.

(f) The remaining vertical end member requirements shall be distributed in the body end of the car. The attachments of these members at bottom shall be sufficient to develop their full shear value. The attachments at the top shall be determined in the same manner as prescribed above for the main end members.

(g) For cars having open end observation platform, the end construction of car body shall be as described above and in addition there shall be two stub end members, located similarly to main vertical members on end of platform extending to top of railing. These members shall have same shear strength value as the two main vertical members.

(h) Cars with large end doors to which the foregoing requirements of this section do not apply, shall be considered to meet these specifications of the doors and attachments are sufficient to develop a shear resistance equivalent to the main members described above.

(i) The top reaction of all vertical end members may be delivered to the roof of car or to a truss, girder or brace construction extending across the car. The structure employed must be adequate to transmit reactions from the posts to the side framing of the car.

Roof

(a) The projected area of the portion of the roof in square feet supported by carlines divided by the sum of the section moduli of the carlines at any section must not be more than 60.

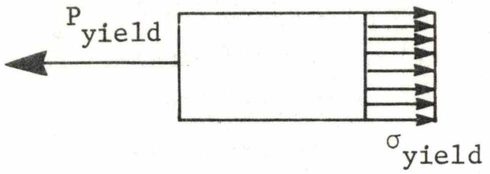
(b) Flat roof sheets of mild open-hearth steel without reinforcements shall be of a minumum thickness of 0.05 inches, adequately attached to the roof framing.

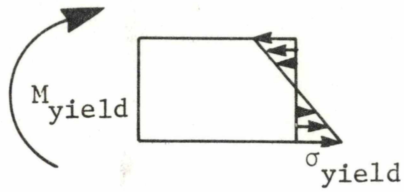
(c) Metal roof sheets of a lesser thickness may be used provided they are reinforced so as to produce at least an equivalent sectional area at right angle to roof sheets specified above.

APPENDIX I.

ENERGY DISSIPATION CONSIDERATIONS

For elastic action, the most efficient use of the load carrying material is in tension/compression since the sections are subjected to the same uniform stress level, as shown in the lefthand sketch below. When the yield stress is reached, the entire section is in the plastic range and nonrecoverable strains occur which dissipate energy. On the other hand, bending is a more inefficient use of the load carrying material in the elastic range because only the outermost fibers reach the yield stress as shown in the righthand sketch below.





Upon entering the plastic range, however, bending offers a more controlled rate of deformation than does the tension/compression action since there is still a reserve elastic capacity within the section even after the outermost fibers are well into the plastic range. For a given maximum allowable strain, a bending section will not dissipate as much energy plastically as will a tension/compression section of equal cross-sectional area. Consider a 1-inch-square steel bar 100 inches long for which the yield stress is 36,000 psi. If a total plastic strain (in addition to the elastic strain) of 0.15 is allowed, the bar could be lengthened by 15 inches due to nonrecoverable plastic deformations. The plastic work performed is then

$$P\Delta = (36,000)\ (15) = 540,000 \text{ in.-lbs.}$$

If the same square steel bar were utilized in bending with the same maximum allowable plastic strain, the angular rotation per unit length would be

$$\phi = \frac{\varepsilon_{p\ max}}{y_{max}} = \frac{0.15}{0.5} = 0.30 \text{ radian/inch.}$$

Then the total angular change in the 100-inch length would be 100 x 0.30 = 30 radians which implies that the bar would have to be bent back upon itself in almost five spirals. If this were feasible, the plastic dissipation would be

$$M_p \theta = 9000 \times 30 = 270{,}000 \text{ in.-lbs.}$$

where M_p was obtained from $M_p = \sigma_y Z = (36{,}000)\ (1/4)$.

Although the use of material bending does not utilize the material as efficiently as in tension/compression, the reserve elastic capacity within the section which has begun to yield provides a more desirable controlled deformation. The controlled deformation and gradual spreading of the plastic hinge zone along the length of the beam indicates the advisability of making the cab structure a space frame where bending predominates, rather than a truss-type structure tension/compression action predominates. However, pure tension members to selectively stiffen the space frame and provide additional plastic dissipation may also be used with the restriction that the tension member contribution is not so great as to reduce the predictability of a controlled collapse of the space frame. The same arguments may be made for the relative use of shear panels versus bending elements, as have been stated for tension/compression members.

It is useful to make some initial estimate regarding the feasibility of providing enough plastic dissipative reserve in the cab structure for an impacting caboose. It is not feasible to dissipate all the kinetic energy of an entire train, but a realistic approach appears to be the goal of providing enough dissipative capacity for the impact of the caboose alone. Consider a 350,000-lb. caboose which is impacted into a locomotive at 1,000 inches/sec (56.8 MPH) for which the kinetic energy is approximately 3.77×10^6 ft-lbs (the kinetic energy would be greater if the locomotive were impacted into the caboose at the same speed). Assume that there are eight uniform vertical column members (four on each side) in the cab and three tiers including the lower survivable space. It is required to determine what approximate size members are required to dissipate the energy in the upper two tiers before the lowermost tier begins to collapse. There would then be:

8 columns x 2 hinges/tier column x 2 tiers = 32 hinges.

The required dissipation for each section would then be $3.77 \times 10^6 / 32 \approx 118{,}000$ ft-lbs = 1.416×10^6 in-lbs. Assume a limiting plastic rotation in the plastic range of 1/2 radian ($\approx 30°$). Since the plastic work performed is $M_p \theta$, then the required plastic moment capacity M_p is given by:

$$M_p = \frac{1.416 \times 10^6}{0.5} = 2.832 \times 10^6 \text{ in.-lbs.}$$

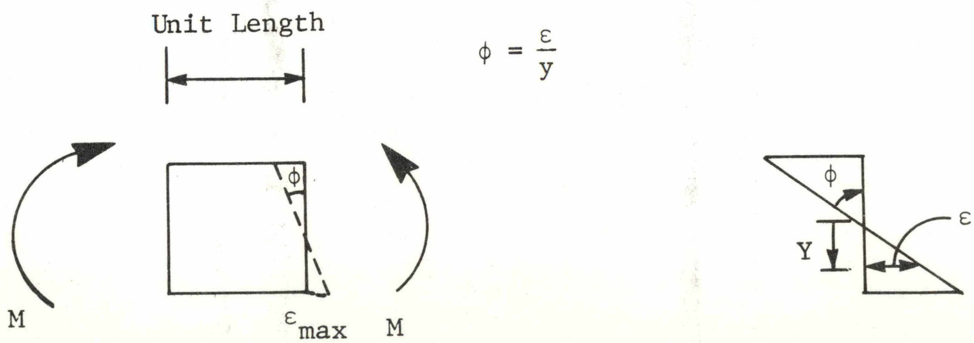
For a fully developed plastic section, $M_p = \sigma_y Z$, so for A36 steel:

$$Z_{Required} = \frac{2.832 \times 10^6 \text{ in.-lbs.}}{36 \times 10^3 \text{ lbs./in.}^2} = 78.7 \text{ in.}^3.$$

A 10" x 10" by 0.625"-wall-square structural tube has an available Z of 82.5 in^3. This is the largest commonly availably square structural tube size. The next size, a 10" x 10" x 0.5" tube, has an available Z of only 67.75 in^3 and would not meet the minimum design requirements. This implies that a dissipative mechanism could be designed only with the largest commonly available size of square structural tube if the allowable rotation is not allowed to exceed 0.5 radian. If a greater rotation were allowable, the required plastic section modulus Z could be reduced. But no infinitesimally thin beam section can withstand 1/2 radian because the strain at rupture would be exceeded. The rotation must occur cumulatively over a finite beam length.

The theory of plastic mechanisms assumes the formation of hinges of infinitesimally small dimensions in an elastic/perfectly plastic material. The rotation of such an infinitesimally thin beam section is shown below where ϕ, the angular change per unit length of the beam, is related to the strain ε at a distance y from the neutral axis by:

$$\phi = \frac{\varepsilon}{y}$$



The maximum strain occurs at the outermost fiber of a given structural section, which for the 10" x 10" x 0.625" tube is a distance of 5 inches. For the case of 1/2 radian rotation then

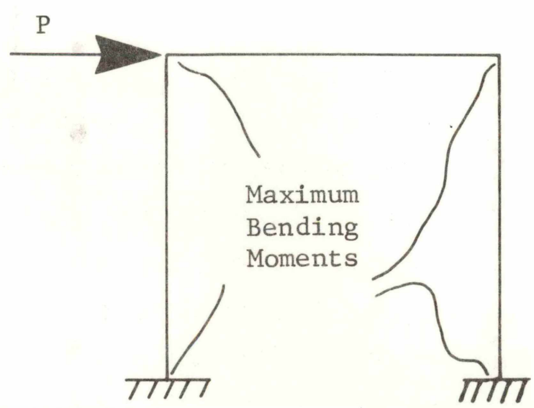
$$\varepsilon = \phi y = (0.5)5 = 2.5 \quad .$$

This means the maximum strain would have to be 2.5, or that the outermost fiber length would be increased by 250%. Of course, rupture would occur at a strain level well below this. Assumming that a maximum permissible strain is 0.15 or 15%, the allowable rotation per unit length of the beam would be $\phi = \frac{0.15}{5} = 0.03 \approx 1.7$ degrees. Obviously, this does not provide sufficient rotation for effective dissipation, and simple physical insight indicates that ductile steel members can withstand more than 1.7 degrees of rotation before rupturing. This is because the rotation does not occur entirely within an infinitesimally small section but is cumulative over a finite length. The total rotation θ would be 0.5 radian, and for a limiting 15% uniform level of strain would be given by:

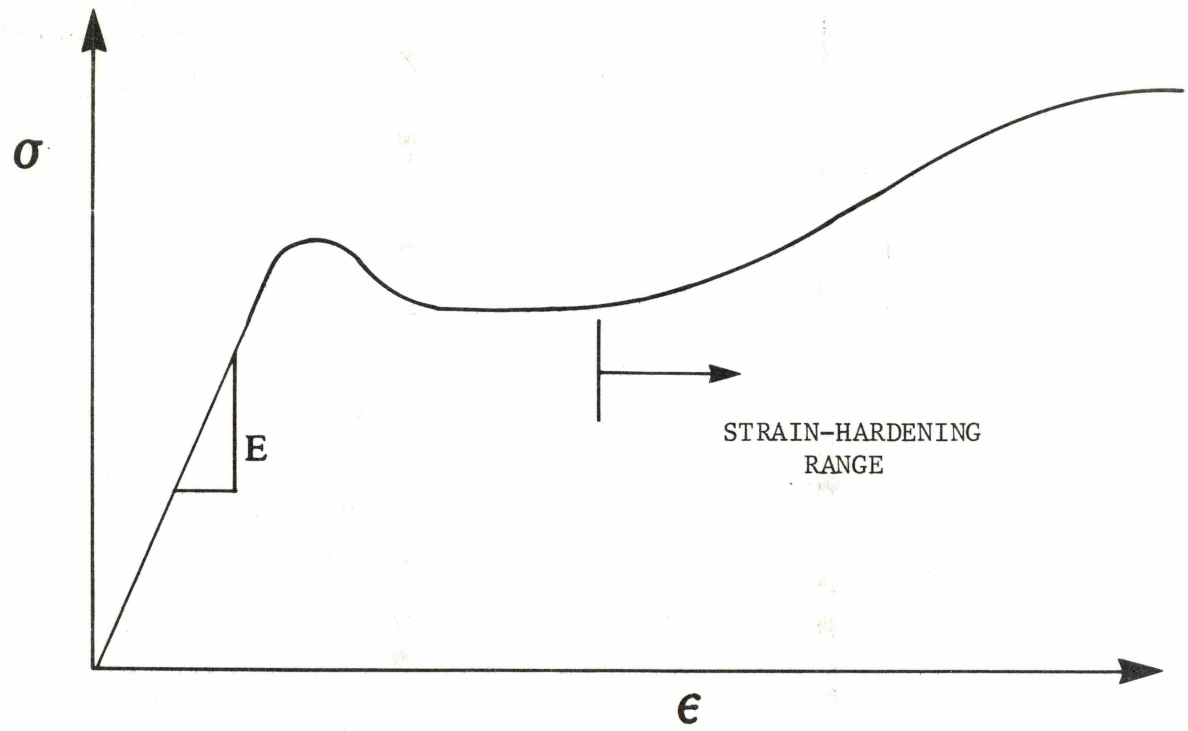
$$\theta = 0.5 = \int_o^{\ell} \phi \, dx = \int_o^{\ell} \frac{\varepsilon_{max}}{Y_{max}} dx = \int_o^{\ell} \frac{0.15}{5} dx = \int_o^{\ell} 0.03 \, dx.$$

If the strain were uniform over the length, the the required length to obtain a 0.5 radian rotation would be $\frac{0.5}{0.03} = 16.7$ inches.

So a new aspect of the dissipative problem is to ensure that an involvement of a certain minimum finite length (in this case 16.7 inches) in the plastic hinge formation is attainable. For the simple structure shown below, the maximum bending moments occur at the column ends.



For a perfectly plastic material, the collapse load will not be increased above the initial failure value, and sections between the column ends will never be subjected to bending moments equal to their full plastic capacity. This is because any attempt to increase the load results in additional rotation of each infinitesimally small plastic hinge which has reached its maximum rotational resistance. If this were the case, a very small rotation would occur before rupture of the material at the hinges took place. In actuality, most steels have a strain-hardening range beyond a perfectly plastic range as shown below.



For such steels, the first sections to form plastic hinges would rotate through the perfectly plastic range, and the collapse load would gradually increase as the material experiences strain-hardening. The increase in load would then result in adjacent sections progressing into the fully plastic range. For the simple structure shown earlier, as the column ends (the first plastic hinges to form) go into the strain-hardening range, the extent of plastic rotation gradually progresses inward toward the center of the column. For the numerical example of the locomotive cab, the fully plastic moment development would have to extend 16.7 inches inward from each end if the maximum strain is a uniform 15% over the 16.7-inch length. Of course, the strain would not be uniform, but would be greatest at those sections that became fully plastic first. The assumption of a limiting strain that is uniform over the length results in a conservative estimate of the length of plastic involvement, so that the actual extent of fully plastic moment development would be less than 16.7 inches.

The above discussion leads to the conclusion that a structural steel type should be utilized that has an exaggerated strain-hardening range following the perfectly plastic range. The greater the slope of the strain-hardening portion of the stress-strain curve, the more effective will the plastic moment region be expanded to allow the attainment of the total limiting rotation that is required for kinetic energy dissipation. The resulting relative stress redistribution also brings other structural elements into more effective service.

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