REPORT NO. FRA/ORD-77/73, IV

RAIL SAFETY/EQUIPMENT CRASHWORTHINESS

Volume IV: Executive Summary

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JULY 1978

INTERIM REPORT

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No. FRA/ORD-77/73, IV	2. Government Accession No. PB289150	3. Recipient's Catalog No.
4. Title and Subtitle RAIL SAFETY/EQUIPMENT CRASHWORTHINESS Volume IV: Executive Summary		5. Report Date July 1978
		6. Performing Organization Code
7. Author(s) M. J. Reilly		8. Performing Organization Report No. DOT-TSC-FRA 77-15, IV D339-10051-1
9. Performing Organization Name and Address Boeing Vertol Company* Philadelphia PA 19142 P.O. Box 16858		10. Work Unit No. (TRAIS) RR728/R8327
		11. Contract or Grant No. DOT-TSC-821-4
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Research and Development Washington DC 20590		13. Type of Report and Period Covered Interim Report 6/1974 - 1976
		14. Sponsoring Agency Code DTS-744

15. Supplementary Notes

*Under Contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

16. Abstract

The Department of Transportation, Transportation Systems Center (TSC), is presently engaged in providing technical assistance to the Federal Railroad Administration (FRA) in a program directed at improving railroad safety and efficiency by providing a technological basis for improvement and possible regulation in rail vehicle crashworthiness, inspection of equipment, and surveillance of equipment, and other areas. As part of this program, TSC has conducted technical analyses of passenger railcar collisions, derailments, and other accidents, directed towards minimizing occupant injuries.

This document, the fourth of four volumes, summarizes the activities and documentation conducted under this contract. The analysis of the accident data highlighted areas where improvements could be made to improve the occupant protection of passenger rail vehicles. Design criteria were determined and some suitable design changes proposed. For the proposed areas of change, typical Federal Standards documentation were prepared.

Volume I reports on the collection of data for a representative accident sample. Volume II is a design guide to assist engineers in understanding the problems associated with the development of crashworthy interiors of locomotives, cabooses, and passenger railcars. Volume III proposes engineering standards in the format of the Code of Federal Regulations (Title 49, Transportation, Parts 200).

17. Key Words		18. Distribution Statement
Railway Accidents	Locomotive	DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161
Human Tolerance	Caboose	
Occupant Protection	Passenger	
Injury Minimization	Railcar	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	75	PCA04/A01

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This document was prepared for the Department of Transportation, Transportation System Center, Cambridge, Massachusetts, by Boeing Vertol Company under Contract DOT-TSC-821.

Appreciation is extended to the following organizations which provided technical assistance, presented information pertaining to rail vehicle operating practices, and provided rail vehicles in which occupant collision impacts were simulated using live models.

- Electro-Motive Division
  General Motors Corporation
  La Grange, Illinois

- International Car Company
  Kenton, Ohio

- Penn Central Transportation Company
  Wilmington, Delaware

Additional credit is due to the many authors listed in the references for their contributions to the field.

In addition, the author would like to acknowledge the advice on presentation techniques provided by J. H. Wiggins Company of Redondo Beach, California.

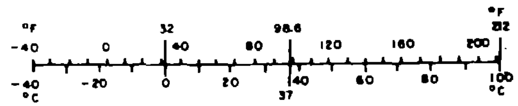
METRIC CONVERSION FACTORS

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	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	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	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°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	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
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	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The Transportation Systems Center (TSC), in providing technical assistance to the Federal Railroad Administration (FRA), has directed a program at improving railroad safety and efficiency through safer rail equipment. The basic problems in minimizing occupant injuries and fatalities (trainmen and passengers) in a collision environment are a function of: primary impact protection (injury due to structural crushing), secondary impact protection (injury due to occupant impacting structure or equipment), and safe post-crash egress.

In support of the TSC effort in improving occupant safety in rail vehicles, Boeing Vertol Company has been contracted to investigate both the primary and secondary impact protection problems under Contract DOT-TSC-856, "A Structural Survey of Classes of Vehicles for Crashworthiness," and Contract DOT-TSC-821, "Rail Safety-Equipment Crashworthiness," respectively.

The structural study (Contract 856) examines the impact effects which result from primary structural failure in several classes of vehicles. The goal of this study is to maintain a survivable occupant living space and to reduce equipment damage.

The rail safety study (Contract 821), the subject of this document, concerns itself with the safety aspects of the interior environment of rail vehicles and addresses the problem of secondary impact effects on the occupants of locomotives, cabooses, and passenger cars. Also part of this study is a technical analysis of railcar accidents including passenger railcar collisions, derailments, and motions causing occupant injuries.

Together, these studies will provide a technological basis for crashworthy railcar structures; improved equipment performance specifications; and possible regulation of rail vehicle crashworthiness, inspection, and surveillance of equipment.

The 821 contract is divided into three tasks. Each task resulted in the preparation of a document as follows:

1. Railway Safety Environment - A Systems Analysis of Injury Minimization In Rail Systems DOT-TSC-821-1.
2. Rail Safety/Equipment Crashworthiness Occupant Protection Design Guide DOT-TSC-821-2.
3. Rail Safety/Equipment Crashworthiness Proposed Engineering Standards DOT-TSC-821-3.

This Executive Summary Report describes the results of the study and the highlights of the contents in the above documents.

2. RAILWAY SAFETY ENVIRONMENT - A SYSTEM ANALYSIS OF INJURY MINIMIZATION IN RAIL SYSTEMS

2.1 SCOPE OF THE INVESTIGATION

This investigation is aimed at determining the causes of injury to rail vehicle occupants in a collision or derailment and studying ways of eliminating or reducing the severity of these injuries. The investigation is limited to occupants of locomotives, cabooses and passenger cars used in inter-city operations. The investigation includes an analysis of data from a representative accident sample to identify injury types, locations, and when possible, injury causal factors. Vehicle interior design details are also considered in conjunction with the accident data to compile a listing of potential improvements to develop occupant protection guidelines.

Secondary impact effects, which is the impact of the rail vehicle occupants with their interior environment, is the subject of this investigation. It is however, only a portion of the overall problem when the crashworthiness of rail vehicles is considered. Figure 2-1 shows the "Basic Requirements for Occupant Survival in a Crash Environment" as a function of three basic problems: primary impact protection, secondary impact protection, and safe post-crash egress.

To aid in the determination of causes of rail vehicle occupant injuries, data surveys of accidents were made. The data was analyzed using the fault tree methodology in an attempt to isolate the major injury causing factors. Typical rail vehicle configurations were investigated in the areas of the occupant's normal seated and standing environment for injury producing potential during an accident. Crash impulses are simulated mathematically for various types of rail vehicles and at different collision velocities. A computer program is used to simulate an occupant's impact within a railcar. Graphs were developed for a simplified determination of impact forces of occupants impacting various interior furnishings.

To prevent and minimize injuries, the crashworthiness state of the art for aircraft and highway vehicles was investigated for application to rail vehicle use. New protective devices are proposed and delethalization procedures discussed. Costs for incorporation of improved crashworthy features in rail vehicles on a new build and retrofit basis are presented.

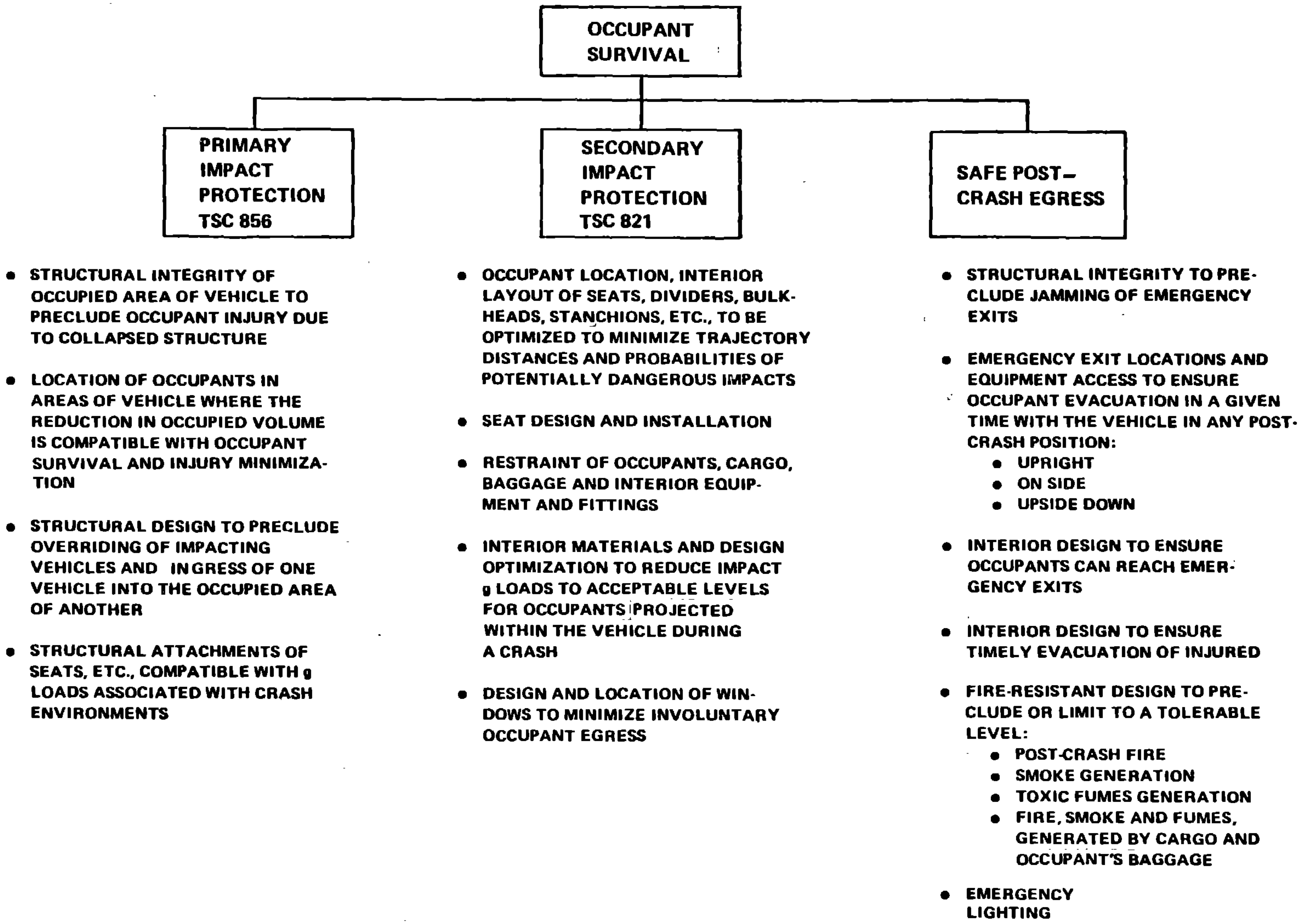


Figure 2–1. ***Basic Requirements for Occupant Survival in a Crash Environment***

2.2 SUMMARY OF KEY FINDINGS

2.2.1 Accident Data

The primary source of data, the FRA T-forms, in general presented the type of accident which occurred, the nature of the injury to the occupant and the type of rail vehicle in which the occupant was riding. The data that was lacking in most of the cases was the injury mechanism or the object that the occupant struck. Of all the fatal injuries reported on FRA T-forms, the injury mechanism was not specified for any of these cases. The great majority of the fatalities were attributed to rail vehicle crushing, after reviewing the few NTSB reports and photographs of the accidents. The more minor injuries and those not attributed to collision received more detailed writeup presumably to justify payment or time off for the injury.

2.2.2 Crash Impulse Simulation

Mathematical simulation of occupants striking typical interior surfaces and furnishings within passenger rail vehicles did not show forces or accelerations generally high enough to produce fatal injury. Although fatal injury can be incurred from a simple fall, the idealized cases analyzed did not show a general trend toward exceeding human tolerance limits.

2.2.3 Injury Mechanisms

Of the 1400 injury cases investigated only 288 presented data on the mechanism producing the injury. Only ten percent of the passenger car injury cases reported the injury mechanism none of which were due to collisions. The mechanism was reported in 18 percent of locomotive accident injuries and 64 percent of caboose injuries. Of the mechanisms reported in the various type rail vehicles, no single one stood out as a chief producer of injury. The 288 injury cases which had the mechanism reported were distributed over 56 items of rail vehicle equipment and structure.

2.2.4 Rail Accidents Contributing to Injury

The initiating accident circumstances contributing to occupant injury is thought to be principally due to collision of two trains. However, there are more incidents of hard coupling and slack action, in which injury occurs, than any other factor. Derailment is the third most frequent occurrence. Rear-end collisions occur at a rate three times as frequently as head-on collisions. Injury due to braking has a high frequency of occurrence while train motion accidents and grade crossing collisions occur at an average frequency.

Derailment accidents produce the greatest number of injuries but rarely cause fatalities. Rear-end collisions produce the next greatest number of injuries and when structural crushing occurs there are a high number of fatalities.

2.3 TYPICAL RAIL VEHICLES INVESTIGATED

Interior arrangements, equipments, furnishings and structures of typical rail vehicles were investigated for their potential to cause injury due to acceleration of occupants within them. One locomotive, three basic types of passenger cars and four cabooses were included in the investigation.

2.3.1 Locomotive

The EMD GP-40 locomotive was selected as the typical general purpose locomotive in large quantity usage on railroads throughout the United States. The occupied cab was investigated and the seating environment reported on. Controls, equipment, furnishings and structure with potential to cause injury when impacted were shown. Other areas with potential to cause injury to trainmen when walking about the cab were described.

2.3.2 Passenger Rail Cars

Three basic type passenger rail cars were reviewed as representing typical passenger environments: coach, parlor car, and snack bar coach. Each car was analyzed for seating arrangement, inherent containment provisions, and surfaces or equipment with potential to cause injury if impacted.

Coach type passenger railcars have similar interior arrangements; however, various types of seats, windows, and furnishings are used. Potential hazards discovered in the investigation were described. The nature of injuries anticipated as a result of the deficiencies in the design of the furnishings was pointed out.

Parlor cars are equipped with swiveling seats, desks and other variances from the coach. The additional hazards of these furnishings were discussed.

Snack bar cars presented many hazards in the stand-up food preparation and eating area. The lethal objects one could impact in this area were shown as well as the hazards for standing occupants to be thrown long distances.

Caboose rail vehicles present many impact hazard areas and are highly vulnerable to rear end collision. Four caboose versions are shown with the areas of potential impact hazards.

2.4 EVALUATION OF SYSTEM SAFETY TECHNIQUES

A formal systematic analysis technique was used for considering the safety aspects of rail vehicle occupied environments. These techniques have only emerged in the last decade as viable methods for dealing with complex systems. The objective of any safety analysis is to identify hazardous conditions and provide for their elimination or control.

Various state-of-the-art system safety analysis techniques employed in such fields as aerospace and nuclear power were investigated for their appropriateness to rail safety analysis. The fault tree analysis and preliminary hazard analysis techniques were selected as the most appropriate for the rail injury minimization program. These analyses were selected because they cover the spectrum of those elements considered essential to a basic safety technique and provide the necessary analytical depth and visibility for this program. The initial analytical step (the fault tree) provides a pictorial display of the scope of the analysis. The preliminary hazard analysis matrix then permits the hazardous conditions to be analyzed for the necessary corrective action. Figure 2-2 displays the safety analysis procedure used for this program.

The procedure is described in three steps: defining undesired event, requiring system understanding and constructing fault tree. Construction of the fault tree procedure is described using Boolean functions with basic; special and matrix gates (Figure 2-3).

2.5 RAIL VEHICLE ACCIDENT DATA

2.5.1 Acquisition of Data

A data file was compiled of major railroad accidents which have occurred since 1967, where personal injuries have been involved. Four primary data sources were used:

- NTSB Railroad Accident Reports
- FRA Railroad Accident Reports
- FRA Accident Bulletins (Annual Summary)
- FRA T-Forms

2.5.2 Classification of Accidents

The data was classified into the following principal types of rail vehicle accidents in which occupants are injured:

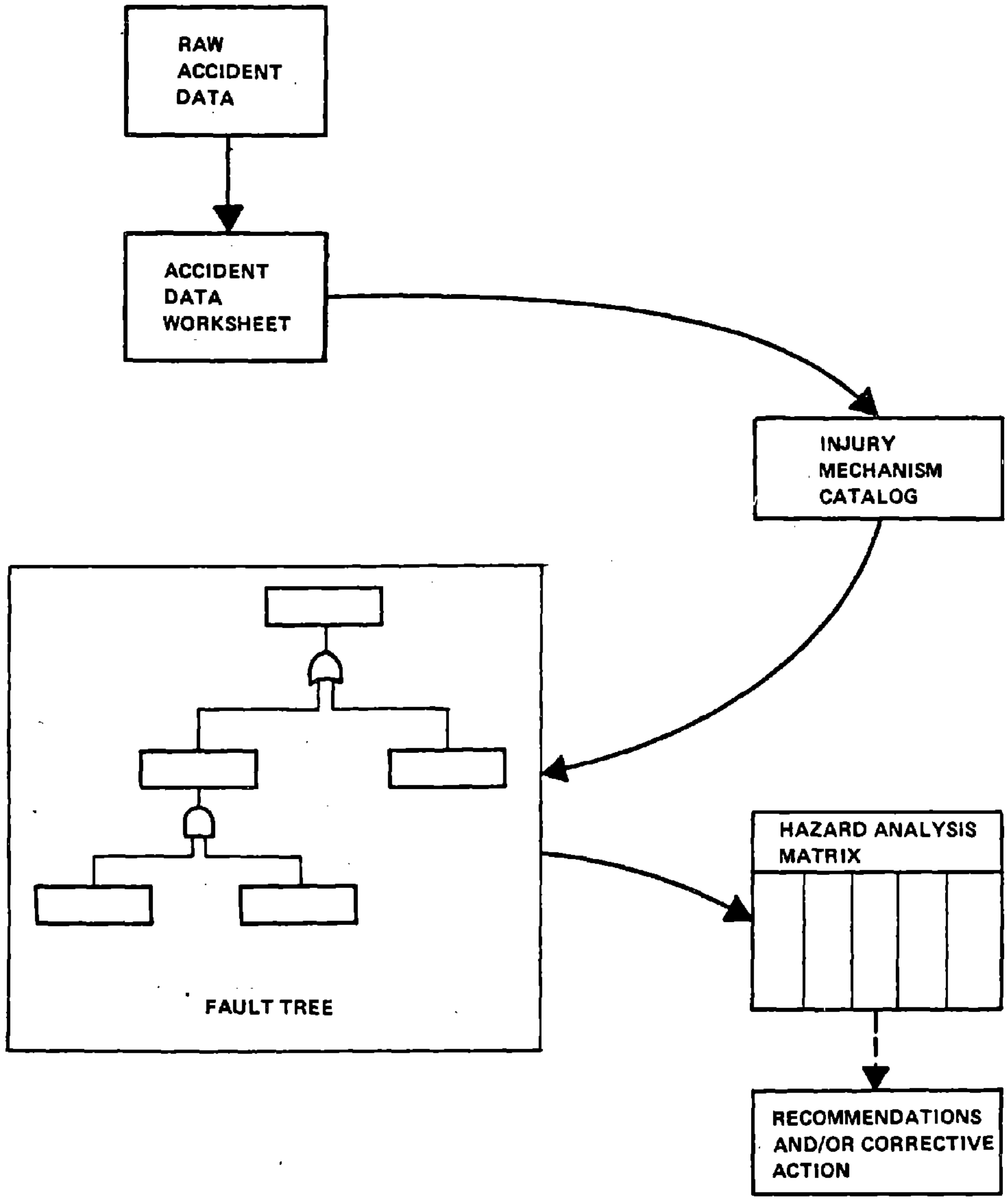
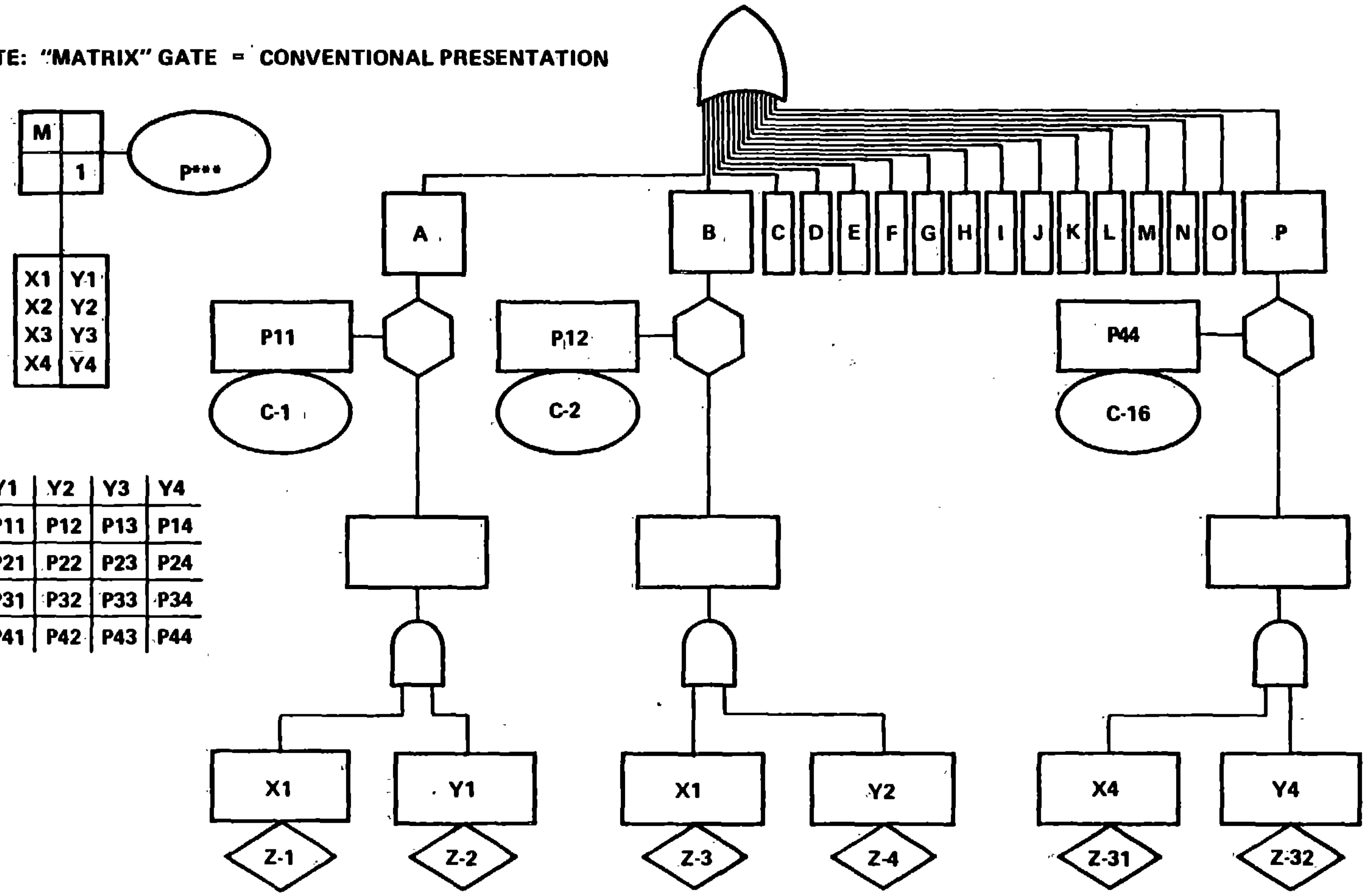


Figure 2–2. Safety Analysis Procedure Used for the Rail Injury Minimization Program

NOTE: "MATRIX" GATE = CONVENTIONAL PRESENTATION



M1	Y1	Y2	Y3	Y4
X1	P11	P12	P13	P14
X2	P21	P22	P23	P24
X3	P31	P32	P33	P34
X4	P41	P42	P43	P44

*Figure 2–3. **Matrix Gate Equivalent***

- Head-on Collision
- Rear-end Collision
- Side or Cross Collision
- Grade Crossing Collision
- Derailment
- Hard Coupling
- Slack Action
- Braking

Collisions and derailments are the more serious type accident and are likely to cause serious or fatal injuries. These type accidents are most relevant to the secondary impact situation. Design requirements for impact protection are established based on the impulses generated during these accidents. A graphic presentation is shown of the cumulative distribution of accidents as a function of impact velocity. The less severe types of accidents are also discussed.

2.5.3 Quality of Accident Data

A detailed investigation was made to pinpoint the cause of injury in rail vehicles so that interior arrangements and equipment design requirements could be established. FRA T-forms for the years 1972 and 1973 were used as the basis of the investigation. Injury data on 1400 persons were reviewed. The extent of the injury, the type of railcar the injury occurred in, and the type of train accident which precipitated the injury were documented on the T-forms. A summary of the number of injuries and types of accident causing the injuries appears in Table 2-1.

T-form data on injury mechanisms was minimal. Of the 1400 cases investigated, only 288 reported the device, structure, or condition which caused the injury. Documentation as to the injury causing mechanism was not available for any of the occupants that received fatal or serious injury in a collision. Injury mechanisms for passenger car occupants were the least documented, amounting to less than 10 percent none of which occurred in a collision. The highest percentage (64 percent) of injury producing factors were documented in caboose accidents. For locomotive injuries, only 18 percent of injury causes were included in the accident reports.

To gain further insight into injury producing circumstances, an investigation was made to determine the areas of the body most frequently injured. The types of injuries received by the particular occupant of a particular type of rail vehicle was compared with the seated environments of that occupant. In most cases an injury trend was evident and could be associated with a particular piece of equipment or structure peculiar to that occupants station. By this analysis the injury mechanism could be pinpointed and recommendations made for crashworthiness improvements.

TABLE 2-1. INJURY MECHANISM CATALOG SUMMARY
(T-FORM DATA FOR YEARS 1972 AND 1973)

ACCIDENT CATEGORY	NUMBER OF INCIDENTS				NUMBER INJURED				NUMBER KILLED			
	LOCO	CAB.	P CAR	TOTAL	LOCO	CAB.	P CAR	TOTAL	LOCO	CAB.	P CAR	TOTAL
A. MISC, TRAIN NOT MOVING	10	1	7	18	10	1	7	18	—	—	—	—
B. MISC, TRAIN MOVING	5	3	12	20	5	3	16	24	—	—	—	—
C. TRIPPED/LOST BALANCE	1	5	8	14	1	5	8	14	—	—	—	—
D. HARD COUPLING	53	33	1	87	60	35	1	96	4	2	—	6
E. TRAIN MOTION	1	4	29	34	1	4	29	34	—	—	—	—
F. EQUIP. FAILURE	11	2	5	18	11	2	5	18	—	—	—	—
G. SLACK ACTION	11	77	0	88	11	78	0	89	—	—	—	—
H. BRAKING (INCL EMERGENCY)	7	44	11	62	7	47	13	67	—	—	—	—
I. SUDDEN LURCH (JERK)	2	5	17	24	2	5	17	24	—	—	—	—
J. GRADE CROSS. COLL.	26	3	4	33	40	4	8	52	1	—	—	1
K. HEAD-ON COLL.	26	1	0	27	47	3	0	50	35	2	0	37
L. CROSS COLLISION	14	4	0	18	26	4	0	30	2	0	0	2
M. REAR END COLL.	38	31	7	76	64	42	271	377	12	6	47	65
N. DERAILMENT	30	36	16	82	46	42	381	469	8	0	2	10
TOTAL	235	249	117	601	331	275	756	1362	62	10	49	121

2.5.4 Analysis of Accident Data

The FRA Accident Bulletin data was used to determine the distribution of major accident types for the years considered in this study. Figure 2-4 shows the percentage distributions for the various accident types and Table 2-2 a breakdown of the accident types per year. Derailment and grade crossing accidents predominate, accounting for 80 percent of all accidents, while switching accidents account for 81 percent of all collisions.

An analysis was made of the percentage of casualties associated with secondary impacts for which this study is concerned. This area accounts for 19 percent, 44 percent and 41 percent of all casualties respectively for locomotives, railcars, and cabooses involved in all accident types. When fatalities are considered, secondary impact effects account for only eight percent, three percent, and twelve percent respectively for locomotives, passenger railcars, and cabooses.

2.5.5 Injury Mechanism Assumptions

Of the many injury and fatality cases investigated in the FRA "T" forms, generally missing was data on the injury mechanism or situation. In an effort to make assumptions as to the unknown mechanisms, the abundant T-form data on the types of injuries incurred was used in conjunction with the known environment in the vicinity of the injured occupant. The cumulative injury data was plotted for the various types of rail vehicles for each type of accident and an example is shown in Figure 2-5 for passenger injuries. An analysis to determine injury mechanisms was made for locomotives, cabooses and passenger railcars.

2.5.6 Fault Tree

The fault tree was used to show the interrelations of the various causes resulting in occupant death or injury. It was developed basically to conform to injury categories established in the FRA T-Form. Each of these injury categories was developed in the fault tree to the level appropriate to the T-Form data. Generalized matrices were developed for the general injury mechanism caused by falls, persons thrown against structure, or by loose objects impacting occupants, M1*, M2*, and M3*. An example of a matrix is shown in Table 2-3 which shows relative frequency and injury severity. An analysis was made of this data and injury mechanism bar chart prepared for each type rail vehicle. An example is shown in Figure 2-6.

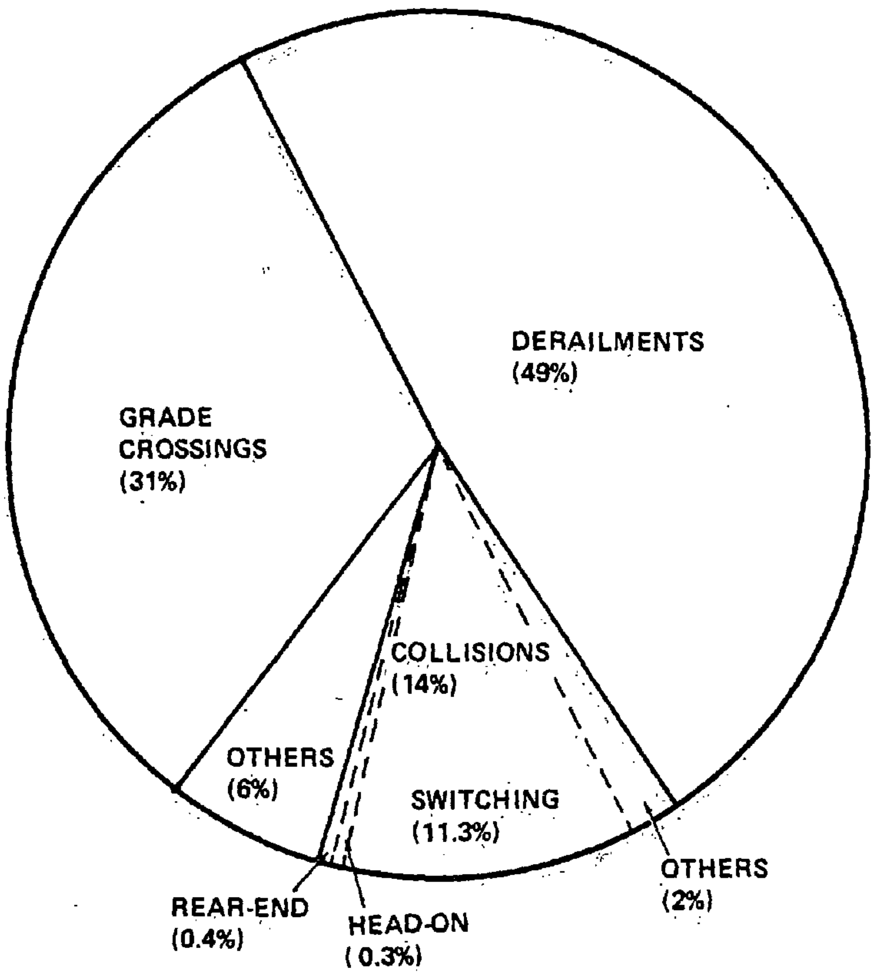


Figure 2–4. FRA Accident Summary (1967 through 1973)

TABLE 2-2. **FRA ACCIDENT BULLETIN DATA SUMMARY**

TYPE OF ACCIDENT	1967	1968	1969	1970	1971	1972	1973	TOTAL	% DIST.
HEAD-ON COLLISION	30	31	29	30	30	26	24	200	0.25
REAR-END COLLISION	24	36	57	48	34	42	59	300	0.37
SWITCHING COLLISION	1,204	1,427	1,409	1,426	1,279	1,090	1,383	9,218	11.32
OTHER COLLISIONS	264	233	315	252	186	190	191	1,631	2.00
TOTAL COLLISIONS	1,522	1,727	1,810	1,756	1,529	1,348	1,657	11,349	13.94
DERAILMENT	4,960	5,487	5,960	5,602	5,131	5,509	7,307	39,956	49.07
OTHERS	812	814	773	737	644	675	411	4,866	5.98
TOTAL TRACK ACCIDENTS	7,294	8,028	8,543	8,095	7,304	7,532	9,375	56,171	68.99
GRADE CROSSING	3,932	3,816	3,774	3,559	3,392	3,379	3,400	25,252	31.01
TOTAL ACCIDENTS	11,226	11,844	12,317	11,654	10,696	10,911	12,775	81,423	100.00

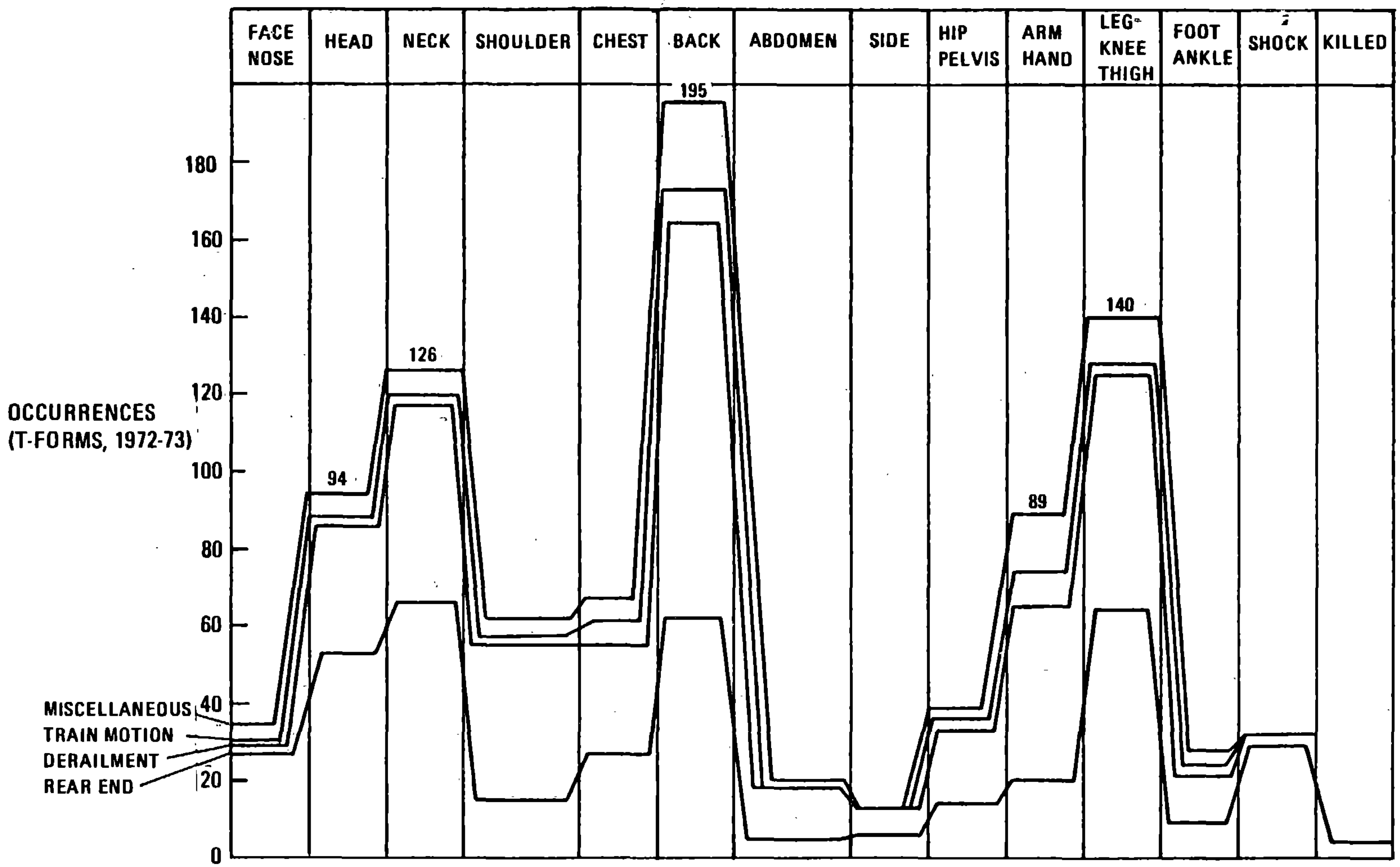


Figure 2–5. Cumulative Injuries in Passenger Cars

TABLE 2-3. MATRIX M2*, GENERAL CASE FOR OCCUPANT DEATH OR INJURY, OCCUPANT THROWN AGAINST HOSTILE STRUCTURE

NOTE: Numbers in matrix are: (Number of Injuries)/(Days Disabled per Injury)

M2* = Occupant death or injury, occupant thrown against hostile structure

.X2*j = Occupant thrown due to j, where j is as follows:

j	INJURY INITIATING FACTOR
01	Tripped or lost balance
02	Rear-end collision
03	Head-on collision
04	Cross collision
05	Grade crossing collision
06	Hard coupling
07	Slack action/lurch/jerk
08	Braking
09	Derailment
10	Equipment failure
11	Person or other person
12	Other train motion
13	Vandal

.Y2*b = Occupant is injured by b, where b is as follows:

b	INJURY PRODUCING FACTOR
01	Floor
02	Table or desk
03	Bulkheads/walls/door flat
04	Stove
05	Shattered glass pane
06	Bars/rails/stancheons
07	Seat
08	Control console
09	Water cooler
10	Cabinet/locker/shelf
11	Door or window edge/frame
12	Persons own reaction
13	Unknown
14	Boxes/baggage
15	Misc. equipment
16	Platform edge

		Y2*01	Y2*02	Y2*03	Y2*04	Y2*05	Y2*06	Y2*07	Y2*08	Y2*09	Y2*10	Y2*11	Y2*12	Y2*13	Y2*14	Y2*15	Y2*16	Total
X2*01	Loco																	
	Pass	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	Cab.																	
X2*02	Loco			1/8						1/5				1/5	1/40			4
	Pass																	
	Cab.			1/8										1/10				2
X2*03	Loco															1/29		1
	Pass																	
	Cab.			1/10														1
X2*04	Loco			1/21			1/30	1/40										3
	Pass																	
	Cab.																	
X2*05	Loco								1/10	1/8	1/60			1/60				4
	Pass																	
	Cab.			1/15														1
X2*06	Loco			3/15				2/50	7/27		1/4	5/26	12/27	7/27				37
	Pass													1/30				1
	Cab.	3/10	8/23	4/37	2/38		1/30	1/14			3/12		2/10	2/38				26
X2*07	Loco			1/90					3/7	2/15		2/10	3/13					11
	Pass	1/14		1/14				3/25					1/21	2/10		1/9		9
	Cab.		12/12	11/20	6/26		6/23	6/16	3/33	1/3	1/28	2/9	4/29	3/5		8/17		63
X2*08	Loco			1/90			1/10		1/30							1/35		4
	Pass	1/3	1/7	4/29			1/21									1/10		8
	Cab.	6/28	6/4	10/23	3/19		7/18	1/34				2/15	3/19	4/12		3/16		45
X2*09	Loco			1/5						1/30				1/45				3
	Pass																	
	Cab.			1/25	1/6			2/13					3/47	1/7				8
X2*10	Loco												1/4					1
	Pass														1/7			1
	Cab.																	
X2*11	Loco								1/50	1/7			1/9					3
	Pass																	
	Cab.						1/4									1/30		2
X2*12	Loco																	
	Pass	1/5	2/10	2/30				1/14				1/3				3/10		10
	Cab.			1/14		1/45		1/2										3
Total		12	29	45	12	1	18	18	16	7	6	12	30	24	2	19		

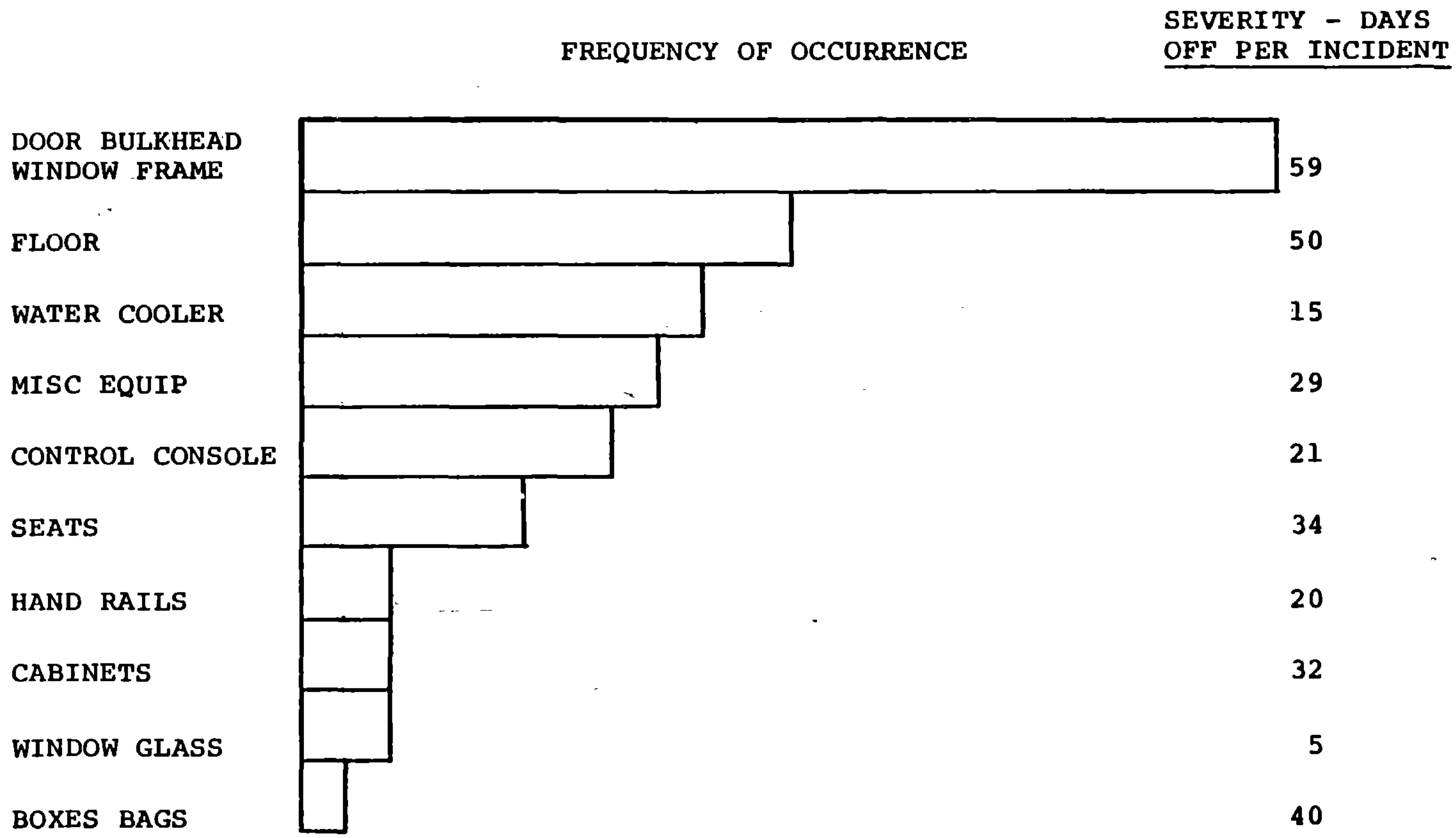


Figure 2–6. LOCOMOTIVE INJURY MECHANISM FREQUENCY

2.6 CRASH IMPACT SIMULATION

2.6.1 Computer Program Mathematical Simulation

The primary purpose of mathematically simulating an injury mechanism is to readily test injury minimization devices and procedures. A review of available mathematical models of vehicle occupants in crash environments was conducted with a view to selecting a prospective candidate for adaptation to rail vehicle accidents. The Prometheus program was selected and modified to adapt it to rail vehicle occupant conditions.

In order to demonstrate the Prometheus model performance a seated rail vehicle occupant was used to show the dynamics during a collision. The scenario is of a seated passenger, in a passenger railcar, during collision, being thrown into the back of the adjacent seat. Velocities, accelerations, and pulse times were determined for the areas of the body which impacted the seat back. Graphic displays of the occupants time history showing plots, critical body segment velocities and accelerations are produced by the Prometheus program. These plots were included in the report.

2.6.2 Alternate Simulation Methods

A simple crash impact simulation method was sought which would be less expensive to run than the computer programs. A single degree of freedom model was developed which provides an excellent initial design tool from which an order of magnitude answer can quickly and easily be determined. This model assumes that an occupant collision which could involve various body segments impacting different surfaces can be represented by a series of individual body segment masses impacting into nonlinear springs. Each individual body segment collision is characterized by an effective mass and impact speed. To simplify the analysis the assumption can be made that the deceleration pulse is completed prior to occupant impact. In some cases this may result in a conservative solution. The idealization of the impact as a pure mass and spring system also is conservative since it does not consider energy losses from friction damping or structural deformation. The predicted impact forces would be slightly greater than actually experienced.

The single degree of freedom simulation method was used with the same accident scenario used for the Prometheus test case which was of a passenger being hurled forward into the adjacent seat back. This alternate method idealizes the accident as two collisions; one involving the mass of the pelvis and upper leg impacting the seat back center and a second collision involving the head mass and the upper seat back cushion. Methods of performing the calculations are presented in the report.

Good correlation was obtained with both methods in obtaining head and knee impact forces. The calculated knee impact force using the one degree of freedom model was 490 pounds compared to a knee force from the Prometheus Program of 325 pounds.

Based on the good correlation between the Prometheus Program results and the alternate simulation results a graphical solution was developed to permit the engineer to quickly evaluate the injury potential of rail vehicle interiors. To use these graphical solutions, the design engineer must know the rail vehicle deceleration pulse, the effective body mass, and the effective stiffness of the object impacted by the occupant. A series of charts and graphs were developed which in conjunction with simple equations can be used to design impact surfaces for energy absorption within human tolerance. Sample calculations are also shown in the report.

2.6.3 Rail Vehicle Deceleration Pulse Simulation

A simple FORTRAN coded program was developed to provide a consistent basis for estimating the vehicle acceleration/deceleration pulses occurring in longitudinal impacts. The program and its inputs and outputs are described.

Analyses were performed to determine the acceleration pulse produced during the collision of various types of train consists in head-on and rear-end collisions at various velocities. The accident scenarios selected for analysis are:

1. Head-on collision between two freight trains
2. Rear-end collision between two freight trains
3. Rear-end collision between two passenger trains.

Graphs of each collision situation and for various impact velocities were prepared.

2.7 INJURY MINIMIZATION CONSIDERATIONS

With the determination of the basic causal factors which produce injury, as discussed previously, consideration can now be taken in identifying the approach to minimizing the injurious effects of accidents. Several approaches can be considered for the minimization of occupant injury as follows:

- o Occupant restraint or containment to prevent impact with hostile surfaces
- o Removal of or cushioning hostile surfaces

- o Retention of loose objects to prevent impact with occupants

Occupant injury can be prevented or minimized by restraining the occupants to their seated positions. A restraint system will prevent the occupant from being accelerated into a hostile surface. Active or passive restraint systems can be used. Each type of restraint system is discussed as well as their advantages, disadvantages and recommended use. Probabilitity of use and costs of active systems are compared to passive systems. Containment systems utilizing conventional seating and partitions are discussed.

Preparation of surfaces for delethalization through construction, padding and removal of protrusions are described.

Retention of loose objects or objects torn loose due to inadequate attachments are discussed. Included is retention requirements for luggage, portable equipment and stationary equipment.

2.8 REVIEW OF RELATED CRASHWORTHINESS TECHNOLOGY

2.8.1 State-of-The-Art

Government requirements have been established for crashworthiness of passenger cars, trucks and buses, and for military aircraft. As a result, the development of crashworthy features has been principally for these vehicles. The Department of Transportation National Highway Traffic Safety Administration and the United States Army have issued regulations, standards and guides for crashworthiness provisions. DOT has issued 26 safety standards and 20 crashworthiness standards for highway vehicles. Highlights of these standards are presented as well as those of the Military Crash Survival Design Guide and various Military Standards.

2.8.2 Concepts Applicable to Rail Vehicles

Of the existing regulations and standards pertaining to crash safety, some can be considered to be applicable in whole or in part for use in locomotives, passenger railcars or cabooses. The applicable concepts or data and their source are summarized in the report along with their application to rail vehicles.

2.9 HUMAN TOLERANCE TO IMPACT

Human tolerance is difficult to establish because of the obvious impracticability of subjecting humans to impact at serious injury levels. Much testing has been done at low acceleration levels using human subjects and at the higher bone fracturing levels using cadavers. The area where minimal data is available and where it is needed for design of rail vehicle crashworthiness is the minor injury threshold level. Existing data was reviewed and where necessary was extrapolated to obtain crash impact deceleration human tolerance limitations for impact surface designs. Human tolerance levels for various parts of the body impacted are discussed and tests reports referenced along with their authors. Various injury criteria and indices used to evaluate the severity of injury are discussed. A table of injury terms and parts of the body are given. Injury data on the parts of the body given are for head impact, face impact, knee-thigh-hip complex impact, neck flexion and extension, whole body impact, limb flailing, back injury, thorax impact, lower limb bending and face-to-face occupant impact.

2.10 CANDIDATE INJURY MINIMIZATION TECHNIQUES

The injury mechanisms causing the greatest number of injuries and those causing the greatest severity of injuries was previously discussed. Using this data candidate techniques for minimizing the injuries are presented. The mechanisms and the severity are peculiar to the type of rail vehicle in which the injury occurs. Therefore the techniques are presented for specific types of rail vehicles.

2.10.1 Locomotive Injury Minimization Techniques

Injuries due to impact with the bulkhead, door and window frame produced the greatest number of injuries and the magnitude of the injuries were more severe than all other injuries. Calculations for impact of the engineman or helper into the front bulkhead or door glass can produce fatal head injuries during a collision. Methods of retaining the locomotive occupants to prevent impact with the injury producing surfaces are presented along with their advantages and disadvantages.

Other injury mechanisms and their minimizing techniques are presented in the order of their frequency of occurrence and severity of injury.

2.10.2 Caboose Injury Minimization Techniques

The injury mechanisms most frequently involved in caboose trainmen injuries were impact with bulkheads, doors, table/desks and railing with moderate injuries resulting. At least half of all injuries occurred from a seated position. These seated position injuries could be prevented by providing adequated restraint or containment in the seated position. Methods of retaining caboose trainmen in their seated positions are presented.

Other injury mechanisms and their minimizing techniques are presented in their order of frequency of occurrence and severity of injury.

2.10.3 Passenger Railcar Injury Minimization Techniques

The most frequently occurring mechanisms in passenger railcar occupant injuries are, bulkheads, doors and window frames. Minor to moderate injuries are produced. The rigidity of these surfaces produced the injuries. Padding on the surfaces of design for deflection would reduce the injuries.

Seats were the next most frequent cause of injury. Armrests were the predominate factor in seat caused injuries. The rigidity of these surfaces produce injuries. Sufficient padding would reduce the injuries.

Other injury mechanisms and their minimizing techniques are presented in their order of frequency of occurrence and severity of injury.

2.11 COST OF THE INJURY MINIMIZING DEVICES

Costs for proposed crashworthiness modifications of locomotives, cabooses and passenger railcars for new construction and retrofit are presented.

2.11.1 Locomotive Collision Safety Provisions Cost

A typical intercity freight locomotive, the EMD GP-40, was used for design modifications of proposed collision safety features. Features selected for costing were as follows:

- o Improved engineman's control console with padded guards
- o Engineman and helper containment buffer
- o Improved seats with high back, headrest and track adjustment
- o Delethalization of cab interior equipment

Descriptions of these modifications are presented and modification costs are listed in Table 2-4.

2.11.2 Caboose Collision Safety Equipment Costs

A typical bay window caboose was used for design modifications of proposed collision safety features. Features selected for costing were as follows:

- o Caboose trainmen restraint system
- o Crashworthy seats
- o Containment for bunks
- o Interior delethalization to include the following:
  - a. Recessed knobs, handles, gages, valves, etc.
  - b. Flush partitions covering oil tank, water tank, water cooler, refrigerator, heater, pipes, etc.

Descriptions of these modifications are presented and modification costs are listed in tabular form similar to Table 2-4.

2.11.3 <u>Passenger Railcar Collision Safety Provisions Cost</u>

A typical passenger railcar having double seats on each side of a central aisle and lavatory partitions or bulkheads at each end was used for design modifications of proposed collision safety features. Features selected for costing are as follows:

- o Passenger seat improvements
- o Partition and bulkhead padding
- o Luggage rack doors

Descriptions of these modifications are presented and modification costs are listed in tabular form similar to Table 2-4.

TABLE 2-4. LOCOMOTIVE INJURY MINIMIZING PROVISION COSTS

ITEM	BASIC REVISIONS	COST PER SYSTEM-$ NEW BUILD	COST PER SYSTEM-$ RETROFIT	NUMBER OF SYSTEMS PER LOCOMOTIVE
Control Console	Relocate Instruments and Handles Add Padded Guard	86	1,975	1
Containment Buffer	Side Wall Structure Add Padded Buffer	115	352	2
Crashworthy Seat	High Back-Arm Rests-Shoulder Pads-Track	300	350	2
Cab Delethalization	Recess Handles, Knobs, Small Equip., Water Cooler- Add Padding	800	2,000	1
Total Cost per Locomotive All Systems		1,716	5,379	

NOTE: Costs include installation

3. RAIL SAFETY/EQUIPMENT CRASHWORTHINESS OCCUPANT PROTECTION DESIGN GUIDE

3.1 BACKGROUND: VEHICLE CRASHWORTHINESS STATE-OF-THE-ART

Crash survivability study, test, and implementation in highway vehicles and aircraft have established a crash survival state-of-the-art.

Government requirements have been established for crashworthiness of passenger cars, trucks, and buses, and for military aircraft. As a result, the development of crashworthy features has been principally for these vehicles. The Department of Transportation (DOT) National Highway Traffic Safety Administration and the U.S. Army have issued regulations, standards, and guides for crashworthiness provisions. Safety and crashworthiness standards have been issued by DOT and are being incorporated in the manufacture of highway vehicles, with some standards directly applicable to rail vehicles.

Rather than being crash-oriented, existing federal regulations of the Department of Transportation's Federal Railroad Administration have been primarily based on accident safety. Amtrak locomotive specifications, however, include some collision requirements for glass, seat structures, fire retardants, and escape provisions.

3.2 DATA SOURCE

Potential interior design improvements presented in this guide are based on:

- accident data
- current state-of-the-art design concepts used in other vehicles (such as automobiles and aircraft)
- development of new concept safety devices through fullscale mockups using live subjects, and the
- results of mathematical simulations of the dynamic response of occupants who impact vehicle interiors in typical accident scenarios.

Data collected from a representative accident sample was analyzed to identify injury types, locations, and when possible, injury causal factors. The analyzed sample consisted of accidents which occurred within the 1967-73 time frame and warranted the issuance of a formal report either by the National Transportation Safety Board (NTSB) or the FRA.

Details on injuries sustained were obtained from FRA T-forms for the years 1972 and 1973. These data included injuries resulting from collisions, train motions, equipment failures and occupant clumsiness. Injuries occurred in locomotive, cabooses and passenger railcars.

3.3 GENERAL DESIGN CRITERIA

The overall objectives in injury minimization to rail vehicle occupants in a collision is to restrain or contain seated occupants to prevent their being thrown into injurious objects, to minimize the distance unrestrained occupants are thrown and to remove injurious or loose objects from their environment. Cost minimization is an important factor in how these objectives are implemented. Another consideration in the implementation is whether the crashworthiness provisions are to be retrofitted into existing rail vehicles or are to be incorporated into new production vehicles. Keeping cost in mind, crashworthiness provisions for a new production vehicle may not be economically feasible to retrofit in an existing vehicle. Above all, consideration must be given to whether the device provided to prevent injury in a collision would be made use of if it required the occupant to willfully apply the device.

In general the design criteria for rail vehicle crashworthiness can be summed up in the following manner:

1. Restrain seated rail vehicle occupants from being thrown forward into an unyielding or hazardous surface.

2. Minimize the distance an unrestrained occupant can travel from their seated position to a non hazardous surface or object in front of them.

3. Assure that the object impacted in front of an unrestrained seated position presents a smooth surface free of protrusions and is sufficiently deformable or padded to absorb the impact energy, to reduce the forces below the injury threshold.

4. Provide sufficient seat back surface and strength to support the upper torso and head to prevent back and neck injury (whip-lash) due to rearward accelerations.

5. Eliminate the capability for passenger seats to be rotated to a face-to-face position or to become unlocked during a collision. (Seat rotation should be limited to train personnel using a special tool or key.)

6. Eliminate the capability for seated occupants legs to become wedged under a seat or equipment in front of them.

7. Eliminate hazardous furnishings such as window shades, unpadded or nonyielding sunvisers, flammable materials or material which give off toxic fumes.

8. Equipment which can be struck by standing rail vehicle occupants which is irregular shaped or has a high temperature should be covered with shrouds, shields or flush panels.

9. Remove small irregular surfaced objects mounted on bulkheads and stow in flush surface compartments.

10. Eliminate protective railings, grab rails and stanchions and replace with recessed hand grabs in flush panels.

11. Flush or recess all knobs, handles, latches, lighting fixtures etc.

12. Secure all portable and fixed equipment to withstand collision forces without tearing loose.

13. Provide closed compartments for passenger luggage.

14. Pad or design for deformation all surfaces subject to impact by rail vehicle occupants.

3.4 RAIL VEHICLE INJURIOUS ENVIRONMENT

Injuries to rail vehicle occupants during collision or derailment when the rail vehicle remains relatively uncrushed are generally caused by acceleration of the occupant into objects in their immediate vicinity. The degree of injury is dependent upon the velocity of the vehicle at the time of collision, the rigidity or irregular surface of the object struck and the distance the occupant is thrown to the object struck. Collision velocity, up to a point, affects the acceleration of the occupant within the vehicle but the distance the occupant travels is the principal determinant of impact velocity. The injury mechanisms characteristics of deformability and surface continuity is of particular importance in injury determination.

3.4.1 Rail Vehicle Coolision Design Pulse

Design of protective devices for occupants of rail vehicles in a collision is dependent upon the deceleration pulse experienced by the vehicle in which they are riding. The magnitude and duration of the pulse varies for different types of rail vehicles such as locomotives, passenger cars and cabooses. The velocity of the car at impact also determines the pulse shape but to a lessor degree.

Plots of deceleration versus time for either of two freight train locomotives in a head-on collision at speeds of 10, 20, 40 and 80 mph are shown in Figure 3-1. Similar impulse plots were made for locomotive impacting the rear of a freight train, and passenger car impulse when impacted by a locomotive. From these impulses occupant accelerations can be determined. Of significance in the study was the fact that the impulses at 80 mph varied only slightly from those at 10 mph.

3.4.2 Injury Producing Environment

Accident injury analysis has associated the major causes of injury, other than those related to structural crushing, to environmental factors such as lack of occupant restraint and deficiencies of equipment design and location. To identify potential design improvements, simulated motions of occupants under collision acceleration are presented using typical high usage locomotives, passenger railcars, and cabooses.

An EMD GP-40 locomotive cab is shown to illustrate a typical interior arrangement and the potential collision hazards to the trainmen. Two or more trainmen occupy the cab: an engineman/engineer and a helper/fireman. The engineman is particularly vulnerable to injury in a collision due to the equipment directly in front of him into which he could be thrown (Figure 3-2).

The locomotive cab space available for the helper and other trainman on the left side, is usually clear and unobstructed. The main hazard for the helper is the potential for him to be thrown into the door or into the glass in the door (Figure 3-3).

Equipment installed in the cab may present an impact hazard to occupants when accelerated from a seated or standing position. Consideration must be given to their placement.

An ICC wide vision cupola type caboose is shown to illustrate a typical interior arrangement and the potential collision hazards to the trainmen. The cupola observation post and the conductor's desk location areas are of particular interest for injury-producing situations (Figures 3-4 and 3-5).

In a caboose injury can result during collision, slack action, or hard coupling by being thrown into the bulkhead, handhold and possibly through the window. Injury is also possible by impacting the side wall, window, or guard railing or by falling from the cupola to the car floor. Additional injury producing hazards are: fuel tank and bunk supporting structure, water coolers and refrigerators, fire extinguishers,

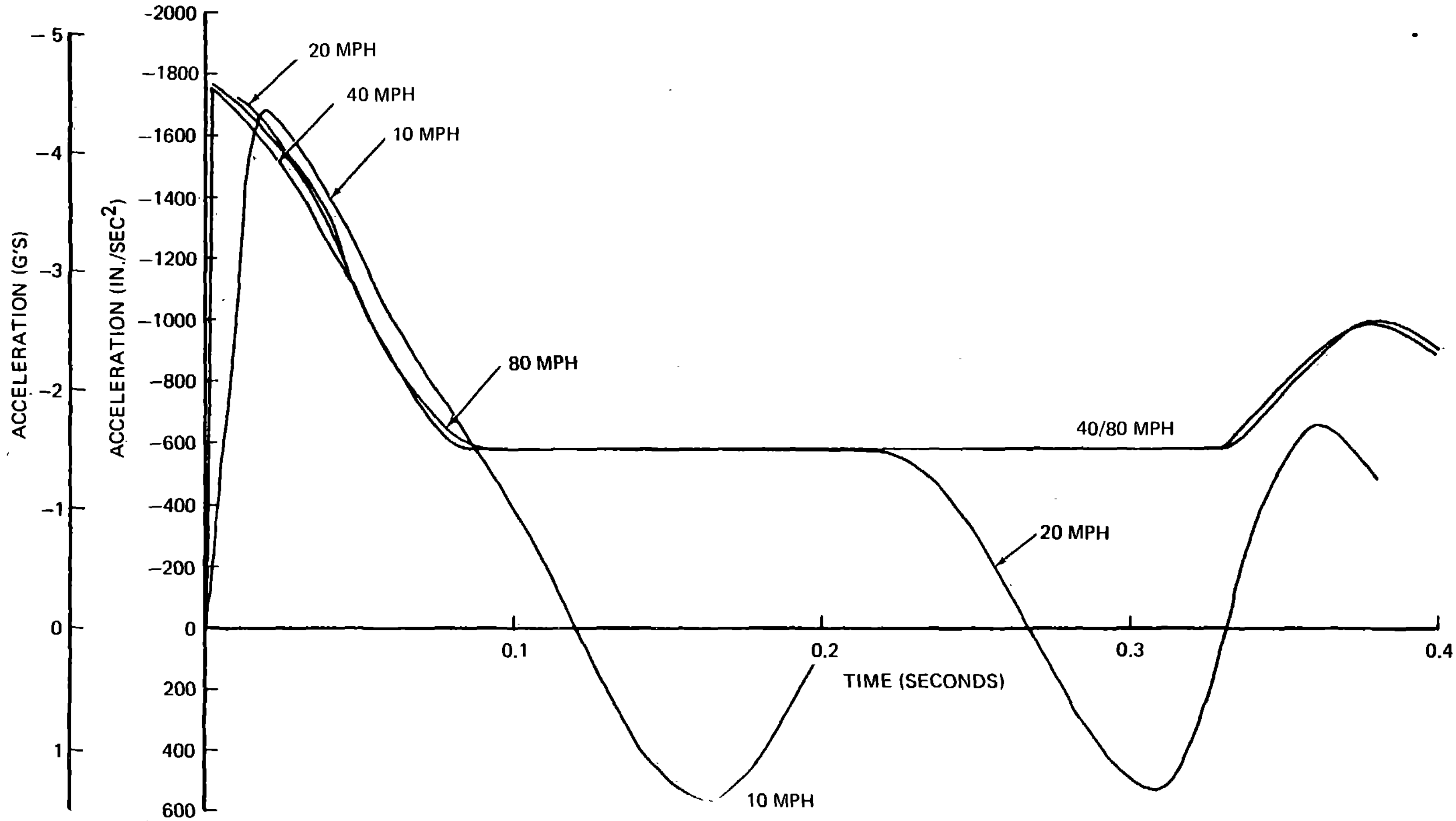


Figure 3–1. Freight Train Locomotives in Head-On Collision: Acceleration vs Time

Figure 3–2. Potential Hazards to Engineman Impact

Figure 3–3. Forward Acceleration Injury Potential

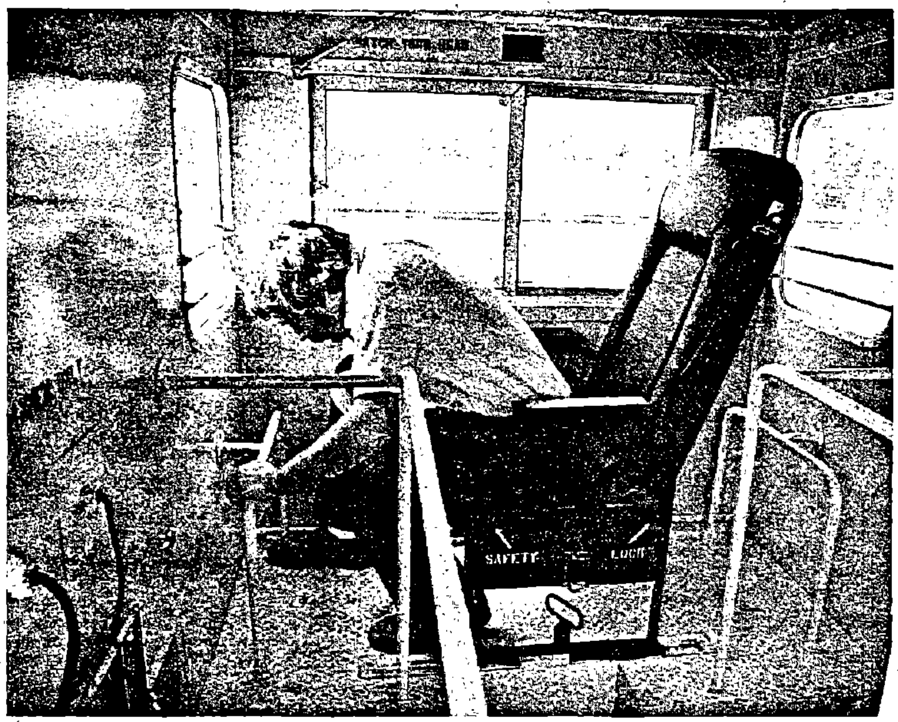


Figure 3–4. Cupola Hazards Under Forward Acceleration

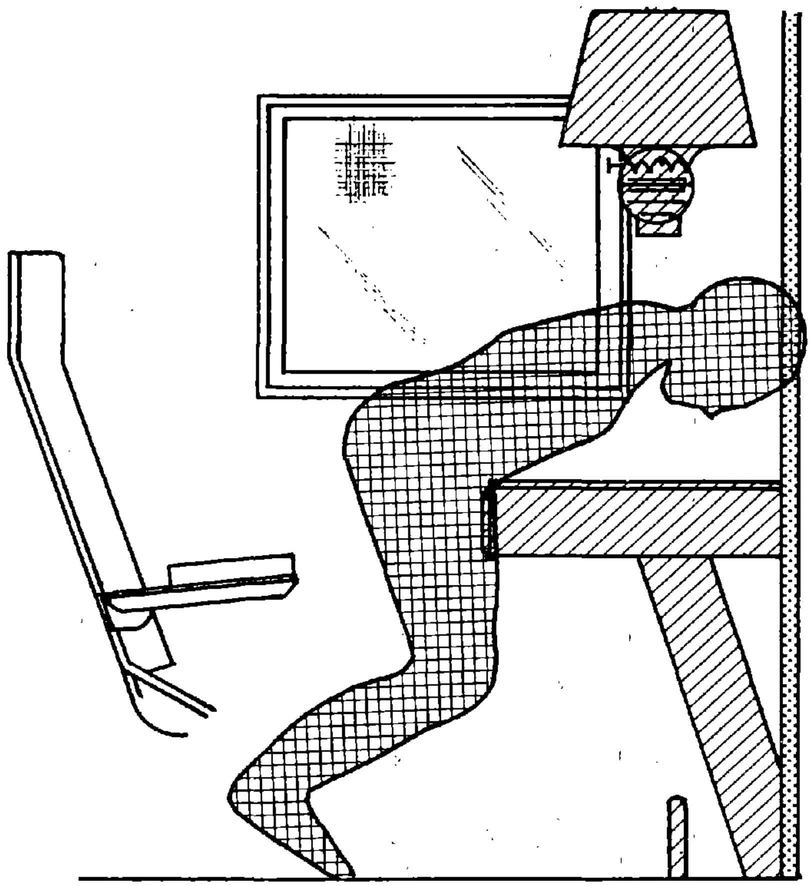


Figure 3–5. Conductor Without Restraint

fusee boxes, protruding door handles, grab rails and stanchions, seat frames, record storage racks, lamps, phones, gauges, valves, and foot-rests.

Hazards to railcar passengers depend upon their seated or standing environment. Environments differ depending upon the type of car in which the occupant is riding. Three types of passenger cars were studied, coach, parlor car, and snack bar coach with their seating arrangement, inherent containment provisions, and surfaces or equipment having potential to cause injury if impacted. Typical impact hazards are shown in Figure 3-6.

3.5 HUMAN TOLERANCE DATA

Human tolerance to impact is difficult to establish because of the obvious impracticability of subjecting humans to impact at injury levels. Much of the data presented is a result of tests conducted with cadavers and minimum forces to produce fractures are documented. Designs for rail vehicle occupant protection in a collision must be for levels considerably below the fracture level. Where data was not available in establishing the non-injury or minor injury levels, an arbitrary force of 10 to 25 percent of the minimum fracture level is given as a design goal depending upon the vulnerability of the body parts. Human tolerance data on the more vulnerable parts of the human body are discussed. A summary of the data is shown in Table 3-1.

3.6 PROTECTIVE DESIGN CONSIDERATIONS

In designing rail vehicle interiors for occupant safety and collision protection the assumption must be made that the structure surrounding occupiable areas remains reasonably intact, without significantly reducing occupant living space. If occupants are injured during a collision because the protective shell around them is crushed, efforts to improve survivability through methods such as occupant containment and delethalization are of little use.

In the design of rail vehicle interiors for crashworthiness the following injury-prevention measures must be considered in conjunction with the various types of vehicle responses to optimize occupant safety environments:

- Provide active or passive restraint or containment systems for occupants
- Provide crashworthy seating
- Delethalize occupant environment

LEG ENTRAPMENT

INTO RECLINED SEAT

INTO BULKHEAD

FACE-TO-FACE SEATING

Figure 3–6. Injuries from Forward Acceleration

TABLE 3-1. HUMAN LOADING TOLERANCES			
Condition	Minimum Fracture Force - lb	Design Load Limit Goal - lbs Rail Vehicle Occupants	Design Load Limit Goal - lbs/in.^{2} Rail Vehicle Occupants
Flat Surface to Head 6 in.^{2}	2200	550	90
1 in.^{2} Object to Head	500	50	50
5/8 in. Diameter Rod to Head	700	70	46
1 in. Diameter to Face Bone (Zygoma)	180	20	25
5.2 in.^{2} to Face Bone (Zygoma)	360	90	20
Nose Impact	<100	10	10
Chin Lips	-	40	20
Knee-Thigh-Hip Complex	1700	450	75
Concentrated Load on Leg (Tibia)	225	25	-
Concentrated Load on Arm	225	55	-
Vertical Load on Dorsal or Lumbar Intervertebral Discs	600	150	-
Chest, Rib (Thorax) Impact 6 in. Diameter Area	800	280	10 to 40

- o Adequately secure interior objects and equipment
- o Employ flame-retardant and antitoxant materials

3.6.1 Occupant Restraint

To minimize railcar occupant injury it is essential to protect the occupant in his seated area and to prevent contact with hostile surfaces within this area. Many types of restraint systems can be considered, both active and passive. Selection of a system will depend upon the proximity of hazardous equipment in relation to the occupant, the effect of the system on the occupant's ability to perform his duties, the cost of the protective system, and the probability of the system being used by the occupant if it requires a willful effort for use.

Passive systems requiring no effort for use on the part of the occupant should be a first preference in system selection provided that in the case of a trainman it does not interfere with the train operation and it is economically reasonable. Active restraining devices, though the least costly, should be limited to use by trainmen and should not be considered for passenger use.

3.6.1.1 Active Restraint Systems

Active restraints are those which must be willfully applied. The forms of basic active restraints are: lap belt only, single diagonal shoulder strap, and shoulder harness. The lap belt only is typical of those used for passengers in commercial aircraft. The diagonal shoulder strap and lap belt system is widely used in highway vehicles and the double shoulder strap system is used for pilots of military aircraft. Each type has application for rail vehicle use.

When properly installed, the lap belt only restraint system restrains the body for forward accelerations at the body's strongest structural elements, and reasonably close to the total body center of gravity. To be effective a lap belt only system must be properly installed or transverse fracture of the vertebral body can occur. The anchor points must not be located too high or too far back. Adequate clearance ahead of the occupant must be available when selecting the lap belt only system. If such clearance is not available then a single or double shoulder strap system should be selected for use in conjunction with the lap belt. Rotational envelopes are presented for the various type restraint systems so that requirements for clearance with equipment and structure can be determined. A lap belt shoulder strap system is shown in Figure 3-7 for a caboose trainman.

Figure 3–7. Brakeman with Lap Belt and Diagonal Shoulder Strap

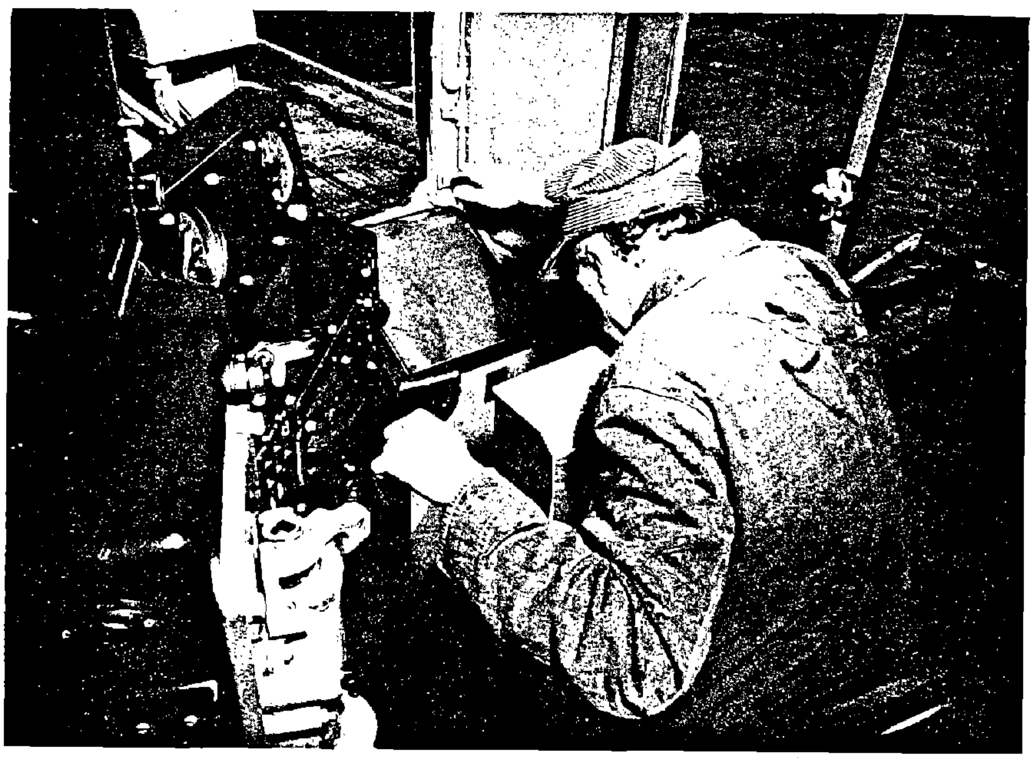


Figure 3–8. Engineman's Restraint Buffer, Forward Impact

3.6.1.2 Passive Restraint Systems

Passive restraint systems are those whose application do not require action on the part of the individual being protected. Two types of passive restraint systems are as follows:

- Fixed passive restraint system which is a fixed part of the seating station
- Deployable passive restraint system which is deployed from a compartment at the instant of collision

3.6.1.2.1 Fixed Passive Restraint Systems - Fixed passive restraint systems should be considered primarily for locomotive and caboose occupants for forward accelerations. The system can consist of a padded structure permanently fixed in close proximity to the front of a seated occupant. This restraint or "buffer" should be configured to cover the abdomen and chest area of the occupant. The buffer should support the occupant at or above his center of gravity and prevent injury due to contact with hazardous items (Figure 3-8). Protection from impact with controls or structure in a lateral direction from the occupant can be provided by curving or extending the padded surface to serve as a shield. An example of a typical design for engineman control console pad and chest buffer installation in an existing locomotive design is shown in Figure 3-9. The buffer design provides restraint for forward acceleration and is extended to prevent impact with the control console handles.

Design of a new locomotive cab configuration permits more latitude in rearrangement of the engineman's controls and instruments. A suggested design concept with improved crashworthiness features is shown in Figure 3-10.

3.6.1.2.2 Deployable Passive Restraint Systems - A deployable restraint system can be considered if the rail vehicle has structure or furnishings that it can be mounted to in close proximity to the front of a seated occupant. The air bag system is an example of a deployable passive restraint. This system consists of an inflatable bag. An acceleration-sensitive switch is needed to cause gas from a storage cylinder to be released into the bag when a predetermined acceleration is exceeded. The space between the structure and the occupant becomes filled with the bag and prevents the occupant from striking the structure or from being thrown from the seat.

Installation of an air bag system requires a suitable structure 18 to 24 inches in front of the occupant for a mounting surface. A control panel, desk or bulkhead would be suitable for installing the system. A conductor's desk is an example of a suitable mounting surface (Figure 3-11).

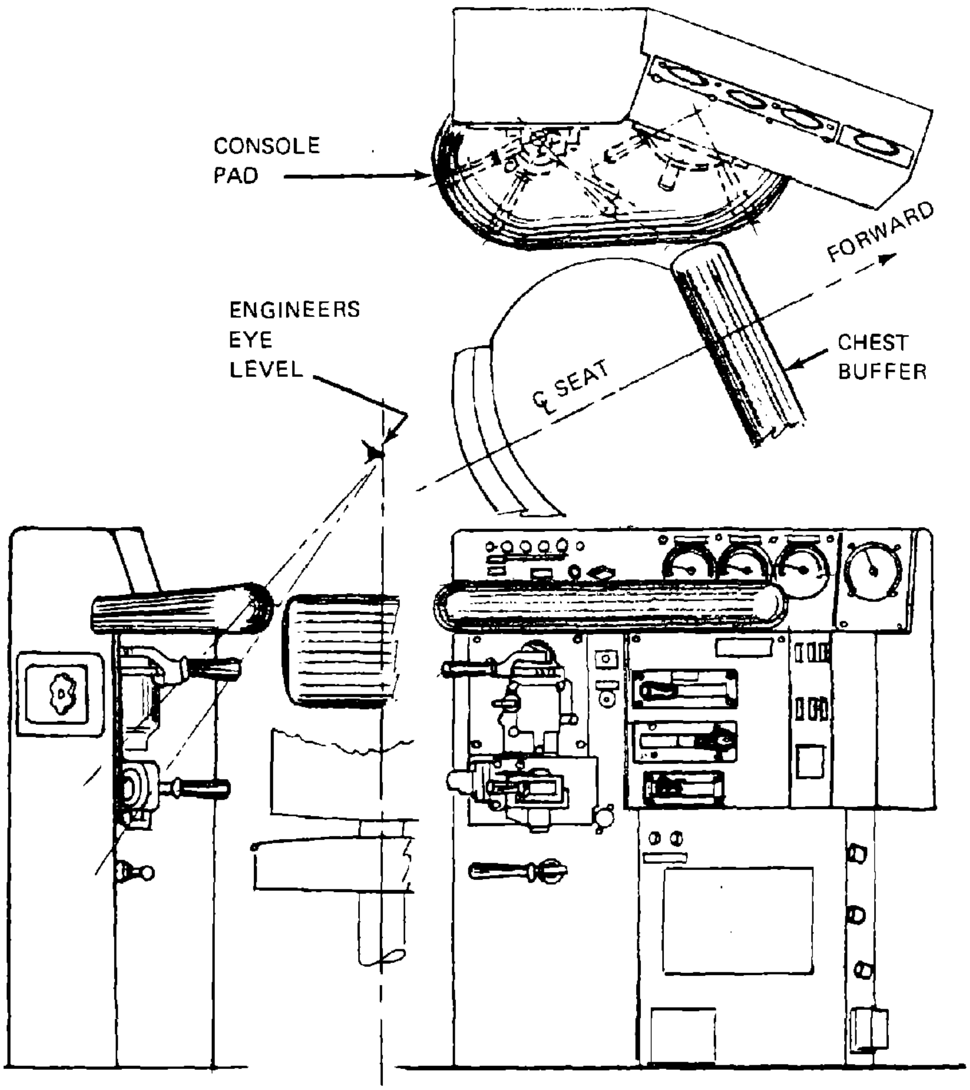


Figure 3–9. Existing Engineman's Station with Buffer and Padding

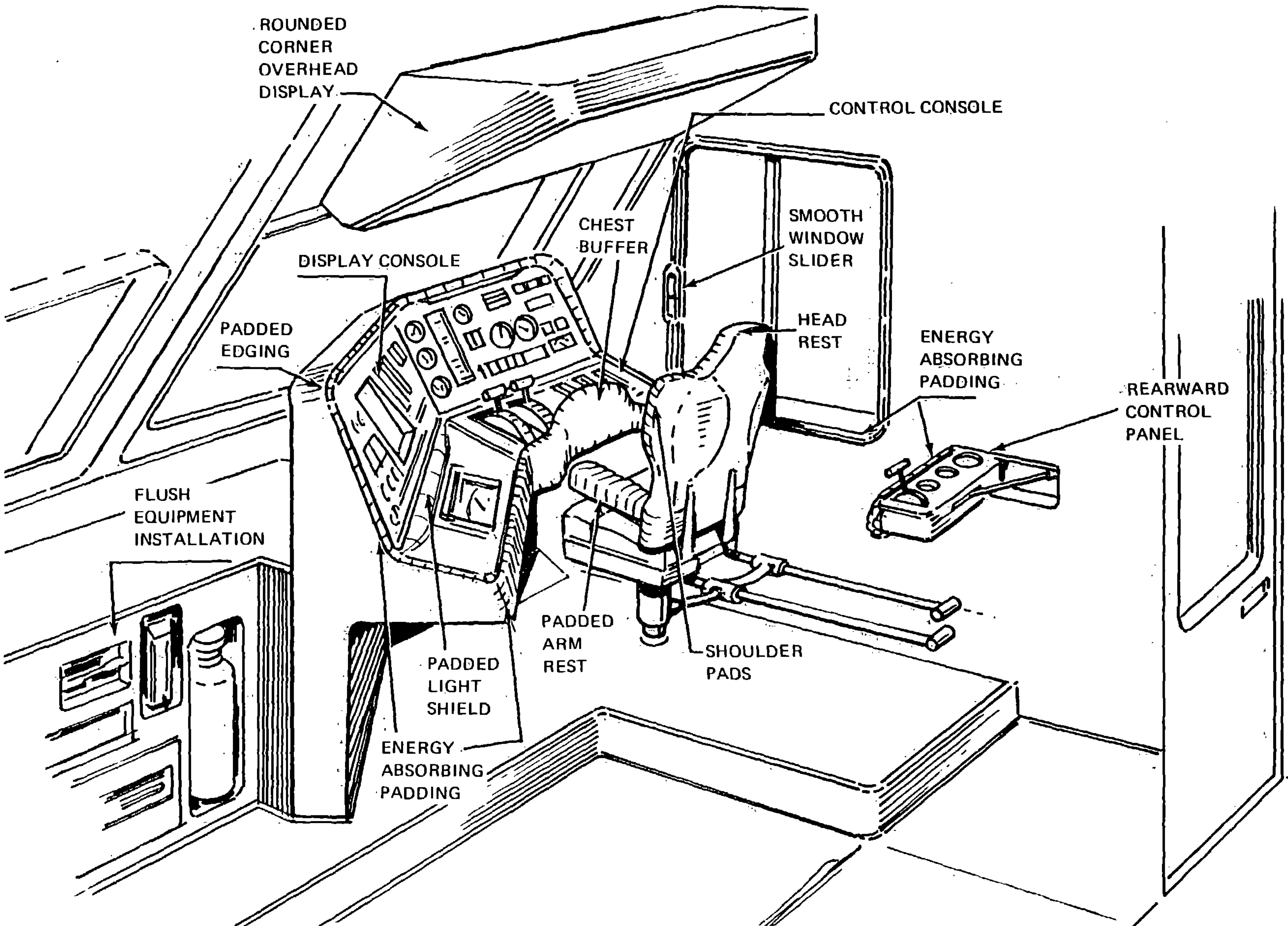


Figure 3–10. Improved Crashworthiness Design Engineman's Station

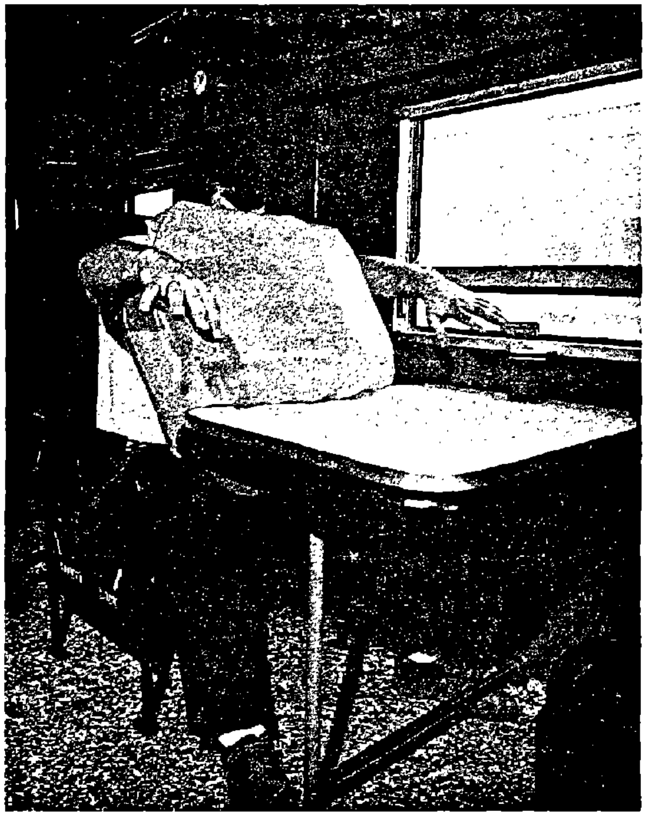


Figure 3—11. Automatic Inflating Air Bag Restraint

3.6.2 Passive Containment and Protection Systems

A containment system is used to limit the distance occupants are thrown from their seat or from a standing position. It provides a surface which will attenuate the impact forces and limit the loads on the occupant to tolerable levels.

Passive containment systems are particularly applicable for rail vehicle passengers and to a limited degree for locomotive and caboose trainmen.

Rail vehicle passengers for the most part are seated while the vehicle is in motion. Therefore the principal consideration for crashworthiness design should be concentrated on the seating area. Maximum advantage should be taken of the furnishings around the passenger for restraint or containment during accelerations resulting from collision and derailment. Specific areas for containment design considerations are as follows:

- Passenger and trainmen seats
- Partitions and bulkheads in front of seats

- Dining car areas
- Snack bar areas
- Lavatories
- Bunks and berths
- Energy absorption design

3.6.2.1 Passenger Trainmen Seats

Since the seat is the closest item to the railcar occupant, it is of prime importance in crashworthiness design. Passenger seats and trainman seats without other restraint provisions serve as the principal containment for occupants. Provisions for impact due to acceleration must not only be added to the occupants' seats but also to the backs of the seats they face. The following crashworthy features should be considered for seat design:

- High seat back
- Impact design for rear of seat back
- Anti-leg-entrapment skirt
- Shoulder wings
- Padded arm rests
- Anti swivel lock
- Impact loads

Seat backs should be sufficiently high to restrain the head during rearward acceleration to prevent whip-lash. Consideration should be given in the design of seat backs to protect the occupant to the rear for knee and head impacts. Provisions should be made to prevent the leg of the occupant to the rear from becoming wedged under the seat in front of them during forward accelerations. Shoulder wings should be added for lateral restraint of occupants. Arm rests must be sufficiently resiliant so as not to cause injury when impacted. Rotatable or swing back double occupancy seats must not become unlocked due to collision accelerations. Seat structure and floor attachments must withstand collision accelerations without tearing loose or without excessive deformation under impact loads. Details for these requirements are discussed.

3.6.2.2 Partitions and Bulkheads

Partitions or bulkheads behind which passengers or trainmen are seated or which are subject to impact from standing occupants should be designed to absorb the impact energy without injuring the occupant. Use of glass, mirrors, pamphlet or magazine racks or other rail vehicle equipment on the partition or bulkhead should be avoided. Seats behind bulkheads used for containment should be located as close to the bulkhead as practical to minimize the distance the occupant can be thrown, thereby reducing the acceleration. Details for bulkhead designs are discussed.

3.6.2.3 Dining Car Occupant Containment

Designs for containment of occupants seated in the dining area should utilize the furnishings to a maximum extent practical. Requirements are presented for the design of the dining car tables and seats. Requirements for padding, impact surface area and structural strength are discussed.

3.6.2.4 Snack Bar Area Containment

Areas of passenger cars normally occupied by standing passengers such as snack bars, club car bars, etc. should be provided with containment provisions to limit the distance occupants can be thrown during a collision. Panels, partitions or compartments can be used for containment. Counters, bars, shelves, etc. should be designed to present as much flat surface area as possible to distribute impact forces over a maximum area of the body. Design of these panels and surfaces for energy absorption to prevent injury when impacted is discussed.

3.6.2.5 Lavatory Area Containment

Provisions should be made to contain seated or standing occupants in lavatories of passenger cars, cabooses and locomotives. Bulkheads, partitions, or doors should be provided as a barrier to limit the occupants travel as a result of collision. Orientation, placement and construction of the partitions and containment provisions are discussed.

3.6.2.6 Bunk and Berth Area Containment

Provisions should be made to contain an occupant lying on a bunk or berth during a collision acceleration. Bunk orientation construction, material selection and design for occupant collision impact without injury are discussed.

3.6.2.7 Containment Surface Energy Absorption Design

Design for occupant protection from injury due to acceleration into a surface during a collision is dependent upon the following factors:

- The velocity of the rail vehicle at the time of collision
- The type of rail vehicle in which the occupant is riding
- The distance the occupant travels to the surface impacted
- The part or parts of the body which contact the surface
- The area of the body that contacts the surface
- The area of the surface contacted
- The energy absorption or deformation characteristics of the surface

These factors must be considered in the design of a bulkhead, seat back, buffer or other padded surface to reduce the impact forces on the occupant to within human tolerance limits.

Energy-absorbing characteristics of surfaces impacted depend upon the stiffness and penetration distance. Using simple calculations and graphs, it is possible to determine the padding stiffness and thickness necessary to insure that specified body pressure or human tolerances are not exceeded during impact. Impact tolerances to various parts of the body are discussed in the section on Human Tolerance and a summary of the body pressure limits are presented in Table 3-1.

In order to determine the required padding or spring rate properties, the impacting body's kinetic energy and the body contact area must be known. The velocity of the body at impact and the masses of the body segments for a 156-pound occupant are given in Figure 3-12; from these the kinetic energy can be calculated. The body contact area is estimated by the designer. From the kinetic energy and the padding contact area, the kinetic energy density, μ, defined as the kinetic energy, per body padding contact area (inch-pounds per square inch), is determined. Assuming a padding thickness, and with the previously calculated kinetic energy density, μ, a minimum padding stiffness value can be obtained (Figure 5-13). With the known body pressure tolerance (Table 3-1) and the kinetic energy density, μ (Figure 3-14), the maximum allowable cushion stiffness is obtained, the designer can then select a suitable padding material within the range of these stiffness values.

BODY SEGMENT	MASS DISTRIBUTION FOR 156-LB OCCUPANT	EQUIVALENT WEIGHT DISTRIBUTION FOR 156-LB OCCUPANT
HEAD	0.05176 LB SEC^2/IN.	20.0 LB
CHEST	0.12008 LB SEC^2/IN.	46.4 LB
PELVIS	0.13200 LB SEC^2/IN.	51.1 LB
UPPER LEG	0.06640 LB SEC^2/IN.	25.7 LB
LOWER LEG	0.03312 LB SEC^2/IN.	12.8 LB

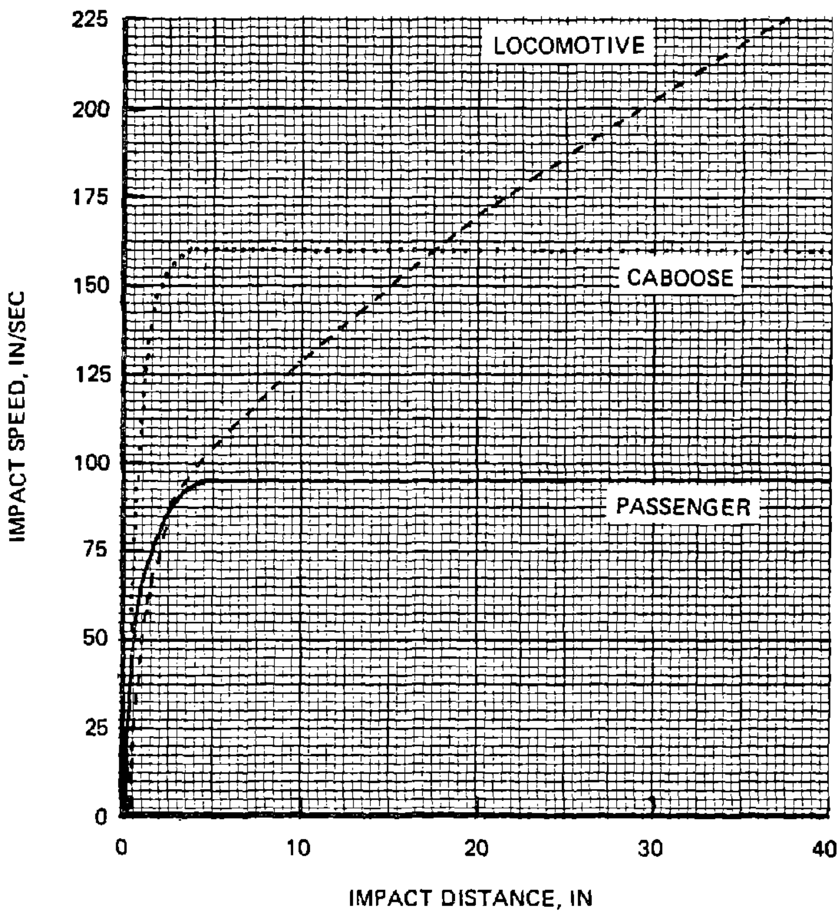


Figure 3–12. Body Impact Velocity vs Distance Traveled

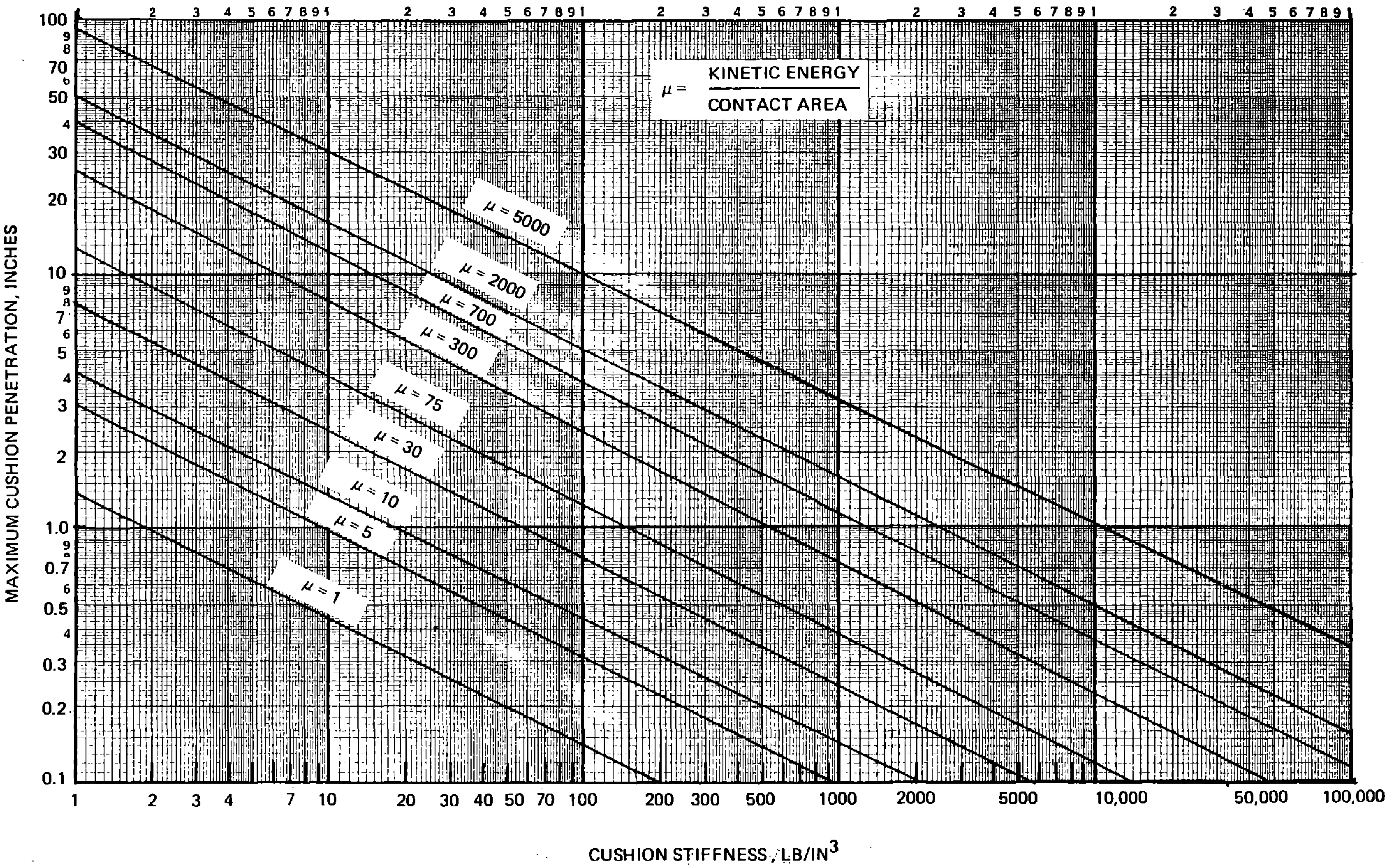


Figure 3–13. Cushion Penetration vs Cushion Stiffness

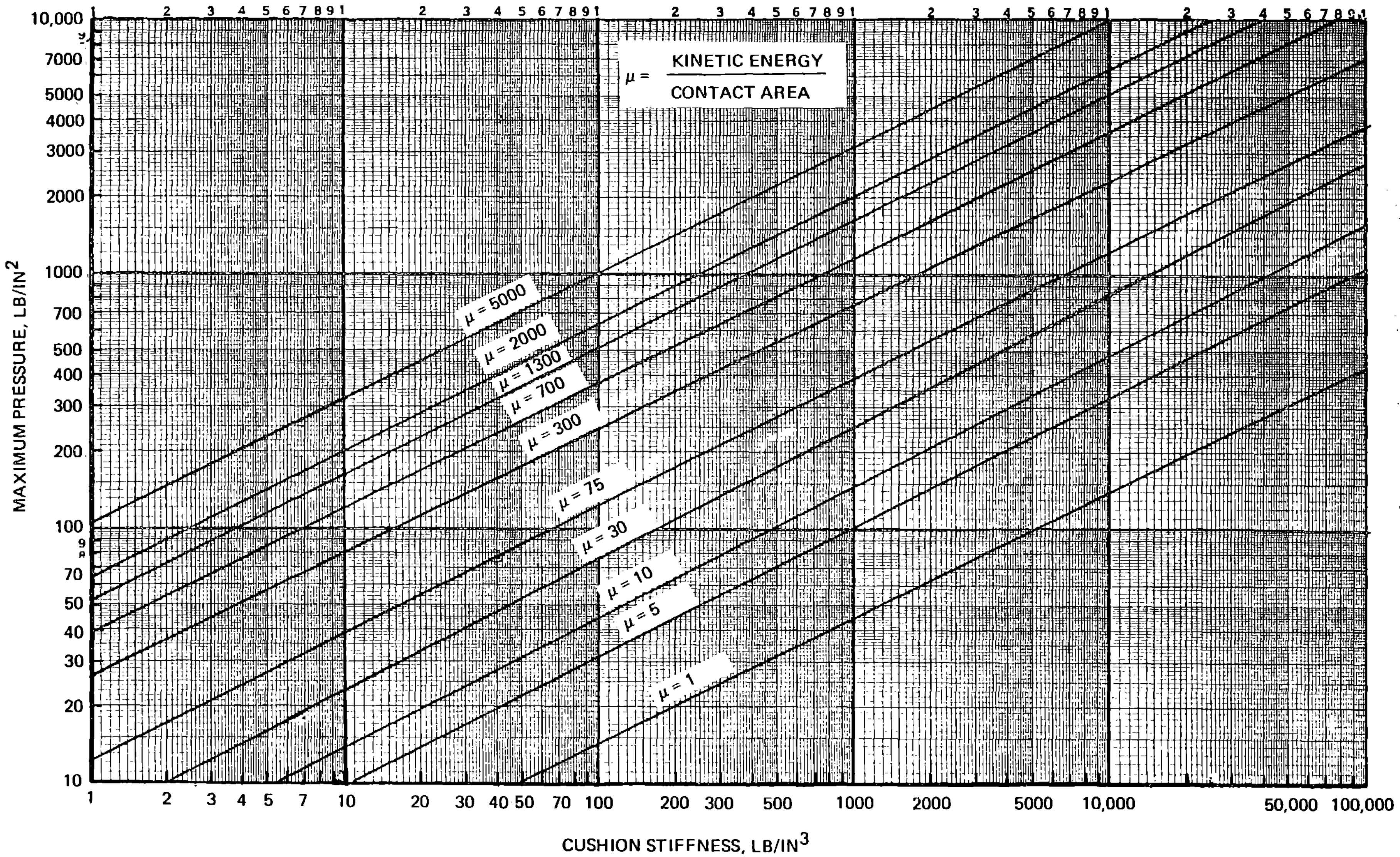


Figure 3–14. Impact Pressure vs Cushion Stiffness

Sample calculations are presented for the design of a padded surface using these charts along with simple equations. Typical occupant impact scenarios for locomotives, cabooses and passenger railcars in collisions were analyzed to determine impact forces on the occupants using these procedures. Energy absorbing properties of equipment, furnishings and structures found in existing rail vehicles were used in determining the impact forces and resulting injuries. Where injuries are determined to be probable, corrective actions and recommended and listed in a matrix (Tables 3-2, 3-3, and 3-4).

3.6.3 Rail Vehicle Interior Delethalization

Rail car delethalization is applicable to locomotives, cabooses, and passenger cars. The degree of delethalization necessary depends on the degree of restraint or containment provided for the occupant. An occupant fully restrained to a seat or confined to an area by buffers and padded surfaces will not strike lethal objects outside of the confined area. However, occupants (passengers or trainmen) are sometimes out of their seats while the train is in motion, and, if accelerated while away from their seats, may strike hazardous objects. Occupants may also be injured due to being struck by loose objects or objects torn loose during a collision. In addition, occupants may be burned or overcome by toxic fumes from burning materials within the rail vehicle.

3.6.3.1 Delethalized Surfaces

Surfaces or objects can be rendered safe for impact by the following techniques:

- Shrouding
- Paneling
- Shielding
- Recessing
- Compartmenting
- Padding
- Remoting
- Fragmenting
- Eliminating

Detailed design guidelines are presented for each of these techniques.

3.6.3.2 Equipment Securement

Whether or not they are permanently bolted to the railcar structure, equipment such as control consoles, water coolers, refrigerators, water tanks, and heaters, or portable equipment such as fire extinguishers, first-aid kits, and luggage should be provided with adequate securement to withstand collision impacts. Methods of securement and structural strength

TABLE 3-2. LOCOMOTIVE COLLISION INJURY MATRIX

Collision Conditions	Injury Mechanism	Impact Surface Properties	Injury Potential	Modifications For Minor or No Injury
10 to 80 MPH Occupant, Impact Vel. 220 in./sec	Fireman's Head into Door from 26.5 in.	5/8 inch Safety Glass K=10,000 lb/in.	Severe to Fatal >500 lb/in.^{2} H.I.C. 1160	Restraint System or 4.5 in. Padded Buffer with Effective Cushion (Stiffness) of 280 lb/in.
10 to 80 MPH Occupant Impact Vel. 120 in./sec	Fireman's Knees into Door from 9 in.	Steel Plate Door K=3000 lb/in.	Moderate to Severe 1200 lb (300 lb/in.^{2}) Force on Knee	Same as above
10 to 80 MPH Impact Vel. 235 in./sec	Engineman's Head into Window from 38 in.	5/8 inch Safety Glass K=10,000 lb/in.	Severe to Fatal >500 lb/in.^{2} H.I.C. >1000	Same as above
10 to 80 MPH Impact Vel. 170 in./sec	Engineman's Knees into Heater from 5 in.	Sheet Steel Construction K=600 lb/in.	Minor to Moderate 600 lb/in.^{2}	Same as above

K = Deflection Stiffness (lb/in.) δ = Deflection (in.)

TABLE 3-3. CABOOSE COLLISION INJURY MATRIX

Collision Conditions	Injury Mechanism	Impact Surface Properties	Injury Potential	Modifications For Minor or No Injury
10 to 80 MPH Forward Acceleration	Chest into 6 in. Desk from 11 in.	Padded Face K=3000 lb/in. δ=1 in.	Moderate to Severe >60 G/3ms	Restraint System or Chest Buffer with 80 $in.^2$ Contact Area
10 to 80 MPH Rearward Acceleration	Occupant into Seat Back	Low Seat Back	Moderate to Severe Neck Hyperextension (Whiplash)	High Seat Back with Headrest
10 to 80 MPH Longitudinal Occupant Acceleration 165 in./sec	Torso into Stantion from 48 in. 10 $in.^2$ Contact Area	Vertical Steel Stantion K=107 lb/in. δ=5.56 in.	Minor to Moderate 12 G over Sustained Time	Replace Vertical Stantions with Horizontal Recessed Grab Rail

K = Deflection Stiffness (lb/in.) δ = Deflection (in.)

TABLE 3-4. PASSENGER RAILCAR COLLISION INJURY MATRIX

Collision Conditions	Injury Mechanism	Impact Surface Properties	Injury Potential	Modifications For Minor or No Injury
10 to 80 MPH Occupant Impact Vel. 95 in./sec	Frontal Head Striking Partition From 36.5 in. 8 $in.^2$ Contact Area	Sheetmetal Over Sheetmetal Former Stiffness 3000 lb/in. Penetration 0.4 in.	Minor Injury 148 $lb/in.^2$ Skull Pressure H.I.C. 27	Reduce Stiffness or Add Padding
10 to 80 MPH Occupant Impact Vel. 95 in./sec	Side of Head Striking Partition From 36.5 in. 3 $in.^2$ Contact Area	Sheetmetal Over Sheetmetal Formers Stiffness 3000 lb/in. Penetration 0.4 in.	Minor Injury 394 $lb/in.^2$ H.I.C. 27	Reduce Stiffness or Add Padding
10 to 80 MPH Occupant Impact Vel. 95 in./sec	Knees into Partitio From 16 in. 6 $in.^2$ contact Area	Sheetmetal Spanning Formers Stiffness 3000 lb/in.	Moderate Injury Knee Force 945 lb Pressure 157 $lb/in.^2$	Reduce Stiffness or Add Padding
10 to 80 MPH Occupant Impact Vel. 95 in./sec	Legs Wedged Under Forward Seat - 1 $in.^2$ Contact Area	Steel Member Across Seat Bottom	Leg Fracture Probable Force >1000 lbs	Add Seat Skirt to Prevent Leg Entrapment
10 to 80 MPH Occupant Impact Vel. 95 in./sec	Face/Head into Seat Back From 30 in.	Standard Padded Seat Back 580 lb/in. Stiffness	No Head Injury H.I.C. 3.5 60 $lb/in.^2$ Nose Injury Likely	Add Softer Padding to Top Back of Seat

K = Deflection Stiffness (lb/in.) δ = Deflection (in.)

TABLE 3-4 - Continued

Collision Conditions	Injury Mechanism	Impact Surface Properties	Injury Potential	Modifications For Minor or No Injury
Roll Over Occupant Impact Vel. 34 in./sec	Rib Impact with Armrest From 3 in. 4 $in.^2$ Contact A	Rigid Armrest Unpadded K=1000 lb/in.	Rib Fracture Rib Pressure 60 $lb/in.^2$	Add Padding to Armrest
Roll Over Occupant Impact Vel. 34 in./sec	Side of Head Striking Window - 3 $in.^2$ Contact Area	Safety Glass K=10,000 lb/in. 260 $lb/in.^2$ to Fracture Penetration .08 in.	Minor Injury @ 13 in. H.I.C.=13 Serious Injury @60 in. HIC >500	Design Glass for Greater Deformation K=1000 Max
10 to 80 MPH Occupant Impact Vel. 150 in./sec	Standing Occupant Head into Door 8 $in.^2$ Contact Area	Conventional Steel Panel Entrance Door 4000 lb/in. Stiffness Penetration 0.34 in.	Minor to Moderate 267 lb/in. Skull Pressure H.I.C. 125	Add Padding to Door or Design for Increased Deflection
10 to 80 MPH Occupant Impact Vel. 150 in./sec	Standing Occupant Rib Cage into Seat Back	Padded Seat Back 500 lb/in. Stiffness Penetration 2.45 in.	Minor Injury GADD 11.71	Increase Seat Back Padding
10 to 80 MPH Occupant Impact Vel. 136 in./sec	Standing Occupant Head into Luggage Rack Rail 3000 lb/in. Stiffness	Structural Member Along Edge of Luggage Rack Penetration 0.56 in.	Minor to Moderate 210 lb/in. Scull Pressure H.I.C. 82	Add Padding to Luggage Rack Rail

K = Deflection Stiffness (lb/in.) δ = Deflection (in.)

requirements are discussed. Design requirements for luggage racks to assure containment of luggage during collisions is also presented.

3.6.3.3 Material Selection

Materials selected for occupied railcar interiors should be flame retardant and antitoxant. All nonmetallic materials and paint properties should be checked before use by reviewing the Transportation Systems Center Material Data Bank Catalog, DOT-TSC-926-3.

3.6.3.4 Glazing

The design of glazing for rail vehicle occupant safety must not only consider the softness or resilience of the glass to reduce occupant injury when impacted but the rigidity of the glass to prevent occupant ejection throught the glass and foreign object penetration into the rail vehicle. A compromise must be reached between these opposing requirements. In addition to these requirements consideration must be given to design for air pressure at top speeds, shock due to passing other trains, shocks due to entering and exiting tunnels and all other pertinent stress and strains. Detail requirements are discussed in the Design Guide.

4. RAIL SAFETY/EQUIPMENT CRASHWORTHINESS PROPOSED ENGINEERING STANDARDS

4.1 INTRODUCTION

Proposed engineering standards were prepared for areas where substantial improvements could be provided in occupant protection in intercity passenger carrying vehicles. The classes of vehicles included are locomotives, cabooses, and passenger railcars.

The standards were prepared in the format of the standards published in the Code of Federal Regulations, Title 49, - Transportation Parts 200. The part numbers selected are representative only and were selected as being the next available numbers at the time of preparation of the original documents. The parts proposed for inclusion in Chapter 11 of Title 49 are highlighted in the following section and the areas discussed are listed below for reference.

PART 253 - Rail Vehicle Occupant Collision Containment Standards

PART 254 - Rail Vehicle Occupant Impact Protection Standards

PART 255 - Railcar Seating System Standards

PART 256 - Trainmen Seat Belts Standards

PART 257 - Rail Vehicle Window Standards

PART 258 - Flammability of Interior Materials

4.2 RAIL VEHICLE OCCUPANT COLLISION CONTAINMENT STANDARDS

PART 253

253.1 Purpose and Scope

This part prescribes requirements for provisions to contain rail vehicle occupants within their seated area during collisions for the purpose of reducing occupant accelerations and preventing impact with hostile surfaces.

253.2 Application

This part applies to all locomotives, cabooses and passenger railcars manufactured or refurbished after January 1, 1978 which are used in interstate service.

253.3 Definitions

Definitions for the various items discussed in the containment standards part are described.

253.4 Locomotive Occupant Containment Requirements

253.4.1 Design Requirements

Locomotive trainmen stations shall be provided with a containment system to limit forward displacement of the occupant during forward collision accelerations. The system shall prevent the occupant from leaving the seat and shall prevent the occupant's torso or head from contacting hostile equipment structure or furnishings forward of the seat. A passive system is recommended and orientation, location, and installation requirements are established. Spring rate requirements for various impact velocities and forces are discussed.

253.4.2 Performance Requirements Locomotive Occupant Containment

The locomotive occupant containment device shall be tested by applying a 1740 pound force to the device over an area of 72 square inches. Procedures for force application and the resulting deflection requirements are discussed.

253.5 Caboose Occupant Containment Requirements

253.5.1 Design Requirements - Seat Containment

Caboose trainmen stations shall be provided with a containment system to limit forward displacement of the occupant. The system shall prevent the occupant from leaving his seat and shall prevent the occupant's torso or head from contacting equipment, structure or furnishings forward of the seat. Methods for restraining the occupant are established and installation requirements discussed. Design loads for the system and installation points are included.

253.5.1.1 Performance Requirements - Seat Containment

The restraint system test specimen shall be installed on the test fixture at the same geometrical points as installation on a caboose seat. Methods of load application and load magnitudes are established. System strength and elongation requirements are discussed.

353.5.2 Design Requirements - Bunk Containment

Caboose bunk containment shall be provided in the form of a barrier at each end of the bunk and restraining devices on the sides to prevent ejection of the occupant during a collision or slack action. Bunk orientation and methods of containing occupants in the bunk are established. Impact load and energy absorption provision requirements are discussed.

353.5.2.1 Performance Requirements - Bunk Containment

A force of 1110 pounds shall be applied over a 5 x 5 inch area to the containment panel at each end of the bunk. A 500 pound load shall be applied to the center of the side containment members. Spring rate and deflection limitations are discussed.

253.6 Passenger Railcar Occupant Containment Requirements

253.6.1 Design Requirements - Seated Occupant Containment

Maximum utilization shall be made of the furnishings in the vicinity of the seated occupant for collision containment. Bulkheads, partitions, seats, windows, wainscoting and the underside of luggage racks shall be designed to provide crashworthy containment during collisions. Locations of containment surfaces and their physical properties are discussed. Impact load requirements, spring rates and deflection limitations are established.

253.6.1.1 Performance Requirements - Seated Occupant's Containment

Bulkheads, partitions and wainscot in the vicinity of passenger seats shall be tested to determine adequate strength and energy absorbing qualities. Impact forces and methods of application are described. Spring rate and deflection requirements are established.

253.6.2 Design Requirements - Standing Occupants Containment

Areas of passengers cars normally occupied by standing passengers such as snack bars, club car bars, etc., shall be compartmented with partitions at each end of the area to limit the distance occupants can be thrown during a collision. Design requirements for the partitions, bulkheads and doors are discussed. Spring rate, impact loading, and deflection limitations are established.

253.6.2.1 Performance Requirements - Standing Occupant Containment

All partitions perpendicular to the centerline of the car and not part of the railcar primary structure, shall be tested for integrity and energy absorbing qualities. Method of load application and impact forces are established. Primary structure bulkheads and entrance door test requirements are also established. Spring rate and deflection limitations for each type of structure is discussed.

253.6.3 Design Requirements - Dining Car Occupant Containment

Orientation and installation of dining car tables for maximum containment is discussed. Methods of containing chairs or seats are described. Design loads, padding, requirements and deflection limitations are established.

253.6.3.1 Performance Requirements - Dining Car Containment

The dining car table loading and method of load application is discussed. Loading requirements for seat containment barriers are established. Deflection limitations for tables, seats and barriers are discussed.

253.6.4 Design Requirements - Lavatory Occupant Containment

Lavatory occupants shall be provided with containment while seated. Bulkheads, partitions, or doors shall be provided to serve as occupant containment barriers to limit the occupants travel as a result of collision. Orientation of toilets and locations for barriers are discussed. Design requirements for barriers including spring rate, impact force requirements and deflection limitations are specified.

253.6.4.1 Performance Requirements - Lavatory Occupant Containment

Lavatory barrier test loads and method of application are discussed. Deflection and integrity requirements are established.

4.3 RAIL VEHICLE OCCUPANT IMPACT PROTECTION STANDARDS

PART 254

254.1 Purpose and Scope

This standard establishes the requirements for treatment of the hazardous interior surfaces of railcar equipment, structure, and furnishings in occupied areas to minimize occupant injuries due to impact.

254.2 Application

This part applies to all locomotives, cabooses, and passenger railcars manufactured or refurbished after January 1, 1978 which are used in interstate service.

254.3 Equipment Concealment Requirements

254.3.1 Design Requirements - Non-Portable Equipment Containment

Non-portable rail vehicle equipment which have corners or surfaces contoured to a radius of less than six inches or have protrusions, or surface temperature in excess of 120 degrees, shall be concealed behind flush panels. These panels shall be flat and void of external corners. Design requirements for openings in panels to allow for air circulation and limited access yet maintain impact surface area are described. Impact force requirements, deflection limitations, and spring rate requirements are discussed. Installation and removal requirements are specified.

254.3.1.1 Performance Requirements - Equipment Concealment

Panels, partitions, bulkheads, grills, etc., shall be tested to determine their structural integrity and to determine their resiliancy for energy attenuation. Testing procedures are described including impact force and velocity. Deflection and spring rate measurement limitations are established.

254.4 Equipment Stowage Requirements

254.4.1 Design Requirements - Portable Equipment Stowage

Rail vehicle equipments which are portable or require emergency access, have a width in excess of six inches, have corners or surfaces contoured to a radius of less than six inches, have protrusions, or have a surface temperature in excess of 120 degrees, shall be stowed in a compartment or locker. Design requirements for the locker structure, door and hardware are described. Impact force levels and spring rate for the construction are established.

254.4.1.1 Performance Requirements - Portable Equipment Stowage

Cabinets, lockers and stowage compartments for locomotives, cabooses and passenger railcars shall be tested for structural integrity and resiliance during simulated occupant impact. Test procedures are discussed and energy absorption requirements established.

254.4.2 Design Requirement - Luggage Stowage

Rail passenger car overhead luggage racks shall be provided with retention doors for the luggage. Dimensional and configuration requirements are discussed. Strength and deformation requirements of the luggage stowage area are established. Energy attenuating property requirements of the side rail and of the underside of the luggage rack for occupant impact are also included.

254.4.2.1 Performance Requirements - Luggage Stowage

Luggage rack doors, partitions and floor shall be tested for structural integrity. Test procedures and loading are established. The crown surface under the luggage rack and rail shall be tested for deformation when impacted by the head of a simulated occupant. Impact test procedures and velocities are discussed. Determination of spring rate and deformation are specified.

254.5 Equipment and Furnishings Recessing Requirements

254.5.1 Design Requirements - Recessing

Rail vehicle equipment, furnishings, controls and lighting requiring continual exposure or access for operation shall be delethalized by recessing within large, flat, structurally supportive surfaces. All interior grab rails and stanchions located below head level shall be recessed within a flush wall, panel, or appliance. Dimensional limitations and configuration requirements are established.

254.6 Equipment Covering Requirements

254.6.1 Design Requirements - Covering

Equipment not requiring continual access which have protrusions or corners having less than six-inch radius and are impractical to conceal or recess, such as a windshield wiper motor, shall be covered with a shroud or box, the corners of which shall not have less than a six-inch radius. Equipments requiring continual access which have protrusions or corners having less than six-inch radius and are impractical to conceal or recess, such as control handles, shall be shielded by a guard. The guard shall present an impact surface above and below or to the sides of the article being shielded. Requirements for materials, clearance and configuration designs are discussed. Impact force requirements and deformation limitations are established.

254.6.2 Performance Requirements - Equipment Covering

External covers extending above a surface and covers with slots for access shall be tested for integrity and energy absorption characteristics. Impact forces and methods of force application are discussed. Deformation limitations are established.

4.4 RAIL VEHICLE SEATING SYSTEM STANDARDS

PART 255

255.1 Purpose and Scope

This part prescribes crashworthy seating requirements for locomotive, caboose, and passenger railcars.

255.2 Application

This part applies to all seats used on locomotives, cabooses, and passenger railcars manufactured or refurbished after January 1, 1978 which are used in interstate service.

255.4 Rail Vehicle Seating Requirements

Crashworthy rail vehicle seats shall be designed to provide the maximum occupant collision protection for the general population under forward, sideward, and rearward accelerations.

255.4.1 Design Requirements - Rail Vehicle Seats

a. Seat Backs - Seat backs shall extend a minimum of 34 inches above the seat reference point to provide upper torso and head support during rearward accelerations. Configuration requirements for headrests, seat back contouring, detail construction and rear surface treatment for occupant impact are discussed. Design requirements for energy absorption padding are specified.

b. Rear Seat Skirt - When seats are used in tandem, the rear surface below the seat cushion of the leading seat shall be partially enclosed with a skirt to avoid leg entrapment. Dimensional limitations and configuration are discussed.

c. Lateral Restraints - All seats in locomotive, caboose, and passenger rail vehicles, except dining car seats and those seats equipped with a shoulder harness, shall have shoulder restraint wings located beside the shoulder. Dimensional requirements and energy absorption padding requirements are established.

d. Armrests - All seats in locomotive, caboose, and passenger rail vehicles, except dining car seats and those seats equipped with a full restraint system shall have an armrest or a padded surface in the position of the armrest. Dimensional requirements and energy absorption requirements are established.

e. Seat Locking and Adjustment - Single or double occupancy walkover or reversible seats shall be provided with a positive locking device to prevent seat back displacement or seat disorientation during collision. Positive locking of adjustable seats is discussed. Requirements for locking device strength under impact loads on the seat are established.

f. Face-to-Face Seating - Although face-to-face seating has been a practice with both walk-over and rotatable passenger seats, the practice shall be eliminated. Use of such arrangements nullify the crashworthy containment features of one direction seat facing. Provisions shall be made to prevent reversal of seats without use of a special tool or key by railroad personnel only.

g. Passenger Swivel Seats - The rotational axis of individual swivel passenger seats shall be at least twelve inches ahead of the seat reference point to permit automatic rotation of the seat to a favorable containment position during collisions. Detail design requirements are established.

h. Seat Loading Design Requirements - Design loading requirements are established for locomotive, passenger car and caboose seats, seat backs, armrests, and shoulder wings. Loading requirements are established for trainmen seats which must react loads from restraint system installations.

255.4.2 Performance Requirements Rail Vehicle Seats

Rail vehicle seats shall be tested for structural strength and for the energy absorbing properties for the various areas of the seat. Test procedures are established for seats used in specific rail vehicles and for various areas of the seats. Loading, deflection and spring rate limitations for each of these areas are to be tested for and are specified in detail.

4.5 TRAINMEN SEAT BELT STANDARDS

PART 256

256.1 Purpose and Scope

This part prescribes requirements for seat belt assemblies when used, to restrain rail vehicle occupants during train accelerations and collisions.

256.2 Application

This part applies to all locomotives and cabooses manufactured or retrofitted after January 1, 1978 which are used in interstate service.

256.3 Definitions

Definitions of the following items are described:

Seat Belt Assembly (Type 1 and Type 2)
Pelvic Restraint
Upper Torso Restraint
Hardware
Buckle
Emergency Locking Retractor

256.4 Design Requirements

Requirements are established for design and installation of each of the following restraint system components:

a. Pelvic Restraint - Installation geometry and retention requirements are given for forward acceleration and rollover.

b. Upper Torso Restraint - Installation geometry, forward and lateral retention requirements, comfort and ease of operation requirements and unencumbered performance of duties while installed are discussed.

c. Emergency-Locking Retractor - Requirements for locking or not locking under various accelerations and retractive forces are discussed.

d. Buckle - Configuration and operation requirements are established.

e. Webbing - Width, thickness, breaking strength and elongation requirements are established.

f. Hardware - Materials, surface finishes, and strengths are established.

g. Assembly - Adjustment requirements, marking and end treatment are discussed.

256.5 Performance Requirements - Restraint Systems

Requirements for the seat belt assembly including webbing and all hardware components and permanent deformation or adjuster slippage under loading is established. Loads and load application procedures are described for each type restraint system. Elongation limitations and measuring procedures are established.

4.6 RAIL VEHICLE WINDOW STANDARDS

PART 257

257.1 Purpose and Scope

This part prescribes requirements for window glazing materials, window retention, impact forces and emergency exit provisions for rail vehicle windows.

The purpose of this standard is to minimizé the probability of foreign objects from entering the rail vehicle from the outside, to reduce injuries resulting from occupant impact to glazing surfaces, to minimize the possibility of occupants being thrown through the vehicle windows in collisions, and to provide glazing removal provisions for emergency egress.

257.2 Application

This part applies to all locomotives, cabooses, and passenger railcars manufactured or refurbished after January 1, 1978 which are used in interstate service.

257.3 Window Glazing - Side Windows

Requirements for side glazing materials are established with reference to the American National Standard. Construction and strength is discussed. Design values are given for wind pressure, shock and impact by objects from the outside of specified size, density, weight and hardness and at a given velocity. Spring rates are established for the protection of occupants who impact the glass from inside to minimize injury yet prevent ejection through the glass.

257.4 Window Glazing - Forward Windows

Requirements are established for window glazing materials used in forward-facing windows in occupied areas of locomotives and cabooses serving as windshields and which are not normally protected by other elements in a consist. The requirements are principally for the prevention of object penetration from outside. Protection for occupant impact is not considered because of other restraint and containment provisions specified for trainmen.

257.5 Window Glazing - Emergency Egress

The minimum number of emergency egress windows are specified for various types of rail vehicles. Window configuration, size and operational requirements are established.

257.6 Window Glazing - Interior Windows

Glass when used in passenger railcar interior doors, lavatories and partitions shall be designed primarily for the prevention of injury to occupants during impact. Requirements for spring rate and retention of granules after impact are specified.

257.7 Performance Requirements - Window Glazing

Procedures for testing the various types of glazing installations are discussed. Test fixture design, impactor configuration, weight,density and impact velocities for each type glazing is specified. Minimum performance requirements are established for each of the test results.

4.7 FLAMMABILITY OF INTERIOR MATERIALS

PART 258

258.1 Purpose and Scope

This standard specified burn resistance requirements for materials used in the occupant compartments of rail vehicles.

The purpose of this standard is to minimize injuries and fatalities of rail vehicle occupants caused by vehicle fires, especially those originating in the interior of the vehicle.

258.2 Application

This part applies to all locomotives, cabooses, and passenger railcars manufactured or refurbished after January 1, 1978 which are used in interstate service.

258.3 Non-Flammability Requirements

All non-metallic materials selected for use in interior of occupiable compartments of rail vehicles shall have flame retardant and non-toxic properties. Limitations on burning or propagation of flame front across a surface are specified.

258.3.1 Performance Requirements - Non-Flammability

Procedures for testing various types of materials for flammability are discussed. Radiant panel testing, application of a flame source, utilization of wire mesh and aluminum foil and application of high temperature sources are specified. Performance limitations for flame propagation, flamming dripping and self extinguishing times are established.

258.4 Non-Toxic Requirements

All non-metallic materials selected for use in interiors of occupiable compartments of rail vehicles shall not give off toxic vapors when burned or subjected to high temperatures. Methods of material selection are referenced.

258.5 Smoke Emission Requirements

Smoke emission D_s ratings and time limitations for various type materials are discussed. Methods of testing and performance requirements are established with reference to the National Bureau of Standards procedures.

5. CONCLUSIONS

The conclusions reached in this study are based on data obtained from accident investigation reports and T-Forms, visual surveys of rail vehicle interiors, analytical determination of occupant impact forces and logical assumptions. Accident data, in the majority of incidents, reported the initiating factors of the accident, the type of vehicle the occupant was injured in and the nature of the injuries. The area of minimal information was on the injury mechanism or object contacted by the occupant. Conclusions as to the items requiring improvement to reduce injuries were based to a great extent on the visual surveys to determine the likely object to cause injury in a collision. This was particularly true for passenger rail vehicle occupants where collision injury mechanism data was practically non-existent. The severity of injuries, based on the assumptions from the visual survey, was determined by the use of mathematical analysis to obtain force levels.

Severity of injuries was found to be less pronounced for passenger railcar occupants than locomotive and caboose occupants. This is assuming that the passenger car does not telescope or become penetrated by an object. Calculations show that acceleration pulses experienced in passenger cars, regardless of the velocity at collision, should not cause occupants to impact interior furnishings at a velocity sufficient to cause fatal injuries. Injuries experienced in passenger cars fell into the minor to moderate level range. Modifications to passenger cars for collision safety will be for the purpose of eliminating or reducing injuries rather than so much to prevent fatalities. The principal modifications to passenger railcars are as follows:

- Prevent double seats from swiveling by providing a positive lock to improve occupant containment
- Prevent leg entrapment under seats by adding a back skirt to reduce high frequency of leg injury in collisions
- Provide padded armrests, headrests and shoulder wings to improve containment
- Provide padding on rigid bulkheads, doors and nonyielding partitions
- Compartment lounge and lavatory areas to minimize distance occupant can be thrown

- Delethalize food preparation areas

- Secure dining car seats or provide compartmentation.

- Provide windows which prevent occupant ejection through yet are sufficiently resilient to prevent occupant injury when impacted

Collision safety provisions in locomotives is of prime importance. Locomotive occupants in a collision have a higher probability of fatal or serious injury than those in any other rail vehicle. Lethal control surfaces in front of the engineman and rugged unyielding bulkhead and door in front of the helper are the principal causes of injury.

To protect the locomotive occupants from injury, they must be prevented from being thrown into these injury producing surfaces. A padded buffer or lap belt/shoulder harness can be used to restrain the occupants and are about equal in cost. The buffer is passive and would be more effective than a lap belt/shoulder harness system which requires a willful act on the part of the occupant to put it on. Seats should be improved by providing high seat backs, headrests and padded armrests. Other areas of improvement to protect standing locomotive occupants are as follow:

- Recessed water cooler

- Equipment normally hung on rear bulkhead placed on cabinets

- Padding added to rear bulkhead and back of control console.

Accelerations experienced by caboose occupants are three times as great as those in locomotives and passenger railcars. Due to the light weight of the caboose, high accelerations are also experienced in non-collision operations such as hard coupling and slack action. Restraint of caboose occupants is a necessity in preventing injury. Padded buffers or webbing restraint systems can be used. Due to the frequent accelerations and decelerations experienced by caboose occupants, the webbing restraint system can be considered and a high frequency of use can be expected. Many of the new cabooses being produced are equipped with lap belts and shoulder harnessed for the trainmen.

Cabooses are equipped with many irregular shaped items of equipment which can produce serious injury if impacted. These items of equipment should be covered by flat surfaced partitions which are padded or sufficiently resiliant to absorb impact energy, reducing forces to a tolerable level.

Cost effectiveness of incorporation of some or all of the features recommended in this study in new build or retrofit rail vehicles is the subject of much debate. The number of occupants killed or seriously injured in rail vehicle accidents where structural crushing does not occur is relatively low. The cost of incorporating the crashworthy features on a retrofit basis is many times higher than on a new build basis. It is therefore recommended that crashworthy features be considered only in new build rail vehicles and for items which are replaced when rail vehicles are refurbished.

APPENDIX
NEW TECHNOLOGY

Volume I

No innovation, discovery, or invention was made in the performance of this study. However, some improvements are noted. For example, in Section 5, pages 56ff, a comprehensive analysis of rail vehicle-accident data is provided for the years 1967-1973, wherein is provided an identification and categorization of injury types, locations, and causal factors, which identification and categorization of these data have not been done before. Also in Section 9, pages 173ff, candidate injury-minimization techniques are presented for the first time for specific types of rail vehicles.

Volume II

No innovation, discovery, or invention was made in the performance of this study. However, some improvements are noted. For example, in Section 5, pages 33ff, protective-design considerations are presented for the first time for locomotives, passenger cars, and cabooses relating to the rail-vehicle interiors and crashworthiness.

Volume III

Although no innovation, discovery, or invention was made in the performance of the work, the engineering standards prepared on pages 5ff are innovative, and indicate for the first time areas where substantial improvements could be provided in occupant protection in intercity passenger-carrying vehicles.